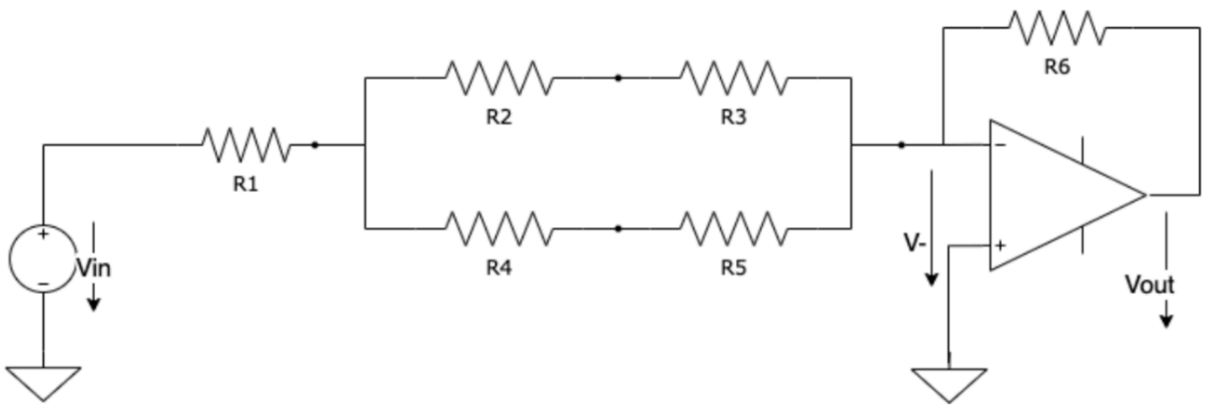
2DT903 : Lab 2 : Samuel Berg(sb224sc) & Jesper Wingren(jw223rn)

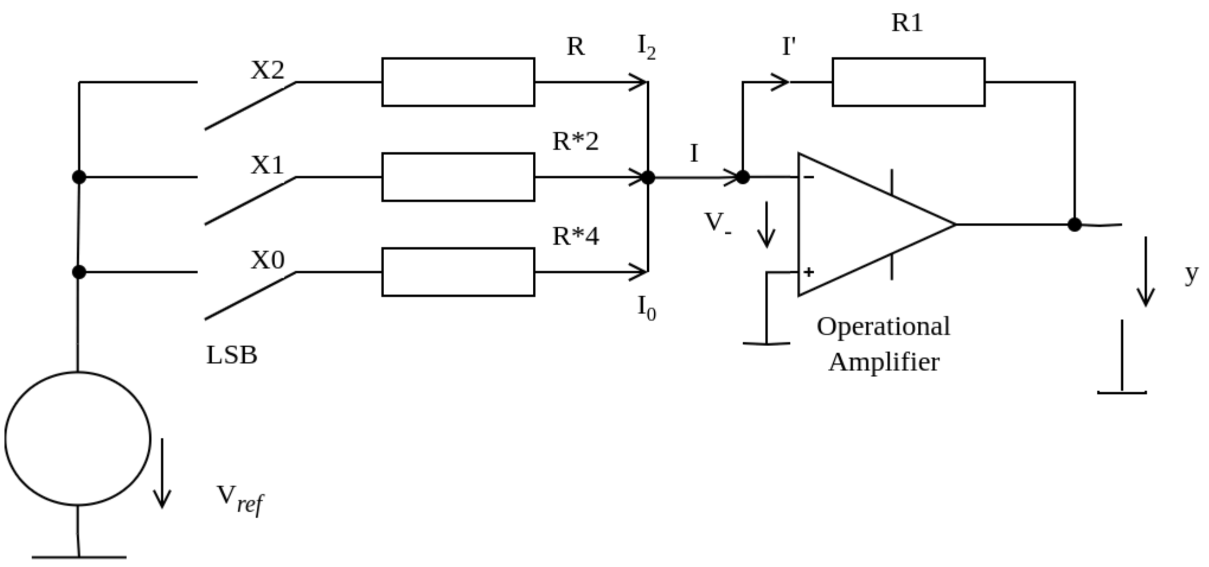
Task 1



Showcasing the circuit the below calculation is for(Taken from lab description document)

```
R24 = R2 + R4
R35 = R3 + R5

Rin = R1 + (R24 * R35)/(R24 + R35)

Rf = R6     (feedback resistance)

g_closed = -(Rf/Rin) = -(R6/(R1 + (R24 * R35)/(R24 + R35)))

=> Vout = g_closed * Vin = -(R6/(R1 + (R24 * R35)/(R24 + R35))) * Vin
```

Task 2



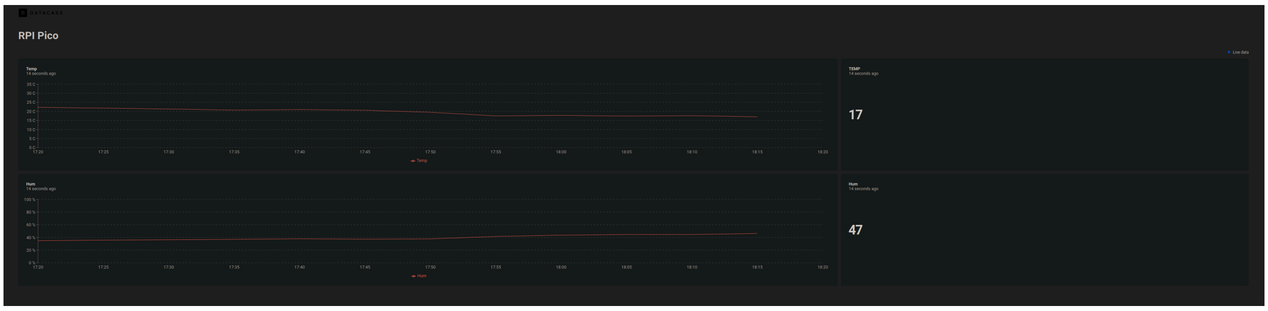
3-bit DAC circuit(Made using drawio)

```
X = {X0, X1, X2} where X2 is the MSB & X0 is the LSB

X2 = 1/2 * Vref (Due to being MSB)
X1 = 1/4 * Vref
X0 = 1/8 * Vref (Due to being LSB)
=>
Vout = Vref * (X2/4 + X1/4 + X0/8)

Example:
If we have the bit value 101, which is represented by X = {1, 0, 1} then,
Vout = Vref * (1/2 + 0/4 + 1/8) = Vref * (4/8 + 0/8 + 1/8) = Vref * 5/8
and this is correct due to (101(in base 2) = 5(in base 10))

Conclusion:
The output voltage of a 3-bit DAC is linearly proportional to the value represented by the input vector X as
```

Task 3

Data preview

Image of dashboard(python implementation)



Link to dashboard(python implementation)

Video of the C code running

Code

Python implementation(sending sensor data to datacake via mqtt)

```python
import network
import time
import machine
import umqtt
import ubinascii
import dht
import json

ssid = 'wifi-name'
password = 'wifi-pass'
topic = "Samuel/RPIPico"
btn = machine.Pin(0, machine.Pin.IN)
led = machine.Pin(1, machine.Pin.OUT)
dht = dht.DHT11(machine.Pin(16))

mqtt_c = None

def conn_wifi():
    wlan = network.WLAN(network.STA_IF)
    wlan.active(True)
    if not wlan.isconnected():
        print(f"Connecting to Wi-Fi: {ssid}")
        wlan.connect(ssid, password)

        while not wlan.isconnected():
            time.sleep(1)
            print(" .", end="")

    print("\nConnected to Wi-Fi")
    print(wlan.ifconfig())

def conn_mqtt():
    global mqtt_c
    try:
        mqtt_c = umqtt.MQTTClient(client_id=ubinascii.hexlify(machine.unique_id()).decode(), server="broker.em
        mqtt_c.connect()
        print("Connected to MQTT")
    except Exception as e:
        print(f"Failed to connect to MQTT: {e}")
        mqtt_c = None

def p_msg(mqtt_c, topic, message):

    if mqtt_c:
        try:
            mqtt_c.publish(topic, message)
            print(f"Message published to {topic}: {message}")
        except Exception as e:
            print(f"Failed to publish message: {e}")
    else:
        print("MQTT client not connected.")
    led.off()

def msg_cb(topic, msg):
    print(f"Received message: {msg.decode()} from topic: {topic.decode()} \n")
    if msg.decode() == "Data comming..." or msg.decode() == "Btn data comming...":
        temp()
        p_msg(mqtt_c, topic, "Data ending...")
    else:
        led.on()

def sub_topic(mqtt_c, topic):
    if mqtt_c:
        mqtt_c.set_callback(msg_cb)
        try:
            mqtt_c.subscribe(topic)
            print(f"Subscribed to {topic}")
        except Exception as e:
            print(f"Failed to subscribe to topic: {e}")
    else:
        print("MQTT client not connected.")

def btn_cb():
    if btn.value() == 1:
        time.sleep(0.05)
        if btn.value() == 1:
            return True
    return False

def temp():
    dht.measure()
    temp = dht.temperature()
    hum = dht.humidity()

    payload = json.dumps({"temp": temp, "hum": hum})
    p_msg(mqtt_c, topic, payload)

def main():
    conn_wifi()
    conn_mqtt()
    if mqtt_c:
        sub_topic(mqtt_c, topic)

        try:
            elapsed_time = time.time()

            while True:
                mqtt_c.check_msg()

                if time.time() - elapsed_time >= 300:
                    p_msg(c, topic, "Data comming...")
                    elapsed_time = time.time()

                if btn_cb():
                    led.on()
                    p_msg(mqtt_c, topic, "Btn data comming...")
                    time.sleep(0.5)
                led.off()

        except KeyboardInterrupt:
            print("Disconnecting from MQTT...")
            if mqtt_c:
                mqtt_c.disconnect()

main()
```

Datacake uplink code

```
function Decoder(topic, payload) {
    try {
        payload = JSON.parse(payload);

        var Temp = payload.temp;
        var Hum = payload.hum;

        return [
            {
                device: "25590695-dd0b-4f08-8f74-987e68bd6ac0",
                field: "TEMP",
                value: Temp
            },
            {
                device: "25590695-dd0b-4f08-8f74-987e68bd6ac0",
                field: "HUM",
                value: Hum
            }
        ];
    } catch (error) {
        console.error("Failed", error);
        return [];
    }
}
```

C implementation(no networking)

```
#include <stdio.h>
#include <dht.h>
#include "pico/stdlib.h"
#include "FreeRTOS.h"
#include "task.h"

#define BTN_PIN 0
#define LED_PIN 1
#define DHT_PIN 16
```

```c
static const dht_model_t DHT_MODEL = DHT11;
dht_t dht;

// Periodically check temp & hum, if DHT returns error improper data is returned
void temp_task(void *pvParameters) {
    for (;;) {
        dht_start_measurement(&dht);

        float temp;
        float hum;
        dht_result_t res = dht_finish_measurement_blocking(&dht, &hum, &temp);

        if (res == DHT_RESULT_OK) {
            printf("Temperature: %.1f °C, Humidity: %.1f%%\n", temp, hum);
        } else if (res == DHT_RESULT_TIMEOUT){
            printf("DHT sensor not responding. Please check your wiring.\n");
        } else {
            assert(result == DHT_RESULT_BAD_CHECKSUM);
            puts("Bad checksum");
        }

        vTaskDelay(pdMS_TO_TICKS(2000));
    }
}

// On button press turn LED ON/OFF dependent on previous state
void btn_task(void *pvParameters) {
    bool ledState = false;

    while (1) {
        printf("Button state: %d\n", gpio_get(BTN_PIN));
        if (gpio_get(BTN_PIN)) {
            ledState = !ledState;
            gpio_put(LED_PIN, ledState);
            vTaskDelay(pdMS_TO_TICKS(500));
        }
        vTaskDelay(pdMS_TO_TICKS(50));
    }
}

int main() {
    stdio_init_all();

    // Init LED
    gpio_init(LED_PIN);
    gpio_set_dir(LED_PIN, GPIO_OUT);

    // Init button
    gpio_init(BTN_PIN);
    gpio_set_dir(BTN_PIN, GPIO_IN);
    gpio_pull_up(BTN_PIN);

    // Init DHT sensor
    dht_init(&dht, DHT_MODEL, pio0, DHT_PIN, true);

    // Create tasks
    xTaskCreate(temp_task, "tempTask", configMINIMAL_STACK_SIZE, NULL, 1, NULL);
    xTaskCreate(btn_task, "btnTask", configMINIMAL_STACK_SIZE, NULL, 1, NULL);

    vTaskStartScheduler();

    while (1); // <- Shall never be reached
    return 0;
}
```

Report

1. Introduction

- Demonstrating the necessity of an RTOS.
- Implementing a similar project in both **Python** and **C**(due to constraints).
- Overview of real-time requirements that MicroPython alone cannot meet.

2. Project overview

Hardware setup

- **RPi Pico W 2040**: Microcontroller.
- **DHT11 Sensor (Pin 16)**: Measures temperature and humidity.
- **Button (Pin 0)**: User input.
- **LED (Pin 1)**: Visual feedback.
- **Wi-Fi Module**: Onboard Pico W for wireless communication.

Communication protocol

- Using MQTT over Wi-Fi.
- Server: `"broker.emqx.io"`.
- Topic: `"Samuel/RPIPico"`.
- Sending sensor data and publishing it to datacake via MQTT.

3. Real-time requirements

Python

Real-time constraints:

- **Button press**: Immediate response to user input & light LED until button press data reaches MQTT.
- **Sensor data transmission**: Collect and transmit data every 30 seconds.
- **Wireless communication**: Real-time communication over Wi-Fi to an MQTT broker.

C

Real-time constraints:

- **Button press**: Immediate response to user input & light LED.
- **Sensor data**: Collect and print data every 2000 ticks.

Task delays: A delayed response (missing button presses or delayed sensor data) impacts the system. If a safety critical system the consequences can be drastic.

4. MicroPython implementation

Real-time challenges in MicroPython

- **No task prioritization**: Sequential task execution can cause delays.
- **Blocking operations**: Network or sensor delays block other tasks.
- **Hardware interrupts**: Lack of hardware interrupts leads to inefficient real-time performance.

Test results

- **Observed issues**: Delayed sensor readings, slow publish times to MQTT.

This demonstrates the need for RTOS.

5. C implementation

Advantages of C with RTOS

- **Precise task scheduling**: Meeting real-time constraints through prioritized tasks.
- **Non-blocking behavior**: Tasks can yield control for immediate responses.
- **Interrupt-driven events**: Efficient handling of button presses and critical tasks.

Test results

- **Improved responsiveness**: Faster reaction to button presses, consistent sensor data.

This demonstrates how RTOS in C meets the real-time requirements in comparison to the MicroPython implementation which **did not**.

6. Comparison and evaluation

MicroPython vs C with RTOS

Feature	MicroPython	C
Ease of Use	Easier to write and debug.	More complex syntax. Better for optimized, performance-critical applications.
Performance	Slower due to the level of abstraction and its interpreted nature.	Higher performance due to compiled code, direct memory access and less overhead.
Real-Time Capabilities	Limited real-time control, less suitable for strict timing constraints.	Highly suitable for real-time tasks, better timing accuracy, and more predictable behavior.
Libraries and Ecosystem	Extensive libraries for sensors, communication, and quick development.	Rich library support, but requires more effort to integrate and manage.

7. Conclusion

RTOS is essential for real-time tasks due to the strict timing requirements involved in many embedded systems.

MicroPython is ideal for simplifying work with sensors, wireless communication, and I/O operations. Its abstractions allow for faster development, but it struggles with real-time performance due to overhead and less precise timing control. It is suited for projects that prioritize ease of use.

C on the other hand, offers greater control over hardware and enables more accurate timing, making it well-suited for real-time systems. Though more complex and time-consuming to develop, C provides the performance and real-time guarantees that MicroPython lacks, especially when combined with an RTOS.