

# MEEC/MIEEC

## ELECTRONICS FOR MICRO-SYSTEMS

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### Lab#1 P1 A Temperature Meter System with 3 Sensors, Relay and GUI

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**Authors:**

Martim Duarte Agostinho (70392)  
Francisco Simões Coelho Sá da Costa (70386)  
Sofia Margarida Mafra Dias Inácio (58079)

[md.agostinho@campus.fct.unl.pt](mailto:md.agostinho@campus.fct.unl.pt)  
[fsc.costa@campus.fct.unl.pt](mailto:fsc.costa@campus.fct.unl.pt)  
[sm.inacio@campus.fct.unl.pt](mailto:sm.inacio@campus.fct.unl.pt)

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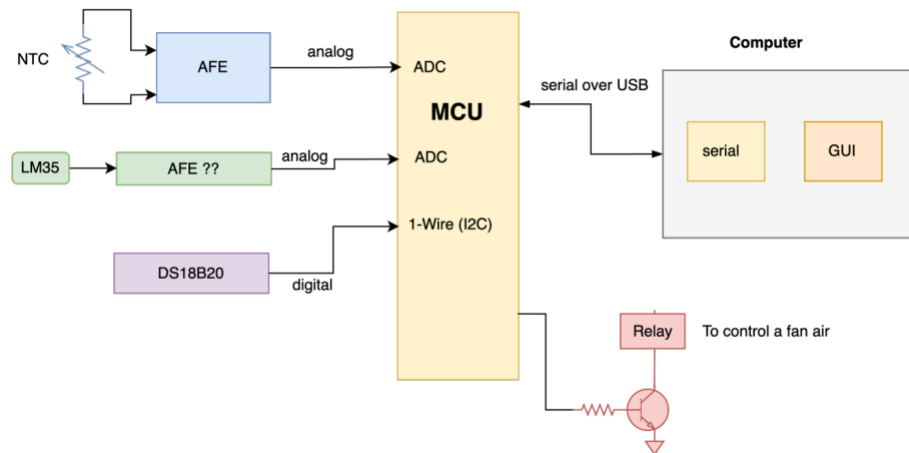
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# 1 Introduction

explain the requirements and the main objectives of the project Se calhar dizer aqui quais sao as metricas por onde podemos avaliar a nossa solucao Linearidade de output para conseguir aproveitar melhor a resolucao do adc Consumo erro



**Figure 1:** Temperature sensing system with 3 three types of sensors.

## 2 Temperature Sensors

### 2.1 NTC - Negative Temperature Coefficient

### 2.2 LM35 - Precision Centigrade Temperature Sensor

### 2.3 DS18B20 - Digital Thermometer

## 3 System Design

### 3.1 Analog FrontEnd (AFE) NTC

A parte onde definimos o intervalo de temperatura nao devia estar aqui pq é para todos os circuitos

In order to design the *NTF AFE* first it's necessary to define the temperature interval in which this circuit will work, thus it was define as  $T \in [10^\circ; 40^\circ]$ . Through the *NTC*'s datasheet the interval of its resistance values is  $R_{NTC} \in [5,282k ; 19,98k]$

For an accurate reading of the temperature it was used the *Steinhart-Hart equation*.

$$\frac{1}{T} = A + B \cdot \ln(R_{NTC}) + C \cdot [\ln(R_{NTC})]^3 \quad (1)$$

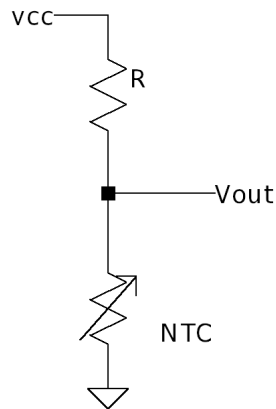
In order to find the parameters  $A$ ,  $B$  and  $C$ , its necessary to use 3 points from the datasheet. The points chosen were the two extremes and the middles point.

$$\begin{cases} R(283,15) = 1,998 \cdot 10^4 \Omega \\ R(298,15) = 10^4 \Omega \\ R(313,15) = 0,5282 \cdot 10^4 \Omega \end{cases} \Leftrightarrow \begin{cases} A = 1,2 \cdot 10^{-3} \\ B = 2,1 \cdot 10^{-4} \\ C = 1,3 \cdot 10^{-7} \end{cases} \quad (2)$$

Para poder dimensionar o AFE do NTC primeiro é necessario definir o intrevalo de temperaturas em que o circuito irá operar. Foi então decidido que seria adequado um temperatura  $T \in [10^\circ; 40^\circ]$ . E pelo datasheet do NTC foi obtido o intrevalo da sua resistencia  $R_{NTC} \in [5,282k ; 19,98k]$

Para usar equacao Steinhart-Hart  $\frac{1}{T} = A + B \cdot \ln(R) + C \cdot [\ln(R)]^3$ , precisamos de usar 3 pontos para encontrar as constantes  $A$ ,  $B$  e  $C$ .  $R(T) = R_{NTC}$  onde  $T$  é a temperatura em kelvin e  $R_{NTC}$  é o valor da resistencia do thermistor *NTC*

The simplest way to convert the resistance to voltage, is to use a voltage divider circuit.

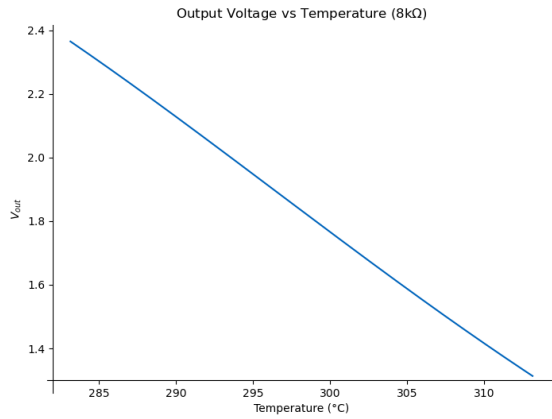


**Figure 2:** NTC voltage divider.

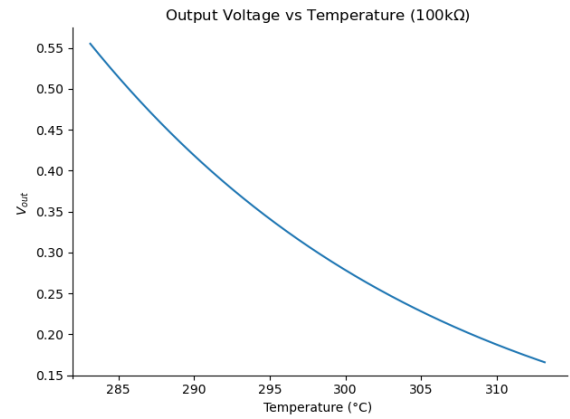
This approach has a few problems:

- The output resistance is really high  $R \parallel NTC$ ,
- The output voltage is highly non linear, which is a problem because this way some *ADC* resolution is lost.

The first problem is solved through a buffer at the entrance of the *AFE*, and the second is somewhat mitigated by using a resistor value around  $8k\Omega$ . To achieve this value it was used the beta model for the *NTC* and through a python script, the resistor value was iterated until an almost linear output was achieved.



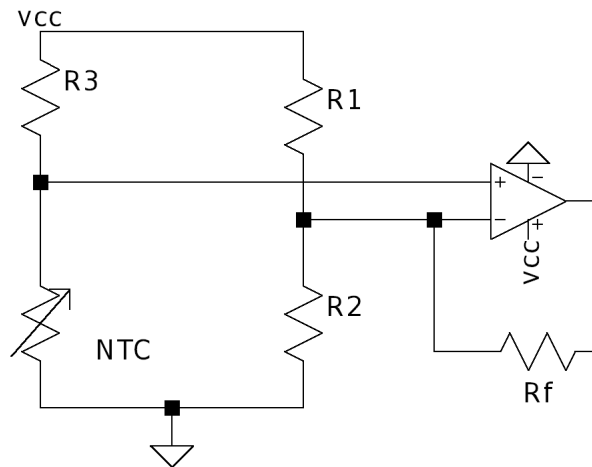
(a)  $8K\Omega$



(b)  $100K\Omega$

**Figure 3:** Output Voltage vs Temperature

With  $R = 8k$  the output signal is  $V_{out} \in [1.31V; 2.36V]$ . But the *ADC* as resolution of 12 bits and a voltage range of  $3.3V$ , meaning that to have the best resolution possible the signal needs an offset and a gain of 2.87 and  $-1.75$  respectively. It's important to note that a  $0.1V$  margin was added to  $V_{out}$  in order to ensure that the *AFE* works properly in the specified range. This gain and offset was achieved through the following topology.



**Figure 4:** NTC's AFE topology

**Nao esquecer de fazer referencia ao codigo funcao AfeNtc()**

As already specified the  $R_3$  value is  $8K \Omega$  and for the purpose circuit dimensioning the circuit the positive node of the opamp will be treated as a variable  $V_p$ .

Using python the circuit function  $V_{out}(V_p)$ :

$$V_{out} = V_p \left[ 1 + R_f \cdot \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \right] - V_{cc} \cdot \frac{R_f}{R_1} \quad (3)$$

Now it's clear to see what part of the equation is responsible for the circuit gain and offset.

$$\begin{cases} V_{offset} = -V_{cc} \cdot \frac{R_f}{R_1} \\ G = \left[ 1 + R_f \cdot \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \right] \end{cases} \quad (4)$$

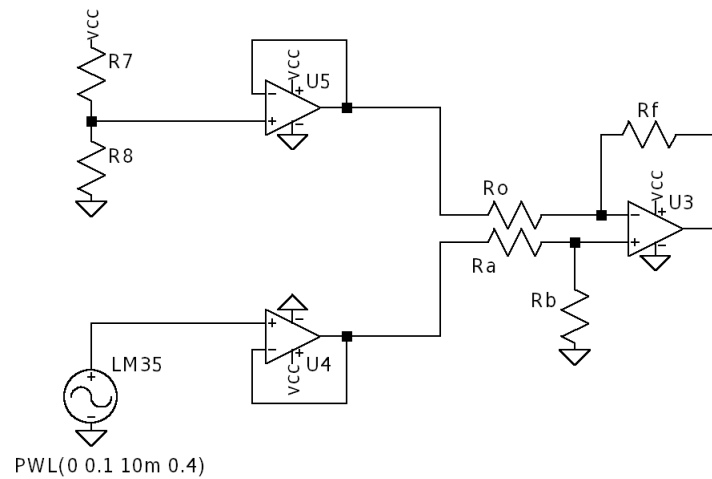
Setting  $R_f = 10K$  the values that satisfy the equation system are  $R_1 = 9348\Omega$  and  $R_2 = 11760\Omega$ . In the simulation this values are a bit too close to the limits so in order to have better margins and to use the available resistors the final values are  $R_1 = 8.2K\Omega$  and  $R_2 = 12K\Omega$ .

### 3.2 LM35

This integrated-circuit temperature sensor, generates an output voltage linearly proportional to the Centigrade temperature.

$$V_{out} = 10^{-2} \cdot T$$

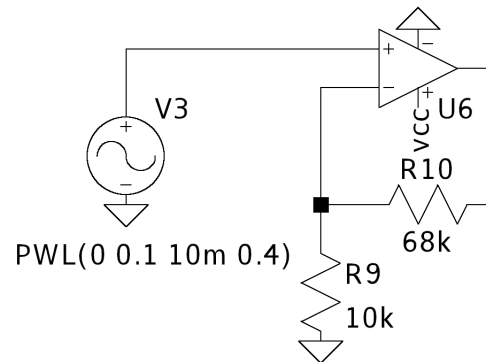
Hence, in the specified conditions  $V_{out} \in [0.1; 0.4]$ . To increase resolution as done in [NTC's AFE subsection](#), it's needed to add gain and an offset. For this purpose a differential amplifier can be used.



**Figure 5:** LM35 Differential Amplifier.

Although this circuit achieves the expected output, the amount of components, increases noise and power consumption, thus the used topology was a non-inverting amplifier.



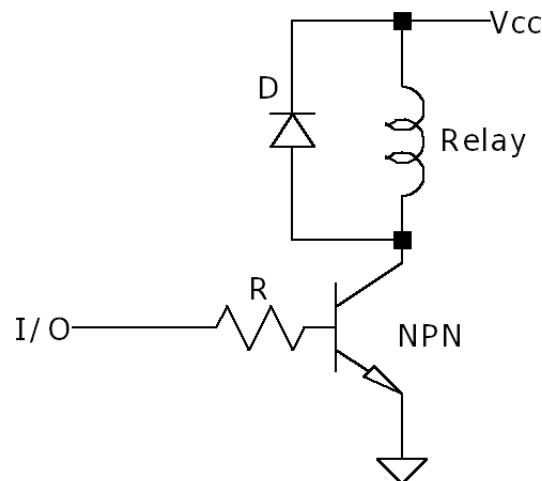


**Figure 6:** AFE for the LM35 sensor.

This way the input impedance is high, only one OpAmp and two resistors are used. But this comes with the cost of lost resolution. With a gain of 8  $V_{out} \in [0.8V, 3.2V]$  0.8V of range in the *ADC* are lost.

### 3.3 Output Relay

Lastly the *MCU* will turn on and off a fan. For this purpose a relay will open and close the fan circuit. Because the *MCU's* *I/O* can drive the relay a *NPN* transistor is used to get enough current. Thus the following circuit also needs to be dimensioned. It's important to note that the diode is needed to protect the circuit.



**Figure 7:** Relay circuit.

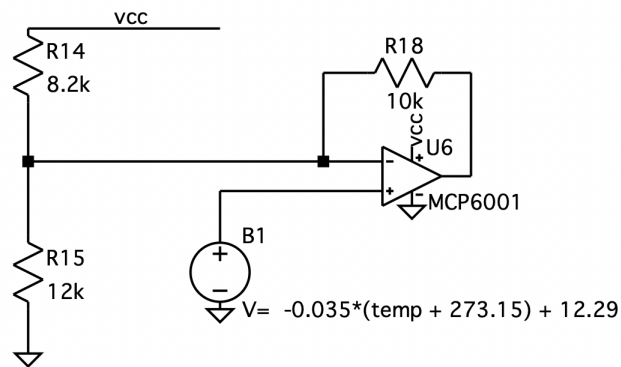
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$$R = \frac{I/O_{HIGH} - V_{BE}}{I_r} \cdot \beta \Leftrightarrow R = \quad (5)$$

## 4 Simulations

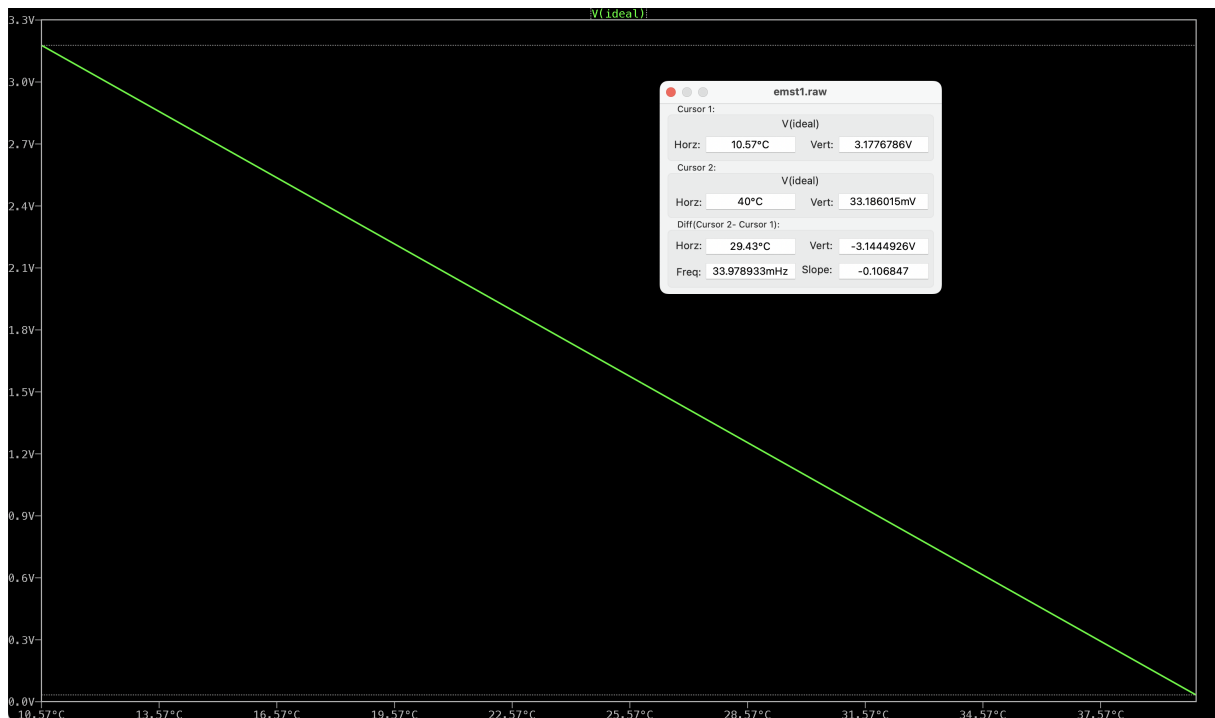
### 4.1 NTC

For the purpose of testing the following circuit was designed. At first with linear voltage supply since as seen in [section](#), this voltage is almost linear.



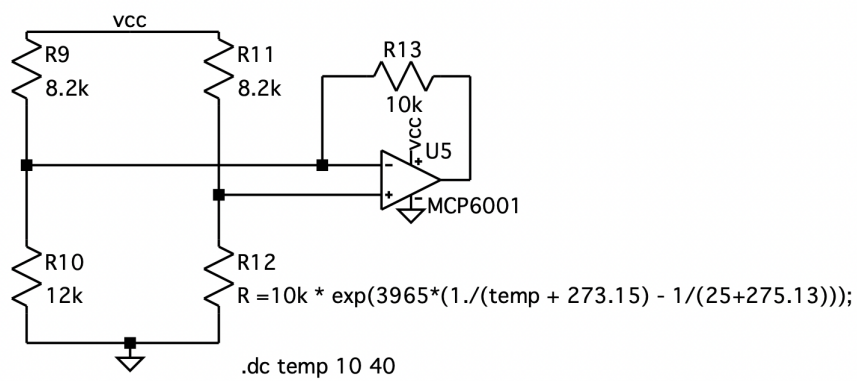
**Figure 8:** Linear supply NTC test circuit.

Producing the following results.



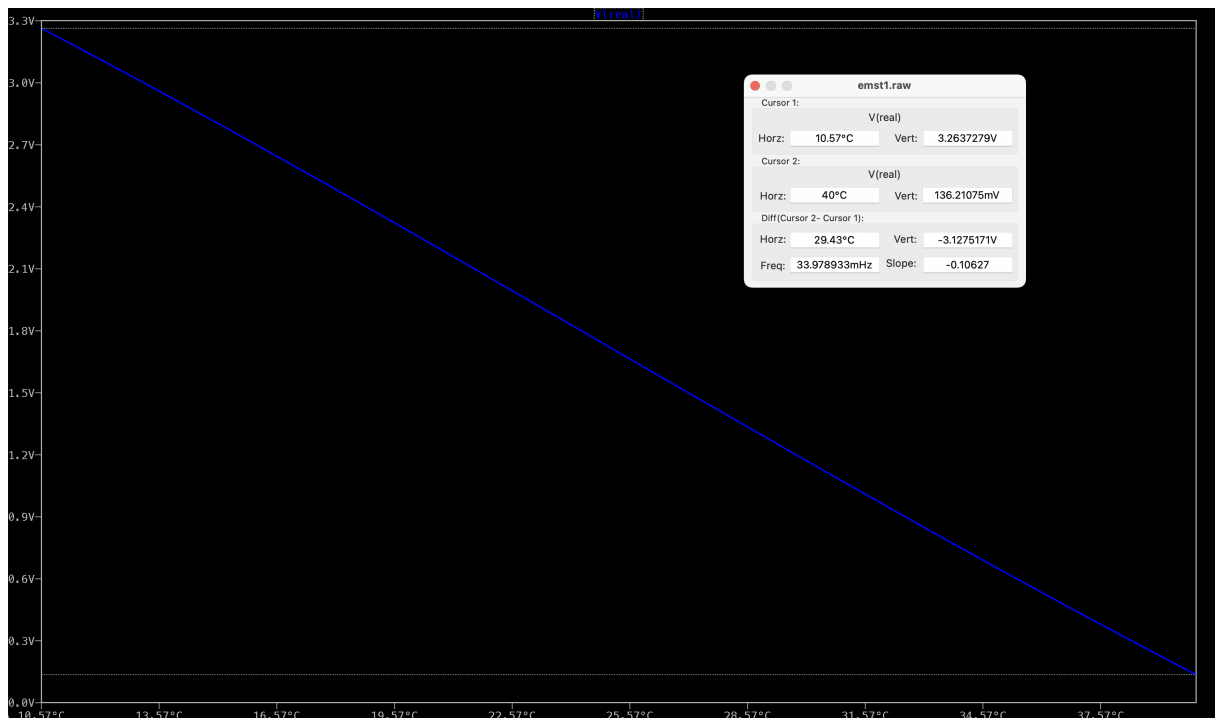
**Figure 9:** Linear supply NTC test results.

Confirming the effectiveness of the *AFE* circuit a more realistic circuit was tested.



**Figure 10:** Realistic NTC test circuit.

With following results.



**Figure 11:** Realistic NTC test results.

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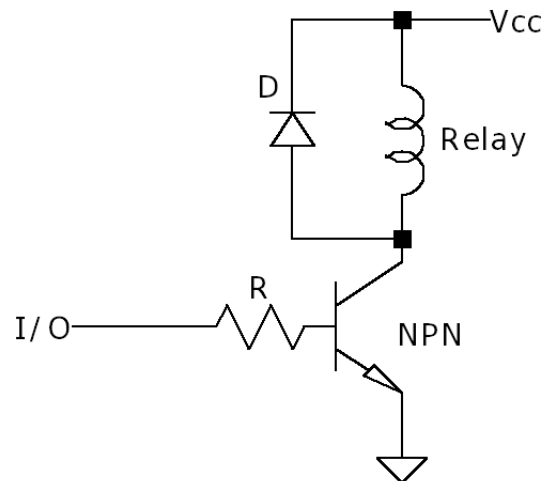
Comparing both results the difference is minimal. Confirming that the output is nearly linear in relation to the temperature variation.



**Figure 12:** NTC Linear and Realistic results comparison.

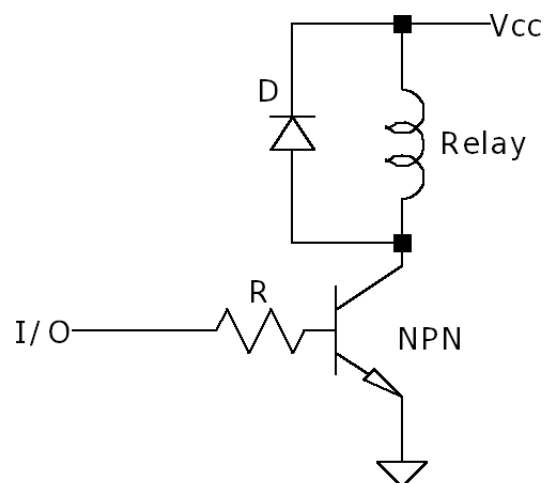
## 4.2 LM35

For this sensor the simulation is straight forward, since the output is linear and proportional to the temperature, it can be simulated with variable voltage supply.



**Figure 13:** Relay circuit.

Giving the following results.



**Figure 14:** Relay circuit.

## **5 Implementation and Experimental Tests**

## **6 Results Analysis**

## **7 Conclusion**