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A low-cost, multi-channel, EMG signal processing amplifier

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Abstract

There is a growing need in studies of movement control to expand the number of muscles from which EMG activity is recorded during performance of motor tasks. Optimal viewing and analysis of this EMG activity requires signal processing which provides adjustable gain and baseline offset as wells as selectable AC coupling, rectification and filtering. This paper presents a low-cost circuit that combines two channels of EMG signal processing capability in one module. © 1998 Elsevier Science B.V.

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1. Introduction

Advances in understanding the neural control of movement have become increasingly dependent on the ability to record EMG activity from a large number of muscles involved in a particular motor task (Kasser and Cheney, 1985; Lemon et al., 1986; Fetz et al., 1989; Cheney et al., 1991; Porter and Lemon, 1993; Maier and Hepp-Reymond, 1995; Miller and Houk, 1995). Even tasks that appear simple and limited to a few muscles, such as moving an individual digit, actually involve the co-activation of many different agonist and antagonist muscles (Schieber, 1991). EMG activity may be used to identify functional relationships between the activity of single neurons and muscles involved in the task. It may also be used to reveal important aspects of the synaptic organization of single premotor neurons. For example, the discharges of single neurons can be used to compute spike triggered averages of the rectified EMG activity of multiple muscles involved in a task (Lemon et al., 1986; Fetz et al., 1989; Cheney et al., 1991). The presence of postspike facilitation (PSpF) in spike triggered averages of rectified EMG activity is evidence that the triggering neuron has an excitatory synaptic linkage with motoneurons of the muscle whose activity was facilitated. Similarly, the presence of postspike suppression (PSpS) is interpreted as evidence of an underlying inhibitory linkage (Kasser and Cheney, 1985). Simultaneous on-line viewing of neuronal activity and the task related activity of multiple recorded muscles in relation to individual movement trials is also critical in many experiments. In these situations, it is optimal to convert the raw EMG signals into a more meaningful form for on-line viewing and analysis. Ideally, the signal should be relatively smooth and its amplitude should reflect the level of EMG activity present. Filter circuits that accomplish this have been published previously and are available commercially (Gottlieb and Agarwal, 1970). However, in addition to this filtering function, other signal processing features, such as gain control, offset control and AC coupling are usually needed. While all of these functions are available as individual modules through commercial sources, most commonly as a single channel per module, the cost of assembling a system capable of handling

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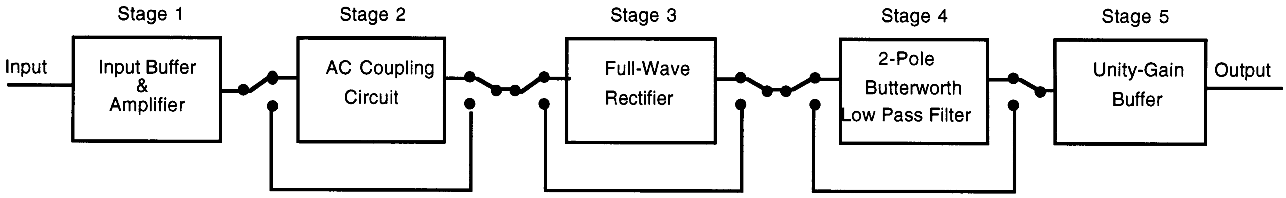

Fig. 1. Each EMG amplifier channel consists of five stages providing signal processing and buffering. Note that stages 2–4 can be by-passed using front panel switches. One module consists of two channels.

large numbers of EMG channels (e.g. 20–30 channels) becomes prohibitive.

To address this need, we have designed a general purpose EMG signal processing amplifier that provides two channels/module and the following commonly needed features – gain and attenuation control, offset control, AC coupling, full-wave rectification and low pass filtering. AC coupling, rectification and filtering can be independently switched in or out of the signal path (Fig. 1). This amplifier is intended to accept signals from a high gain, differential input stage.

2. Circuit description

Each amplifier module provides processing for two channels and is designed to be mounted on a Vectorboard™, which can then be inserted into a standard Vector™ rack mount chassis. Each channel consists of five separate stages, three of which can be by-passed using front panel switches (Fig. 1). The first stage provides input isolation, allows for correction of either positive or negative DC offsets in the raw EMG signal, and provides a range of amplification from 0 to 10 fold. The second, third and fourth stages provide AC coupling, full-wave rectification and filtering, respectively. Stages 2–4 can be individually by-passed using front panel switches. Stage 5 provides output isolation and low output impedance.

The amplification stage (stage 1) consists of a high precision Burr Brown™ instrumentation amplifier type INA101HP followed by a variable gain operational amplifier (Fig. 2). The instrumentation amplifier has a high input impedance, thus minimizing loading of the signal source. DC offset adjustment is accomplished by varying the polarity and amplitude of the potential applied to the instrumentation amplifier bias port. Gain control is provided through adjustment of feedback around the '741' operational amplifier.

The AC coupling circuit (stage 2) consists of a high pass filter and an operational amplifier buffer. The high pass filter eliminates unwanted DC offsets that might be present in the EMG without significantly distorting the EMG signal itself. The high pass filter provides a 6-dB/octave roll-off below 5 Hz.

Full-Wave rectification (stage 3) is implemented using an Analog Devices™ AD630 chip. The AD630 is a multi-function signal processing IC used here as a precision absolute value device. This is accomplished by configuring the AD630 as a balanced modulator with the input signal serving both as the carrier and the modulating signal. This device requires no additional circuits or components to provide high accuracy rectification.

Stage 4, a low pass filter, smoothes the rectifier output and generates a signal whose amplitude reflects the level of EMG activity (Fig. 3). The filter is a 2-pole Butterworth using a Scanlan/Key configuration and buffered by a unity gain amplifier. This filter provides 12 dB/octave attenuation above 20 Hz. Thus frequencies at 30 Hz will be attenuated by more than a factor of two and frequencies above 200 Hz will be virtually eliminated. This Butterworth filter configuration was chosen to provide a short integration constant or step response of 30 ms and a constant gain of 1.56 in the pass band below 20 Hz.

Stage 5 of the module is simply a unity gain buffer amplifier providing output isolation and low output impedance.

Systems, such as this, utilizing high gain, high performance operational amplifiers require special care in power supply isolation and 'filtering'. Shunt capacitors used between ground and the positive and negative power supply busses at each IC minimize undesired IC to IC interaction and enhance stability.

Switches providing stage by-passing and 10-turn potentiometers used for gain control and DC offset adjustment are mounted on a silk screened face plate. At the rear of the printed circuit board, an edge card connection allows access to the Vector™ rack's back plane where power sources and input/output signals are routed.

3. Fabrication considerations and costs

The circuit in Fig. 2 is implemented on a printed circuit board that can be mounted in a Vector™ card module. Module assembly includes populating the circuit board, mounting potentiometers and switches to the face plate, and wiring the appropriate connections

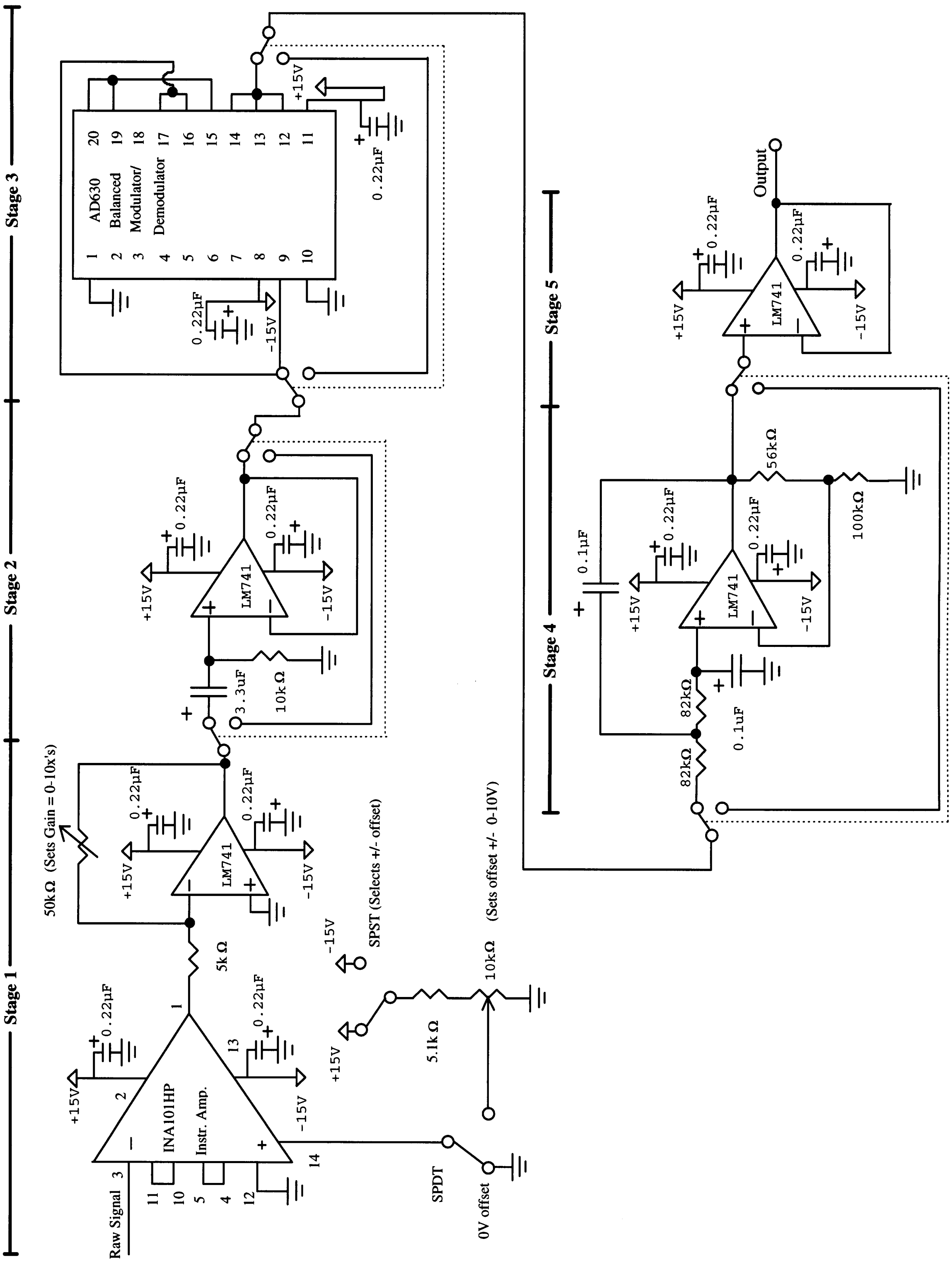

Fig. 2. Detailed circuit for each stage of the EMG amplifier. Circuit components comprising different stages of the amplifier are indicated. Dotted lines indicate to double pole double throw switches.

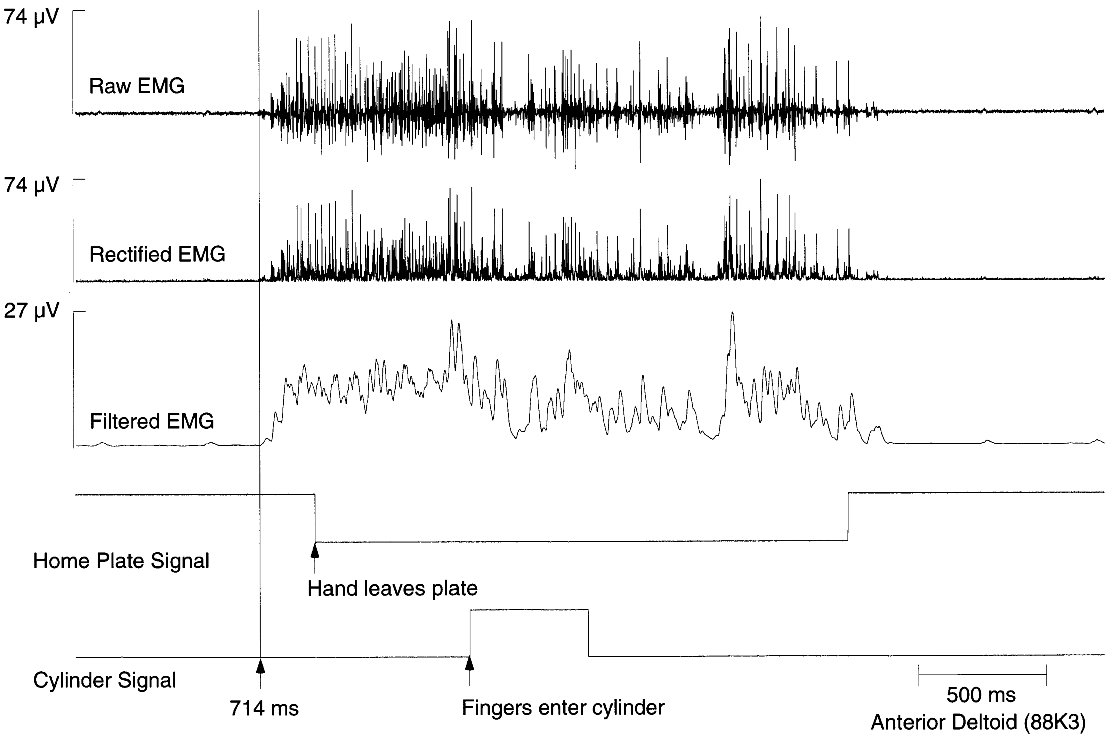

Fig. 3. Examples of EMG records obtained from stages 2 and 3 of the amplifier. These EMG records were obtained from the anterior deltoid muscle in a monkey trained on a reach and prehension task (Miller et al., 1993). In this task the monkey begins by resting its hand on a home plate device located at waist level. When a go signal appears the monkey lifts its hand off home plate (home plate signal goes low) and reaches for a cylinder containing a food pellet. Infrared LEDs indicate when the monkey's hand is in the target cylinder (cylinder signal high). The monkey then brings the food to its mouth and completes the task cycle by returning its hand to the home plate (home plate signal high). AC coupling was on for collection of these records.

between the circuit board and the face plate. Populating the circuit board involves soldering the IC sockets, resistors, and capacitors to the circuit board and seating the ICs in their sockets. An IDC right-angle latching header with a ribbon cable socket was used to make connections from the face plate components to the circuit board. This design allows the circuit board to be easily removed from the module should any repairs be needed. Total assembly time for one 2-channel module is approximately 4 h. The cost of components for a 2-channel module including Vector™ card components is about $150. Printed circuit boards, a detailed parts list and the front panel silk screen layout are available from the authors.

4. Discussion

In this paper we describe a 2-channel amplifier module that combines several commonly needed functions for EMG signal processing. These functions include gain and attenuation control, baseline offset adjustment, AC coupling, full wave rectification and low pass filtering. Functions can be switched in or out to meet the needs of different applications. An important feature of this amplifier is its low-cost, making large numbers of channels feasible on a modest budget. Although many of the functions which this amplifier brings together in a single module could be purchased commercially, the cost for large numbers of channels would become prohibitive. For example, the cost of duplicating the gain and DC offset adjustments using modules from commercial sources would be about $1000/channel. Similarly, low pass filter capability is also available at about $1000/channel. We estimate that the hardware cost per channel for the EMG signal processing amplifier presented in this paper is about $75/channel.

In summary, this paper details a general purpose, versatile signal processing amplifier applicable to a wide range of studies involving EMG recording. This amplifier/signal processing module represents a particularly cost effective solution for experiments which require recording large numbers of EMG channels.

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