MEEC/MIEEC

Electronics for Micro-Systems

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

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1 Introduction

The primary objective of this project is to design, implement, and evaluate a temperature meter system that integrates three distinct temperature sensors: an NTC thermistor, an LM35 analog sensor, and a DS18B20 digital sensor. The system also incorporates a relay-controlled fan and a graphical user interface (GUI) for data visualization and control.. This project aims to compare the performance of each sensor in terms of accuracy while assessing the system's overall power consumption and efficiency.

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For the system Design it's important to define the temperature interval in which this system will work, thus it was define as $T \in [10°C; 40°C]$.

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

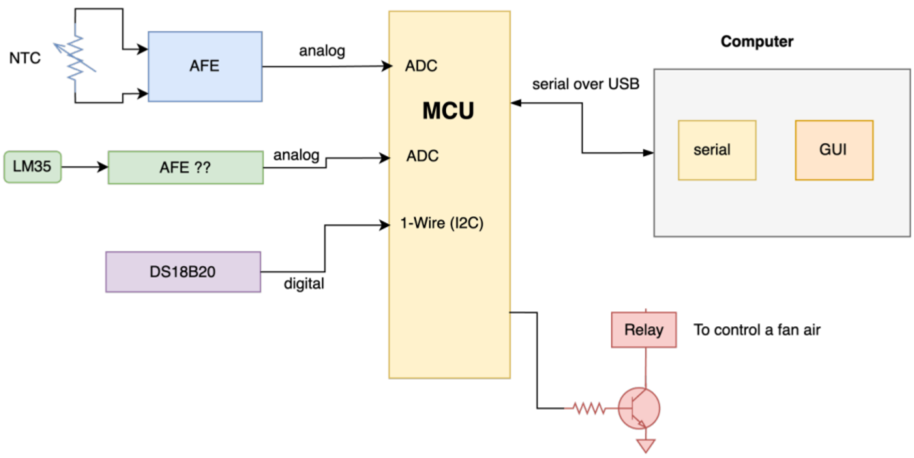


Figure 1: Temperature sensing system with 3 three types of sensors.

2 Temperature Sensors

2.1 NTC - Negative Temperature Coefficient

Temperature Coefficient (NTC), means that the sensor resistance decreases as temperature increases. This behavior exhibits a predictable response to temperature variations.

o que]e info da datasheet tirar o primeiro paragrafo de 3.1

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

Through the NTC's datasheet, according with the system requirements, 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.

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

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 middle point. DAR FIX AOS ABCS nao sei os valores

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

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

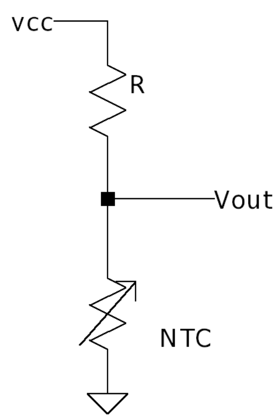
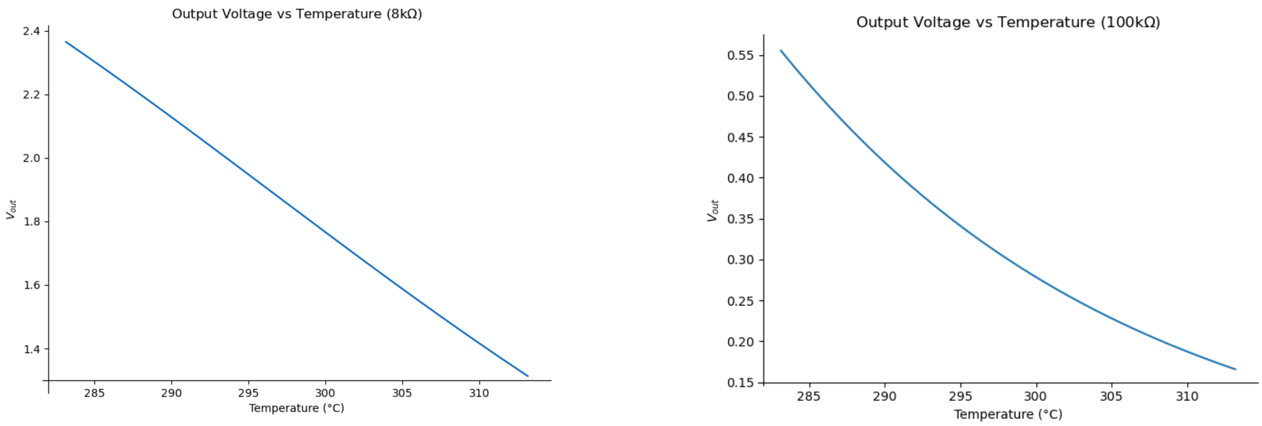


Figure 2: NTC voltage divider.

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. See NtcTempToVoltage() function in the attached python script.



(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.

The most obvious way to achieve this values would be with a differential amplifier, as seen in the following circuit.

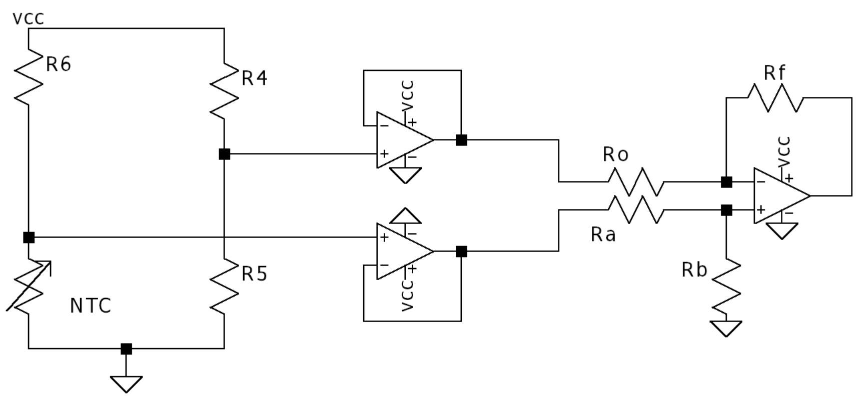


Figure 4: NTC's AFE Differential Amplifier

Although in the simulation this yields the expected result, using the wheatstone with a precision OpAmp as bridge amplifier, it's possible to achieve gain and offset using less components, yielding better results in terms of power consumption and thermal noise.

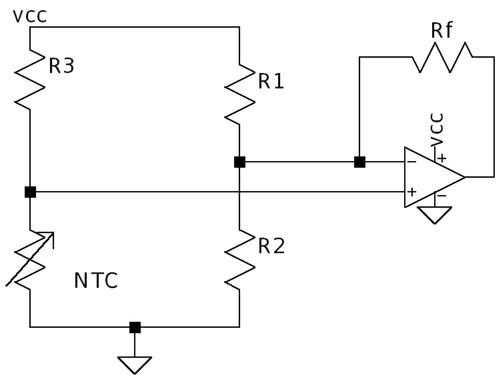


Figure 5: NTC's AFE topology

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 $V_{out}(V_p)$:

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

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

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

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.

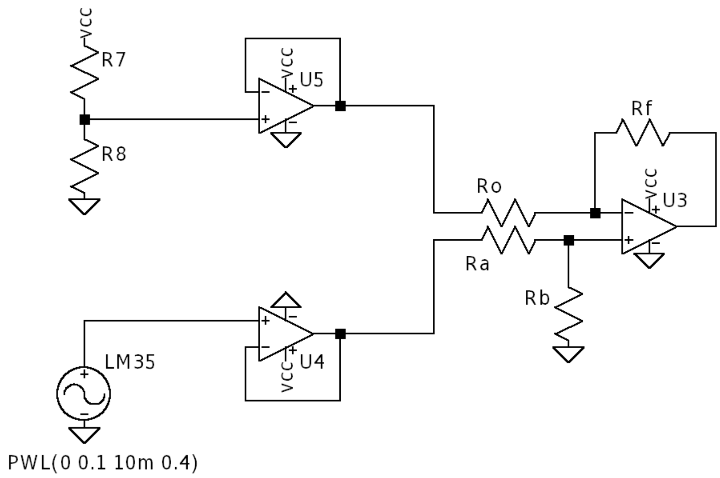


Figure 6: LM35 Differential Amplifier.

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.

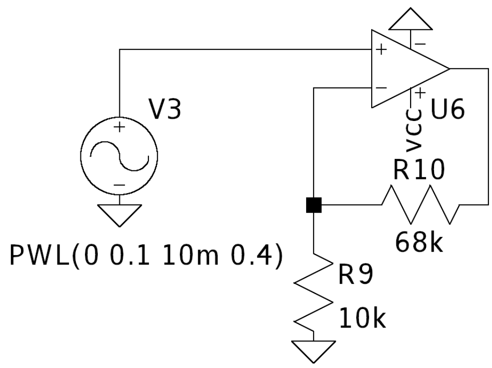


Figure 7: AFE for the LM35 sensor.

FALTA DIZER O GANHO COM A RES REAL 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 $V_{out} \in [0.8V, 3.2V]$ $0.8V$ or 24% 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't drive the relay a *NPN* transistor is use 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.

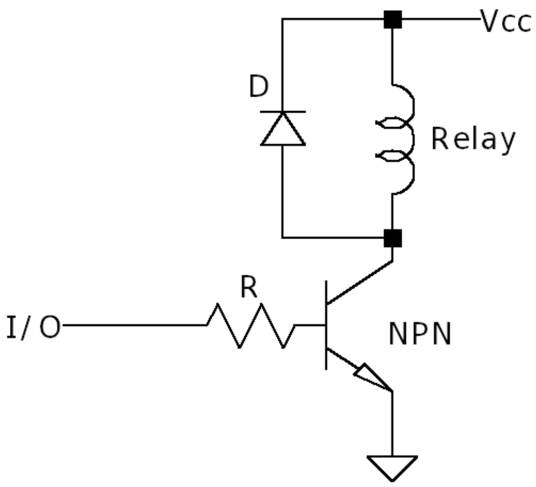


Figure 8: Relay circuit.

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

4 Simulations

4.1 NTC

4.1.1 Titulo ?

Martim: Achei que se cahlhar separar entre esta sim e montecarlo For the purpose of testing the following circuit was designed. At first with linear voltage supply since as seen in ection, this voltage is almost linear.

Producing the following results.

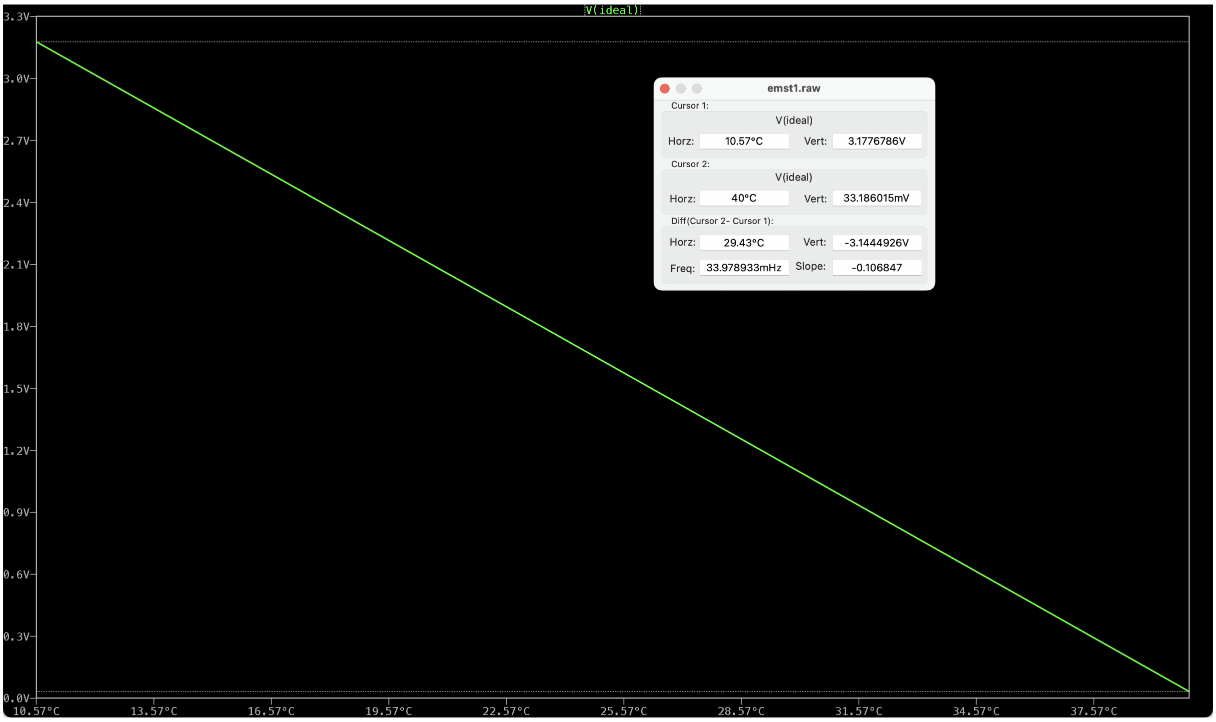

Figure 9: Linear supply NTC test results.

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

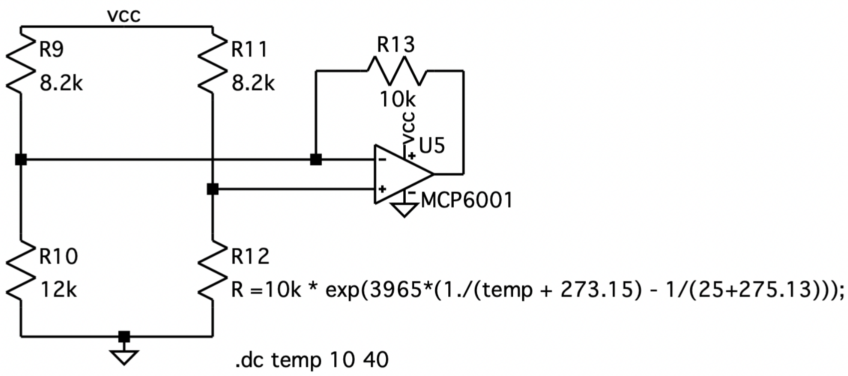

Figure 10: Realistic NTC test circuit.

With the following results.

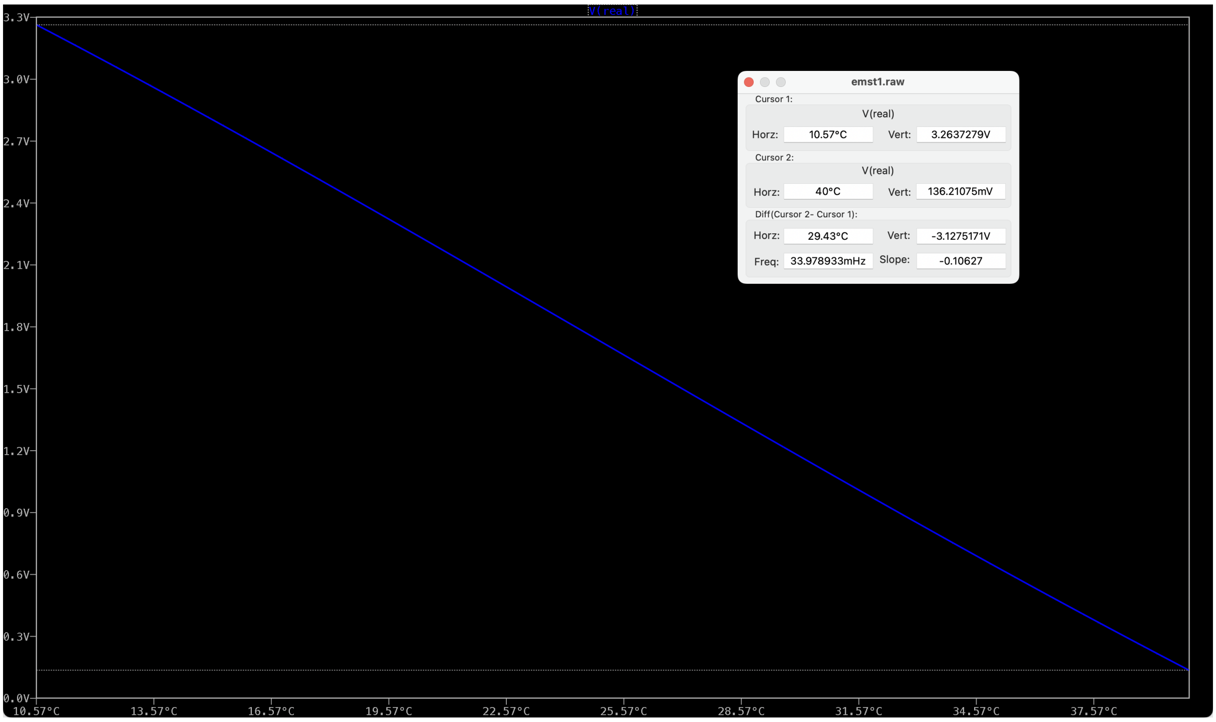

Figure 11: Realistic NTC test results.

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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.

4.1.2 Montecarlo

A Montecarlo simulation is done in order to evaluate the AFE's output in relation to the normal distribution of the resistor values. Giving a sense of how reliable the circuit is.

Figure 13: NTC Linear and Realistic results comparison.

Esta justificacao esta fraquinha Since the output voltages surpass the defined range, the AFE gain should be lowered and/or the offset augmented. This was not done because this only happens in some cases and this way no resolution is lost.

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 a variable voltage supply.

The circuit used to test was the same seen in the lm35 design section. Giving the following results, confirming that this approach works as expected.

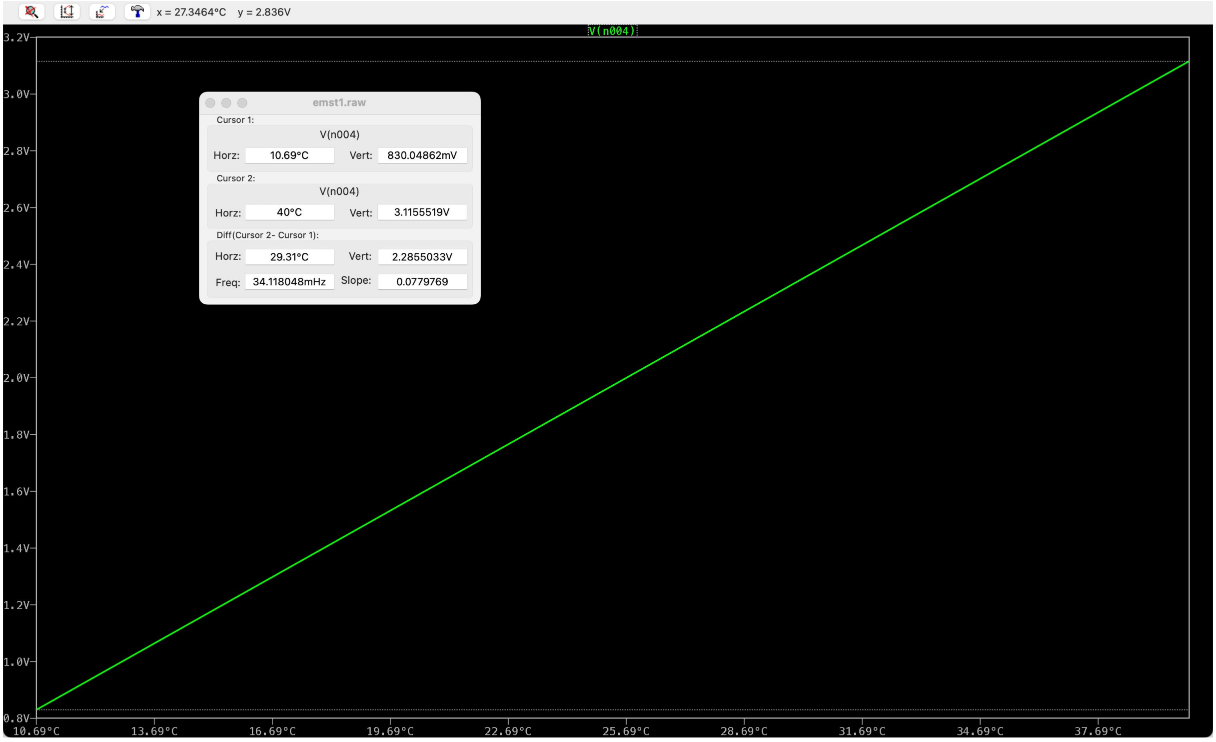

Figure 14: LM35 AFE test results.

4.2.1 Montecarlo

For the same reasons explained in section 4.1.2 a Montecarlo simulation is needed for this AFE.

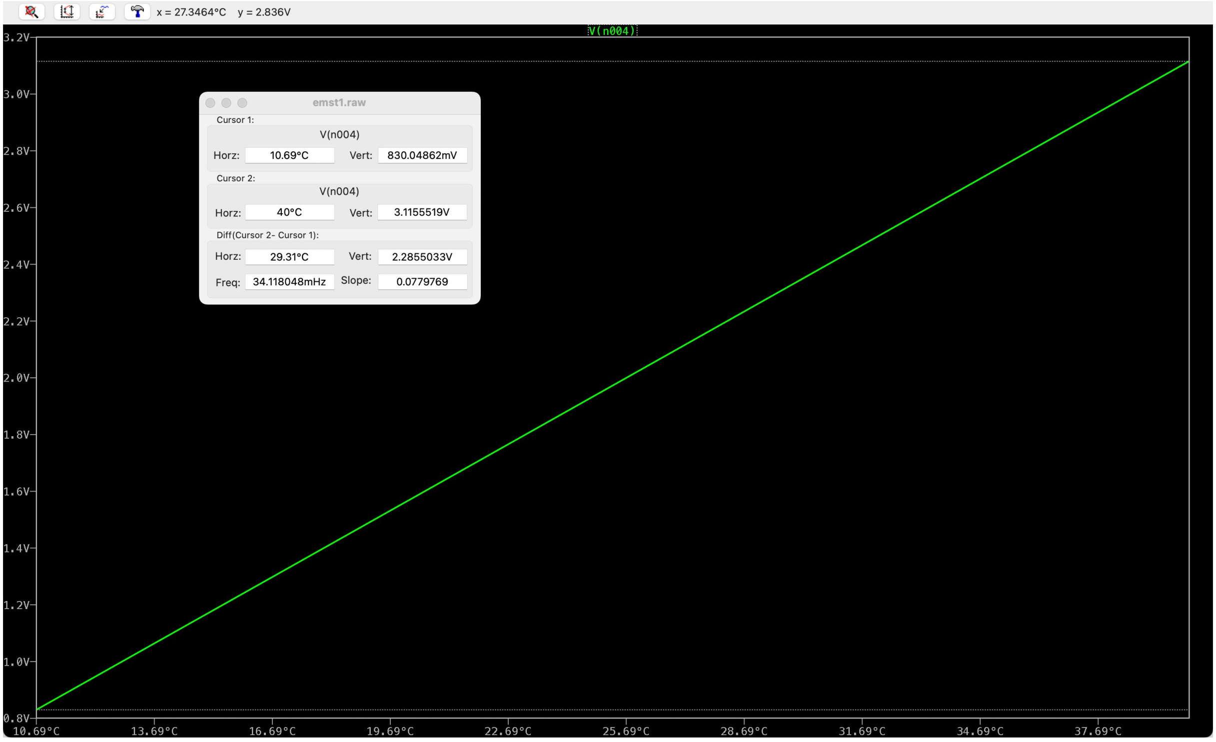

Figure 15: LM35 AFE test results.

4.3 Power Consumption

In modern electronic systems, power consumption plays a crucial role.This section analyzes the power consumption of the temperature meter system as whole.

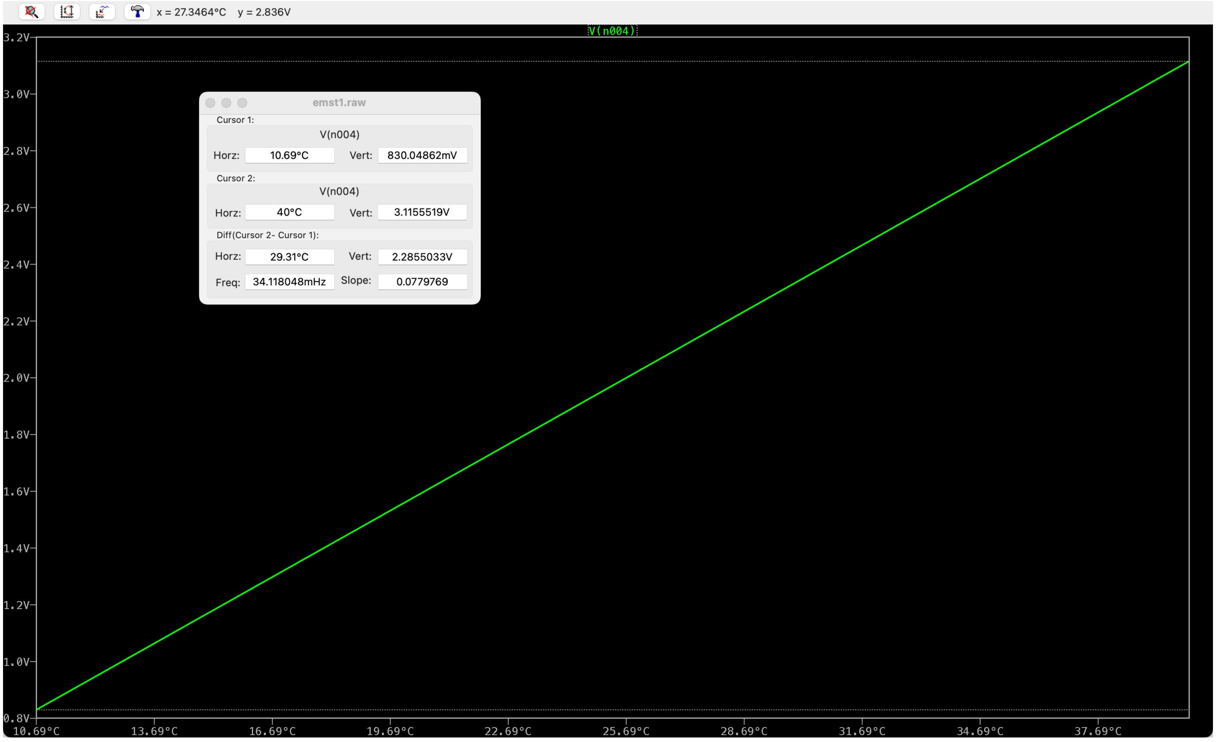

Figure 16: LM35 AFE test results.

5 Implementation and Experimental Tests

6 MCU Code

7 Results Analysis

8 Conclusion