A VLSI-BASED SYSTEM FOR LOCALIZATION OF EXTRACELLULAR POTENTIALS

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ABSTRACT

In this study, an interface between a biological nerve fiber and an arbitrary electromechanical device was implemented using an analog VLSI–based amplifier/filter circuit. A silastic cuff was fitted over a live nerve bundle, and an electrode of Teflon coated silver wire was used to sense extracellular potentials. A dedicated CMOS VLSI–based circuit then filtered and amplified those signals to an amplitude appropriate for triggering an arbitrary circuit such as the four–phase stepper motor used in this study. In circuit tests, the amplifier/filter circuit was capable of sensing signals as low as 50 microvolts in an *in vitro* preparation of the optic nerve of *limulus polyphemus*, and effect rotation of the four–phase stepper motor with detected impulses. Using a silastic cuff electrode and dedicated VLSI circuitry for compactness and reliability, this circuit has excellent long term potential as a component of a surgically implanted system. It is also a pivotal first step in the implementation of a comprehensive cybernetic interface.

INTRODUCTION

Currently employed methods for control of prosthetic devices are inherently limited by the number and resolution of system inputs available. Creating additional control inputs to such devices is often achieved at the expense of other facets of bodily motion and control. The cable operated arm [1,2], for example, is conceptually simple, yet it is very limited and awkward in comparison with ideals for rehabilitative devices. Myoelectrically operated devices such as the Boston Elbow [3], and the Utah Arm [4] represent a significant step forward in prosthetic control. However, they still require visual feedback and do not offer high resolution in reaching and maintaining a position. Additional degrees of freedom and enhanced precision have been achieved with microprocessor–based controllers [5], but such devices are still limited in the number of control inputs available. Cybernetic prosthesis [6], make use of neuroelectric activity alone, or in combination with myoelectric activity, and, as such, offer as many control inputs as the electrodes used will accommodate. The objective of this study was to assemble a working prototype of a first step toward a cybernetic interface between a live nerve fiber and an arbitrary electromechanical device. This requires selecting a suitable electrode, as well as designing a custom VLSI–based filter/amplifier and a digital on–chip interface to an electromechanical device.

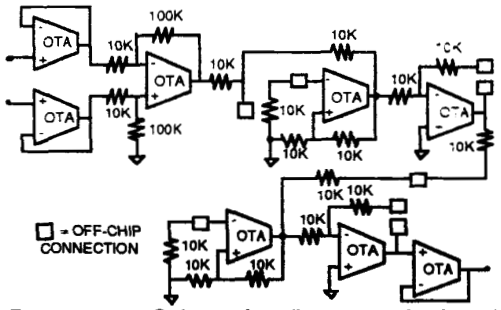

Figure 1.-Schematic diagram of the IC-based amplifier/filter prototype.

CIRCUIT DESCRIPTION

The IC–based filter/amplifier used in this study is organized as shown in Figure 1. The filtering and amplification stages of the circuit were simulated and characterized using SPICE3, and the physical design was produced using MAGIC6. The circuit was assembled using discrete components before submitting the design for fabrication. The only devices not translated were the two 0.047µF capacitors resident in each filter stage and the potentiometers controlling the gains of the fourth and sixth stage amplifiers. The VLSI buffer circuit was structured in six stages. Stage one buffers the input signal through a pair of voltage follower circuits. In the second stage, these signals are differentially amplified with a gain of 10, followed by two successive iterations of band–pass filtering and amplification. The third and fifth stage filters were left with a gain of unity, and the fourth and sixth amplification stages were set for inverting gains that are adjustable from unity to 100. Filtering is done by a Sallen and Key bandpass network, whose center frequency was tuned to the fundamental lobe of the *limulus* action potential. The operational amplifier employed in all filter and amplifier stages is a CMOS operational transconductance amplifier (OTA). Although providing limited gain and output impedance, the OTA is very compact, noise–immune, and offers an extremely high input impedance.

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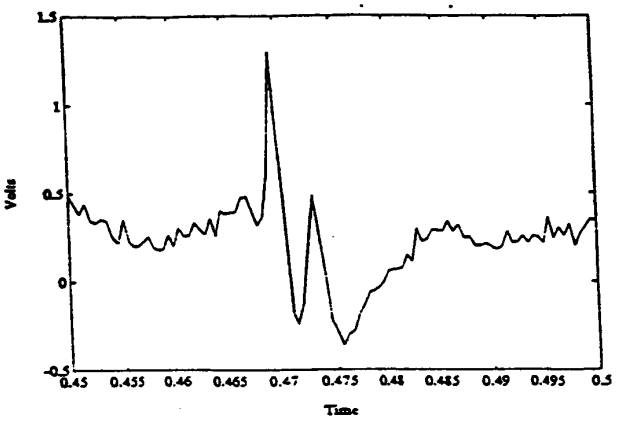

Figure 2-Digitally sampled extract of transient response of the buffer to an extracellular potential, as measured in vitro from the optic nerve of limulus.

RESULTS

Gain and frequency response of the discrete prototype were evaluated using a Hewlett–Packard 3562A Dynamic Signal Analyzer. The circuit was initially configured for a 40dB gain at the center of a pass–band located at 600Hz. The frequency response measurement indicates a gain of 39.6dB at 582.1Hz. Tests of the circuit set for a higher pass–band gain showed comparably positive results. At the highest ranges, however, the input signal had to be artificially attenuated in order to prevent saturating the amplifier output stage. Based on these results the design of the on–chip prototype commenced.

The first tests conducted on the fabricated prototypes were on individual OTA's. Open loop gain was found to be 25.4dB, which was within 3dB of its simulated value. Frequency response of the OTA was found to be flat to within 0.5dB over the frequency range from 100 to 1000kHz. The buffer/amplifier was then assembled and tested. It was set for the maximal gain of 80dB and the resulting frequency response measurements showed the center of the pass–band at 649.4Hz, with a peak gain of 75.5dB and a CMMR of 51.1dB. In addition, a rolloff of 40dB per decade on either side of the pass–band, as would have been expected from a two pole filter, was also confirmed.

The filter/amplifier was then tested on cellular action potential waveforms provided by signals from the optic nerve of *limulus* . A nerve cuff electrode was constructed from a piece of silastic tubing with a Teflon coated silver wire installed as a sensing element. The cuff was installed on an *in vitro* preparation of lateral eye and optic nerve of *limulus* . Impulses were elicited by illumination of the eye with an incandescent light source. Detection of extracellular potentials was achieved, as shown in the digitally sampled extract of figure 2. With the buffer gain set at 80dB and the filter output typically 2 volts in amplitude, it is estimated that the extracellular potentials giving rise to these signals had amplitudes of 200 microvolts.

DISCUSSION

Nerve cuff electrodes have been demonstrated to be stable and nondestructive to the nerve in the long term. Cuffs may be fitted with more than one sensing element, allowing for triangulation of an extracellular potential within some region of a nerve bundle. In this study, it was demonstrated that a sensitive buffer/amplifier circuit capable of interpreting extracellular potentials from a living nerve fiber could be fabricated on a small silicon microchip. The device described makes maximal use of CMOS VLSI–based components which are compact, reliable, power–efficient, and noise immune. As such, they are ideal for surgical implantation in immediate proximity to the nerve being interfaced.

The filters used in this study provide gain and selectivity sufficient to perform successful detection, but they necessitated capacitance values too large to be accommodated on–chip. As an alternative, analog filters specifically suited to on–chip implementation, such as Matched filters and switched capacitor filters, are currently being investigated.

REFERENCES

[1] Klopsteg, P.E. and Wilson, P.D., Human Limbs and their Substitutes, Hafner, New York, 1968.

[2] Wilson, A.B., Limb Prosthetics–1970, Artificial Limbs, Vol. 14, no. 1, pp. 1-52, Spring 1970.

[3] Jerard, R.B., Williams, T.W., and Ohlenbush, C.W., Practical Design of an EMG Controlled Above-Elbow Prosthesis , Proc. 1974 Conference on Engineering Devices for Rehabilitation, Tufts University School of Medicine, Boston, Ma, May, 1974.

[4] Jacobsen, S.C., Knutti, D.G., Johnson, R.T., and Sears, H.H., Development of the Utah Artificial Arm, IEEE Trans. Biomed. Eng. vol. BME-29, pp.240-269, April, 1982.

[5] Freedy, A., Lyman J., and Salamonov M., A Micro-Computer Aided Prosthesis Control, Second CISM-IFTOMM Symposium, p.110.

[6] Mann,R.W., Cybernetic Limb Prosthesis, Ann. Biomed. Eng., vol. 9, no.1, pp. 1-43, 1981.