National Polytechnic Institute
Superior School of Computer Sciences

Analog Electronics.

Practice 7 - Instrumentation Amplifiers.

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Contents

1 Objective:

The student will implement the following circuits:

- **Instrumentation Amplifier.**
- **Bridge-Type Amplifier.**

2 Introduction:

A popular area of op-amp application is in instrumentation circuits such as dc or ac voltmeters. A few typical circuits will demonstrate how op-amps can be used.

2.1 Instrumentation Amplifier:

A circuit providing an output based on the difference between two inputs (times a scale factor) is shown in Figure 1.1.0. A potentiometer is provided to permit adjusting the scale factor of the circuit. While three op-amps are used, a single-quad op-amp IC is all that is necessary (other than the resistor components). The output voltage can be shown to be:

$$\frac{V_o}{V_1 - V_2} = 1 + \frac{2R}{R_p}.$$

so that the output can be obtained from:

$$V_o = (1 + \frac{2R}{R_p})(V_1 - V_2) = k(V_1 - V_2).$$

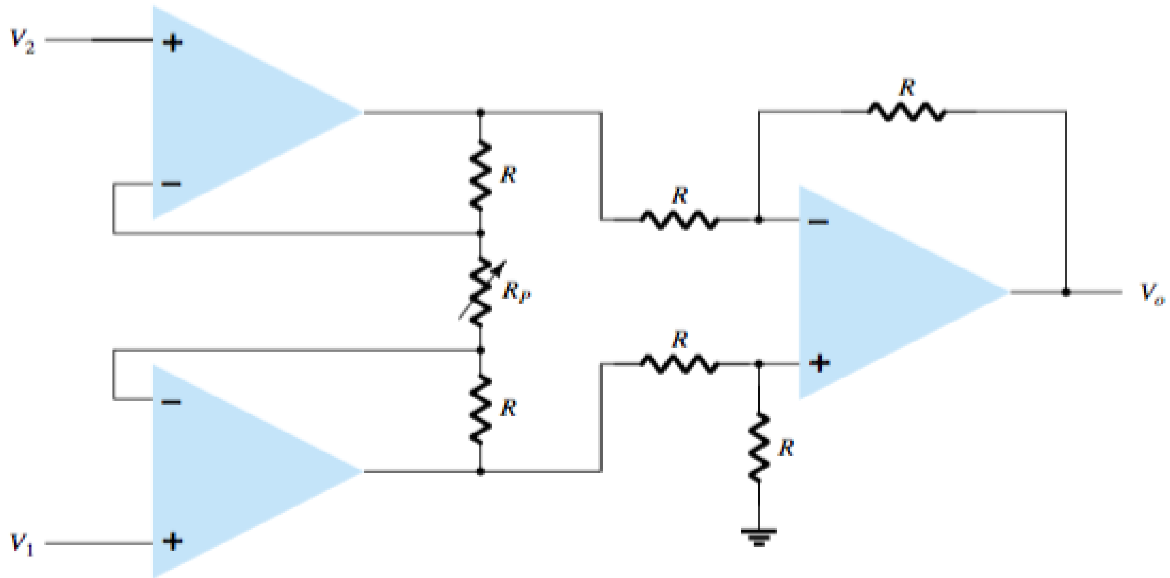

Figure 1.1.0: Instrumentation Amplifier.

3 Development:

We are going to analyze the **Instrumentation** circuits implementing an op-amp **TL071** with a 12 V source.

Observation: *For all the circuits we need a positive and negative voltage source in terminals 7 and 4 of the op-amp respectively. In the sources, we choose the option* ***SERIES*** *and connect both* E_1 *and* E_2 *in series by connecting the negative terminal of* E_1 *to the positive terminal of* E_2*, this "new" terminal will be connected to the common ground, thus, the positive terminal of* E_1 *and the negative terminal of* E_2 *will be the positive and negative voltages respectively.*

3.1 Bridge-Type Amplifier:

In Figure 3.1.0 it's presented the differential instrumentation amplifier, after we assembled this circuit, we adjust the output voltage V_o to zero volts with the preset help. As we can see we are using a *thermistor*, this device must be in ambient temperature, the measures consist in:

- Measure the output voltage with the *thermistor* in ambient temperature.
- Measure the output voltage pressing with your fingers the *thermistor* to make it variate its temperature.
- Measure the output voltage by putting very close to the *htermistor* lighter.

After measuring this output voltages, we capture our results in Table 1.

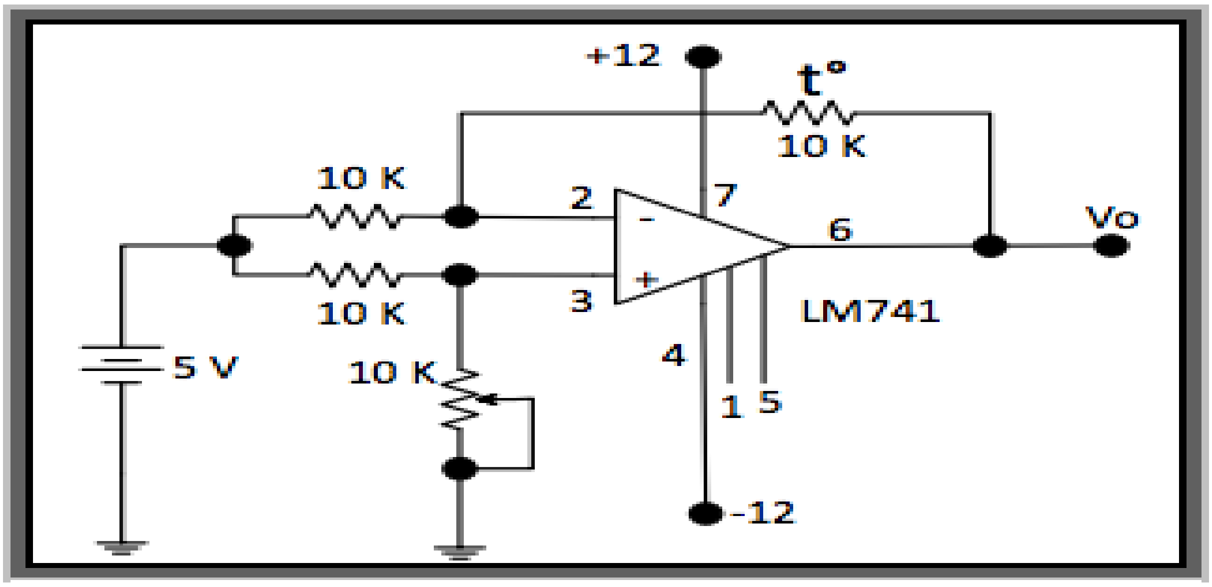

Figure 3.1.0: Instrumentation Amplifier.

Temperature	Output Voltage
Ambient	0.40 mV
Pressing with fingers	0.96 V
Putting a lighter close	2.21 V

Table 1: Figure 3.1.0 measured values.

3.2 Instrumentation Amplifier:

In Figure 3.2.0 it's presented the differential instrumentation amplifier, after we assembled this circuit, we adjust the output voltage V_o to zero volts with the preset help. As we can see we are using a *thermistor*, this device must be in ambient temperature, the measures consist in:

- Measure the output voltage with the *thermistor* in ambient temperature.
- Measure the output voltage pressing with your fingers the *thermistor* to make it variate its temperature.
- Measure the output voltage by putting very close to the *thermistor* lighter.

After measuring this output voltages, we capture our results in Table 2.

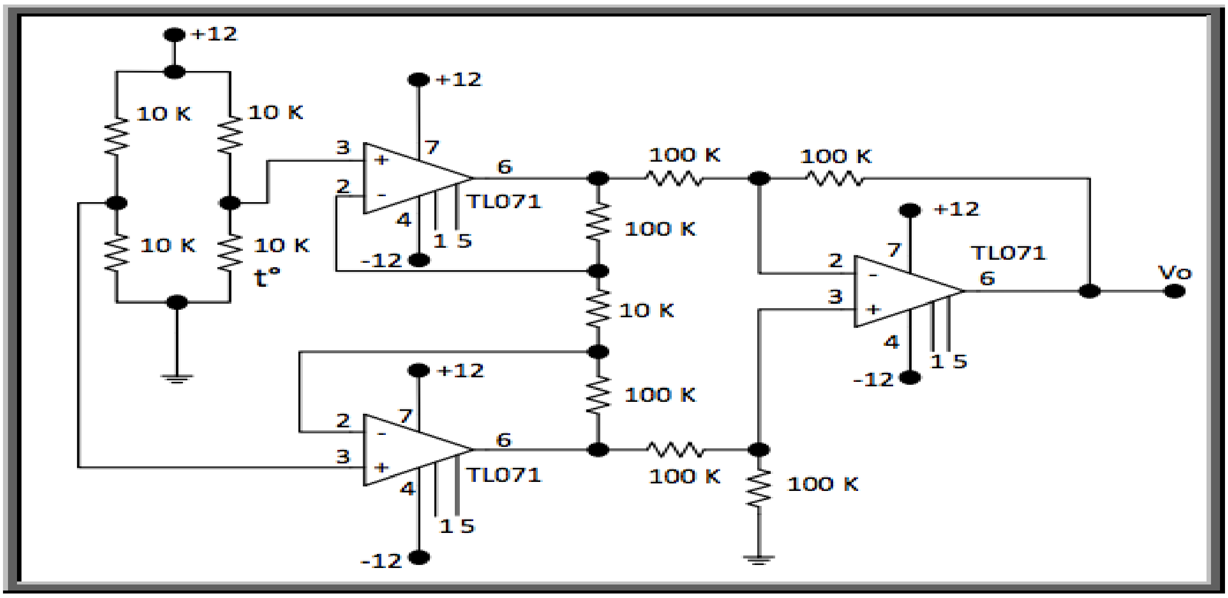

Figure 3.2.0: Instrumentation Amplifier.

Temperature	Output Voltage
Ambient	0.8 V
Pressing with fingers	3.9 V
Putting a lighter close	11.2 V

Table 2: Figure 3.2.0 measured values.

Finally, we let the *thermistor* to cold down and we set the oscilloscope in the channel one with a scale of *time/division* of 0.5 seconds, then, we connect the positive terminal to V_o and the negative terminal to the common ground. Finally the oscilloscope starts to show the variations by letting cold the *thermistor* and approaching repeatedly times the lighter to it as we can see in Figure 3.2.1.

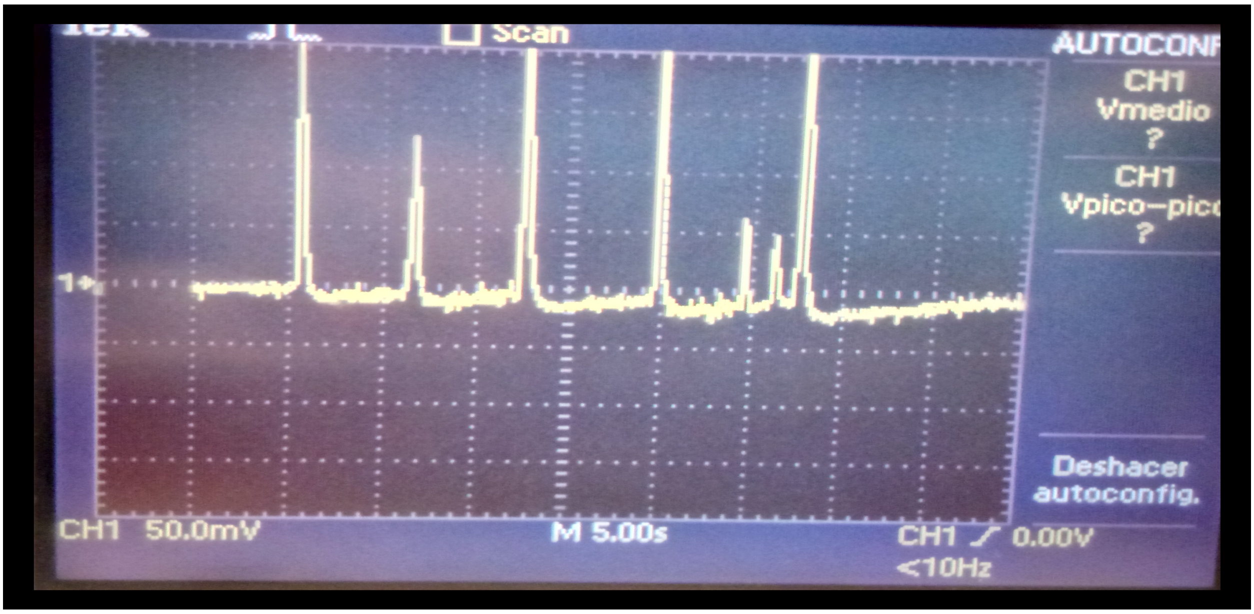

Figure 3.2.1: Instrumentation Amplifier output signal.

4 Simulations:

For each circuit that we have analyze in the section 3, we simulate each one of them, and we proceeded to make a comparative table with all the simulated, theoretical and development results.

4.1 Bridge-Type Amplifier:

For the circuit in Figure 3.1.0 we simulate it and captured in Figures 4.1.0 and 4.1.1, the results of the measures where registered in Table 3:

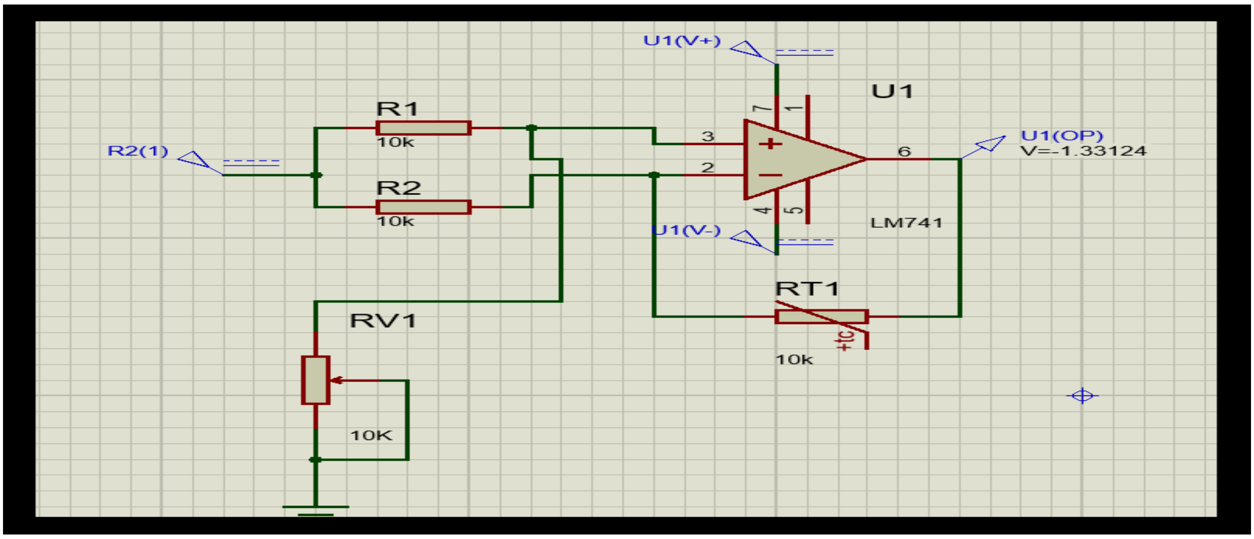

Figure 4.1.0: Bridge-Type amplifier with thermistor in ambient temperature.

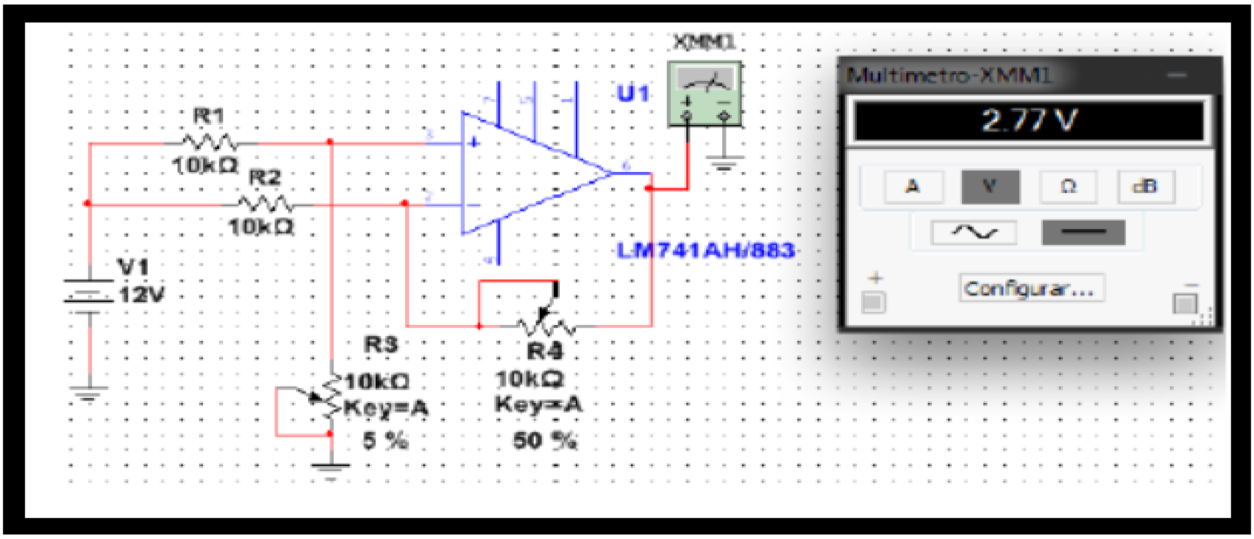

Figure 4.1.1: Bridge-Type amplifier with thermistor in high temperature.

Temperature	Output Voltage
Ambient	1.33 V
Putting a lighter close	2.77 V

Table 3: Figures 4.1.0 and 4.1.1 measured values.

4.2 Instrumentation Amplifier:

For the circuit in Figure 3.2.0 we simulate it and captured in Figures 4.2.0 and 4.2.1, the results of the measures where registered in Table 4:

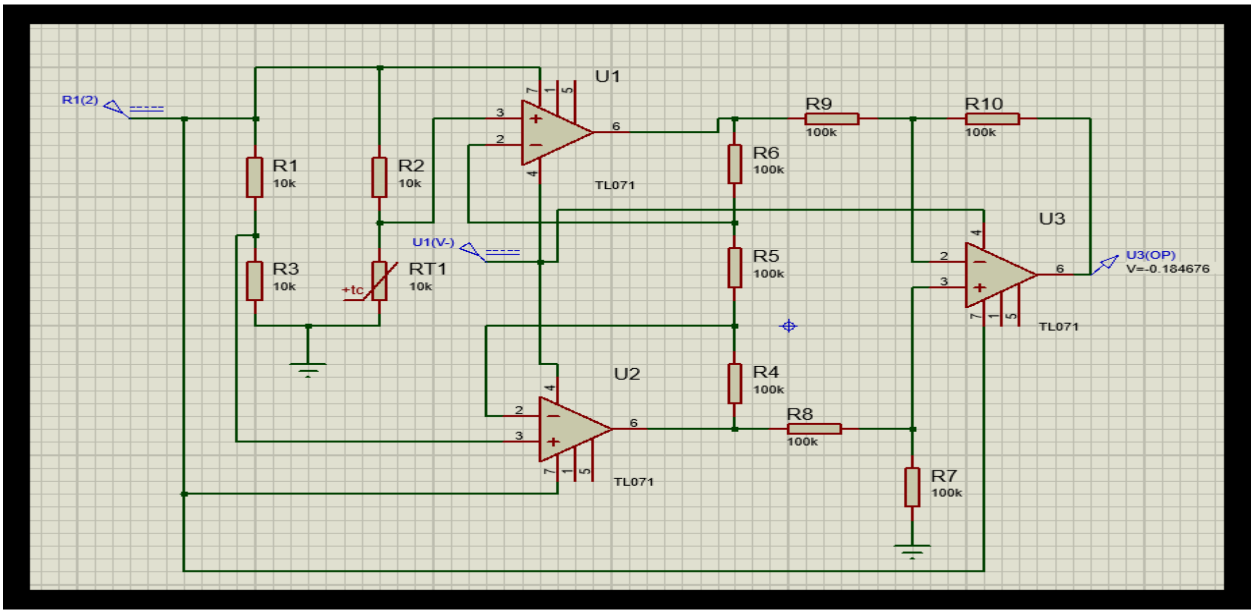

Figure 4.2.0: Instrumentation amplifier with thermistor in ambient temperature.

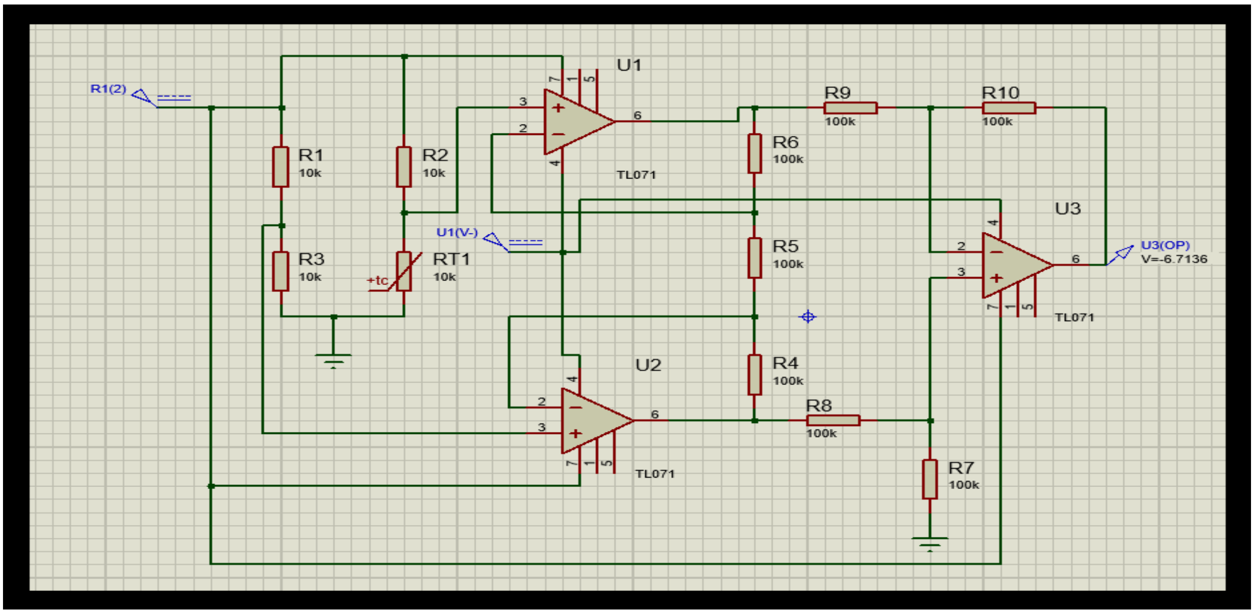

Figure 4.2.1: Instrumentation amplifier with thermistor in high temperature.

Temperature	Output Voltage
Ambient	0.18 V
Putting a lighter close	6.71 V

Table 4: Figures 4.2.0 and 4.2.1 measured values.

5 Theoretical Analysis:

For each circuit that we have analyze in the section 3, we calculate each one of them, and we proceeded to make a comparative table with all the theoretical, simulated and the development results.

5.1 Bridge-Type Amplifier:

The circuit that we are going to analyze it's the one in Figure 3.1.0 using the following parameters:

- **With a V_o = 0.4 mV.**
- **With a V_o = 0.9 V.**
- **With a V_o = 2.2 V.**
- **R = 10KΩ.**
- **V_i = 5 V.**

- ***For ΔR:***

With the V_o already calculated in the development, we want to know the variation in the resistance of the *thermistor*, so, we clear ΔR from the following formula.

Formula: $V_o = \frac{(\ V_i\ )(\Delta R\ )}{2R}$**.**

$$\Delta R = \frac{(\ 2\ )(\ R\ )(\ V_o\ )}{V_i}. \quad (1)$$

- ***From equation (1), we substitute V_o = 0.4 mV:***

$$\Delta R = \frac{(\ 2\ )(\ 10K\Omega\ )(\ 0.4mV\ )}{5V}$$

$$= \frac{8}{5}\Omega.$$

- ***From equation (1), we substitute V_o = 0.9 V:***

$$\Delta R = \frac{(\ 2\ )(\ 10K\Omega\ )(\ 0.9V\ )}{5V}$$

$$= 3600\Omega.$$

- ***From equation (1), we substitute V_o = 2.2 V:***

$$\Delta R = \frac{(\ 2\ )(\ 10K\Omega\ )(\ 2.2V\ )}{5V}$$

$$= 8840\Omega.$$

5.2 Instrumentation Amplifier:

The circuit that we are going to analyze it's the one in Figure 3.2.0 using the following parameters:

- **With a V_o = 0.8 V.**
- **With a V_o = 3.9 V.**
- **With a V_o = 11.2 V.**
- R_g = **10KΩ.**
- **R = 100KΩ.**
- E_2 = **6 V.**

- ***For E_1:***

With the V_o already calculated in the development, we want to know the variation in the resistance of the *thermistor*, so, we clear R_t from the following voltage divider.

Formula: $E_1 = \frac{(\ V_i\ )(\ R_t\ )}{R_1\ +\ R_t}$.

$$E_1 = \frac{(\ 12V\ )(\ R_t\ )}{10K\Omega\ +\ R_t}$$

$$12V \cdot R_t = (\ E_1 \cdot 10K\Omega\ ) + (\ E_1 \cdot R_t\ )$$

$$\frac{E_1 \cdot 10K\Omega}{R_t} = 12V - E_1.$$

Finally:

$$R_t = \frac{E_1 \cdot 10K\Omega}{12V - E_1}. \tag{1}$$

Then, we need to find E_1, so, from the following formula we clear this value:

Formula: $V_o = [\ 1 + \frac{2R}{R_g}\ ]\ (\ E_2 - E_1\ )$.

$$V_o = [\ 1 + \frac{2R}{R_g}\ ]\ (\ E_2 - E_1\ )$$

$$V_o = [\ \frac{2R + R_g}{R_g}\ ]\ (\ E_2 - E_1\ )$$

$$-E_1 = \frac{R_g \cdot V_o}{R_g + 2R} - E_2.$$

Finally:

$$E_1 = E_2 - \frac{R_g \cdot V_o}{R_g + 2R}. \tag{2}$$

- ***From equation (2), we substitute V_o = 0.8 V:***

$$E_1 = 6V - \frac{10K\Omega \cdot 0.8V}{10K\Omega + 2 \cdot 100K\Omega}$$

$$= 5.96V.$$

- ***From equation (2), we substitute V_o = 3.9 V:***

$$E_1 = 6V - \frac{10K\Omega \cdot 3.9V}{10K\Omega + 2 \cdot 100K\Omega}$$

$$= 5.81V.$$

- ***From equation (2), we substitute V_o = 11.2 V:***

$$E_1 = 6V - \frac{10K\Omega \cdot 11.2V}{10K\Omega + 2 \cdot 100K\Omega}$$

$$= 5.48V.$$

Then, for R_t we substitute the previous E_1 calculated values:

- ***From equation (1), we substitute E_1 = 5.96 V:***

$$R_t = \frac{5.96V \cdot 10K\Omega}{12V - 5.96V}$$

$$= 9867.5\Omega.$$

- ***From equation (1), we substitute E_1 = 5.81 V:***

$$R_t = \frac{5.81V \cdot 10K\Omega}{12V - 5.81V}$$

$$= 9386.1\Omega.$$

- ***From equation (1), we substitute E_1 = 5.48 V:***

$$R_t = \frac{5.48V \cdot 10K\Omega}{12V - 5.48V}$$

$$= 8404.9\Omega.$$

6 Comparisons:

In this sections we will compare the development, simulated and theoretical results for each circuit in each configurations.

6.1 Bridge-Type Amplifier:

Comparison of subsection's 3.1, 4.1 and 5.1 results:

	Ambient V_o	Near to a lighter V_o
Practical	0.40 mV	2.21 V
Simulated	1.33 V	2.77 V
Theoretical	0.4 mV	2.21 V

Table 5: Comparison results for the Bridge-Type Amplifier.

6.2 Instrumentation Amplifier:

Comparison of subsection's 3.2, 4.2 and 5.2 results:

	Ambient V_o	Near to a lighter V_o
Practical	0.8 V	11.2 V
Simulated	0.18 V	6.71 V
Theoretical	0.8 V	11.2 V

Table 6: Comparison results for the Instrumentation Amplifier.

Observation: *We believe that there is some discrepancy in the simulated and development results because the simulated ones are in an ideal atmosphere.*

Observation: *The theoretical and development results are the same because we took this last measured values and calculate in the theoretical analysis the variations in the thermistor.*

7 Questionnaire:

- **What is the difference between the instrumentation amplifier and the subtracter?**

  The main difference is that in the instrumentation amplifier is that the inputs that go to the operational amplifier are connected to each other and in the subtracter are separated. Another of the main differences is that the instrumentation amplifier works with very small voltages such as the micro volt scale

- **Mention 3 examples where the instrumentation amplifier is used:**

  1. To amplify biological electrical signals (for example in electrocardiograms).
  2. As part of circuits to provide constant current power.
  3. In power supplies.

- **How is the gain of the instrumentation amplifier calculated?**

  It is divided into 2: pre-amplified gain and differential gain, the product of these two mentioned gains is the total gain of the instrumentation amplifier.

- **Which is the purpose to add him a resistance in parallel to the capacitor in the integrador and a capacitor in parallel to the resistance of the derivator?**

  Common differential amplifiers are used in circuits where the impedance of the source is low. Strain gauge transducers, for example, typically have elements with lower resistance than 1KΩ.

8 Conclusion:

The amplifiers, as far, are the most complicated and important device that we think, we analyze in this course, this because, they have a lot of applications and different configuration for a so tiny and simple device. Its functionality it's based on the transistor principle and we have seen and demonstrated that depending of the devices that we connect around of the amplifier it will do a specified operation as a addition, product, subtraction, integration, derivation, inclusive the Fourier Transform. This device has a lot of applications in the industry and in out daily life. Also, the positive and negative inputs can be used to have a level detector by using this voltage as saturation V_{sat}. In every new class we discover that this device has more and more configurations and applications, like the one with hysteresis voltage by feedback the non-inverting input with the V_{sal} output. In this time we were able to analyze the Instrumentation and Bridge-Type amplifier, witch applications in the industry are required because they work with very low levels of voltage. Also, as an extra, we have the opportunity to add to this circuits a *thermistor*, this allow us to increase or decrease the output voltage of each circuit depending on the temperature of this resistor, a very interesting device this is.

9 Bibliographic References:

[1] BOYLESTAD, Robert L. "Electronic Devices and Circuit Theory". Edit. Prentice Hall. 2009.