MISR UNIVERSITY FOR SCIENCE AND TECHNOLOGY
COLLEGE OF ENGINEERING
MECHATRONICS DEPARTMENT

MTE 405 SENSORS AND MEASUREMENTS

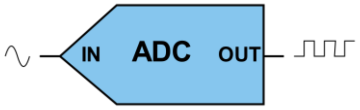
LAB 2 – SPRING 2020

Lab 1

Goals Of The Lab

Introduction to Sensors and Signal Conditioning with Virtual Prototyping

Introduction to temperature sensors



Spreading signal output range

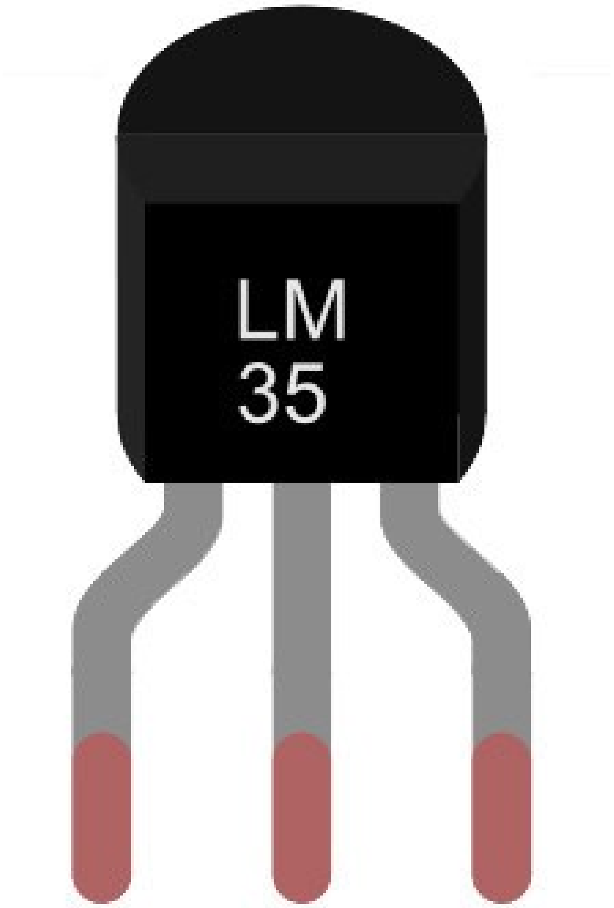
Lab 2

Sensing Temperature

Analog sensors

Learning outcome

- LM35 characteristics.
- Simulation of LM35 on Proteus.
- Improving LM35 range.
- Practical implementation

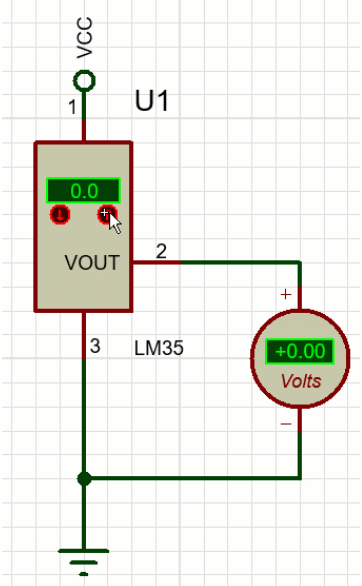


Lab 2

Sensing Temperature

LM35

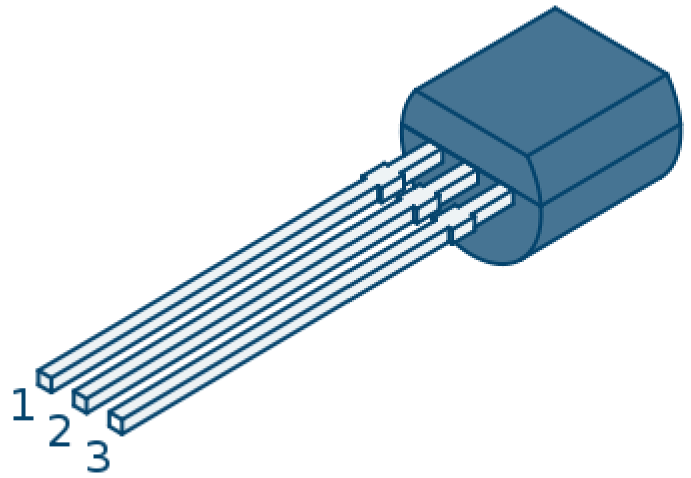
- Voltage supply : 4 – 30 V
- Sensitivity : 10 mV / ºC
- Useful range : 2 – 150 ºC
- Less then 50 µA



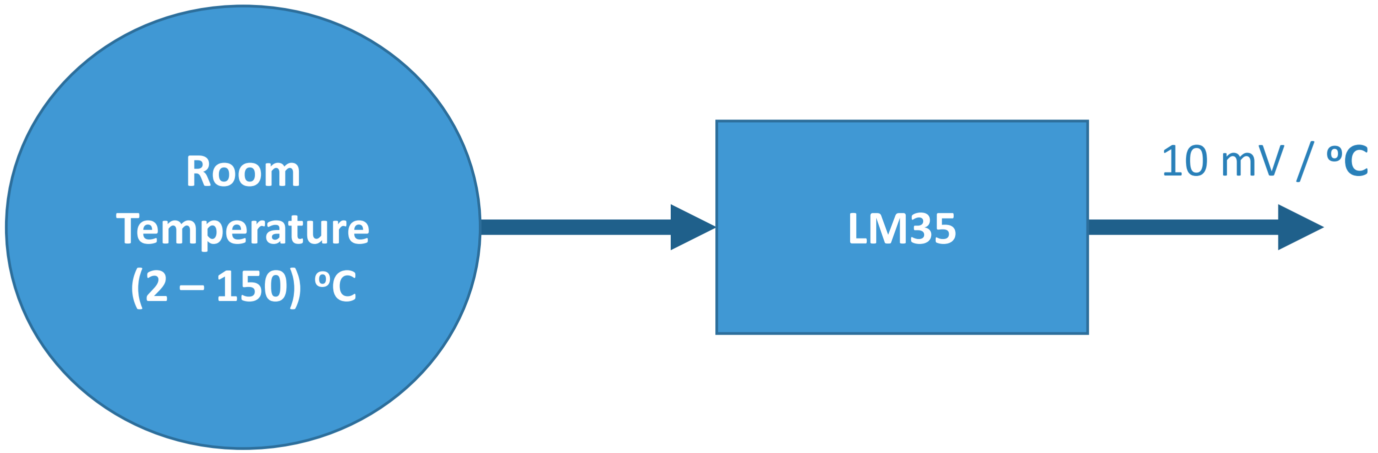
LM35 Precision Centig

1 Features

- Calibrated Directly in Celsius (Centigrade)
- Linear + 10-mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at 25°C)
- Rated for Full −55°C to 150°C Range
- Suitable for Remote Applications
- Low-Cost Due to Wafer-Level Trimming
- Operates From 4 V to 30 V
- Less Than 60-µA Current Drain
- Low Self-Heating, 0.08°C in Still Air
- Non-Linearity Only ±¼°C Typical
- Low-Impedance Output, 0.1 Ω for 1-mA Load



1. Vcc
2. Output
3. Gnd



Lab 2

Sensing Temperature

LM35

Temp → LM35 V = Temp * K → ADC → Temp = V /K

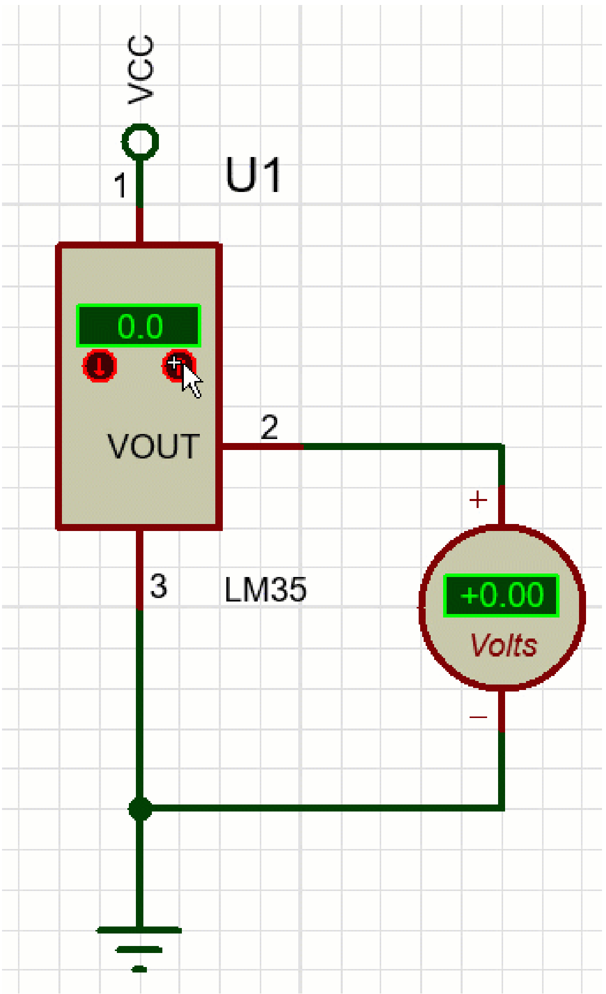
Acquisition Transfer Function

Where

K …. Conversion factor

And

K = (10 mV / 1000 mV)



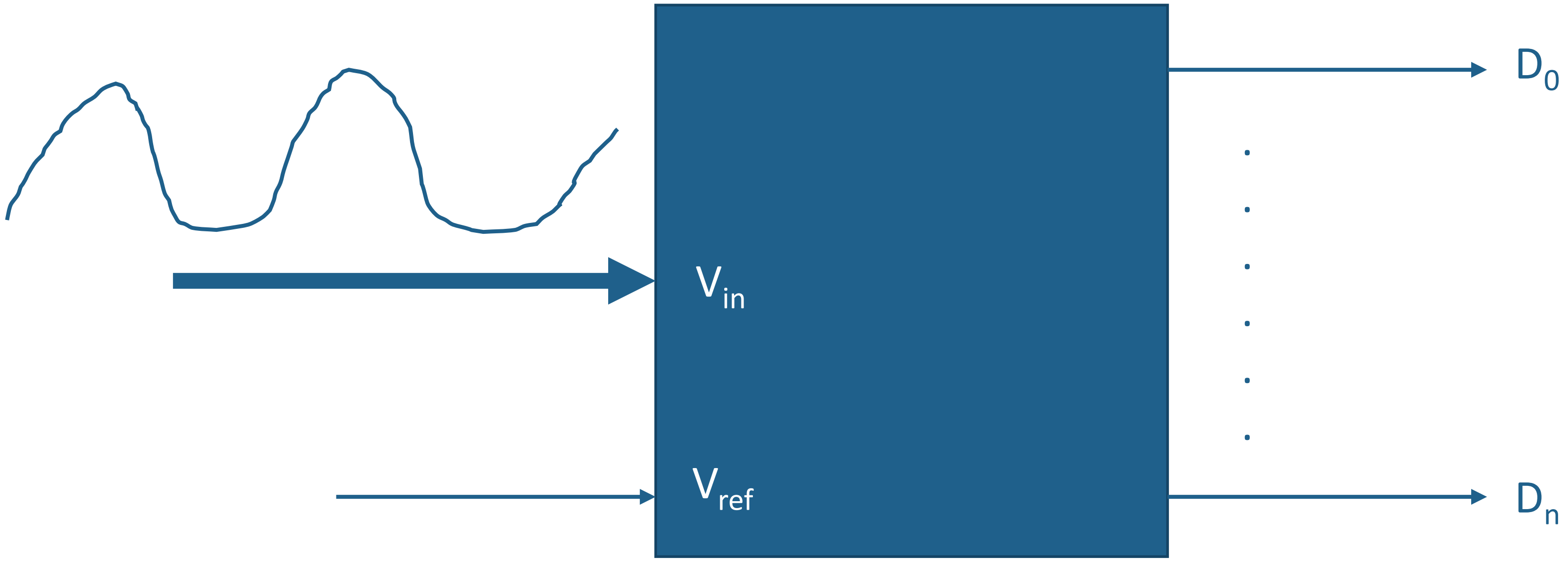
Lab 2

Improving Sensor Range

Case Study

PROBLEM DEFINITION

- You wish to build an embedded system for monitoring **temperature** using LM35.
- Your temperature **range** is expected to vary from **5 – 45 ºC**
- You have **built-in 10-bit ADC** with **reference** voltage of **5V** (**resolution?**).
- You are **assigned** to **improve the voltage range of LM35** to match ADC input voltage range for the input temperature range



$$ADC\ Resolution = \frac{V_{ref}}{2^n}$$

$$Digital\ Value = \frac{V_{in}}{\text{ADC Resolution} - \mathbf{1}}$$

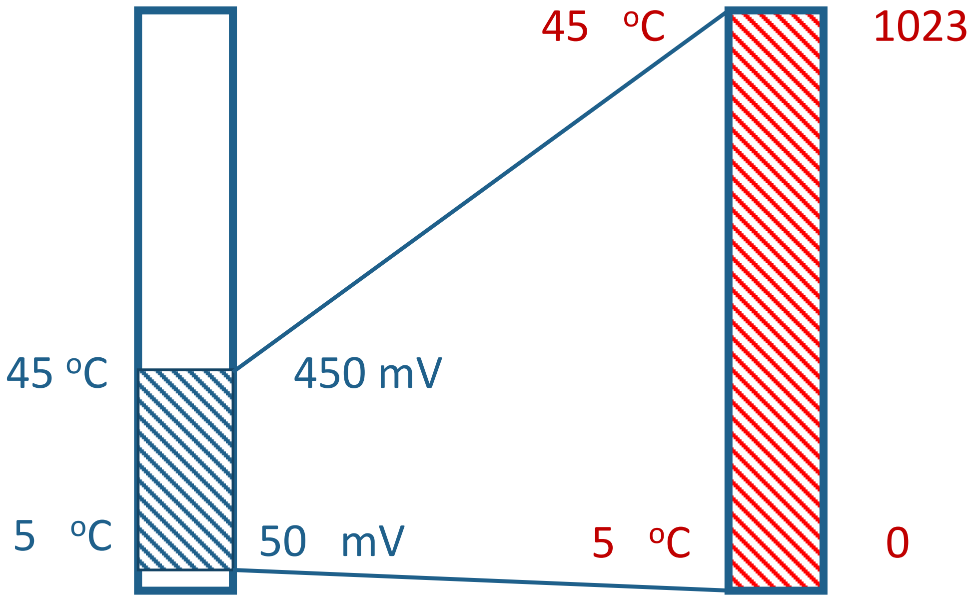
Lab 2

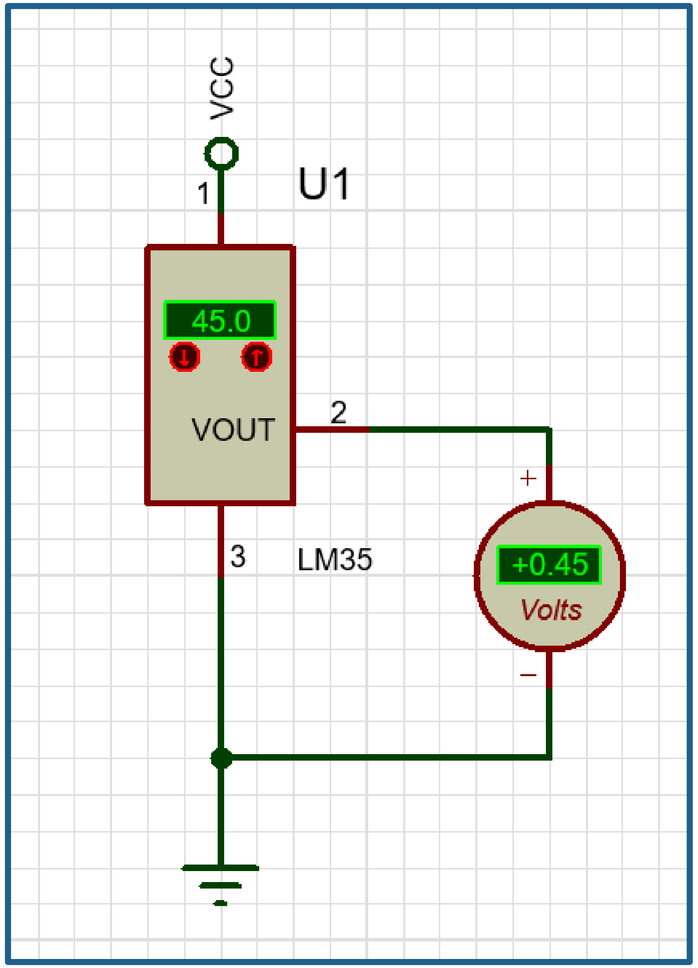
Improving Sensor Range

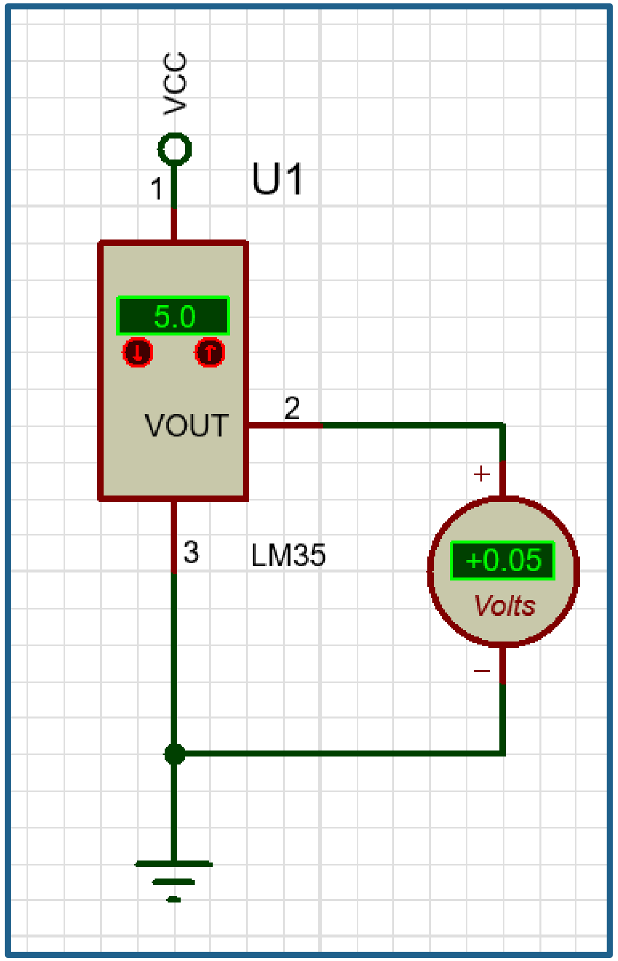
Case Study

FOR LM35

- At 5 ^{0}C → V_{lm35} = 5 * 10mV = 50 mV
- At 45 ^{0}C → V_{lm35} = 45 * 10mV = 450 mV







What is the loss percentage in ADC range?

Lab 2

Improving Sensor Range

Case Study

FOR LM35

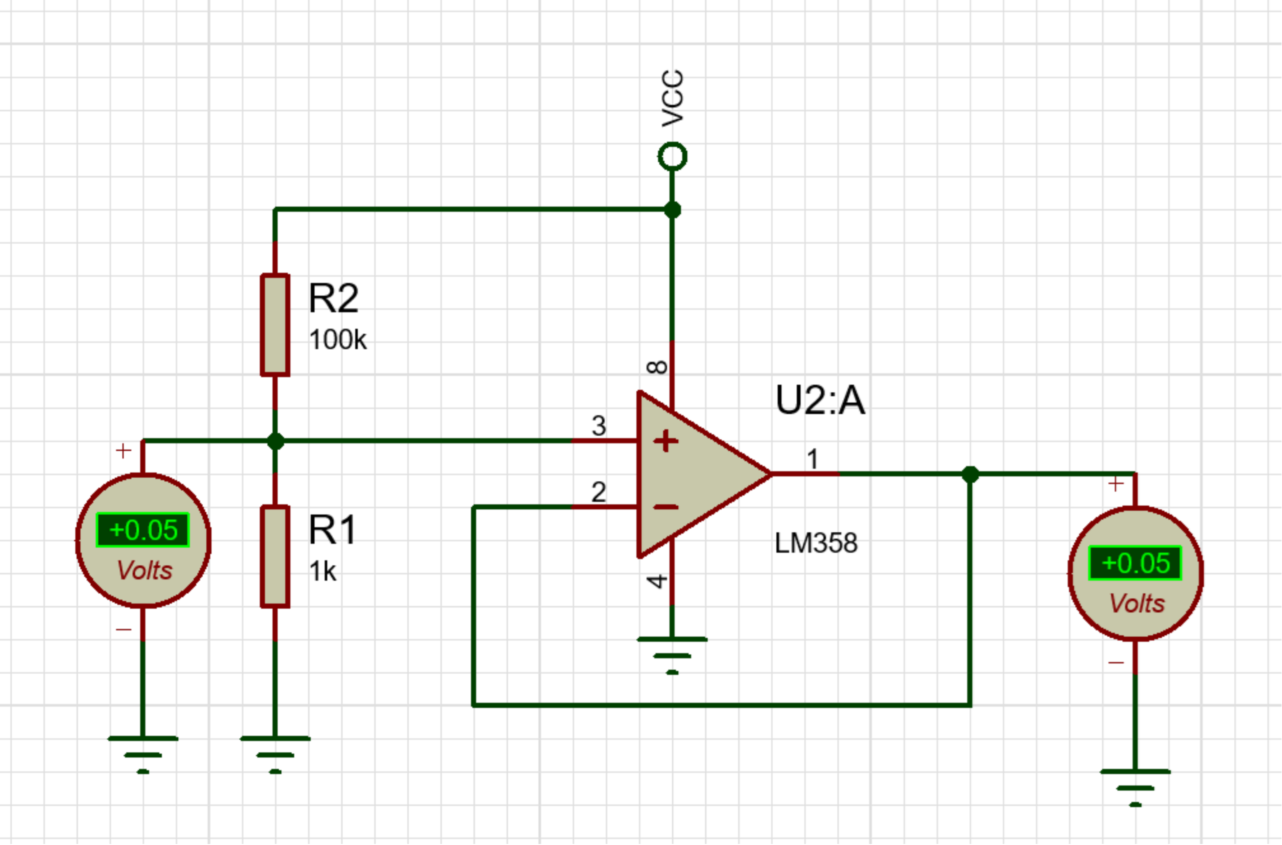
- At 5 ^{0}C → V_{lm35} = 5 * 10mV = 50 mV
- At 45 ^{0}C → V_{lm35} = 45 * 10mV = 450 mV

STEP 1 (Range Mapping)

- 50 mV → 0V (ADC Vin min)
- 450 mV → 5V (ADC Vin max) = V_{ref}

STEP 2 (Shifting)

- 50 mV → 0V (Voltage Divider + Buffer "why?")



Lab 2

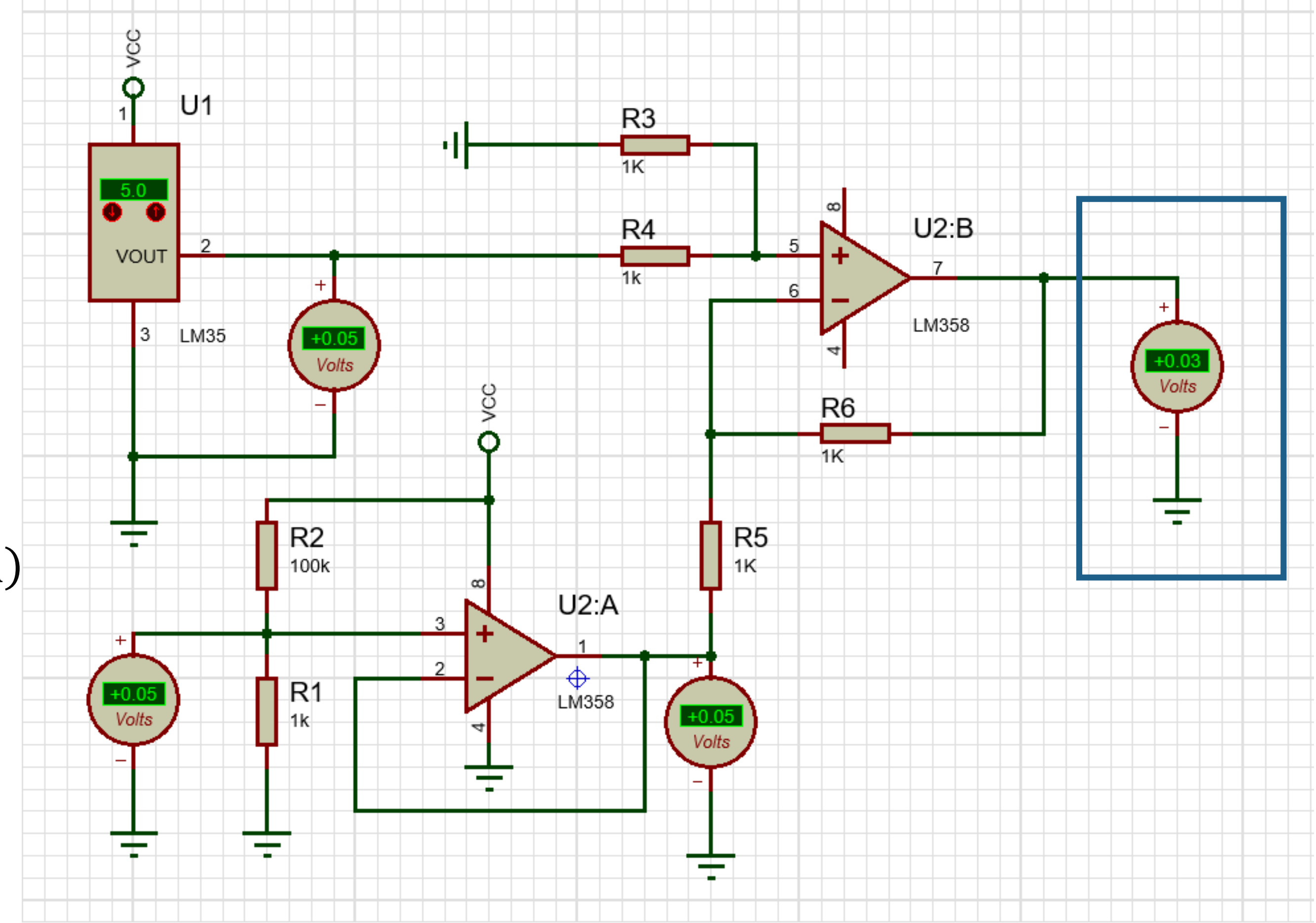
Improving Sensor Range

Case Study

$$V(offset) = 5 * \frac{100k}{1k} = 50\ mV$$

$$V(out) = V_{LM \to 50^oC} - V(offset) = 0\text{V(Theoretical)}$$

$V(out)$ = 0.05 – 0.05 = 0V + Amplifier DC offset



STEP 2 (Shifting)

- 50 mV → 0V (Voltage Divider + Buffer "why?")

Read about **amplifier DC offset**

Lab 2

Improving Sensor Range

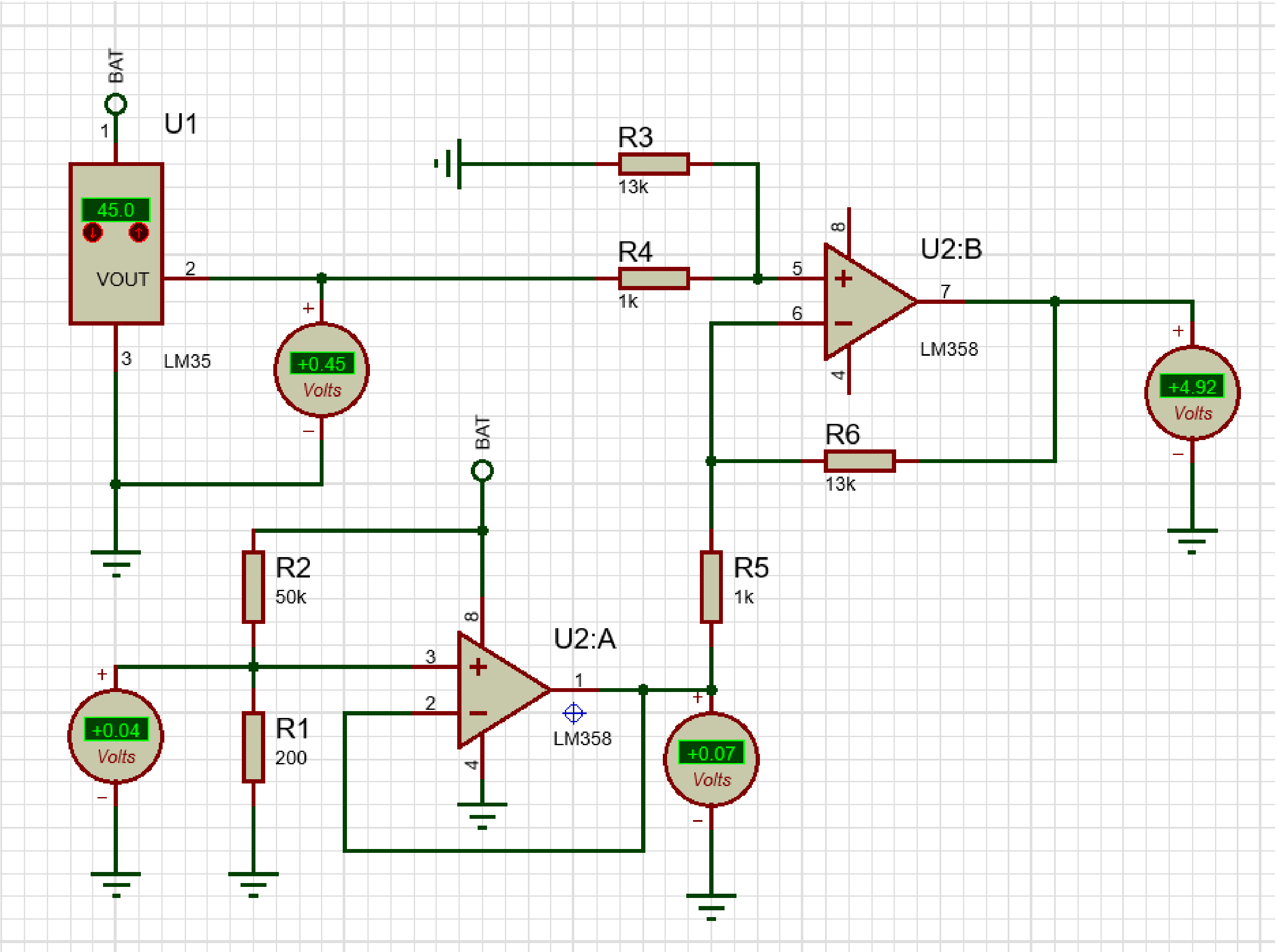
Case Study

After min voltage removal

$$V(450) = 0.45\ - 0.05 = 0.$$

Gain

$$G = \frac{5}{0.4} = 12.5$$



STEP 3 (Amplification)

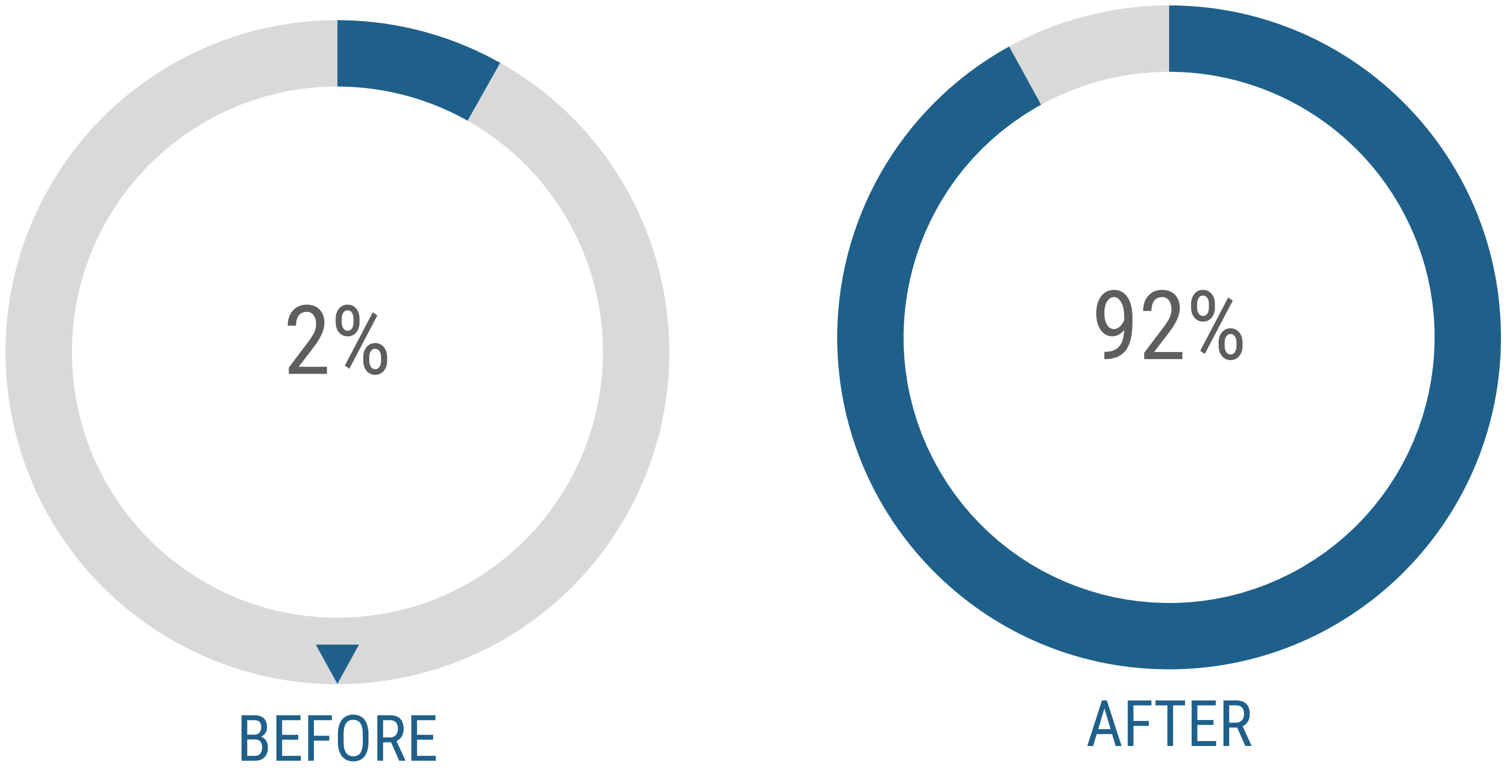
- 450 mV → 5V (Gain of differential amplifier)

V_{bat} = 12V (**why changed?**)

Lab 2

Improving Sensor Range

Case Study



Lab 2

Improving Sensor Range

Case Study

PROBLEM DEFINITION

- You wish to build an embedded system for monitoring **temperature** using LM35.
- Your temperature **range** is expected to vary from **10 – 100 ^{o}C**
- You have **built-in 10-bit ADC** with **reference** voltage of **5V**.
- You are **assigned** to **improve the voltage range of LM35** to match ADC input voltage range for the input temperature range

APPLY THE DESIGN IN SIMULATION AND PRACTICAL CIRCUIT

Improving Sensor Range

Case Study

SOLUTION Steps

1. Get sensor minimum and maximum voltages corresponding to given range

$$T_{min} = 10^o \ \rightarrow V_{min} = T \ * sensor\ sensitivity = 10^o \ * \frac{10mV}{C} = 0.1\ V$$

$$T_{max} = 100^o \ \rightarrow V_{max} = T \ * sensor\ sensitivity = 100^o \ * \frac{10mV}{C} = 1.0\ V$$

$$V_{min} = 0.1\ V \qquad V_{max} = 1.0\ V$$

Lab 2

Improving Sensor Range

Case Study

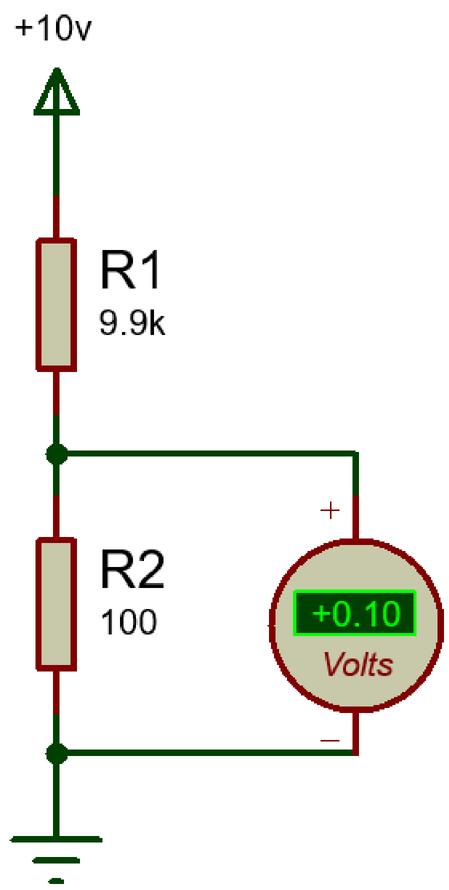
SOLUTION Steps

2. Remove min voltage offset V_{min} by subtracting it from the same voltage created by a voltage divider

$$Desired\ voltage\ divider\ output = V_{min} = 0.1\ V$$

$$V_o = V_s \frac{R_2}{R_1 + R_2} \rightarrow R_1 = R_2\left(\frac{V_s}{V_o} - 1\right)\ (Derive\ it\ if\ you\ like)$$

$$Assuming\ V_s = 10V, R_2 = 100 \ \rightarrow\ R_1 = 100\left(\frac{10}{0.1} - 1\right) = 9.9k$$



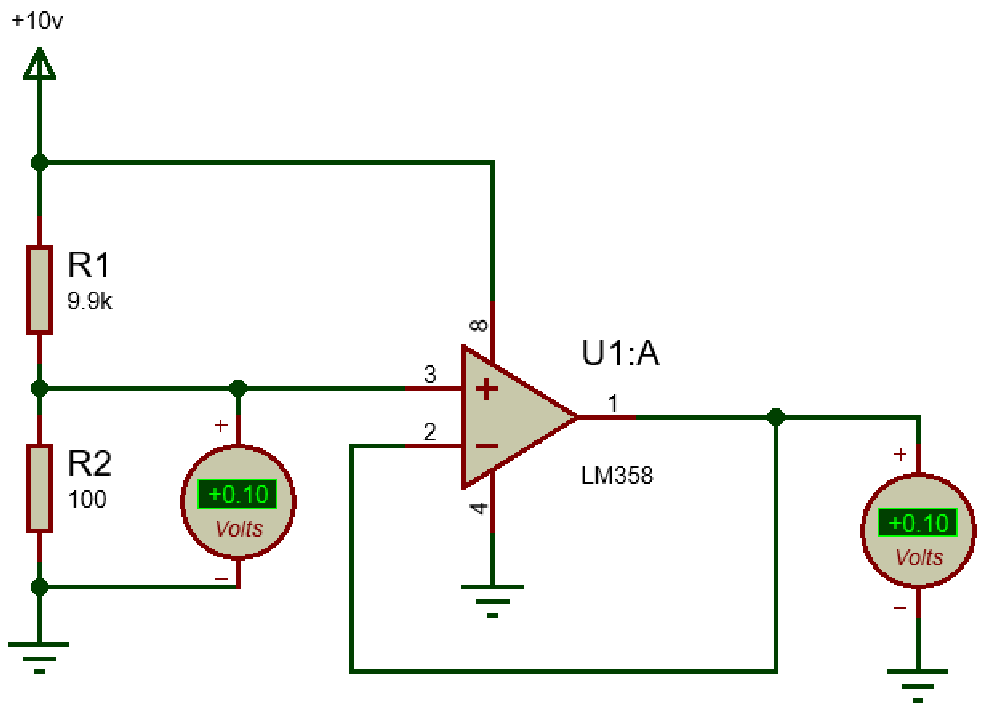
Lab 2

Improving Sensor Range

Case Study

SOLUTION Steps

3. Apply buffering stage (*as discussed in the lab*)



Lab 2

Improving Sensor Range

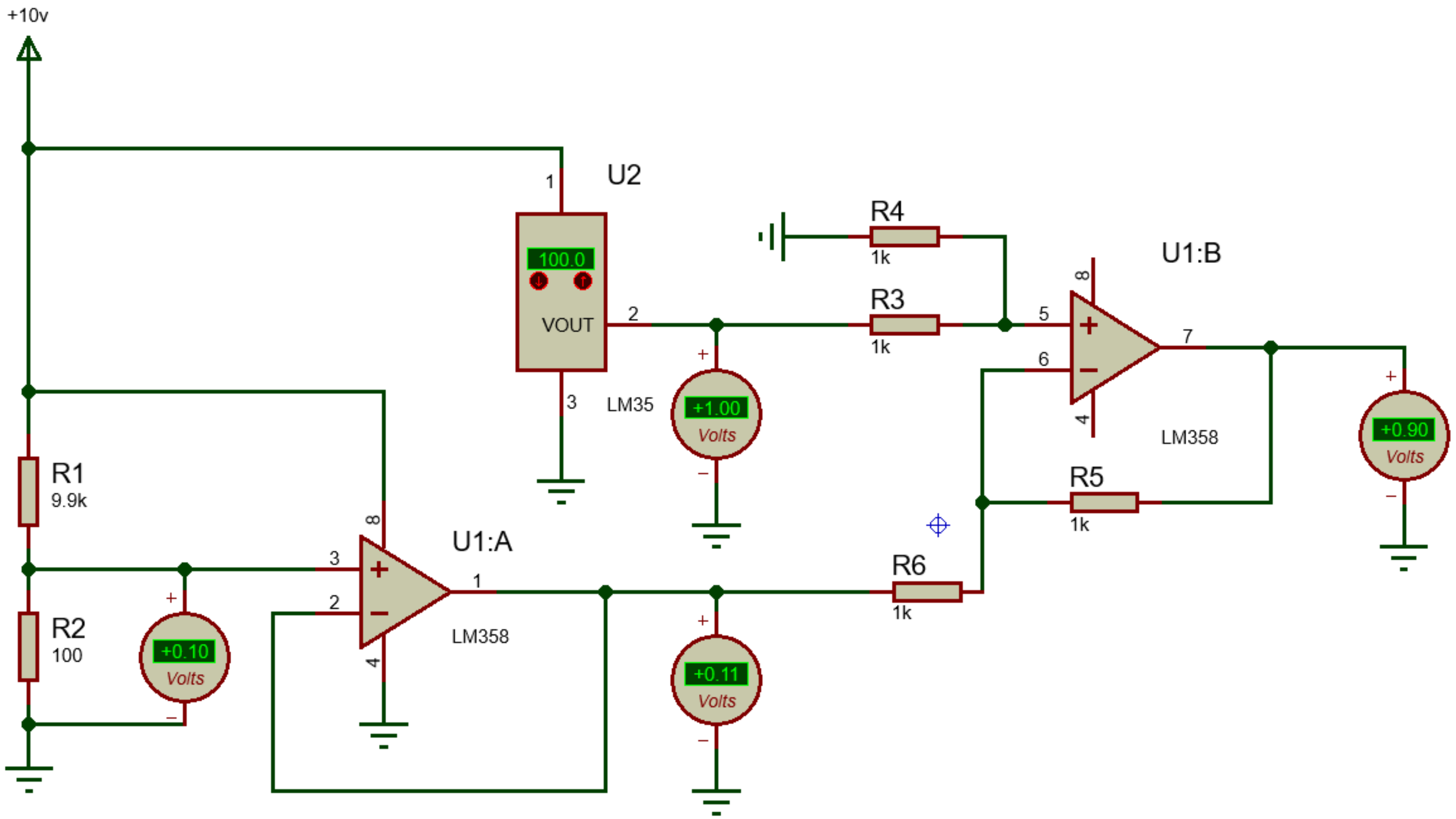
Case Study

SOLUTION Steps

4. Subtract sensor min and max output voltage from buffer and check new V_{min} and V_{max} after subtraction. (use differential amplifier for subtraction with G = 1

$$V_{min-new} = 0.1 - 0.1 = 0V$$

$$V_{max-new} = 1.0 - 0.1 = 0.9V$$



Improving Sensor Range

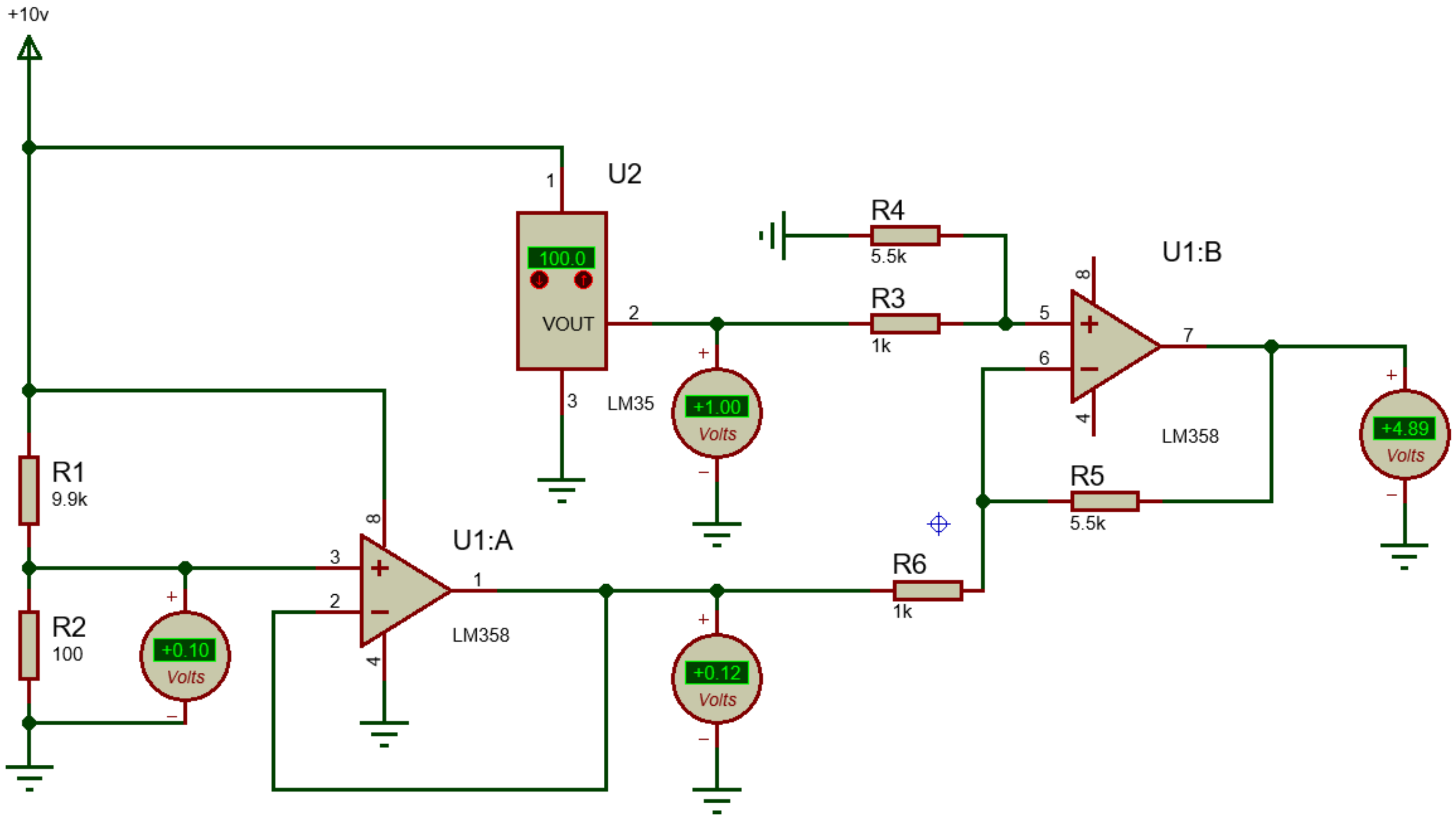
Case Study

SOLUTION Steps

5. To maximize the sensor voltage to ADC V_{ref}, the amplifier gain is set to:

$$G = \frac{V_{\mathrm{ref}(ADC)}}{V_{\mathrm{max-new}(sensor)}} = \frac{5.0}{0.9} = 5.56 \cong 5.5$$

$$If\ R_f\ is\ 5.5k \rightarrow R_1 = 1k$$



$\therefore$ @ $T = 10\ ^oC$ → V = (0.1 -0.1) * 5.5 = 0V and @ $T = 100\ ^oC$ → V = (1.0 -0.1) * 5.5 = 4.95V

Lab 2

SENSITIVITY IMPROVEMENT

Before and After

$$Sensor\ sensitivity = \frac{10mV}{{}^{o}C}\ (before\ signal\ conditioning)$$

$$Sensor\ sensitivity = \frac{10mV}{{}^{o}C} * 5.5 = \frac{55.5mv}{{}^{o}C}\ (After)$$

$Sensor\ sensitivity\ is\ improved\ 5.5\ times$
$the\ original\ sensitivity$

Don’t forget to pull the lab update from.

http://github.com/wbadry/mte405

END OF LAB 2