VLSI Brightness Module for Robot Retinas

R. C. Ajmera
Department of Physics
East Carolina University
Greenville, NC 27834

R. W. Newcomb
Microsystems Laboratory
Electrical Engineering Department
University of Maryland
College Park, MD 20742

S. A. Chitale and A. Nilsson
Department of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27650

Abstract

The B-Module and G-Module neural-type circuits are presented using CMOS devices. These modules emulate the behavior of biological cells associated with the human retina. The interconnection of these modules to produce the brightness type of response is studied experimentally on lumped electronic circuits. VLSI circuits using CMOS devices for these modules have been designed on the CALMA computer and the resulting VLSI layout for the brightness module is presented.

I. Introduction

At the present time robotic systems are mainly composed of mechanical functions connected for the purpose of achieving a specific form of automation. As in the human body, the robot processing system is looked upon as the controlling system for visual and sensory functions. The objective of neural-type robotic vision is to obtain a vision system mimicking as much as possible the mammalian visual system as we know it, and, thereby, suggesting ways of organizing visually sensed information.

The retina is a network of nerve cells which are "hard wired" according to a particular organizing scheme. The neuron networks of the vertebrate retina have been investigated by physiologists by stimulating the retina with various light patterns and observing the corresponding output activity of single retinal cells using microelectrodes inserted in these cells [1]. The photoreceptor cells in the retina, called rods and cones, sense the information in the visual field and send this information as coded signals to ganglion cells through Horizontal, Amacrine and Bipolar cells [2]. The axons of ganglion cells exit from the eye and form the optic nerve. The fibers of the optic nerve synapse in the lateral geniculate nucleus in the thalamus. Axons of neurons in the lateral geniculate nucleus relay the information from each eye to the primary visual cortex.

In an engineering context related work on neural-type systems was begun in the early 1960's when H. Crane introduced the neuristor [3] as a basic concept for new types of systems based upon neural-type pulse processing. However, due to a lack of useful realizations, the ideas lay dormant until recently when breakthroughs in circuit realizability of integrated circuits, and very large scale integrated (VLSI) circuits, took place [4], [5]. Consequently, VLSI applications now appear possible for the design of systems which have pulse processing behavior similar to the retina [6], [7].

Physiological systems possess properties which man made systems yet can not duplicate, however, for example, real-time three-dimensional picture processing and information extraction from audio spectrograms. Because of the availability of VLSI circuits, these types of signal processing now appear within the realm of realization by electronic circuits. These VLSI neural-type systems have line structures where a unit length of an axon-like device can be repeated to any length. The lines "fire" an action potential-like pulse for an above threshold input and will not fire again until the input crosses the threshold from below. There also exists in biological systems excitable-oscillatory neurons which fire repetitively to maintained input excitation. This phenomenon had been noted from the Hodgkin-Huxley equations [8] but no electronic realization existed until recently, where our integrable MOS lines [9] were shown to oscillate with only a change in the resistive parameters of these lines.

The objective of this work is to design integrable electronic circuits using IC types of structures emulating the bipolar and ganglion cells of the vertebrate retina. For this we use CMOS devices and also study the interconnection of these cells to emulate brightness detection behavior.

II. Neural-Type Modules

Based upon the properties of biological cells associated with the retina, the following modules have been introduced [9].

B-Module:

This circuit generates slow, graded (single output) responses to (multiple) inputs coming from Receptor (R) modules and a (single) Horizontal (H) module. These inputs are summed to give the B-module output. This summation is nonlinear, but monotonic, and shows quick saturation when sufficient inputs are excited. There are two types for negative (B^--module) and positive (B^+-module) going pulse inputs from the H-module. This leads to two correspondingly different polarity types for the output signal which is accomplished through MOS inverters. B-modules behave like bipolar cells in the retina system, for which there are those that are stimulated to give excitatory outputs and those that are stimulated to give inhibitory outputs.

The circuit diagram of the B-module is shown in Fig. 1(a). V_1, V_2, ..., V_n are multiple inputs and V_o is the output. V_H is the signal coming from the H-module; V_H controls the current through the p-type MOS transistor in the circuit. The behavior of the B-module is experimentally studied in lumped circuits using the SIL 4007AE CMOS integrated circuit chips (V_{DD} = 12 volt and R = 5.6KΩ). For inputs of the rectangular pulse type the output response of the B-module circuit is shown in Fig. 1(b). The horizontal scale is 5μ sec/division and the vertical scale is 5 volt/division. For input voltages below threshold (2.3v) the output of the B-module remains high, near V_{DD}. As the input increases, the output shows sudden dips with quick saturation.

G-Module:

The G-module circuits get their (multiple) input signals from A and B modules. On a single output lead these circuits generate "all-or-none" responses to positive input pulses and have repetitive spike train outputs with a frequency dependent on the level of the above threshold input. The G-module behaves like ganglion cells. The ganglion cells have a concentric, center-surround structure (i.e., the center is excitatory and the surrounding is inhibitory). These cells respond

CH1962-0/83/0000-0672/$00.75 © 1983 IEEE

mainly to brightness contrasts.

The circuit diagram of a G-module is shown in Fig. 2(a). V_{in} is the input and V_o is the output of the circuit. The behavior of the G-module is experimentally studied in lumped circuits using the SIL 4007AE (V_{DD} = 12 v, $R_1 = R_2 = 5.6$ KΩ, $R_3 = 2.7$KΩ and C = 100 pf). Figure 2(b) shows the response of a G-module. The vertical scale is 5 volts/division and the horizontal scale is 2μ sec/division). For input voltages below threshold (2.3 volts), the output is zero. As the input rises above threshold, the output follows it and quickly reaches a high value.

III. Interconnection

The interconnection of the above mentioned modules to form the brightness-type detection circuit is shown in Fig. 3(a). The name is derived from the functions perceived for the analogous interconnections of biological cells in the retina.

An oscilloscope picture of the response of the brightness type interconnection is shown in Fig. 3(b) for a rectangular pulse type of input. The horizontal scale is 5μ sec/div. and the vertical scale is 5 volts/div.. When the input is above threshold, the output goes negative. When the input crosses threshold from above, the output shows a sudden sharp rise but quickly settles down to a normal steady level. The dip in the output, as well as the sharp peak level, corresponds to the input voltage level.

IV. VLSI Circuit Description

CMOS structures have certain advantages in terms of low power dissipation, high noise immunity and wide supply voltage range. The CMOS VLSI circuit layouts for the B-module, the G-module, and the brightness type interconnection are shown in Fig. 4(a) to Fig. 4(c). Figure 4(d) shows a number of brightness modules in parallel to represent a large collection of biological cells in the retina. The design rules for CMOS integrated circuits in VLSI are discribed in detail in [10]. The dimensions are given in units of the scaling parameter 'lambda,' which is equal to one-half of the minimum feature size. Lambda equal to 2.5 microns is used in this design. CMOS has both n and p type diffusion. P-channel transistors are inside a p+ region and inside a p well. There must be a minimum clearance (specified by certain number of lambda) between two strips of the same type on the same layer or of different type on different layers. For example, between two metal strips there must be a minimum of 3 lambda separation to avoid short circuits. Also a diffusion strip must have a width of at least 2 lambda. A resistor is realized by a depletion mode transistor with its gate tied to its source. The channel width and length determine the value of resistance. The capacitance between the diffusion layer and the metal layer is utilized to achieve the required capacitance [11], [12]. When a required amount of diffusion area is overlapped by a metal plate, a capacitor is formed which has its value proportional to the area. The various layers in the CMOS fabrication process are represented by different colors according to a conventional color code.

The CALMA computer was used to design the above mentioned VLSI circuit layouts. CALMA, manufactured by General Electric, is a powerful color graphics computer used for computer aided design. Resolution details up to 1 micron are possible. Huge and complicated circuit layouts for chips can be designed with ease using various functions on the CALMA system. Besides a 'design rule check' a software package allows the user to check for errors in design.

V. Conclusions

The B and G-modules have been designed using CMOS analog circuits. The threshold characteristic of the MOS devices has been utilized to realize the desired response. The behavior of the brightness type of interconnection circuit has been experimentally studied and found to emulate the response of retinal cells.

The brightness function module models the point-by-point transformation from light intensities to their neural representation. Because of the availability of VLSI circuits, it is now possible to have a number of pulse processing circuits grouped together to emulate the large collection of different types of biological cells in the vertebrate retina. This will lead us to realize vision systems for robots.

VI. References

[1]. F. Werblin and J. Dowling, "Organization of the retina of the mud puppy, Necturus Maculus, II - intracellular recordings," J. Neurophysiol., Vol. 32, 1969, pp. 339 - 355.

[2]. D. Granath and B.R. Hunt, "Two channel model of image processing in the human retina," SPIE, Advances in Display Technology, Vol. 199, 1979.

[3]. H. D. Crane, "Neuristor - A Novel Device and System Concept," Proceedings of the IRE, Vol. 50, No. 10, October 1962, pp. 2048 - 2060.

[4]. B. Wilamowski, Z. Czarnul, and M. Bialko, "Novel Inductorless Neuristor Line," Electronics Letters, Vol. 11, No. 15, July 1975, pp. 355 - 356.

[5]. C. K. Kohli and R. W. Newcomb, "An Integrable MOS Neuristor Line," Proceedings of the IEEE, Vol. 64, No. 11, November 1976, pp. 1630 - 1632.

[6]. R. G. Runge, M. Uemura, S. S. Viglione, "Electronic Synthesis of the Avion Retina," IEEE Transactions on Biomedical Engineering, Vol. BME 15, No. 3, July 1968, pp. 138 - 151.

[7]. R. Eckmiller, "Electronic Simulation of the Vertebrate Retina," IEEE Transactions on Biomedical Engineering, Vol. BME 22, No. 4, July 1975, pp. 305 - 311.

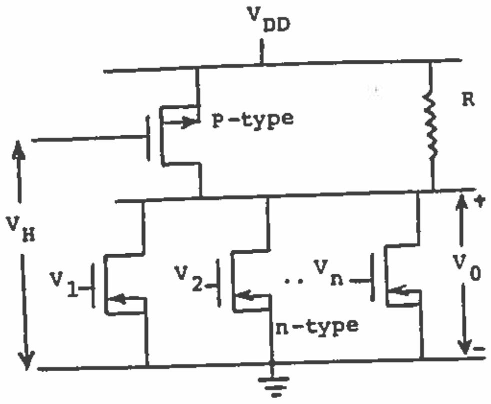
[8]. R. Fitzhugh, "Mathematical Models of Excitation and Propagation in Nerve," Biological/Engineering, Edited by H. P. Schwan, McGraw-Hill Book Co., 1969, pp. 1 - 85.

[9]. R. C. Ajmera, C. K. Kohli, and R. W. Newcomb, "Retinal-Type Neuristor Sections," Proceedings of Southeastcon 80, Nashville, April 1980, pp. 267 - 268.

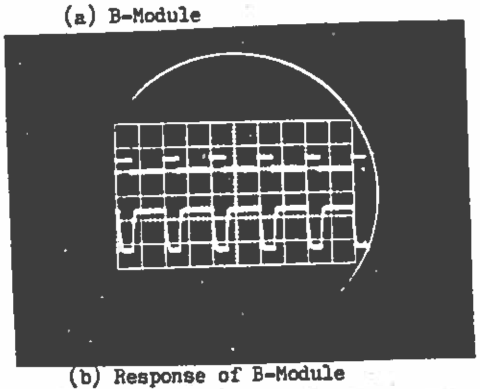
[10]. T. W. Griswold, "Portable Design Rules for Bulk CMOS," VLSI Design, Sept./Oct. 1982, pp. 62 67.

[11]. P. Richman, "Characteristics and Operation of MOS Field - Effect Devices," McGraw-Hill Book Co., NY, 1967.

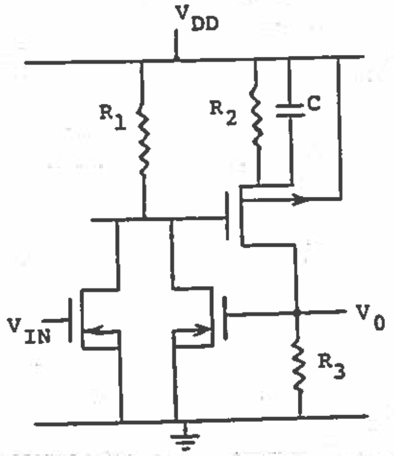
[12]. A. S. Grove, "Physics and Technology of Semiconductor Devices," John Wiley & Sons, NY, 1967.



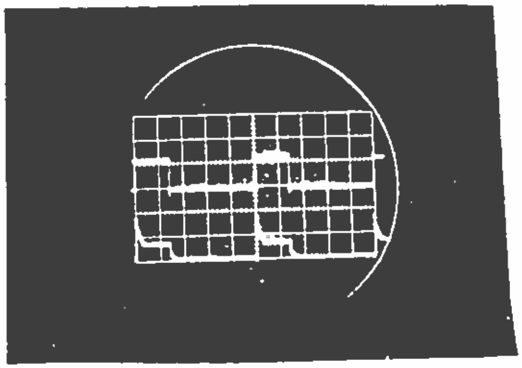
(a) B-Module



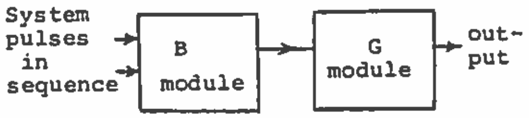
(b) Response of B-Module
Figure 1



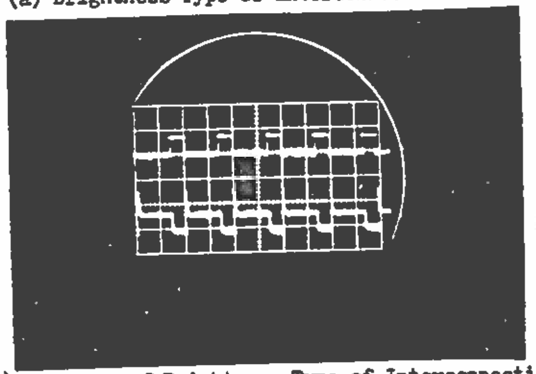
(a) G-Module



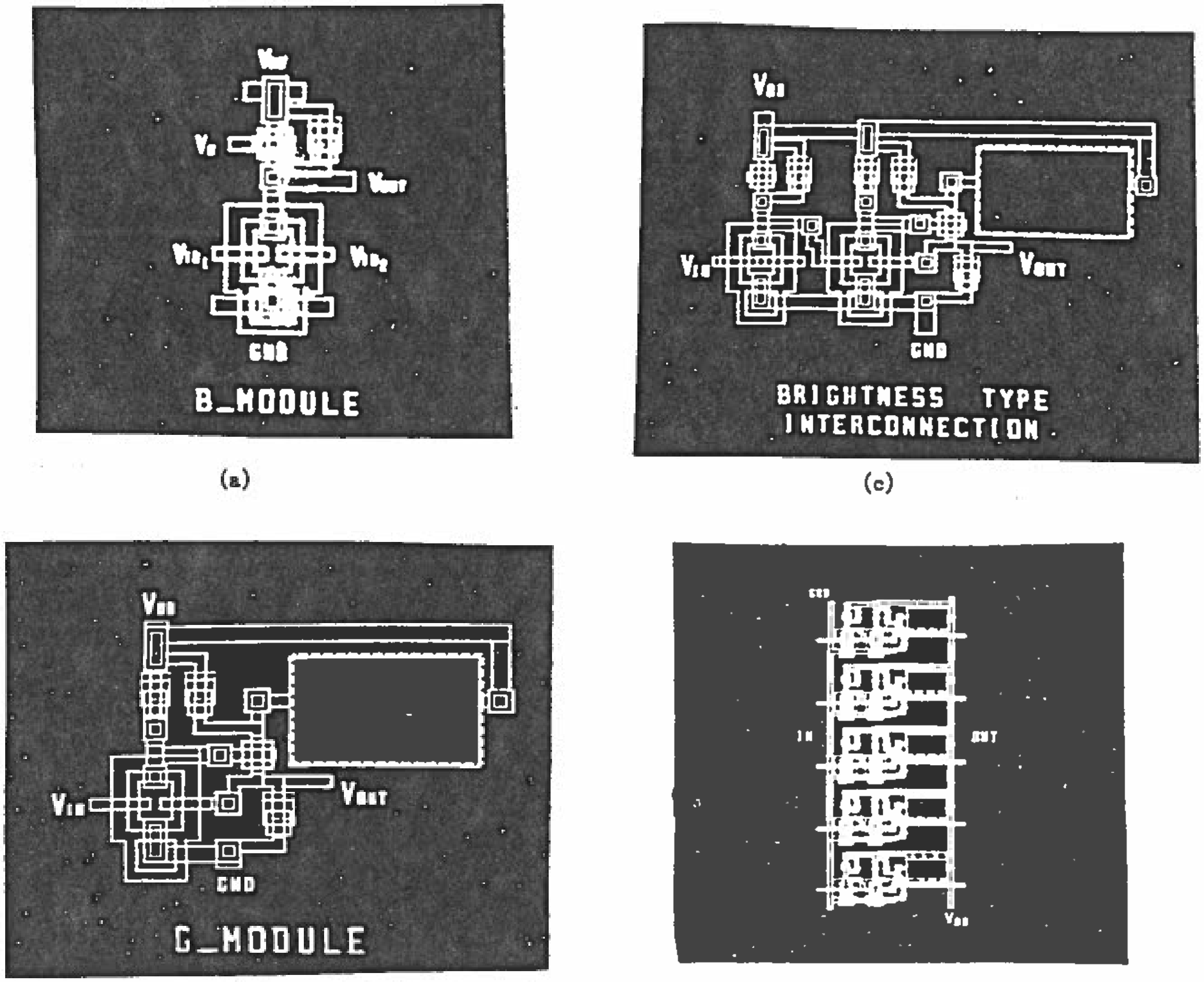
(b) Response of G-Module
Figure 2



(a) Brightness Type of Interconnection



(b) Response of Brightness Type of Interconnection
Figure 3



(a) (c)

(b) (d)

Five Modules in Parallel

Figure 4
VLSI Brightness Module Layout

1884 1984
A CENTURY OF ELECTRICAL PROGRESS
IEEE

1983

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON SYSTEMS, MAN AND CYBERNETICS

Volume I : Bombay

December 29, 1983-January 7, 1984

Sponsored by :
IEEE Systems, Man and Cybernetics Society

IEEE - India council
Bombay and New Delhi,
India

83CH1962-0