

I2C & USB 2.0

Lecture 7

I2C & USB 2.0

used by RP2040

- Buses
 - Inter-Integrated Circuit
 - Universal Serial Bus v2.0





I2C

Inter-Integrated Circuit

Bibliography

for this section

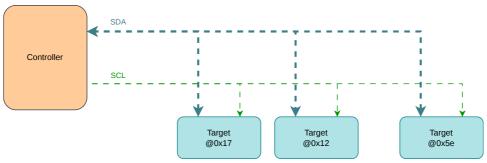
- 1. Raspberry Pi Ltd, RP2040 Datasheet
 - Chapter 4 Peripherals
 - Chapter 4.3 *I2C*
- 2. Paul Denisowski, *Understanding I2C*



I2C

a.k.a I square C

- Used for communication between integrated circuits
- Sensors usually expose an SPI and an I2C interface
- Two device types:
 - controller (master) initiates the communication (usually MCU)
 - target (slave) receive and transmit data when the controller requests (usually the sensor)

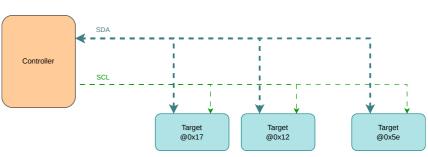






- SDA Serial DAta line carries data from the controller to the target or from the target to the controller
- SCL Serial CLock line the clock signal generated by the controller, targets
 - sample data when the clock is low
 - write data to the bus only when the clock is high
- each target has a unique address of 7 bits or 10 bits
- wires are never driven with LOW or HIGH
 - are always *pull-up*, which is HIGH
 - devices pull down the lines to write LOW







7 bit address

- 1. controller issues a START condition
 - pulls the SDA line LOW
 - waits for ~ 1/2 clock periods and starts the clock
- 2. **controller** sends the address of the **target**
- 3. **controller** sends the command bit (R/W)
- 4. target sends ACK / NACK to controller

5. **controller** or **target** sends data (depends on

R/W)

- receives ACK / NACK after every byte
- 6. **controller** issues a STOP condition
 - stops the clock
 - pulls the SDA line HIGH while CLK is HIGH

Address Format



Transmission





Transmission Example



10 bit address

- 1. controller issues a START condition
- 2. **controller** sends 11110 followed by the *upper address* of the **target**
- 3. **controller** sends the command bit (R/W)
- 4. target sends ACK / NACK to controller
- 5. **controller** sends the *lower address* of the **target**
- 6. target sends ACK / NACK to controller

- 7. **controller** or **target** sends data (depends on R/W)
 - receives ACK / NACK after every byte
- 8. controller issues a STOP condition

Address Format



Transmission



controller writes each bit when CLK is LOW, target samples every bit when CLK is HIGH





Mode	Speed	Capacity	Drive	Direction
Standard mode (Sm)	100 kbit/s	400 pF	Open drain	Bidirectional
Fast mode (Fm)	400 kbit/s	400 pF	Open drain	Bidirectional
Fast mode plus (Fm+)	1 Mbit/s	550 pF	Open drain	Bidirectional
High-speed mode (Hs)	1.7 Mbit/s	400 pF	Open drain	Bidirectional
High-speed mode (Hs)	3.4 Mbit/s	100 pF	Open drain	Bidirectional
Ultra-fast mode (UFm)	5 Mbit/s	?	Push-pull	Unidirectional





Transmission	half duplex	data must be sent in one direction at one time
Clock	synchronized	the controller and target use the same clock, there is no need for clock synchronization
Wires	SDA / SCL	the same read and write wire and a clock wire
Devices	1 controller several targets	a receiver and a transmitter
Speed	5 Mbit/s	usually 100 Kbit/s, 400 Kbit/s and 1 Mbit/s

Usage

- sensors
- small displays
- RP2040 has two I2C devices



Embassy API

for RP2040, synchronous

```
pub struct Config {
    /// Frequency.
    pub frequency: u32,
}
```

```
pub enum ConfigError {
    /// Max i2c speed is 1MHz
    FrequencyTooHigh,
    ClockTooSlow,
    ClockTooFast,
}
```

```
pub enum Error {
   Abort(AbortReason),
   InvalidReadBufferLength,
   InvalidWriteBufferLength,
   AddressOutOfRange(u16),
   AddressReserved(u16),
}
```

```
use embassy_rp::i2c::Config as I2cConfig;

let sda = p.PIN_14;

let scl = p.PIN_15;

let mut i2c = i2c::I2c::new_blocking(p.I2C1, scl, sda, I2cConfig::default());

let tx_buf = [0x90];

i2c.write(0x5e, &tx_buf).unwrap();

let mut rx_buf = [0x00u8; 7];

i2c.read(0x5e, &mut rx_buf).unwrap();
```

Embassy API



for RP2040, asynchronous

```
use embassy rp::i2c::Config as I2cConfig;
     bind_interrupts!(struct Irqs {
         I2C1 IRQ => InterruptHandler<I2C1>;
     });
     let sda = p.PIN 14;
     let scl = p.PIN_15;
 9
10
      let mut i2c = i2c::I2c::new async(p.I2C1, scl, sda, Irqs, I2cConfig::default());
11
12
     let tx_buf = [0x90];
13
     i2c.write(0x5e, &tx_buf).await.unwrap();
14
15
     let mut rx buf = \lceil 0 \times 000 u8; 7 \rceil;
     i2c.read(0x5e, &mut rx buf).await.unwrap();
```



USB 2.0

Universal Serial Bus

Universal Serial Bus

2.0

- Used for communication between a host and several devices that each provide functions
- Two modes:
 - host initiates the communication (usually a computer)
 - device receives and transmits data when the host requests it
- each device has a 7 bit address assigned upon connect
 - maximum 127 devices connected to a USB host
- devices are interconnected using hubs
- USB devices tree



Bibliography

for this section

- 1. Raspberry Pi Ltd, RP2040 Datasheet
 - Chapter 4 Peripherals
 - Chapter 4.1 *USB*
- 2. USB Made Simple



USB Device

- can work as **host** or **device**, but not at the same time
- uses a differential line for transmission
- uses a 48 MHz clock
- maximum 16 endpoints (buffers)

48 MHz

Clock

- *IN* from **device** to **host**
- *OUT* from **host** to **device**
- endpoints 0 IN and OUT are used for control



USB Packet



the smallest element of data transmission

Token



Data



Handshake







usually asks for a data transmission

Type	PID	Description
OUT	0001	host wants to transmit data to the device
IN	1001	host wants to receive data from the device
SETUP	1101	host wants to setup the device

Address: ADDR: ENDP







transmits data

Type	PID	Description
DATA0	0011	the data packet is the first one or follows after a DATA1 packet
DATA1	1011	the data packet follows after a DATAO packet

Data can be between 0 and 1024 bytes







acknowledges data

Туре	PID	Description
ACK	0010	data has been successfully received
NACK	1010	data has not been successfully received
STALL	1110	the device has an error
		18

Packet ID

Transmission Modes

- Control used for configuration
- Isochronous used for high bandwidth, best effort
- *Bulk* used for low bandwidth, stream
- Interrupt used for low bandwidth, guaranteed latency





Error-

used to control a device - ask for data

Setup - send a command (*GET_DESCRIPTOR*,...)



Status - report the status to the host

Data - optional several transfers, host transfers data







Error-

used to control a device - send data

Setup - send a command (*SET_ADDRESS*,...)



Data - *optional* several transfers, device transfers the requested data



Status - report the status to the device



Isochronous



fast but not reliable transfer

- has a guaranteed bandwidth
- allows data loss
- used for functions like streaming where loosing a packet has a minimal impact

OUT - transfer data from the host to the device

Token OUT Data, DATAx

IN - transfer data from the device to the host







slow, but reliable transfer

- does not have a guaranteed bandwidth
- secure transfer
- used for large data transfers where loosing packets is not permitted

OUT - transfer data from the host to the device

IN - transfer data from the device to the host







transfer data at a minimum time interval

- the endpoint descriptor asks the host start an interrupt transfer at a time interval
- used for sending and receiving data at certain intervals

OUT - transfer data from the host to the device

IN - transfer data from the device to the host



Device Organization

configuration, interfaces, endpoints

- a device can have multiple configurations
 - for instance different functionality based on power consumption
- a configuration has multiple interfaces
 - a device can perform multiple functions
 - Debugger
 - Serial Port
- each interface has multiple interfaces attached
 - endpoints are used for data transfer
 - maximum 16 endpoints, can be configured IN and OUT
- the device reports the descriptors in this order





Connection





Token SETUP Packet

The DATA packet of the SETUP Control Transfer



bmRequestType field







Mode	Speed	Version
Low Speed	1.5 Mbit/s	1.0
Full Speed	12 Mbit/s	1.0
High Speed	480 Mbit/s	2.0





Transmission	half duplex	data must be sent in one direction at one time
Clock	independent	the host and the device must synchronize their clocks
Wires	DP/DM	data is sent in a differential way
Devices	1 host several devices	a receiver and a transmitter
Speed	480 MBbit/s	

Embassy API

for RP2040, setup the device

```
use embassy rp::usb::{Driver, Instance, InterruptHandler};
use embassy usb::class::cdc acm::{CdcAcmClass, State};
bind interrupts!(struct Irgs {
    USBCTRL IRQ => InterruptHandler<USB>;
});
let driver = Driver::new(p.USB, Irqs);
let mut config = Config::new(0xc0de, 0xcafe);
config.manufacturer = Some("Embassy");
config.product = Some("USB-serial example");
config.serial number = Some("12345678");
config.max power = 100;
config.max packet size 0 = 64;
// Required for windows compatibility.
config.device class = 0xEF;
config.device sub class = 0 \times 02;
config.device protocol = 0 \times 01;
config.composite with iads = true;
```

```
// It needs some buffers for building the descriptors.
let mut config descriptor = [0; 256];
let mut bos descriptor = [0; 256];
let mut control buf = \lceil 0; 64 \rceil;
let mut state = State::new():
let mut builder = Builder::new(
  driver.
  config,
  &mut config descriptor,
  &mut bos descriptor,
 &mut [], // no msos descriptors
 &mut control buf,
);
// Create classes on the builder.
let mut class = CdcAcmClass::new(&mut builder, &mut state, 64
```

// Build the builder.

// Run the USB device.

let usb driver = usb.run();

let mut usb = builder.build();





for RP2040, use the USB device

Embassy API

```
let echo loop = async {
       loop {
          class.wait connection().await;
         info!("Connected");
         let _ = echo(&mut class).await;
         info!("Disconnected");
 6
     };
 9
10
     // Run everything concurrently.
     join(usb_driver, echo_loop).await;
     async fn echo<'d, T: Instance + 'd>(class: &mut CdcAcmClass<'d, Driver<'d, T>>) -> Result<(), EndpointError> {
         let mut buf = \lceil 0; 64 \rceil;
         loop {
             let n = class.read_packet(&mut buf).await?;
             let data = &buf[..n];
             info!("data: {:x}", data);
             class.write_packet(data).await?;
```



Sensors

Analog and Digital Sensors

Bibliography



BOSCH, BMP280 Digital Pressure Sensor

- Chapter 3 Functional Description
- Chapter 4 Global memory map and register description
- Chapter 5 *Digital Interfaces*
 - Subchapter 5.2 *I2C Interface*



Sensors

analog and digital

Analog

- only the transducer (the analog sensor)
- outputs (usually) voltage
- requires:
 - an ADC to be read
 - cleaning up the noise



Digital

- consists of:
 - a transducer (the analog sensor)
 - an ADC
 - an MCU for cleaning up the noise
- outputs data using a digital bus









schematics









registers map

Register Name	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Reset state
temp_xlsb	0xFC		temp_x	sb<7:4>		0	0	0	0	0x00
temp_lsb	0xFB				temp_l:	sb<7:0>				0x00
temp_msb	0xFA				temp_m	isb<7:0>				0x80
press_xlsb	0xF9		press_xlsb<7:4> 0 0 0 0						0x00	
press_lsb	0xF8		press_lsb<7:0>						0x00	
press_msb	0xF7		press_msb<7:0>						0x80	
config	0xF5		t sb[2:0] filter[2:0] spi3w en[0]						0x00	
ctrl_meas	0xF4		osrs_t[2:0]						0x00	
status	0xF3		measuring[0] im_update[0]						0x00	
reset	0xE0		reset[7:0]						0x00	
id	0xD0		chip_id[7:0]					0x58		
calib25calib00	0xA10x88				calibrat	ion data				individual

Registers:

Type:

Reserved Calibration Data Control **Status** Revision Reset data registers registers registers registers do not read only read / write read only read only read only write only

Datasheet



Reading from a digital sensor

using synchronous/asynchronous I2C to read the press_lsb register of BMP280

```
const DEVICE_ADDR: u8 = 0x77;
const REG_ADDR: u8 = 0xf8;

i2c.write(DEVICE_ADDR, &[REG_ADDR]).unwrap();

let mut buf = [0x00u8];
i2c.read(DEVICE_ADDR, &mut buf).unwrap();

// use the value
let pressure_lsb = buf[1];
```

```
const DEVICE_ADDR: u8 = 0x77;
const REG_ADDR: u8 = 0xf8;

i2c.write(DEVICE_ADDR, &[REG_ADDR]).await.unwrap();

let mut buf = [0x00u8];
i2c.read(DEVICE_ADDR, &mut buf).await.unwrap();

// use the value
let pressure_lsb = buf[1];
```



Writing to a digital sensor

using synchronous/asynchronous I2C to set up the ctrl_meas register of the BMP280 sensor

```
const DEVICE_ADDR: u8 = 0x77;
const REG_ADDR: u8 = 0xf4;

// see subchapters 3.3.2, 3.3.1 and 3.6
let value = 0b100_010_11;

i2c.write(DEVICE_ADDR, &[REG_ADDR]);

let buf = [REG_ADDR, value];
i2c.write(DEVICE_ADDR, &buf).unwrap();
```

```
const DEVICE_ADDR: u8 = 0x77;
const REG_ADDR: u8 = 0xf4;

// see subchapters 3.3.2, 3.3.1 and 3.6
let value = 0b100_010_11;

i2c.write(DEVICE_ADDR, &[REG_ADDR]);

let buf = [REG_ADDR, value];
i2c.write(DEVICE_ADDR, &buf).await.unwrap();
```

Conclusion

we discussed about

- Buses
 - Inter-Integrated Circuit
 - Universal Serial Bus v2.0