MISR UNIVERSITY FOR SCIENCE AND TECHNOLOGY
COLLEGE OF ENGINEERING
MECHATRONICS DEPARTMENT

# MTE 405 SENSORS AND MEASUREMENTS

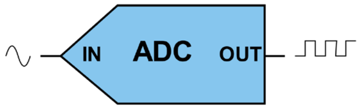
LAB 2 – SPRING 2019

Lab 1

# Goals Of The Lab

Introduction to Sensors and Signal Conditioning with Virtual Prototyping


Introduction to temperature sensors




Spreading signal ouput range

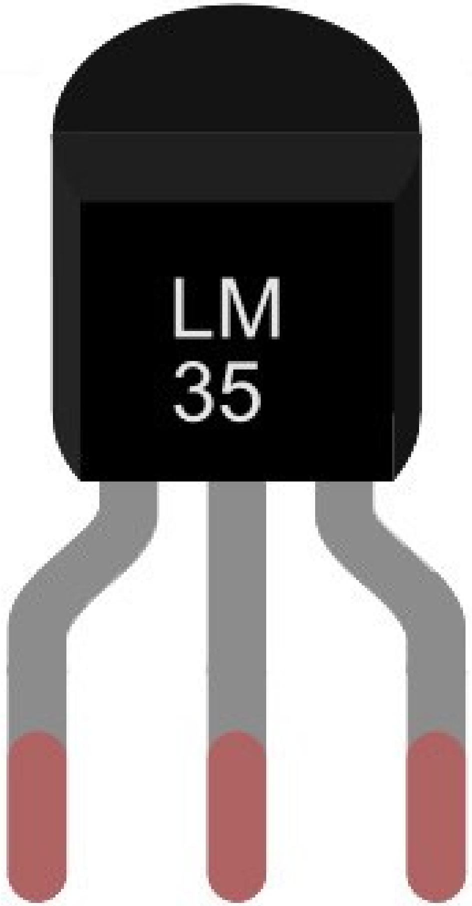
Lab 2

# Sensing Temperature

Analog sensors

## Learning outcome

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



Lab 2

# Sensing Temperature

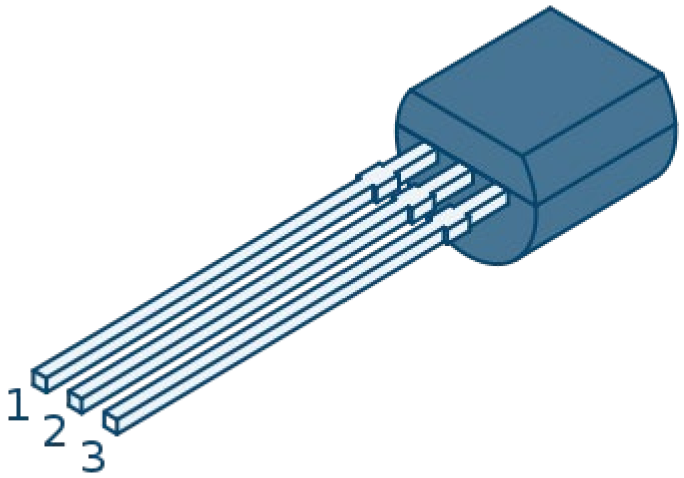
LM35

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

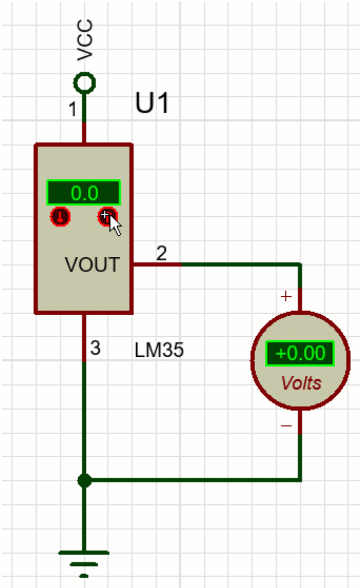
**LM35 Precision Centig**

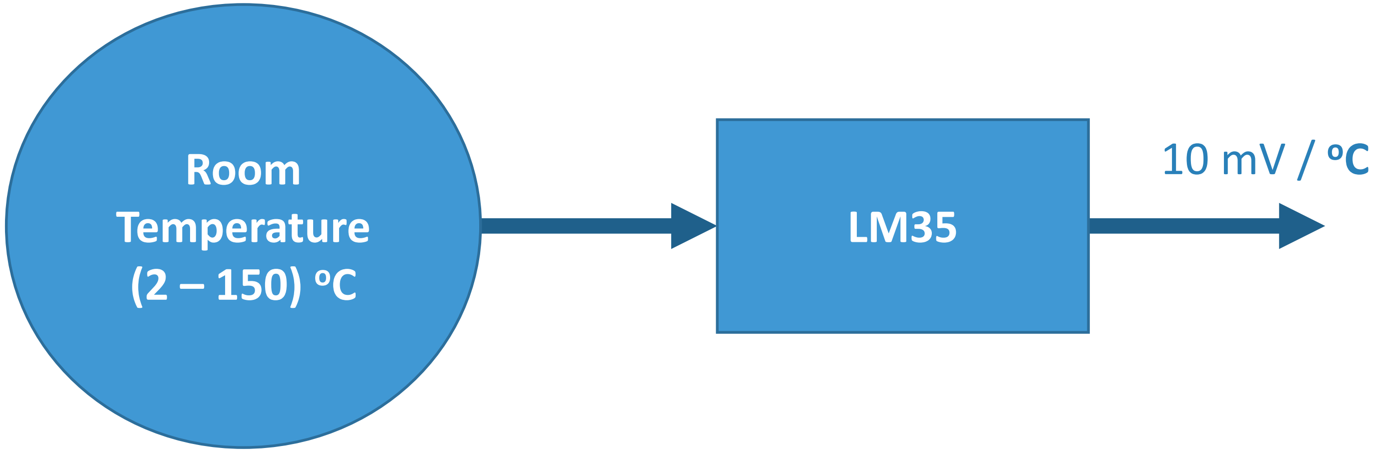
## 1 Features

- 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

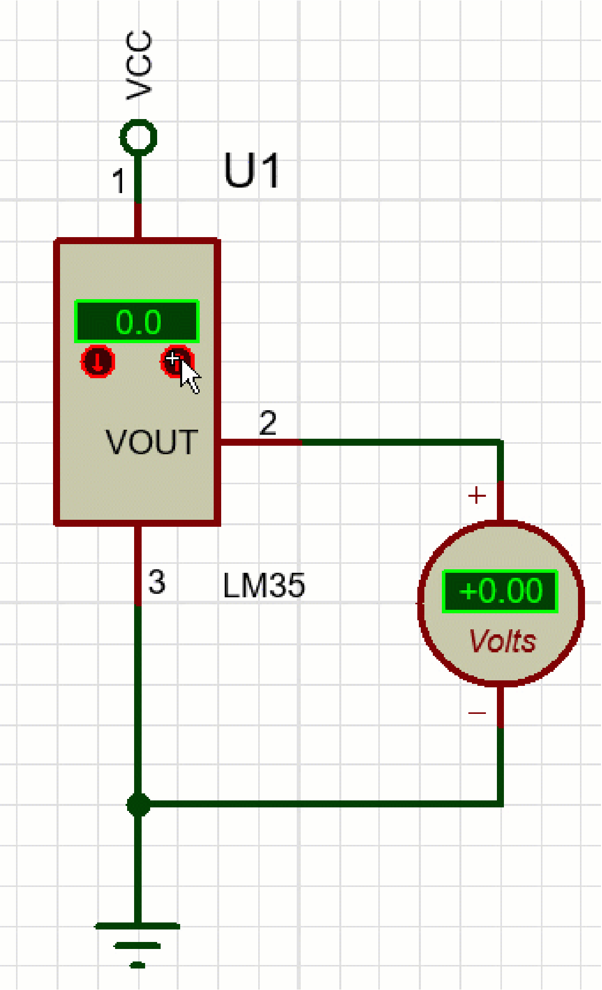
## Acquisition Transfer Function

*Where*

K …. Conversion factor

And

**K** = (10 mV / 1000 mV)

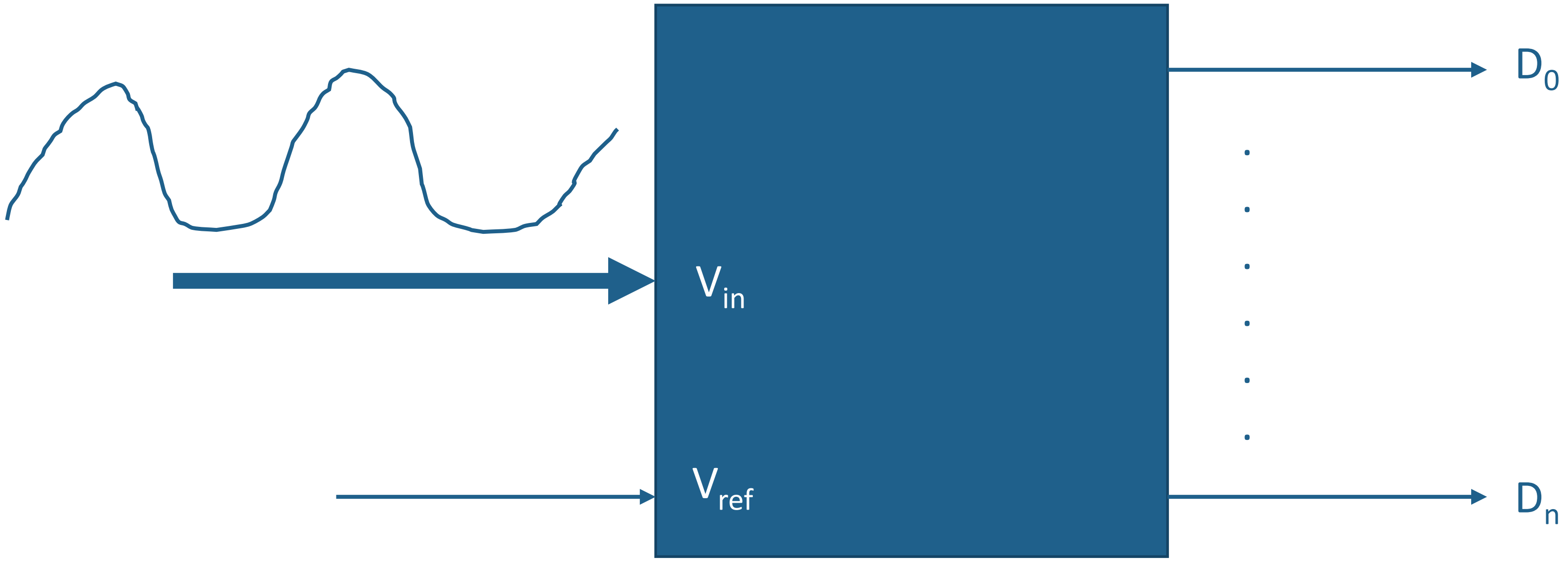


# Improving Sensor Range

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




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

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

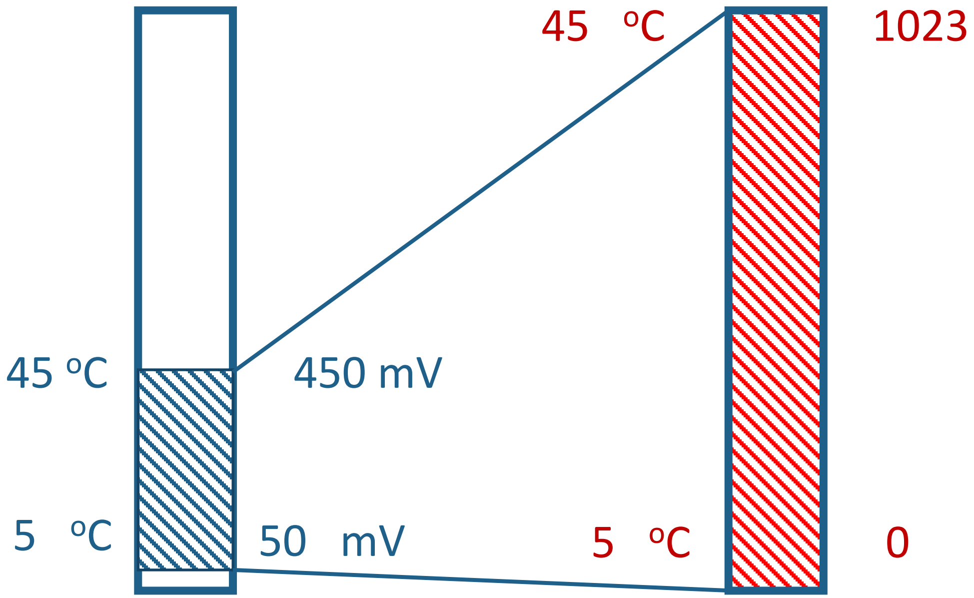
Lab 2

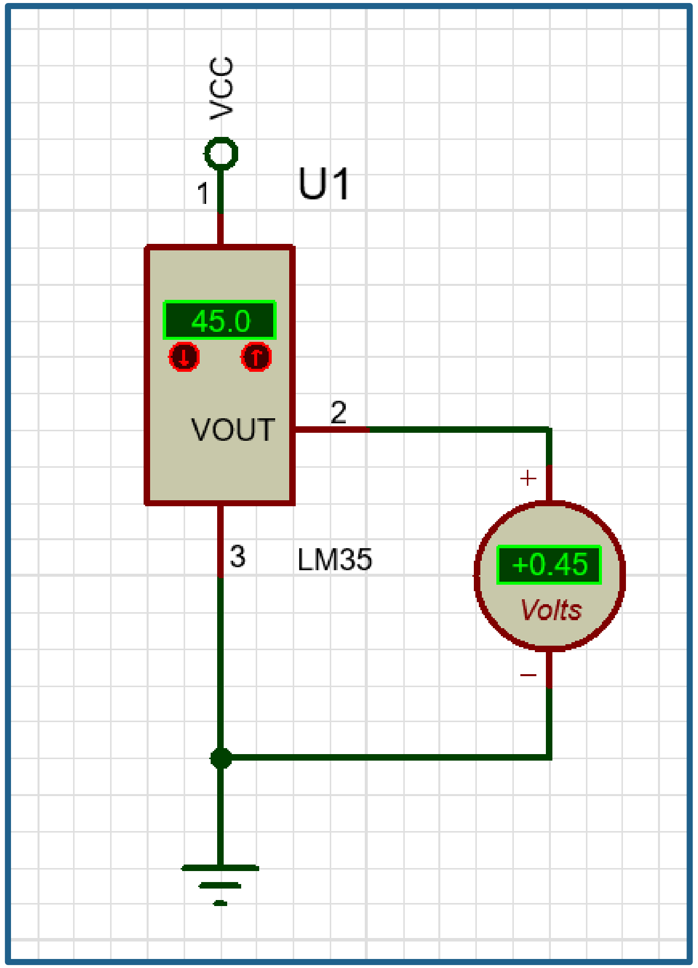
# Improving Sensor Range

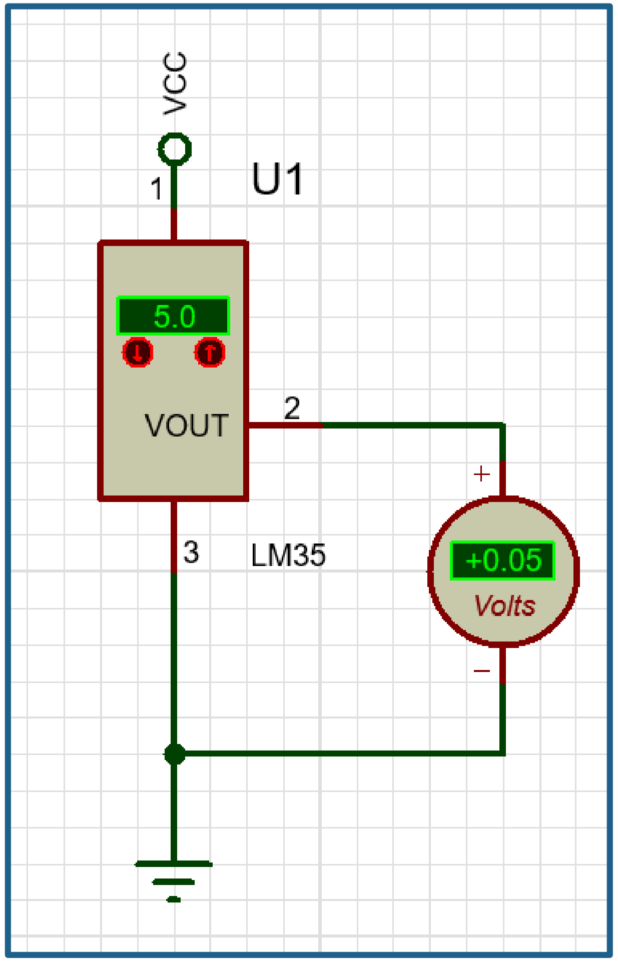
Case Study

## FOR LM35

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




What is the loss percentage in ADC range?

Lab 2

# Improving Sensor Range

Case Study

## FOR LM35

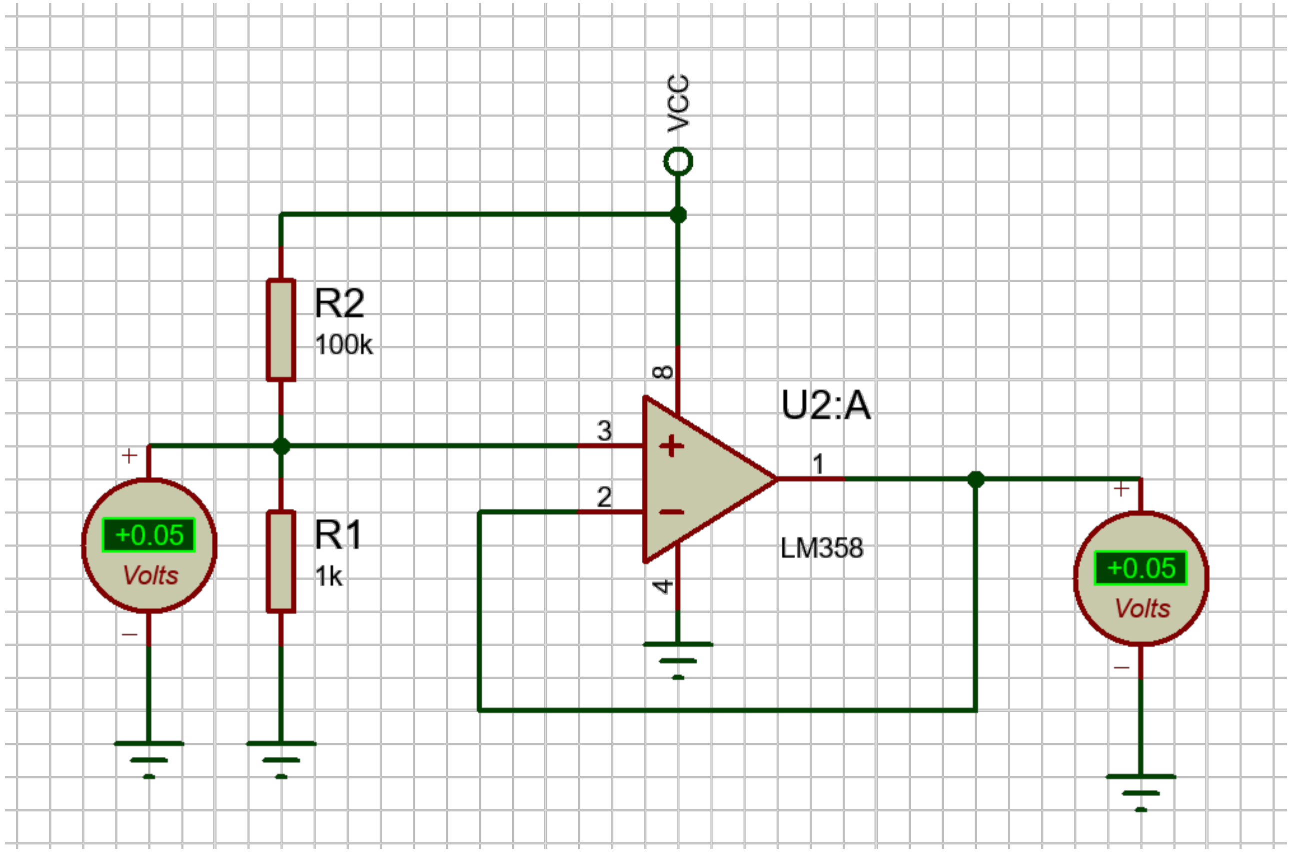
- At 5 $^0$C → $V_{lm35}$ = 5 * 10mV = 50 mV
- At 5 $^0$C → $V_{lm35}$ = 45 * 10mV = 450 mV

## 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?")



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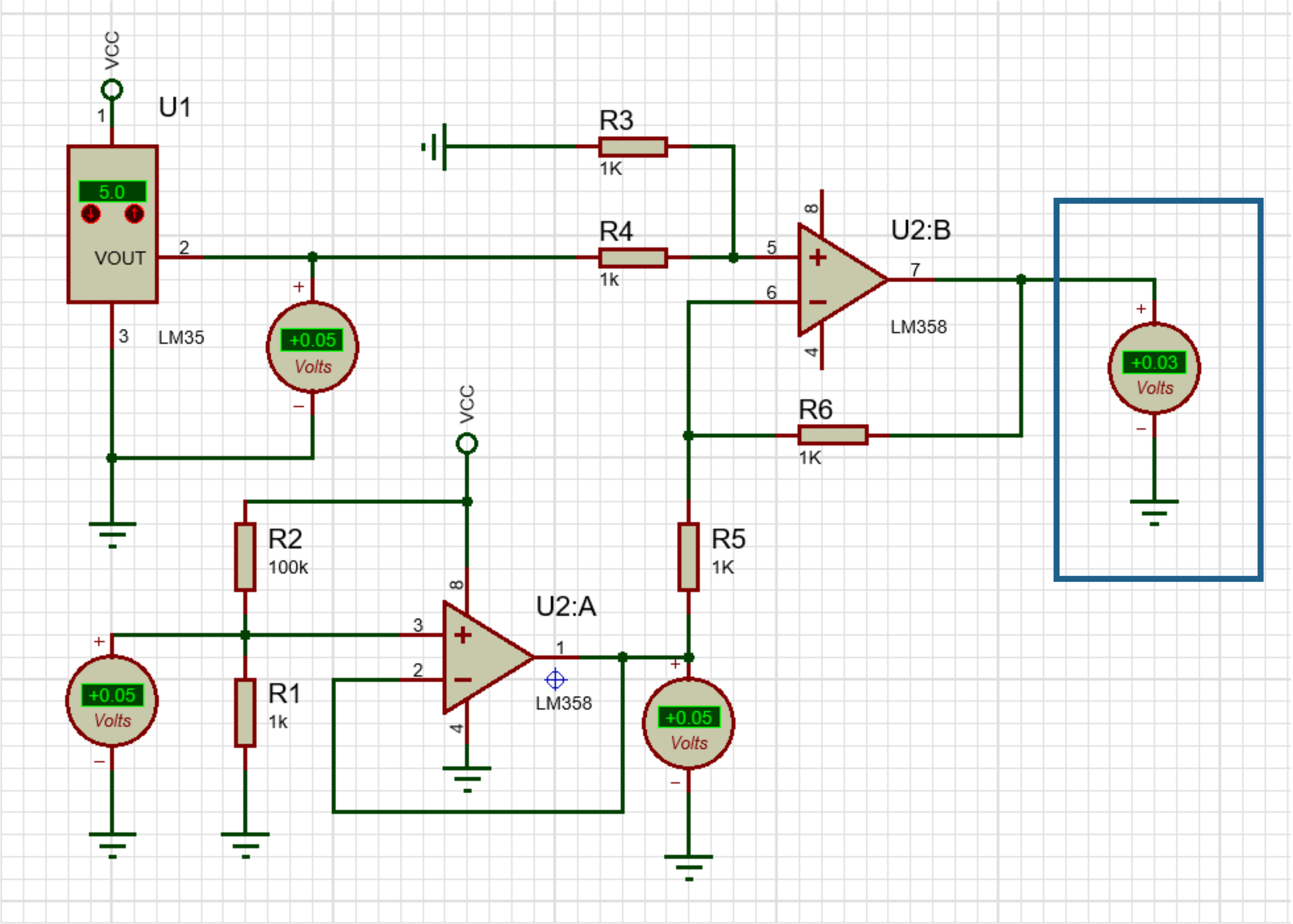
# Improving Sensor Range

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

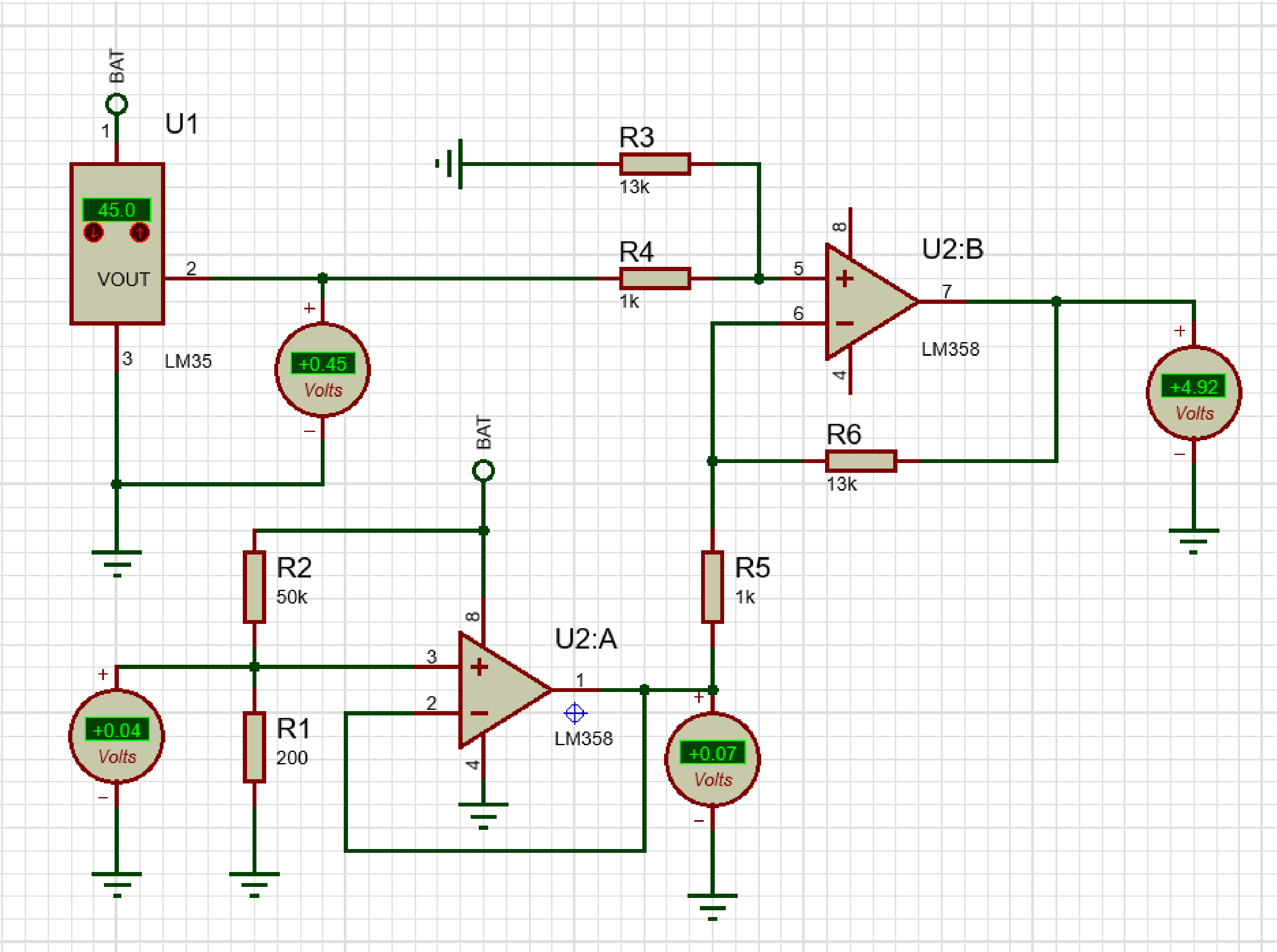
Case Study

*After min voltage removal*

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

*Gain*

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




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

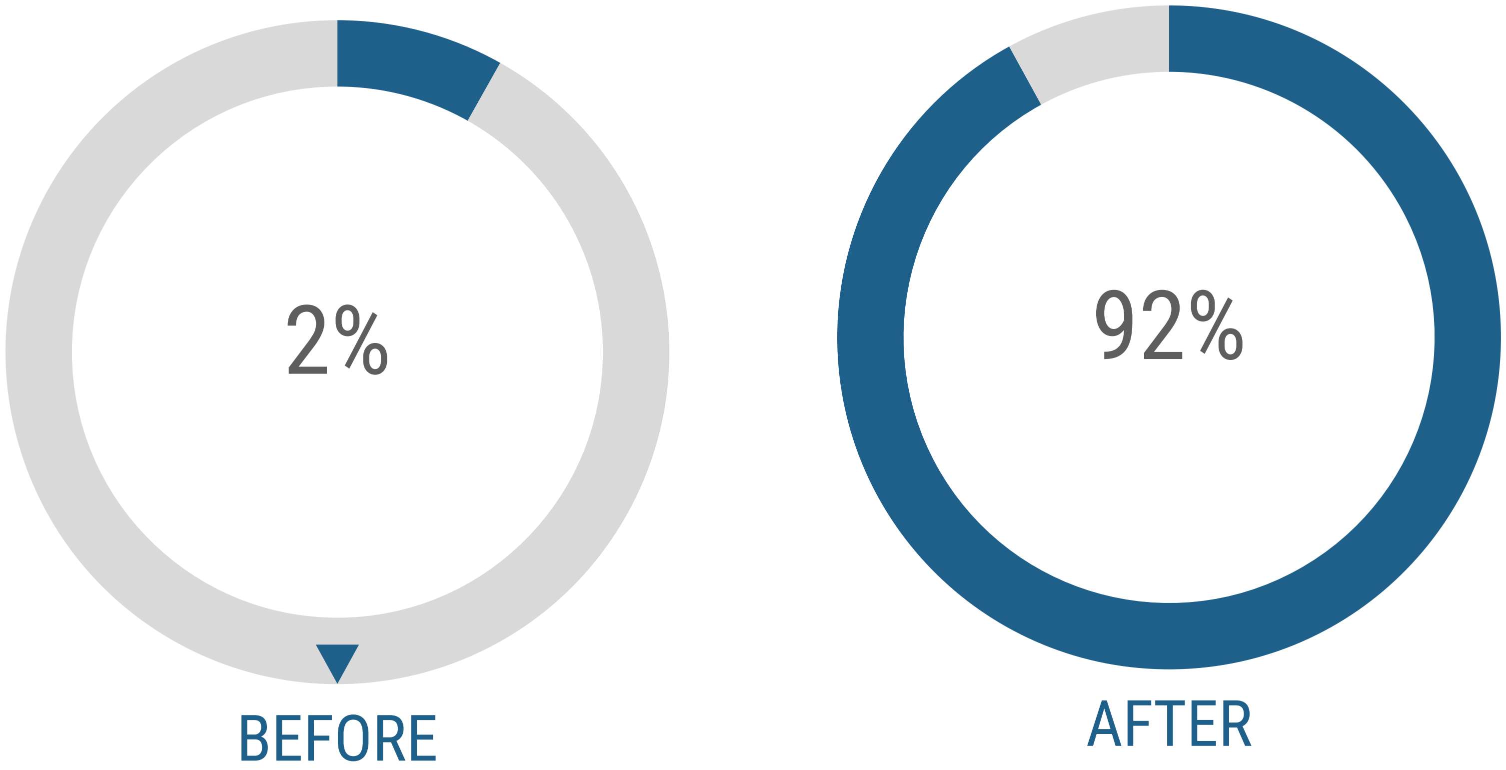
## STEP 3 ( Amplification)

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

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 ºC**
- 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

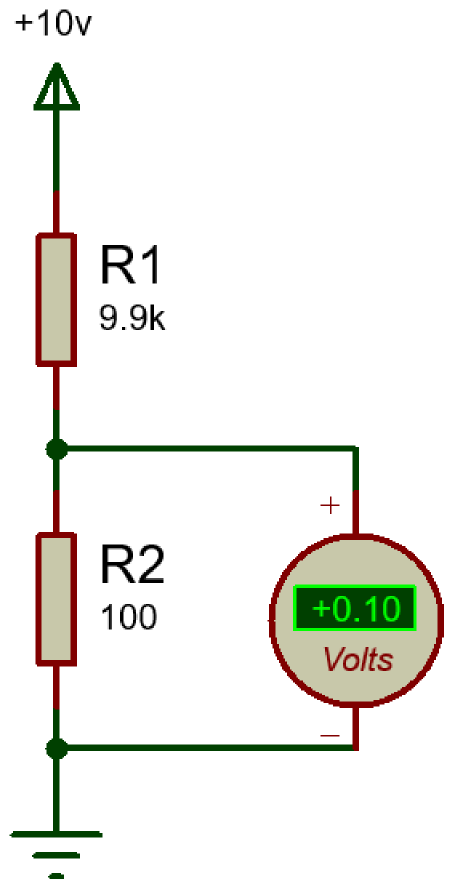
## SOLUTION Steps

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

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

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

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



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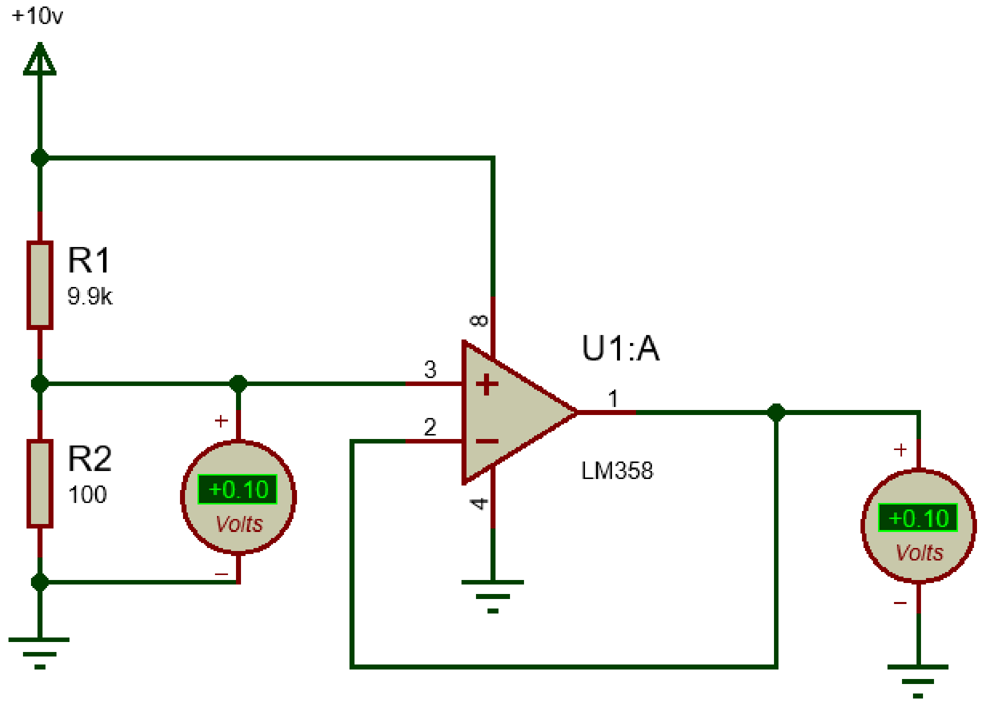
# Improving Sensor Range

Case Study

## SOLUTION Steps

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



Lab 2

# Improving Sensor Range

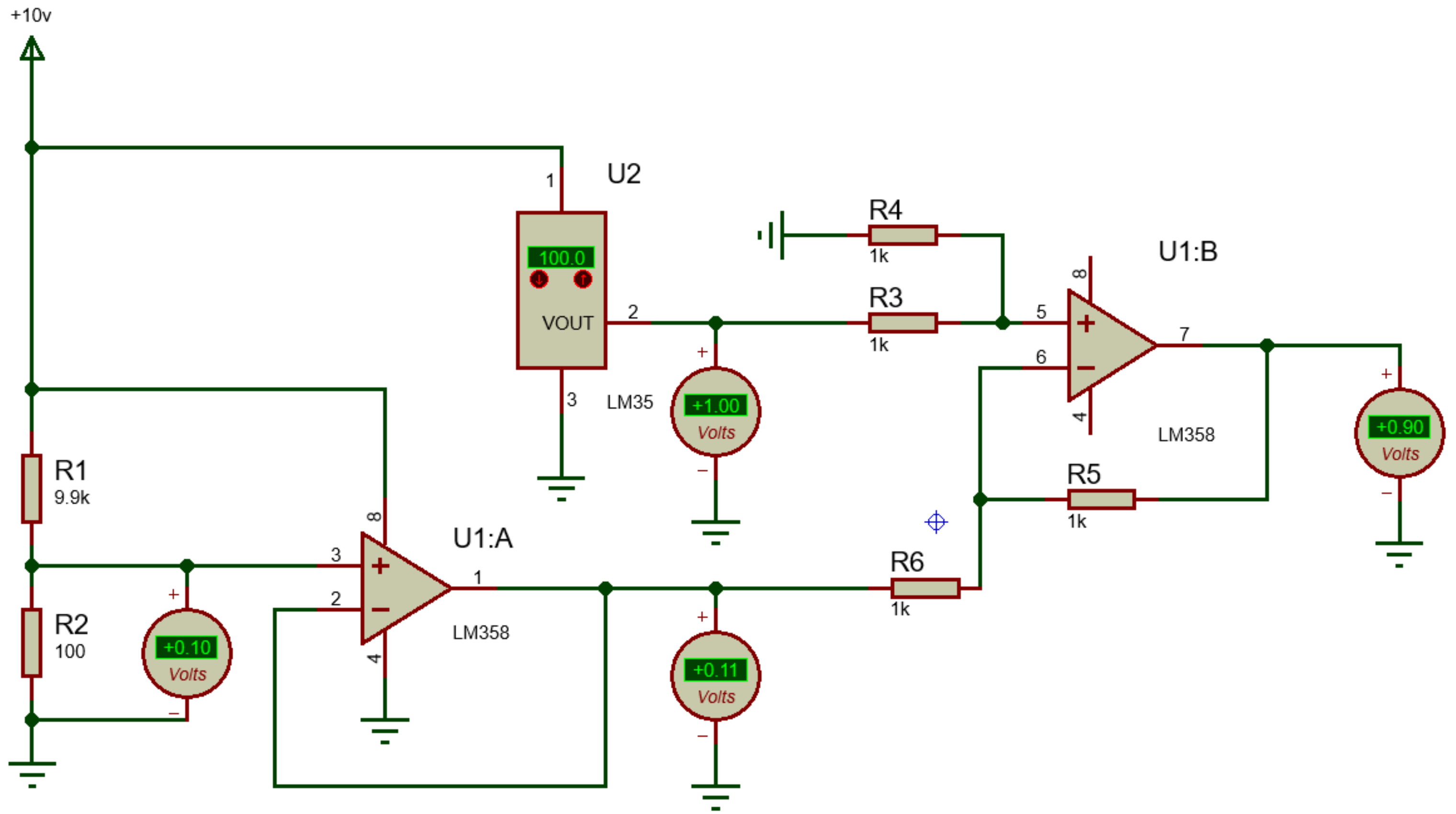
Case Study

## 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

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

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



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# Improving Sensor Range

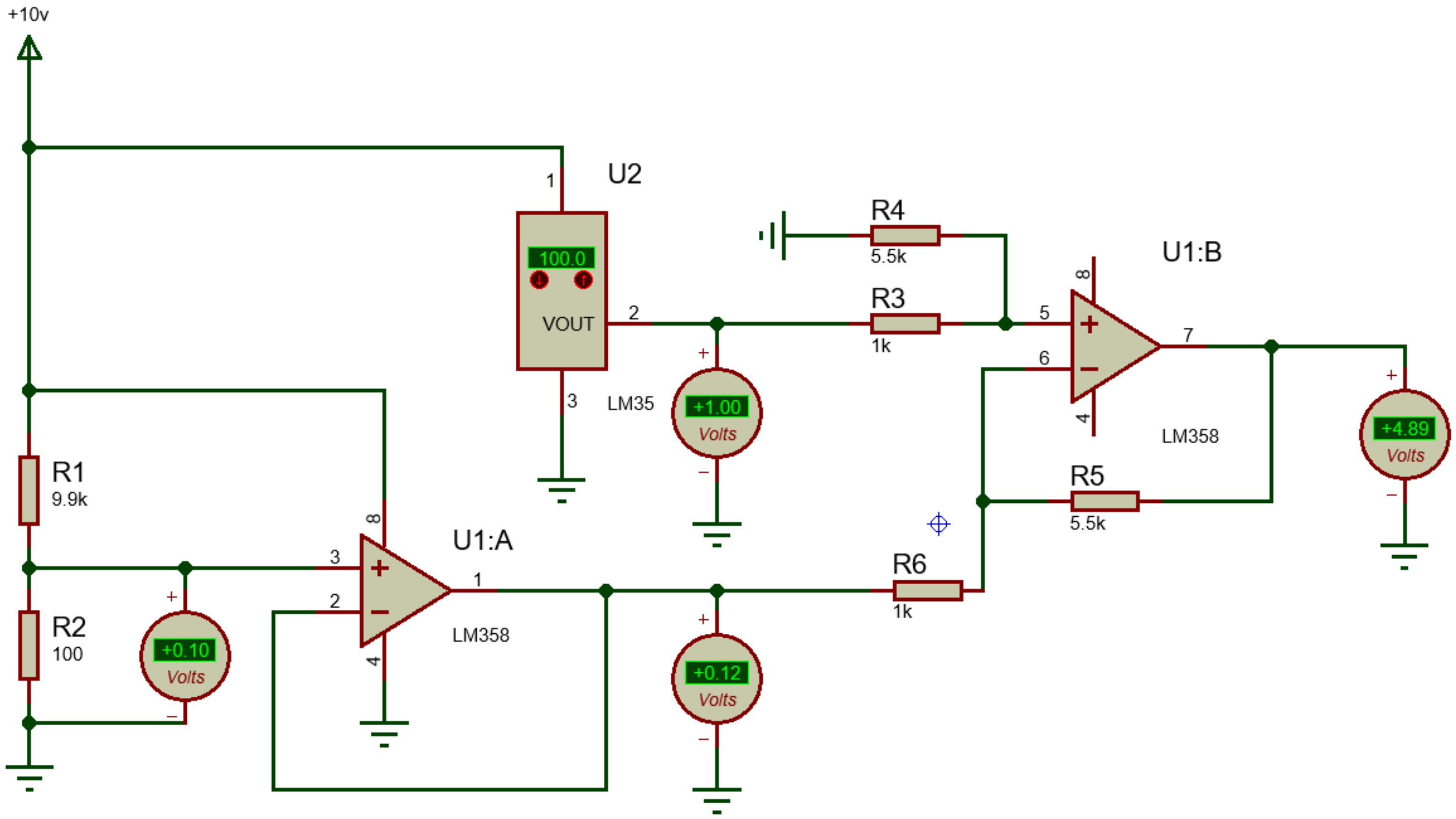
Case Study

## SOLUTION Steps

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

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

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




∴ $@\ T = 10\ ^oC$ → 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