

LECTURE VI

Communication Protocols II

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T-Shirts!!

- Here is the design for this year's OPS t-shirts!
- The T-Shirts have been ordered and will arrive sometime before the end of the quarter
- We will send out an announcement about t-shirt pickup closer to when they arrive



SECTION I

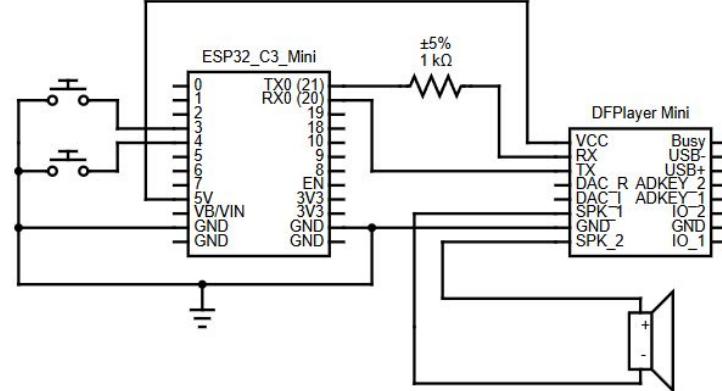
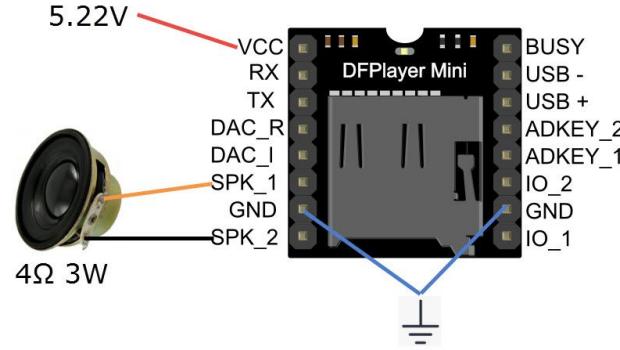
Project V Review

Project 5 Review

- Build and program a **music player** with ESP32, customized to play **your own tunes**.
- Due date: 1/26/2026 at 11:59PM

Learning Concepts:

- Communication Protocols
- UART
- Pull-Up Resistor Circuits
- Serial Library

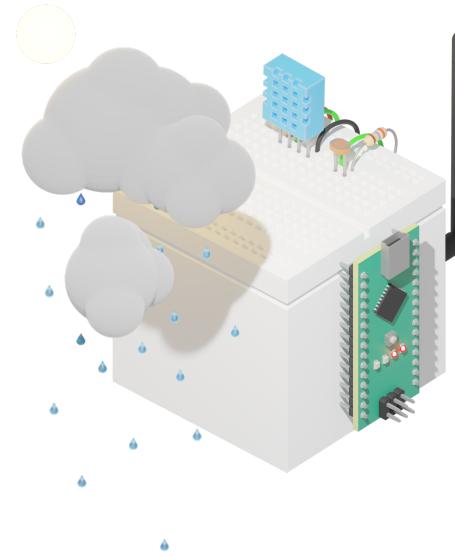


Project 6 Overview

- Build a **weather station** that wirelessly transmits **temperature** and **humidity data** to an indoor display.
- Due date: 2/9/2026 at 11:59PM

Learning Concepts:

- Communication Protocols Pt. 2
- I²C Protocol
- SPI Protocol
- Arduino IDE Libraries (Continued)



SECTION II

UART Review

UART Protocol

- UART is a **communication protocol with certain characteristics**. It has rules for data transmission:
 - UART can be configured to **__-duplex, __-duplex, and __plex modes**
 - There are only **__ lines** (electrical connections)
 - The data transmission speed is determined by a **__ rate**
 - It is quite **(slow/fast?) compared to other protocols**

UART Protocol

- UART is a **communication protocol with certain characteristics**. It has rules for data transmission.
 - UART can be configured to **full-duplex, half-duplex, and simplex modes**
 - There are only **two lines** (electrical connections)
 - The data transmission speed is determined by a **baud rate**
 - It is quite **slow compared to other protocols**

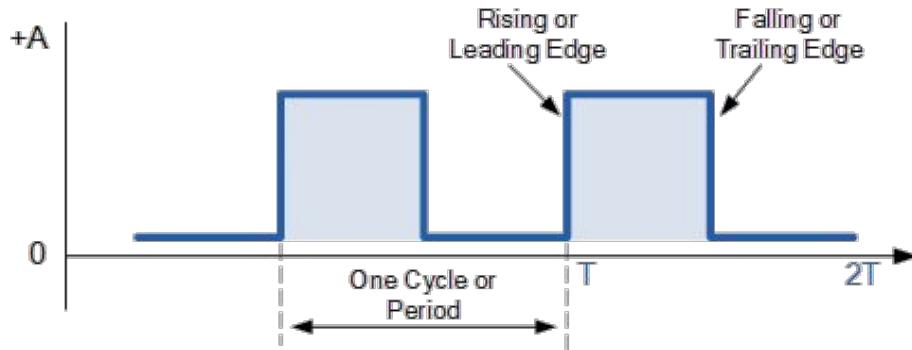
SECTION III

SPI



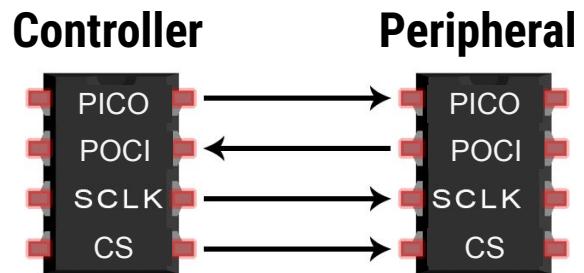
Clock Signals

- **Digital signals** are timed to a **clock signal** - most often, a square wave with a 50% duty cycle
 - For example, in a serial signal, one bit of data is sent per clock cycle
 - The bit might be timed to the rising or falling edge of the clock signal
- **Clock speed** determines the rate at which data is transmitted
 - measured as **frequency (Hz)**
 - inversely proportional to cycle (or period)



SPI Protocol

- **Serial Peripheral Interface** or **SPI** is a serial communication protocol which is **synchronized with a clock**
- Unlike UART, **data is transferred continuously** in SPI
 - There are no packets, start bits, stop bits, parity bits, or anything else
- One device acts as a **controller** to one or more **peripheral** devices
- Supports **full-duplex** communication
 - Bi-directional communication



A Note on Terminology

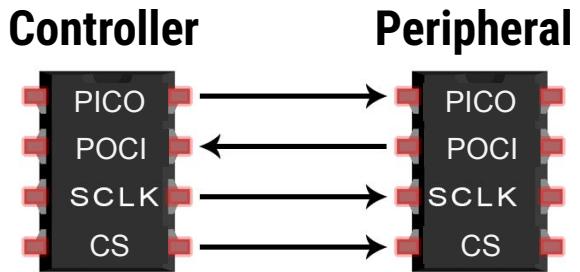
The words **master** and **slave** pervade modern software and electronics documentation. The terms are inappropriate, so we are transitioning to new terminology in OPS documentation.

There will be a discrepancy between what is discussed in lecture/lab and what is written in our parts' datasheets.

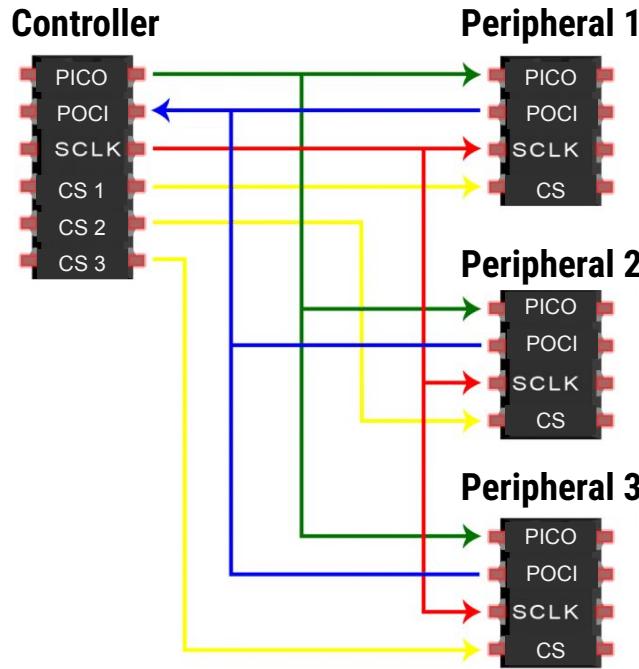
Old Term	New Term
Master	Controller
Slave	Peripheral
MISO	POCI
MOSI	PICO
SS	CS

SPI Layout

- **PICO** (**Peripheral-In/Controller-Out**) - line for the controller to send data to the peripheral
- **POCI** (**Peripheral-Out/Controller-In**) - line for the peripheral to send data to the controller
- **SCLK** (**Clock**) - line for the clock signal
- **CS** (**Chip Select**) - line for the controller to select which peripheral to send data

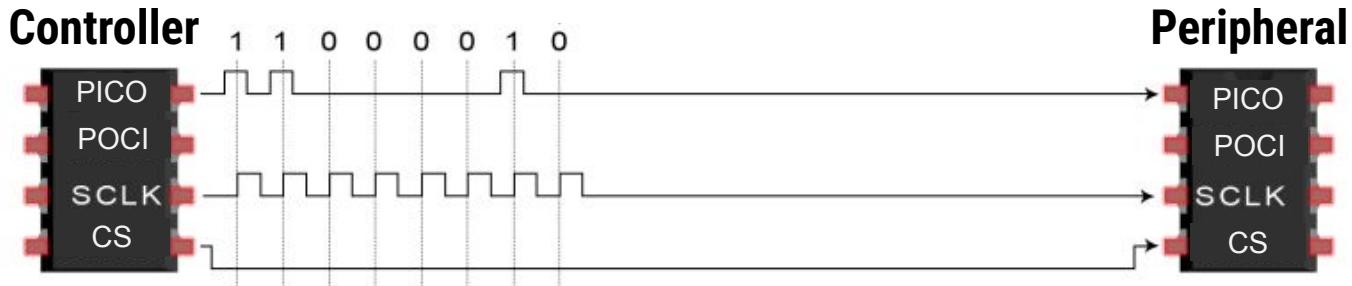


SPI Layout (Cont'd)



- There is **one controller**
 - Often a microcontroller (ESP32)
 - Generates the clock signal
- The controller controls **one or more peripherals**
 - i.e. Radio module, sensor, actuator
 - In the configuration to the left, there is an **additional Chip Select (CS) line for each peripheral**

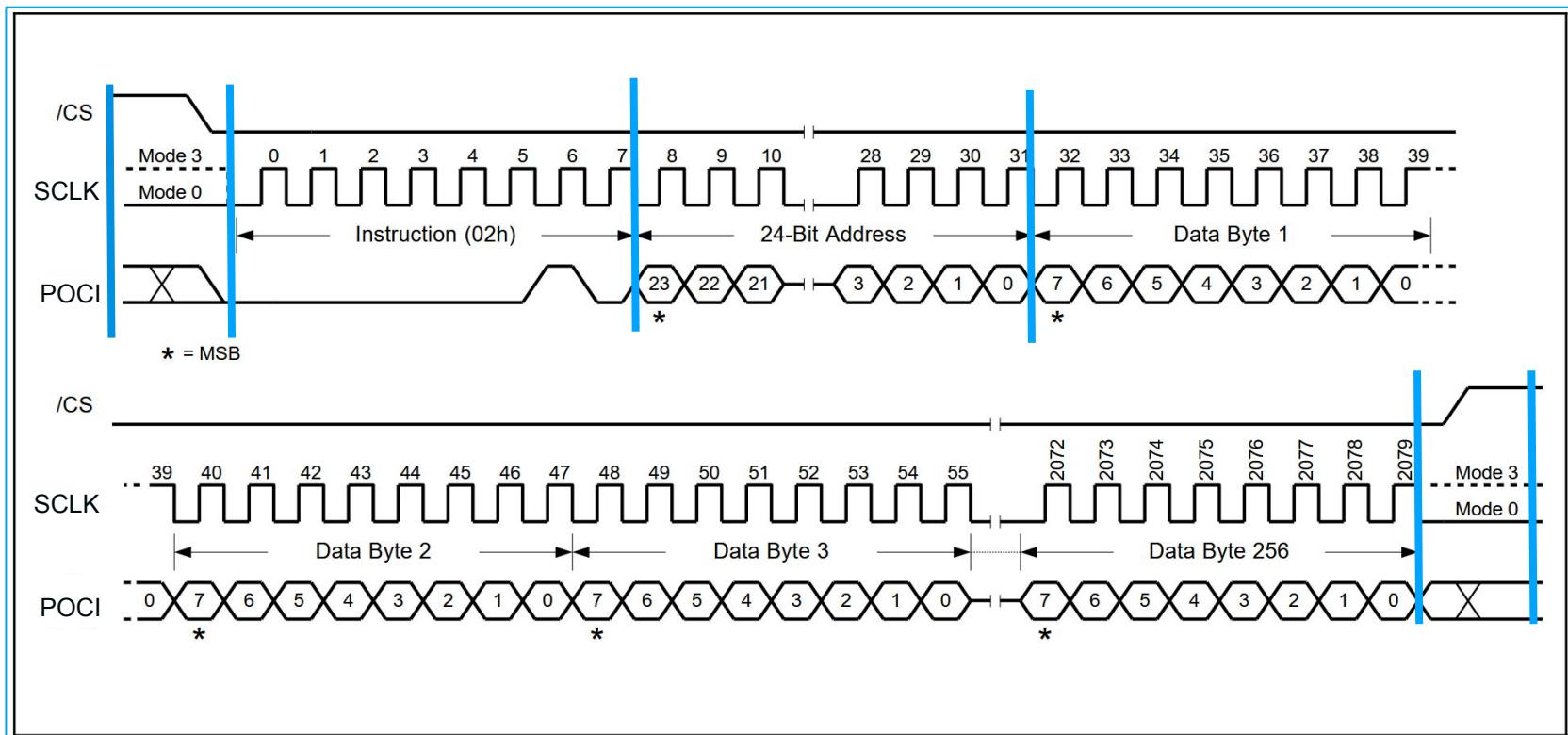
SPI Transmission



1. The controller first **selects a peripheral** by pulling a HIGH signal to LOW along the Chip Select (CS) line
2. The controller **sends data** to the selected peripheral along the Peripheral-In/Controller-Out (PICO) line
 - Bits in the PICO signal are **synchronized with the rising edge** of the oscillating clock signal
 - Alternatively, the peripheral sends data along the Peripheral-Out/Controller-In (POCI) line

SPI Transmission Example

Example is of writing data into a flash memory. (WinBond W25q1128jv)



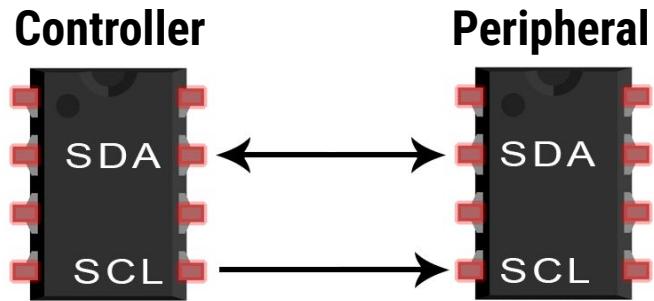
SECTION IV

I²C



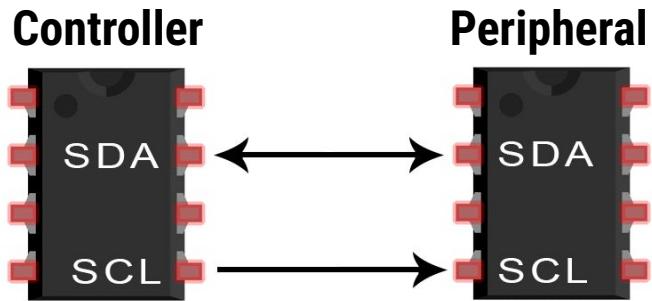
I²C Protocol

- **Inter Integrated Circuit** or **I²C** is another synchronized, serial protocol
- Unlike UART and SPI, I²C supports **multiple controllers**
- I²C features addressing for peripherals and **acknowledgements** to confirm if messages are received
- Supports **half-duplex** communication
 - One way communication



I²C Layout

- **SDA (Serial Data)** - the line for the controller and peripheral to send and receive data
- **SCL (Serial Clock)** - the line that carries the clock signal
- All peripherals can share the same two SDA and SCL lines
- Both SDA and SCL lines are connected to pull-up resistors, default HIGH



I²C Frame Format

- Data is transferred as **messages**
- A **start condition** from the controller begins the message
 - Pulls **Serial Data** (SDA) line to LOW before **Serial Clock** (SCL) switches HIGH to LOW
- Each message contains an **address frame** with an address to identify the receiving peripheral

I²C Message



I²C Frame Format (Cont'd)

- The **read/write bit** indicates whether the controller is sending or requesting data
 - LOW for controller sending, HIGH for controller receiving
- Then, the peripheral with the matching address sends an **acknowledgement (ACK)** of the message as a single bit
 - Pulled the SDA line from HIGH to LOW

I²C Message



I²C Frame Format (Cont'd)

- Depending on whether the message is read or write, either the controller or peripheral will send **data frames**
- The device receiving data will send an **ACK** before the transmission of the next data frame

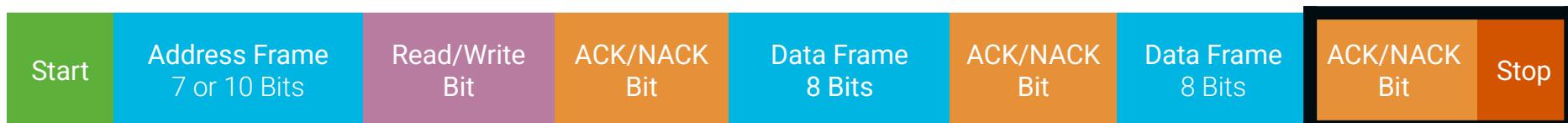
I²C Message



I²C Frame Format (Cont'd)

- The devices may transfer as many data frames in one message as desired
- If the controller is reading from the peripheral, it will send a **NACK** to end data transmission
- The controller terminates communication by signalling the **stop condition**
 - Pulls **Serial Data** (SDA) line to HIGH after **Serial Clock** (SCL) switches LOW to HIGH
 - Another controller may send a message upon seeing the stop signal

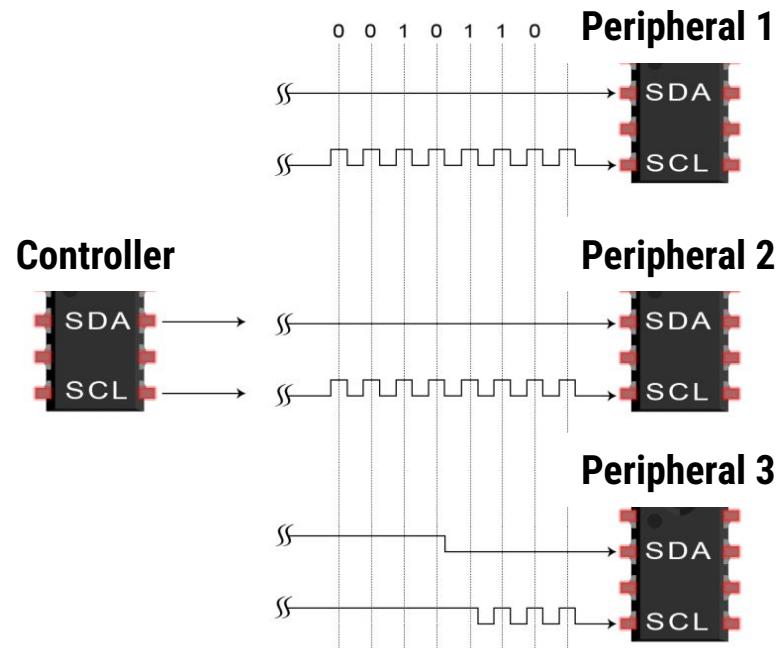
I²C Message



I²C Transmission (Cont'd)

1. The controller outputs the **start condition** to all connected peripherals

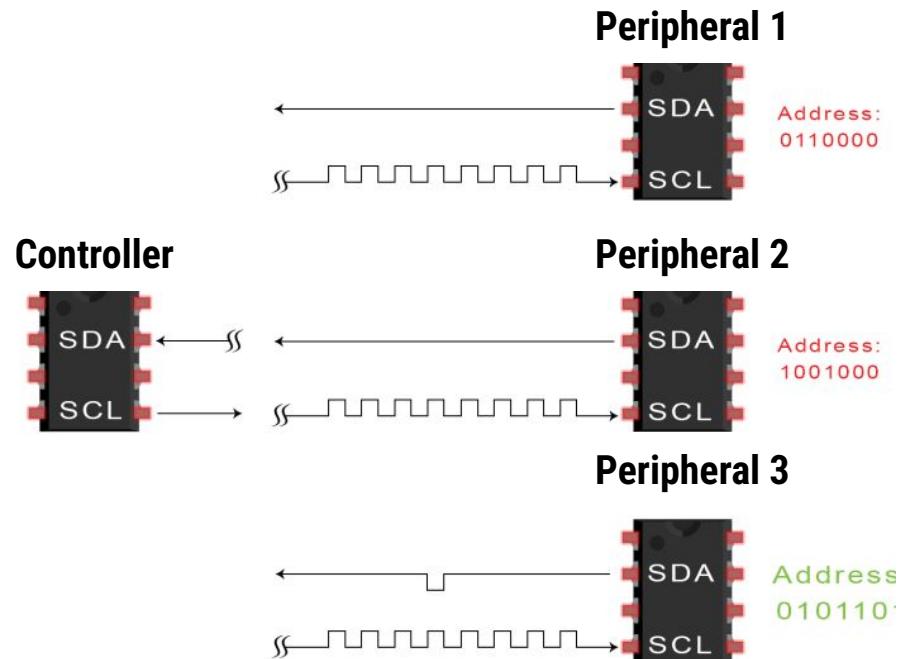
Starting from a **HIGH** voltage in idle, the controller pulls the SDA line voltage to **LOW** then the SCL line voltage to **LOW**



I²C Transmission (Cont'd)

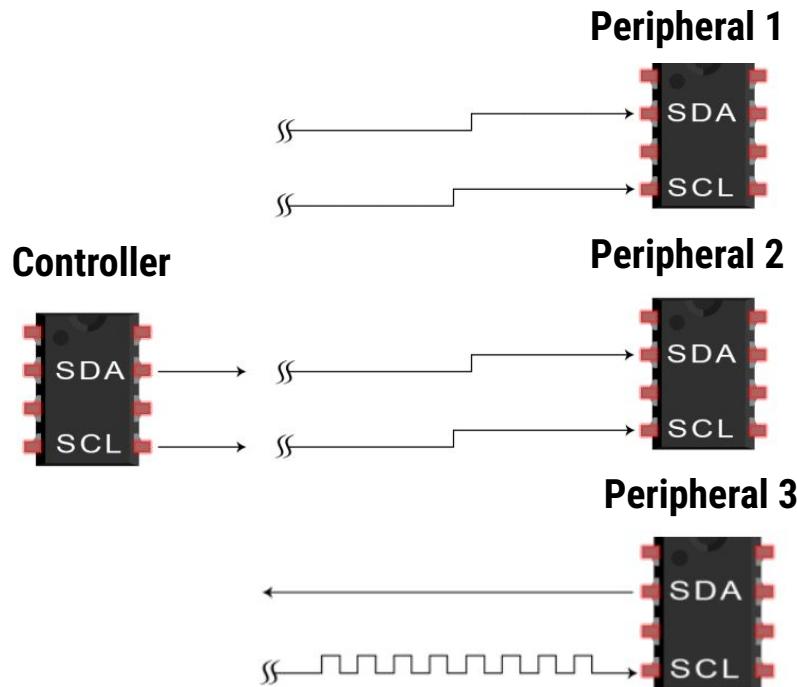
2. The controller then **sends the address** of the peripheral it would like to communicate with

The **last bit of the address is the read/write bit** that indicates whether the controller is sending or receiving data



I²C Transmission (Cont'd)

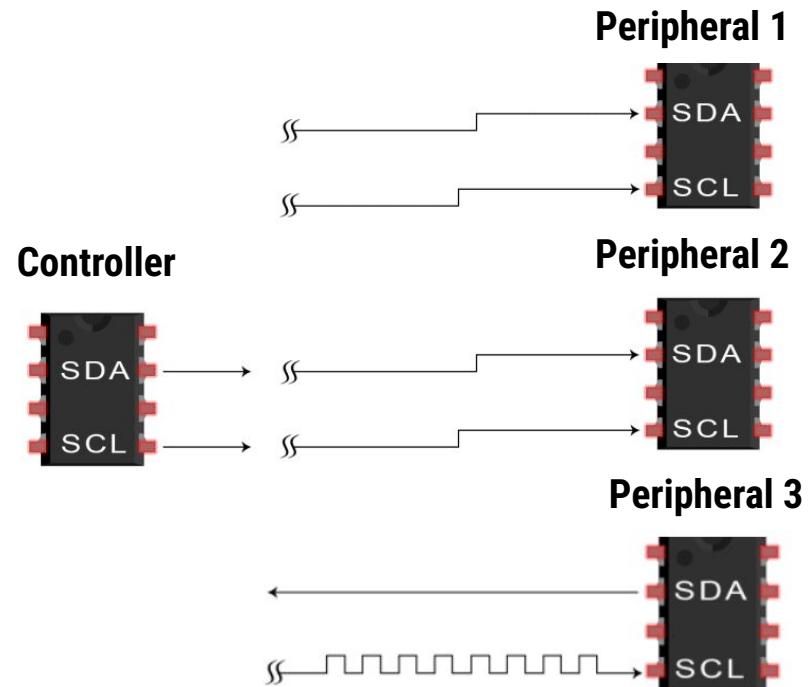
3. The peripheral with the matching address responds with an **ACK**
 - Note: The ACK signal would go to every peripheral on the I²C line, but communication will now be exclusively from the controller to peripheral 3 in the example.



I²C Transmission (Cont'd)

4. The controller **sends or receives the data frame**, depending on the read/write bit

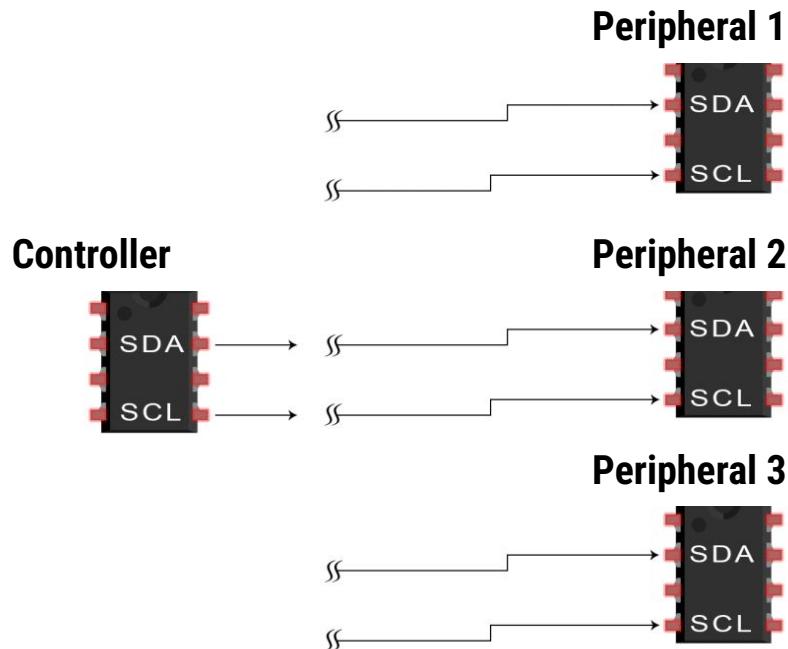
After each transmission, the receiving device sends an ACK for a successful transmission



I²C Transmission (Cont'd)

- Finally, the controller switches the voltage of the SCL line then the SDA line to **HIGH**, signalling the **stop condition**

The message is complete



SECTION V

Comparing Protocols

UART vs SPI vs I²C

Protocol	UART	SPI	I ² C
# of Lines	2	4+	2
# of Controllers	1	1	1+
# of Peripherals	1	1+	1+
Transmission Type	Full-Duplex	Full-Duplex	Half-Duplex
Error-Checking	✓	✗	✓
Speed	Slowest	Fastest	Slower

SECTION VI

WiFi



WiFi Protocol

- WiFi a wireless networking protocol based on the **IEEE 802.11** standards
 - WiFi is a brand name, does not stand for Wireless Fidelity
- Enables devices to wirelessly connect with radio waves
 - Frequencies like 2.4 GHz, 5 GHz
- Half-duplex communication
 - Delay is known as **latency**, can be measured using **PING** (Packet InterNet Groper)



WiFi Communication

- Data is broken into packets before being sent over RF
- In **Packet Switched Communication**, devices share the same wireless channel
 - Devices compete for the same bandwidth and take turns transmitting
- Will be discussed in **Workshop 6**

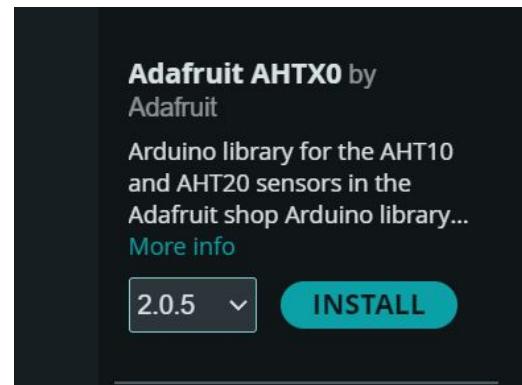
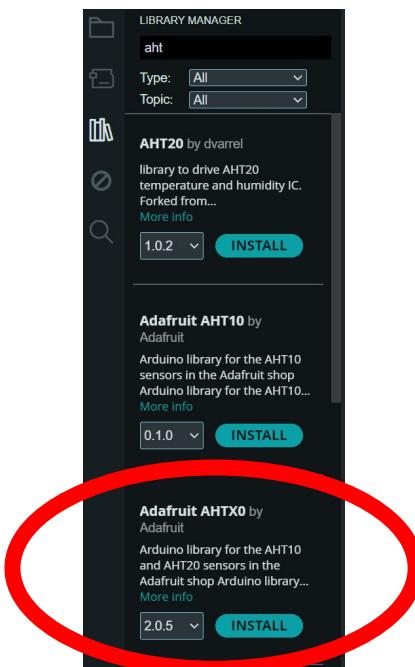


SECTION VII

AHT20 Exercise

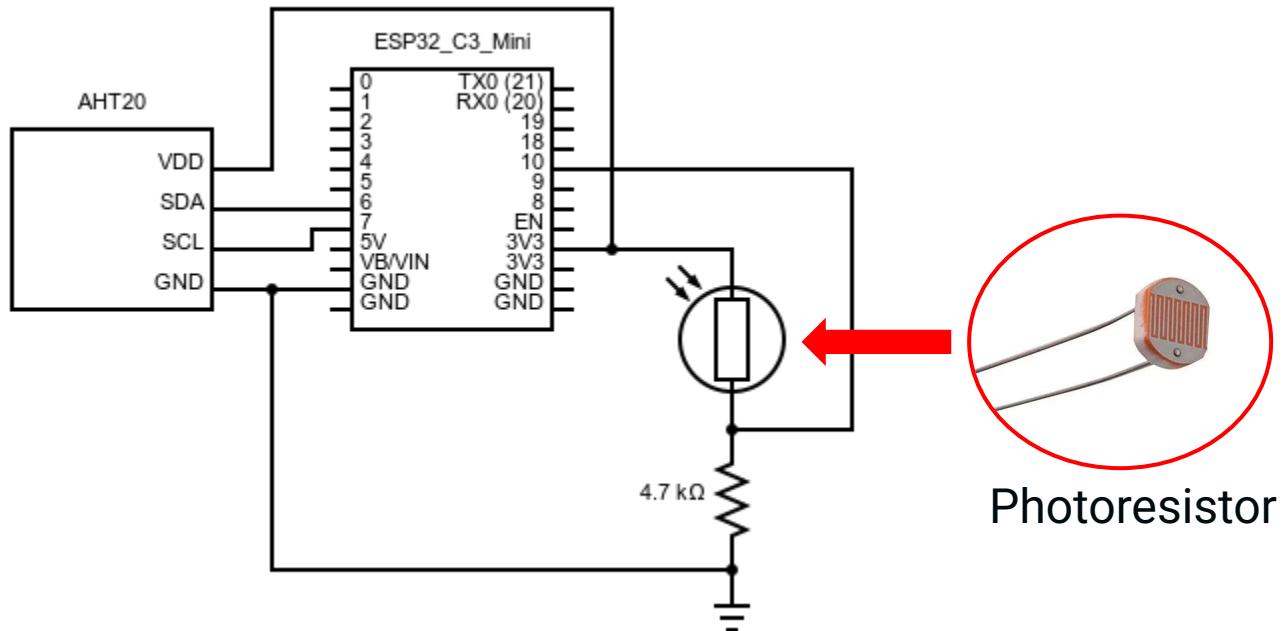
AHTX0 Library Installation

- Find and install the Adafruit AHTX0 library
- You can include this library with `#include <Adafruit_AHTX0.h>`



AHT20 Exercise Schematic

Build this circuit here:



Wire Library

- Built-in library that allows us to set our own SDA and SCL pins for I²C
- Include this library with `#include <Wire.h>`
- `Wire.begin(int I2C_SDA, int I2C_SCL);`
 - Initializes the Wire library and allows the ESP32 to participate in I²C as a controller or peripheral.
 - Takes two pin numbers and configures them to be SDA and SCL pins, respectively.
 - Need to connect AHT20's SDA and SCL to the ESP32 pins configured with this function

```
// Define I2C pins
#define I2C_SDA 6
#define I2C_SCL 7

void setup() {
    // configure I2C for pins 6 and 7
    Wire.begin(I2C_SDA, I2C_SCL);
}
```

AHT20 Functions

- `aht.begin()` finds the AHT sensor via the ESP32's SDA and SCL pins
- `aht.getEvent(sensors_event_t *humidity, sensors_event_t *temperature)`
 - Stores the AHT's humidity and temperature readings into two `sensors_event_t` objects (named humidity and temperature in this example)

```
void setup() {
    Serial.begin(115200);

    // configure I2C for pins 6 and 7
    Wire.begin(I2C_SDA, I2C_SCL);

    aht.begin();
}
```

```
void loop() {
    sensors_event_t humidity, temp;
    aht.getEvent(&humidity, &temp);

    delay(500);
}
```

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SECTION II

**OPS Project Highlight:
“Rockquestor” by Dane Hobrecht**

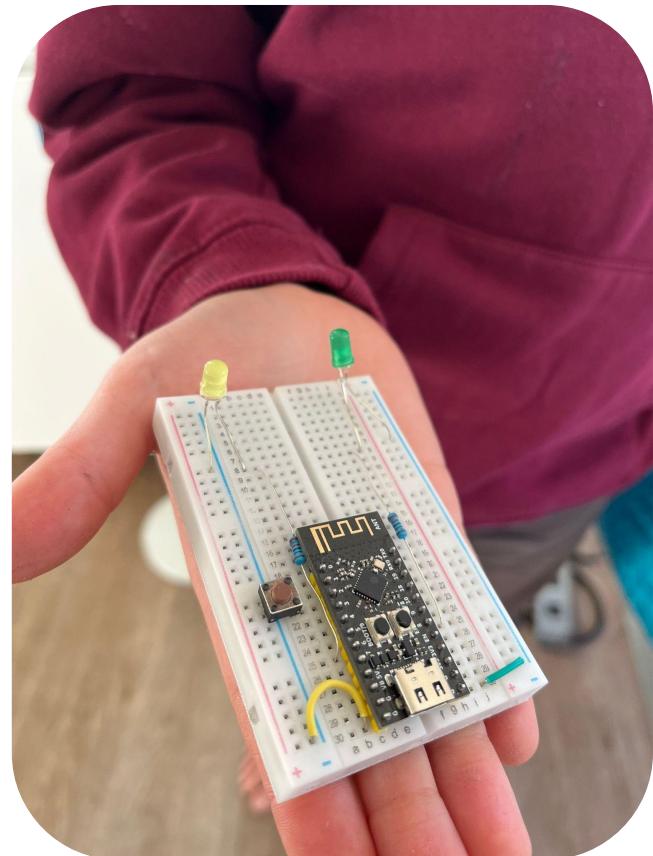
The Problem



- “My little brother, Rocky, is 9 years old, and isn't allowed to digitally communicate on his own yet.”
- “He lives a couple cities away, and in order to hang out, we've had to go through my dad's cell phone as a medium.”

The Solution

- “I was tired of our communications being dependent on my dad's availability, so I made him the **“Rockquestor”** (Rocky + Requestor = ‘Rockquestor’).”
- “When he wants to hang out, he presses the button, which sends me an email notification and illuminates the Yellow LED, confirming his request was sent.”
- “When I see the email, I go onto a web dashboard and remotely enable the other LED, telling him that I've seen his ‘rockquest’ and that I'm ready to hang out!”



The Solution

```
void loop() {
    // put your main code here, to run repeatedly:
    Blynk.run();
    if (digitalRead(BTN_BRN) == 0) {
        digitalWrite(LED_YLW, HIGH);
        Blynk.logEvent("hang_out"); // Trigger Blynk event to send email notification
        delay(1000); // Debounce, prevent spam, and extend LED illumination
    } else {
        digitalWrite(LED_YLW, LOW);
    }
}
```

- It uses the **Blynk** service for connecting IoT hardware to the cloud.
- It waits for a particular log event (in this case, `hang_out`) and triggers an

Blynk
email notification:

12/28/2024

Rockquestor: Rocky wants to hang out!
Rocky wants to hang out! Open in the app --
Date: Saturday, December 28, 2024,

The Result



- “He's already used it once so we could go see a movie together. OPS was definitely the reason I was able to get it off the ground so quickly.”

Comparing Protocols

Which one of the following is a full-duplex communication protocol?

- A. SPI
- B. I²C
- C. Both SPI and I²C
- D. Neither SPI or I²C

Comparing Protocols (Cont'd)

Which of the following protocols doesn't require an additional line to support multiple devices on the same bus?

- A. SPI
- B. I²C
- C. Both SPI and I²C
- D. Neither SPI or I²C

Comparing Protocols

Which of the following protocols supports multiple controllers and peripherals?

- A. SPI
- B. I²C
- C. UART
- D. Both UART and I²C

Comparing Protocols

Which of the following protocols doesn't have start and stop bits?

- A. SPI
- B. I²C
- C. UART
- D. Both UART and I²C

Comparing Protocols

The SCLK, PICO, POCL, CS are the four data lines in _____ protocol.

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

Which of the following communication protocols is a type of synchronous protocol?

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

Which one of the following protocols needs a clock?

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

The receiver and transmitter are the two data lines in _____ protocol.

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

Which of the following protocols needs a chip select line?

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

Which of the following protocols is a single controller, single peripheral communication protocol?

- A. SPI
- B. I²C
- C. UART
- D. Both SPI and I²C

Comparing Protocols

How many signal lines does I²C Protocol require?

- A. 1
- B. 2
- C. 4

Comparing Protocols

How many signal lines does UART Protocol require?

- A. 1
- B. 2
- C. 4

Comparing Protocols

Which of the following protocols is best for multiple peripherals over the fewest lines?

- A. SPI
- B. I²C
- C. UART

Comparing Protocols

Which of the following protocols is best for multiple peripherals with the highest transmission rate?

- A. SPI
- B. I²C
- C. UART

Comparing Protocols

Which of the following protocols is best for full-duplex communication with multiple peripherals?

- A. SPI
- B. I²C
- C. UART

Comparing Protocols

Which of the following protocols consumes less power?

- A. SPI
- B. I²C