Smart Multimeter using Microcontroller Systems

Assignment 1

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Introduction

This assignment focuses on simulation of real world circuits on Tinkercad. Objective is to understand how voltage, resistance, and capacitance are measured in multimeters. The project applies theoretical concepts including voltage dividers, Ohm's Law, RC time constants, and analog-to-digital conversion, and translates them into circuit simulations.

TASK A – Voltage Divider Measurement Module

Purpose of a Voltage Divider in Measurement Systems

A voltage divider is used to reduce a higher voltage to a lower voltage that can be safely measured by electronic circuits. In measurement systems, voltage dividers allow analog-to-digital converters to measure voltages that would otherwise exceed their input range. This principle is widely used in digital multimeters for voltage measurement.

ADC Reading-to-Voltage Conversion Formula

Arduino Uno uses a 10-bit ADC, producing values from 0 to 1023 for input voltages between 0 and 5 volts. The measured voltage is calculated using:

$$V = \frac{\text{ADC Reading} \times 5}{1023}$$

Circuit Diagram

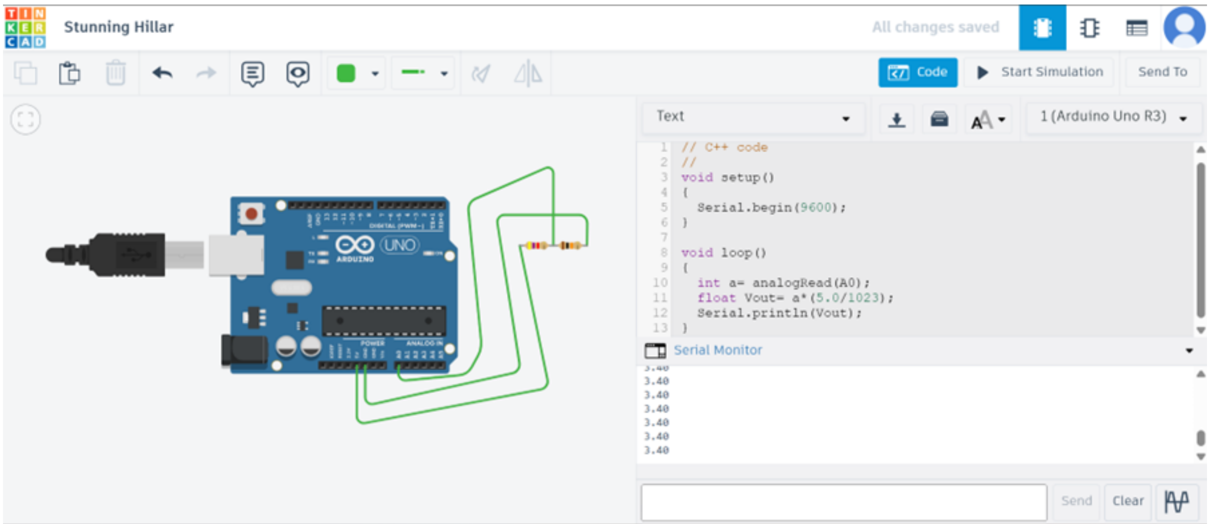


Figure 1: R1=4.7Ω and R2=10Ω

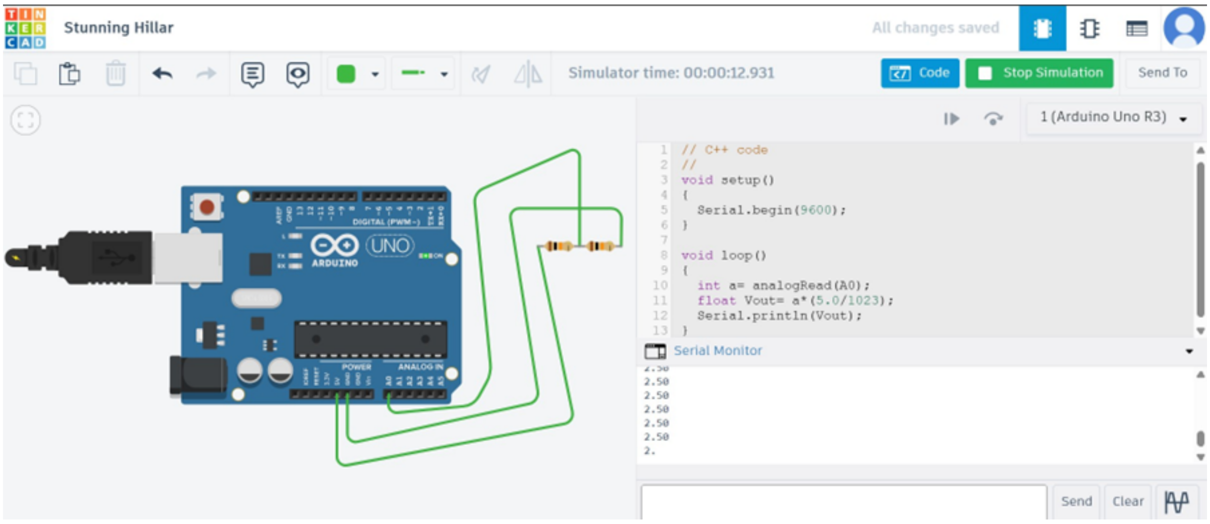


Figure 2: R1=10Ω and R2=10Ω

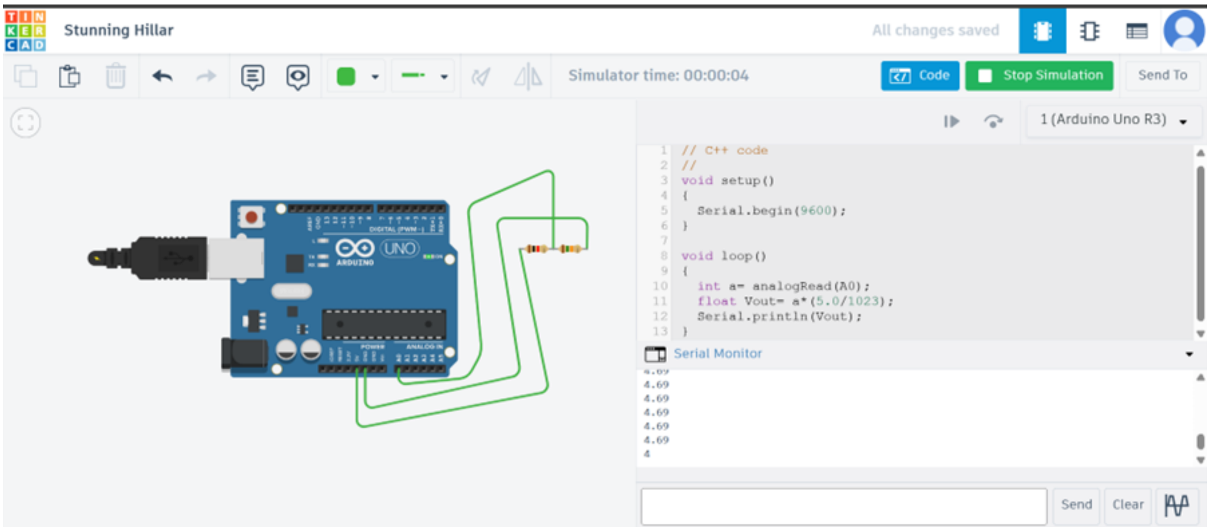


Figure 3: R1=1Ω and R2=15Ω

Arduino Code

```
void setup()
{
  Serial.begin(9600);
}

void loop()
{
  int a = analogRead(A0);
  float Vout = a * (5.0 / 1023);
```

```
  Serial.println(Vout);
}
```

Observation Table

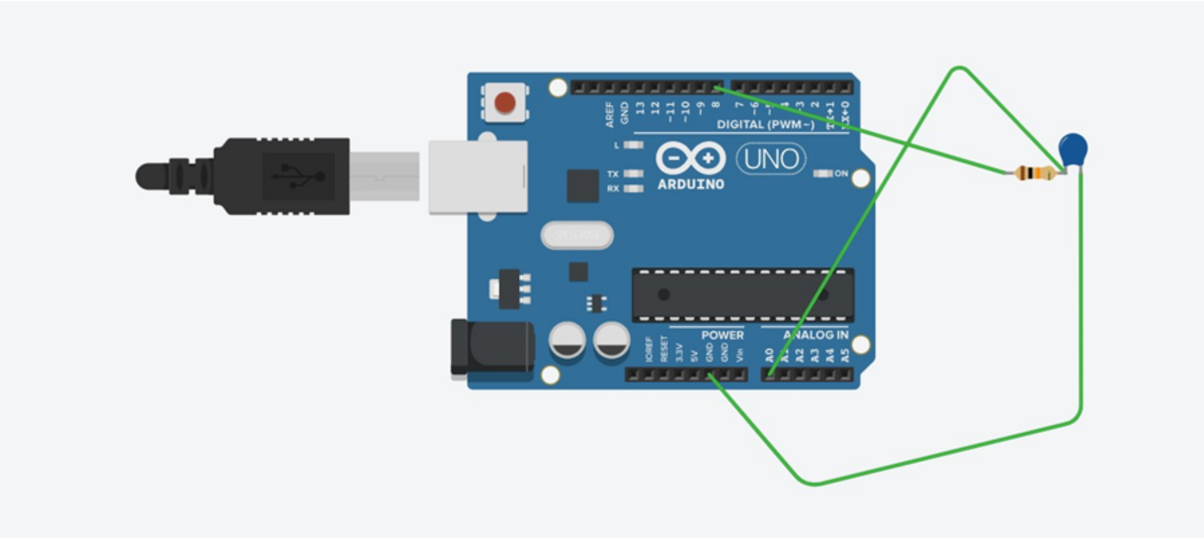
R1 (kΩ)	R2 (kΩ)	Theoretical Voltage (V)	Measured Voltage (V)	Error (%)
4.7	10	3.4014	3.40	0.00
10	10	2.5000	2.50	0.0411
1	15	4.6875	4.69	0.0533

Error Discussion

Practical components do not have exact values. Resistor tolerances, internal resistance of the Arduino voltage supply pin contribute to error.

TASK B – Capacitance Measurement Using RC Time Constant

Circuit Diagram



Arduino Code

```
unsigned long R = 10000;

void setup()
{
  Serial.begin(9600);
  pinMode(8, OUTPUT);
}

void loop()
{
  digitalWrite(8, LOW);
  delay(200);

  unsigned long T1 = micros();
  digitalWrite(8, HIGH);

  while (analogRead(A0) < 648);
```

```
  unsigned long T2 = micros();
  unsigned long time = T2 - T1;

  float C_nF = (time * 1000.0) / R;

  Serial.print("Capacitance: ");
  Serial.print(C_nF);
  Serial.println(" nF");
}
```

RC Time Constant Explanation

The voltage across a capacitor during charging through a resistor follows an exponential relationship given by:

$$V_C(t) = V_s\left(1 - e^{-t/RC}\right)$$

Substituting $V_C/V_s = 0.63$ into the charging equation:

$$0.63 = 1 - e^{-t/RC}$$

$$e^{-t/RC} = 0.37$$

$$-\frac{t}{RC} = \ln(0.37) \approx -1$$

$$t = RC$$

Thus, the time required to reach 63% of the input voltage is equal to the RC time constant.

Observation Table

Capacitance (nF)	R (Ω)	Measured Time (μs)	Expected Time (μs)	Calculated C (nF)	Error (%)
100	10000	1044	1000	104.4	4.4
20	10000	236	200	23.6	18

Error Discussion

- The analogReead() operation is not instantaneous and takes approximately 100 μs per conversion. When measuring small RC time constants (such as 20 nF with an expected time of 200 μs), this delay becomes comparable to the actual charging time error
- The capacitor voltage crosses the 63% level between two ADC samples, but the while-loop detects it only at the next available reading.
- Practical components do not have exact values. Resistor and capacitor tolerances, internal resistance of the Arduino output pin, breadboard contact resistance contribute to error

TASK C – Ohmmeter Prototype

Calculation

Let:

- V_{in} = supply voltage
- V_{out} = measured midpoint voltage
- R_{ref} = reference resistor
- R_x = unknown resistance

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_x}{R_{\text{ref}} + R_x}$$

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{R_x}{R_{\text{ref}} + R_x}$$

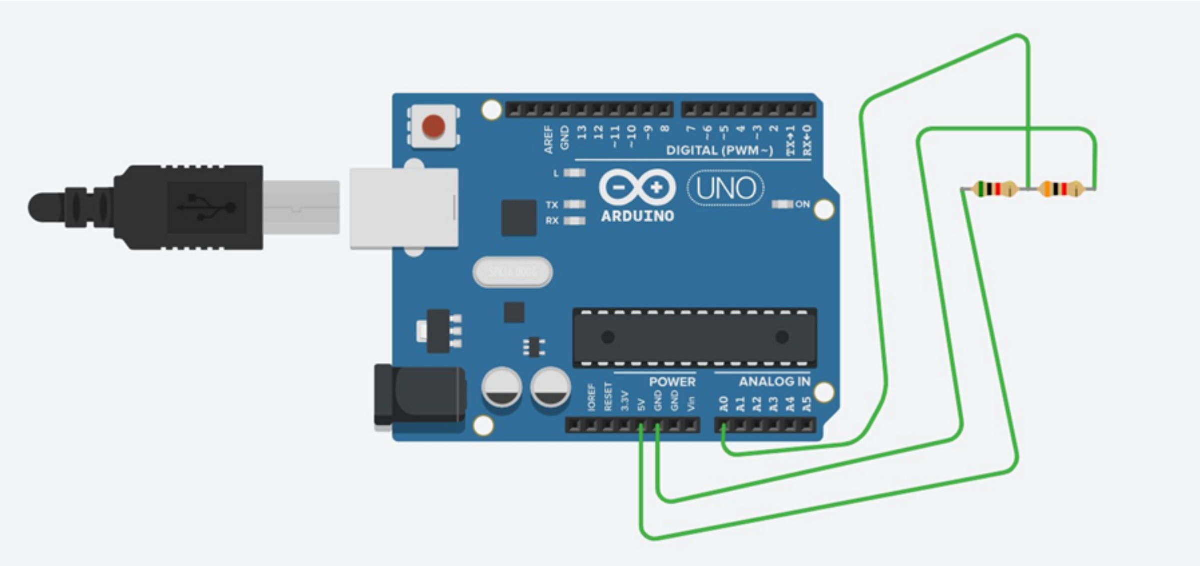
$$V_{\text{out}}(R_{\text{ref}} + R_x) = V_{\text{in}} \times R_x$$

$$V_{\text{out}} \times R_{\text{ref}} + V_{\text{out}} \times R_x = V_{\text{in}} \times R_x$$

$$V_{\text{out}} \times R_{\text{ref}} = R_x\,(V_{\text{in}} - V_{\text{out}})$$

$$R_x = R_{\text{ref}} \times \frac{V_{\text{out}}}{V_{\text{in}} - V_{\text{out}}}$$

Circuit Diagram



Arduino Code

```
int R = 5000;

void setup()
{
  Serial.begin(9600);
}

void loop()
{
  int a = analogRead(A0);
  float Vout = a * (5.0 / 1023.0);
  float R_unknown = R * (Vout / (5.0 - Vout));

  Serial.print("Unknown Resistance: ");
  Serial.print(R_unknown);
  Serial.println(" ohms");
  delay(2000);
}
```

Observation Table

Actual Resistance (Ω)	Measured Resistance (Ω)	Error (%)
3000	3004.69	0.16
4700	4705.98	0.13
15000	14980.47	0.13

Error Discussion

Practical components do not have exact values. Resistor tolerances, internal resistance of the Arduino 5V pin contribute to error