A Technical Note

A small and lightweight three-channel signal-conditioning unit for strain-gage transducers: A technical note

Joan E. Sanders, PhD; Lezley M. Smith, MSE; Francis A. Spelman, PhD
Center for Bioengineering, Regional Primate Research Center, University of Washington, Seattle, WA 98195

Abstract—A small and lightweight signal conditioning unit for use with strain-gage transducers is described. The unit provides bridge-balancing, amplification, and filtering for three channels of Wheatstone bridge circuits. The electronics are housed within a 4.5 cm x 3.0 cm x 2.5 cm box that allows connection to a transducer and to a cable that extends to power supplies and a data storage facility. Evaluation tests showed the signal conditioning unit had low noise (0.356 µV, peak-to-peak, referenced to input) with crosstalk between channels of less than 0.02% of the peak-to-peak input signal. The signal conditioning unit has application in biomechanics where a small and lightweight unit is needed; for example, skin/support interface stress measurements in prosthetics and orthotics research.

Key words: instrumentation amplifier, prosthetics, signal conditioning, strain-gage transducer.

INTRODUCTION

Strain-gage transducer applications in biomechanics research can require a small and lightweight signal conditioning unit. A signal conditioning unit typically provides bridge-balancing, amplification, and filtering for each channel of the transducer and should be positioned as near to the transducing element as possible to avoid noise pickup. Typical cases where a small lightweight unit is required are portable applications where instrumentation must be carried by a moving human or animal subject. For example, skin/support interface stress transducers in prosthetics and orthotics require an unobtrusive unit so that the subject's gait is not altered by the presence of the instrumentation. In addition to being small and lightweight, the unit must be sufficiently durable to withstand the mechanical motion induced during ambulation and the manipulation during application and removal.

Some portable commercial signal conditioning units are available. For example, the 1B31 and 1B32 by Analog Devices (Norwood, MA) provide bridge balancing, amplification, and filtering for a single channel. However, the mounting card is large (11.4 cm x 10.5 cm). Other commercial units offer low noise and excellent performance (e.g., Vishay Amplifier, Micromeasurements Group, Raleigh, NC) but include a power supply within the signal conditioning unit, making it large and heavy. For biomedical applications where it is preferable to house the power supply several centimeters from the transducer, and connect it via a cable (e.g., batteries...
in a waist belt or a stationary power unit), the availability of commercial products is limited.

In the biomedical literature, several instrumentation amplifier circuits for multichannel applications are described. Most of them are for collecting physiological data such as EEG (1-3) or ECG (4,5). Though the circuits performed well, they were custom-designed for specific applications, fixed in configuration, and thus lacked the versatility for easy change of gain and filter settings. Also, because the circuits had many components, they were large. Discrete fabrication technology was used, increasing the cost and reducing the versatility of the signal conditioning unit.

In this technical note, a small, lightweight three-channel signal conditioning unit for a strain-gage transducer is described. Thirteen modules have been used to record from 13 three-channel strain-gage transducers. The unit allows bridge balancing and changes in gain and filter cut-off frequencies. It is sufficiently durable to withstand mechanical motion induced during ambulation.

**METHODS**

The signal conditioning unit is a 4.5 cm x 3.0 cm x 2.5 cm box housing electronics for conditioning data from three channels (Figure 1). The unit is designed to be connected to three full Wheatstone bridge circuits, a circuit typically used in strain-gage force transducers. In force measurement systems, three channels are common, one for each of the three orthogonal directions.

Bridge balancing, amplification, low-pass filtering, and power regulation are performed by low-power surface mount electronic circuitry on boards housed in the unit. A schematic is shown in Figure 2, and a list of the principal components is given in Table 1. The potentiometers to balance the Wheatstone bridges are accessible through holes in the plastic housing. For amplification, two AD620 instrumentation amplifiers (Analog Devices) are used in cascade. Gains ranging from 0 to 10,000 are possible; gains of 667 V/V, 2604 V/V, or 5538 V/V are typically used. The gain is set by switching R4, R5, or R6 into the circuit. After the second stage amplifier, there is a single-pole, low-pass, passive RC filter set at a cut-off frequency of 106 Hz, a value typical for gait analysis studies. Power regulators are used for the three DC levels for the bridge voltage, positive supply rail, and negative supply rail to limit noise into the bridge and amplifier integrated circuits.

The signal conditioning circuitry for the three-channel unit is on two surface mount boards of dimension 3.7 cm x 2.3 cm x 0.1 cm. A commercial software package (Tango-PCB, Accel Technologies, Inc., San Diego, CA) was used to lay out the boards.

The mechanical housing of the signal conditioning unit was designed to be lightweight and stable but was easily disassembled for access to the boards. A schematic is shown in Figure 3. Each of the two aluminum side plates holds one connector, a 12-pin (FR-12S-4, Microtech, Inc., Boothwyn, CT) that connects to the transducer, or a 7-pin (Microtech ER-7S-4) that attaches to a cable extending to power supplies and a data acquisition system. The connectors are modified by making a groove into the connector, then epoxying an external retainer ring (Q-RE-6 and Q-RE-5, Small Parts Inc., Miami Lakes, FL) into the groove to act as a lip that a set screw can hold to the aluminum frame. For four sides of the box, a plastic frame is made by heating a butyrate tube until it is molten and then forming it onto a 3.8 cm x 1.9 cm aluminum block. Holes are made in the walls to allow access to the potentiometers to balance the bridges. Four threaded rods extend through the plastic housing, aluminum plates, and boards to hold the unit together. Once constructed, the unit weighs approximately 15 grams.
RESULTS

Evaluation tests were conducted to determine the noise, crosstalk, and bandwidth for the signal conditioning unit. All tests were conducted at the intermediate gain setting of 2604 V/V. Results showed that for an input signal of 2.0 mV peak-to-peak the measured noise referenced to the output was more than 75dB below the signal of interest. Using a spectrum analyzer, the circuit demonstrated a flat passband that had a 3 dB roll-off at 100 Hz. The group delay in the passband was 500-600 μs, measured at the cutoff frequency. The delay was constant for a decade below the cutoff frequency. Crosstalk to the two off channels when a 2.0 mV peak-to-peak sine wave was input to the third channel was less than 75dB below the signal of interest. The signal-to-noise ratio was greater than 75dB.

Figure 2.
Electronic schematics of the signal conditioning circuitry: (a) bridge-balancing, amplification, and filtering for one channel; (b) regulated supply circuits for a signal conditioning unit. B1, B2, and B3 are batteries.

Table 1.
Electronic componentry used in the three-channel signal-conditioning unit.

<table>
<thead>
<tr>
<th>Component</th>
<th>Supplier</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC amplifier</td>
<td>Analog Devices, Norwood, MA</td>
<td>AD620</td>
</tr>
<tr>
<td>Amplifier regulators</td>
<td>Maxim, Sunnyvale, CA</td>
<td>MAX663, MAX664</td>
</tr>
<tr>
<td>Bridge regulators</td>
<td>National Semiconductor, Santa Clara, CA</td>
<td>LP2951</td>
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Table 2.
Optimization of the bridge-balancing and signal amplification circuitry.

<table>
<thead>
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channel averaged 0.407 µV peak-to-peak, 0.02 percent of the input signal. The current consumption of a three-channel unit was 30 mA when it was connected to a four-arm bridge where each arm was of 350 ohms resistance.

The signal conditioning unit has been used repeatedly with interface stress transducers mounted on the prosthetic sockets of subjects with amputation. After several hours of ambulation testing, the units showed no degradation in performance and no parts were found loosened.

**DISCUSSION**

A simple and lightweight unit for conditioning three channels from a strain-gage transducer is described in this technical note. The unit has application principally in force measurement, where force is to be measured in three orthogonal directions simultaneously. Several units have been used to measure triaxial forces from many locations simultaneously.

Evaluation testing of the unit showed good performance. The on-board regulators minimized noise on the supply lines, a common source of poor circuit performance. Mechanical motion has minimal effect on performance because the unit is small and lightweight and the boards are well-stabilized in the box. The wires extending from the connectors to the boards are the principal sources of noise and crosstalk. However, these levels introduce minimal error to the signal.

The signal conditioning unit has potential use in rehabilitation medicine and other biomedical fields where a small and lightweight unit is required.

**REFERENCES**