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Low-cost conditioning amplifier based on operational amplifier array for Michelson interferometer

Amplificador-acondicionador de bajo costo basado en arreglo de amplificadores operacionales para interferómetro Michelson

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Abstract

A low-cost conditioning amplifier was designed and assembled with four operational amplifiers LM741. The objective of the design was the adequate amplification of electrical signals and with a design that allows the replacement of components if necessary. The performance of the conditioning amplifier was tested with the diode output signal of a Michelson interferometer, achieving an amplification ratio of 1:10 and the removal of DC voltage.

Amplification, Operational amplifier, Conditioning amplifier, Electrical signal conditioning

Resumen

Se diseñó y elaboró un amplificador-acondicionador de bajo costo con un arreglo de cuatro amplificadores operacionales LM741. El objetivo del diseño fue la adecuada amplificación de señales eléctricas con un diseño que permita el reemplazo de componentes del circuito en caso de ser necesario. El amplificador acondicionador se probó con la señal de salida del diodo de un interferómetro Michelson, obteniendo una adecuada razón de amplificación de 1:10 y la remoción de la tensión en CD.

Amplificación, Amplificador operacional, Amplificador acondicionador, Acondicionamiento de señal eléctrica

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1. Introduction

Interferometry techniques for the measurement of dynamic quantities requires to condition and amplify electrical signals of photodiodes, which transduce the received light beams into an electrical signal proportional to the optical power directed to its active area.

In a Michelson interferometer, silicon photodiodes are used. These diodes generate low-power electrical signals, so a conditioning amplifier is used to remove the DC voltage and to improve the performance of the signal acquisition systems (Hohenstein et al., 2013).

A conditioning amplifier is a device that is connected to the output of a device that generates an electrical signal (commonly a transducer) with the objective of altering this signal before it enters the data acquisition system.

A usual application for conditioning amplifiers is to amplify a signal at a specific ratio, being 1:10 and 1:100 common amplification ratios. In the present work, a conditioning amplifier was design to remove the DC voltage and amplify the diode output of a Michelson interferometer in a 1:10 ratio.

An operational amplifier is a voltage amplifier with extremely high gain. The operational amplifier LM741 has a typical gain of 200 V/mV (Franco, 2002).

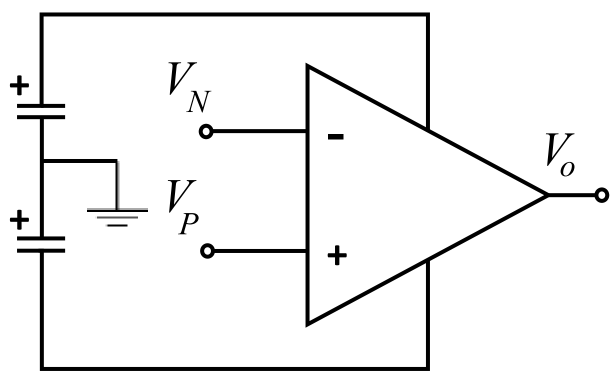

Figure 1 Symbolic representation of an operational amplifier. Made with PowerPoint.

Figure 1 shows the symbolic representation of the operational amplifier. The inputs identified with the symbols "-" and "+" in figure 1 are the *inverting* and *non-inverting* input, respectively. The voltages at these inputs are V_N and V_P. The *differential input voltage* is defined by the difference:

$$V_D = V_P - V_N \quad (1)$$

where:

V_D: Differential input voltage
V_P: Voltage at the non-inverting input
V_N: Voltage at the inverting input

Therefore,

$$V_O = A\,V_D = A(V_P - V_N) \quad (2)$$

where A is the gain and V_O the voltage at the output.

Depending on the way additional components are connected to the operational amplifier's terminals, the circuits can condition the input signal in diverse ways. The circuit configurations used in the conditioning amplifier presented in this work are the noninverting amplifier, the voltage follower, and the summing amplifier.

2. Basics

Non-inverting amplifier

To obtain a non-inverting amplifier circuit, the input signal must be connected to the noninverting terminal of the operational amplifier, as shown in figure 2. A non-inverting amplifier circuit has a positive gain value.

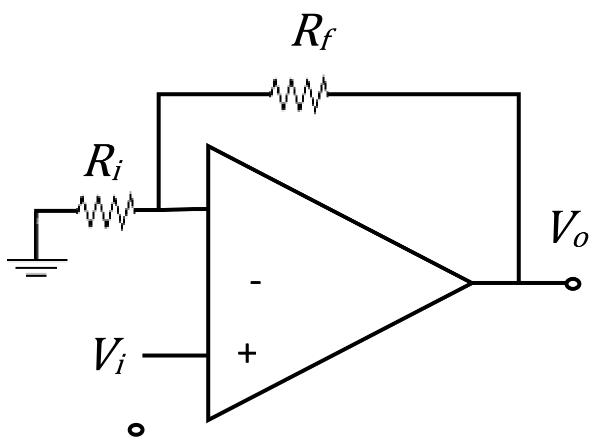

Figure 2 Schematic representation of a noninverting amplifier circuit. Made with PowerPoint.

In this configuration, the output voltage is given by:

$$V_O = V_i\left(1 + \frac{R_f}{R_i}\right) \quad (3)$$

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where:

V_o: Output voltage
V_i: Input voltage
R_f: Resistance in the negative feedback
R_i: Resistance between the inverting terminal an earth

As the gain is positive, the polarity of the output voltage will be the same as that of the input voltage (Coughlin & Driscoll, 1998).

Voltage follower amplifier

Letting $R_i = \infty$ and $R_f = 0$ in the non-inverting amplifier array (as is the case in figure 3) makes it a unit gain amplifier or voltage follower (Franco, 2002).

The application of a voltage follower lies in acting as an impedance transformer, from its input an open circuit its observed, while from its output a short circuit to a source of value $V_o = V_i$ is observed.

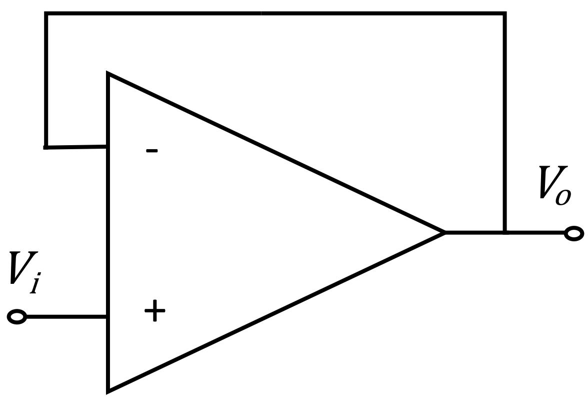

Figure 3 Schematic representation of a voltage follower. Made with PowerPoint.

The operational amplifier in voltage follower configuration does not amplify the input signal in any way; the output signal follows the input voltage directly. Its specialty, however, is to act as a resistance transformer, since looking into its input we see an open circuit, but looking into its output we see a short circuit to a source of value $V_O = V_i$ (Franco, 2002).

As the operational amplifier has remarkably high impedance, it demands little current. For this reason, the operational amplifier as a voltage follower acts as isolation dampers, nullifying the charge effects. The role of the follower is thus to function as a buffer between source and load (Franco, 2002). This makes it a useful circuit of first stage.

Non-inverting summing amplifier

The summing amplifier has two or more inputs and one output. In this configuration, the amplifier circuit delivers a voltage equal to the sum of the voltages at its input terminals.

Particularly in a non-inverting summing amplifier circuit, the input voltage will be connected to the noninverting input terminal of the operational amplifier, and the inverting input terminal will have an array of resistances in feedback with the output terminal and earth, as shown in figure 4.

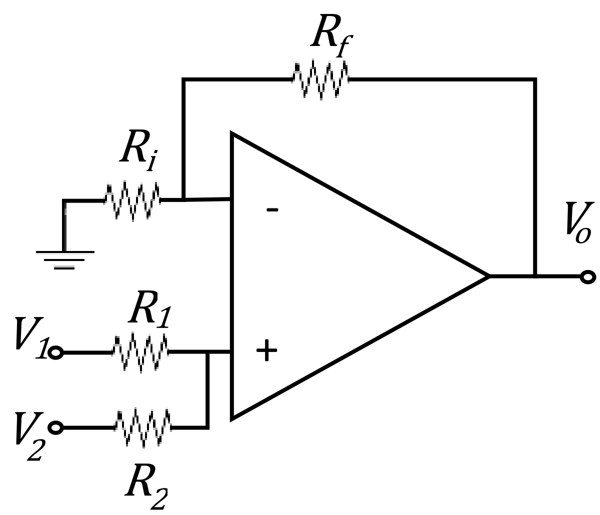

Figure 4 Schematic representation of a summing amplifier circuit. Made with PowerPoint

In this configuration, with an array with two inputs, the output voltage is given by:

$$V_O = \frac{(R_i + R_f)(V_1 R_2 + V_2 R_1)}{R_i(R_1 + R_2)} \quad (4)$$

where:
V_1: Input voltage 1
V_2: Input voltage 2
R_1: Input resistance 1
R_2: Input resistance 2

3. Methodology

Design of the conditioning amplifier

A conditioning amplifier circuit was designed and assembled with the goal of removing the DC voltage and amplify ten times the input signal.

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Figure 5 shows the diagram of the design conditioning amplifier circuit, which has four LM741 operational amplifiers in different modes of operation. The photodetector used is a BPW34 of Vishay, and its output signal is the signal to condition and amplify (V_i).

The first stage of the circuit is an operational amplifier in follower configuration (follower), with V_i as its input voltage. Therefore,

$$V_{o,f} = V_i \quad (5)$$

In parallel, a second operational amplifier in follower configuration (conditioner) has at its input a potentiometer which supplies the voltage offset.

The outputs of the conditioner and follower stages are connected in parallel to the input of a third operational amplifier that is connected in a noninverting summing configuration (summing).

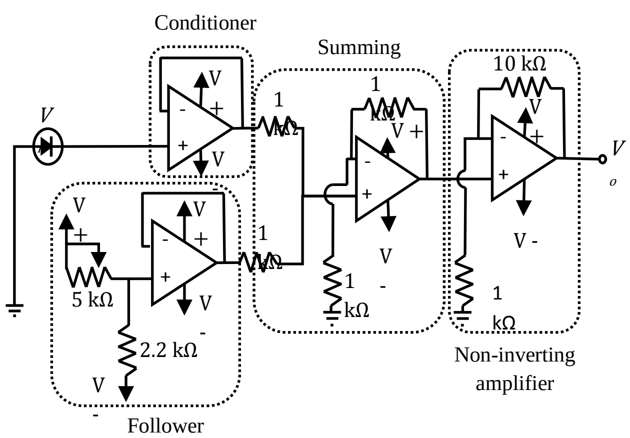

Figure 5 Schematic representation of the conditioning amplifier circuit with its four stages. Made with PowerPoint

From equation (4), the output voltage of summing amplifier in figure 5 is:

$$V_{o,s} = V_{o,c} + V_{o,f} \quad (6)$$

where:
$V_{o,s}$: Output voltage of the summing amplifier
$V_{o,c}$: Output voltage of the conditioner

In this case, $V_{o,f} = 0$, so the output of the summing amplifier is equal to the output of the conditioner:

$$V_{o,s} = V_{o,c} = V_i\ , \quad (7)$$

This voltage $V_{o,s}$ enters then to the last stage of the circuit, which consists in an operational amplifier in noninverting amplifier configuration (amplifier). From equation (2) and (7), the voltage at the output of this amplifier is:

$$V_{O,a} = V_{O,s}\left(1 + \frac{10\ k\Omega}{1\ k\Omega}\right) = 11V_i \quad (7)$$

This means that, in ideal conditions, the signal that enters the conditioning amplifier circuit is expected to be amplified in a ratio of 1:11.

Implementation

The circuit was assembled on four universal perforated circuit boards CL-005 (figure 6). On each circuit board a stage of the conditioning amplifier was assembled in accordance with the diagram presented in figure 5.

In addition to the components shown in this design, capacitors were used as filters of the voltage supply.

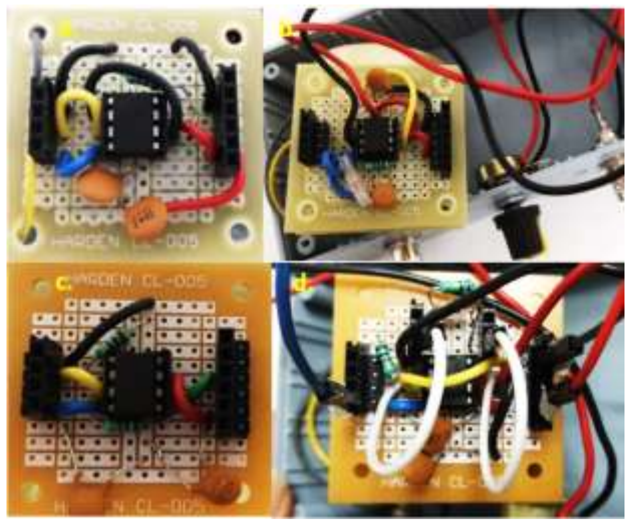

Figure 6 Stages of the assembled circuit: a) Conditioner b) Follower c) Summing amplifier and d) Non-inverting amplifier

Pin connectors were added on the circuit boards so that these could be connected one on top of the other as shown in figure 7.

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Figure 7 Conditioning amplifier circuit.

The real values of the resistances used in the non-inverting amplifying stage were measured with a multimeter before the circuit was stored in the case.

The cables for the input and output of the circuit were connected to the BNC connector previously embedded in the case for this purpose.

To generate the target signal to test the designed circuit, a conventional Michelson interferometer was used (Rojas-Ramirez & Pavon-Aguirre, 2013). This Michelson interferometer is used to measure mechanical vibration at UNAQ laboratories.

Ten direct measurements were made of the peak-peak value of the signal given by the interferometer. Subsequently, through a BNC cable the photodetector's output was connected to the input of the conditioning amplifier assembled. Ten measurements were made of the peak-peak value of the signal at the output of the conditioning amplifier's circuit.

4. Results

Table 1 shows the values of the resistances used in the amplifying stage of the conditioning amplifier circuit.

Resistance	Value [Ω]
R_f	9.88
R_i	0.99

Table 1 Real resistance values of the amplifying stage

Then, from equation (3), the expected relation between the circuit's input and output is given as $V_o = 10.98\ V_i$.

Table 2 shows ten voltage measurements at the input and output of the conditioning amplifier circuit.

Measurement	Input voltage [mV]	Output voltage [mV]
1	80.2	788
2	81.3	797
3	79.9	790
4	80.6	795
5	81.0	786
6	80.7	796
7	80.5	791
8	80.4	794
9	80.3	791
10	81.6	792

Table 2 Measurements read from oscilloscope of the peak-peak value of the interferometer's signal at the input and output of the conditioning amplifier

From the input measurements, an average peak-peak voltage of 80.6 mV was obtained, while from the measurements taken at the output of the conditioning amplifier an average peak-peak voltage of 792 was obtained. These measurements give an average gain of 9.82 attributed to the conditioning amplifier.

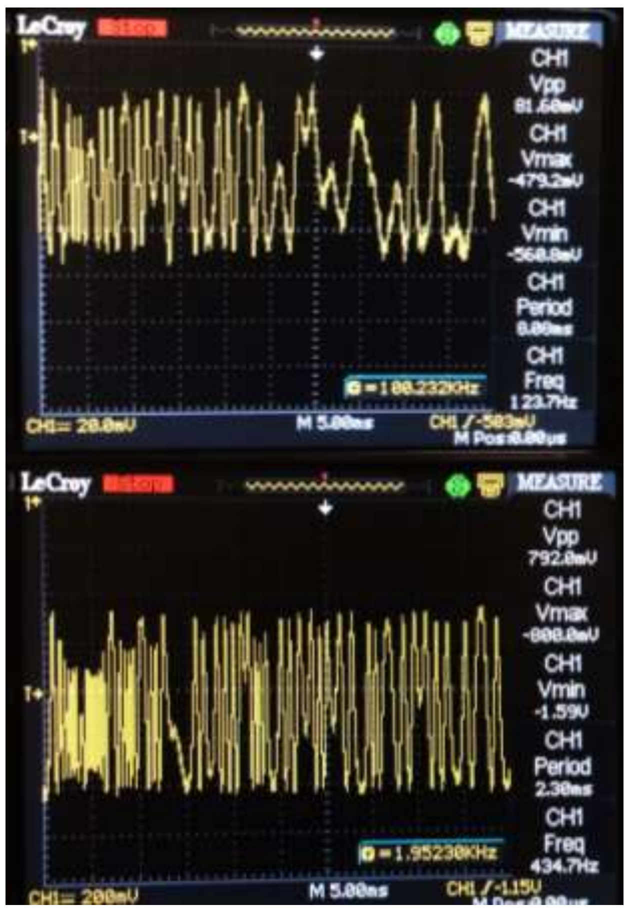

Figure 8 Original not treated signal (upper) and treated signal (lower) of the Michelson interferometer

5. Conclusions

The assembled conditioning amplifier was a low-cost device with an amplification of 9.82, which is close to the expected gain of 10. This 2% difference may be reduced by changing the feedback resistance in the amplification stage of the circuit.

It is important to note that the conditioning amplifier presented in this work was designed to be used with a conventional Michelson interferometer, which has a single output signal.

6. Acknowledgments

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