



# UART & SPI

## Lecture 6



# UART & SPI

used by RP2040

- Direct Memory Access
- Buses
  - Universal Asynchronous Receiver and Transmitter
  - Serial Peripheral Interface
- Analog and Digital Sensors



# DMA

Direct Memory Access



# Bibliography

for this section

**Raspberry Pi Ltd, *RP2040 Datasheet***  
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- Chapter 2 - *System Description*
  - Chapter 2.5 - *DMA*



# DMA

- offloads the MCU from doing **memory to memory** operations
- due to MMIO, usually implies **transfers from and to peripherals**
- raises an interrupt when a transfer is done

△ DMA does not know about the data stored in cache.

- for chips that use cache
  - the DMA buffer's memory region has to be set manually to *nocache* (if MCU knows)
  - or, the cache has to be flushed before and, possibly after, a DMA transfer





# UART

Universal Asynchronous Receiver and Transmitter



# Bibliography

for this section

1. **Raspberry Pi Ltd**, *RP2040 Datasheet*
  - Chapter 4 - *Peripherals*
    - Chapter 4.2 - *UART*
2. **Paul Denisowski**, *Understanding Serial Protocols*
3. **Paul Denisowski**, *Understanding UART*



# UART

aka serial port

- connects **two devices**
- uses two **independent** wires
  - *TX* - transmission wire
  - *RX* - reception wire
- cross-connected



## Transmission example







# UART Device

## properties

*bits* the number of bits in the payload, between 5 and 9

*parity* add or not the parity bit

*stop* the number of stop bits to add, 1 or 2

*baud rate* number of elements sent per s, most used **9600** or **115200**



$$baud_{rate} = \frac{f_{clock}}{divider \times (1 + payload_{bits} + parity_{bits} + stop_{bits})}$$



# UART Device

## types

- **TTL** - *Transistor Transistor Logic* connects devices at 0 - 3.3V or 0 - 5V, used for short cables and jumper wires
- **RS232** - used for external connections and longer cables, uses -12V to 12V.
- **RS485** - industrial, uses differential voltage



# Receiver

RX part of the serial port



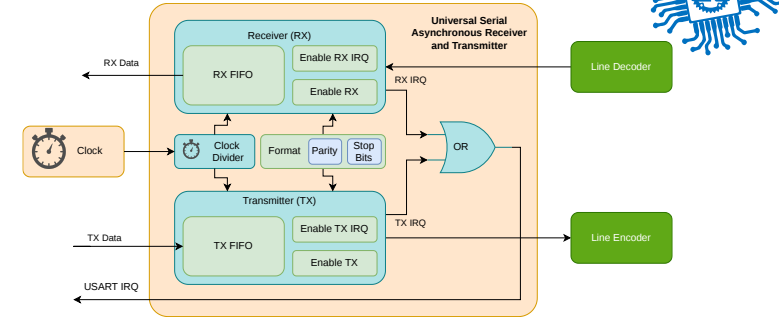
- *Shift Register* to read **serially every bit**
- Triggers an interrupt
  - when data was received
  - (optional) when FIFO is half full
  - (optional) when FIFO is full
- FIFO is optional
  - may have a capacity of 1

# Transmitter

TX part of the serial port



- *Shift Register* to output **serially every bit**
- Triggers an interrupt
  - when data was sent
  - *(optional)* when FIFO is half empty
  - *(optional)* when FIFO is empty
- FIFO is optional
  - may have a capacity of 1





# Transmission Examples

| Setup | Payload | Parity | Stop   |
|-------|---------|--------|--------|
| 8N1   | 8 bits  | no     | 1 bit  |
| 8P2   | 8 bits  | yes    | 2 bits |
| 9P1   | 9 bits  | yes    | 1 bit  |





# Successive Transmission

using the 8N1 data format

## Back to back



## With delay





# Facts

|              |                    |   |
|--------------|--------------------|---|
| Transmission | <i>duplex</i>      | data can be sent in both directions at the same time  |
| Clock        | <i>independent</i> | there is no clock sent between the two devices, the <b>receiver</b> has to <b>synchronize its clock with the transmitter</b> to be able to correctly read the received data |
| Wires        | <i>RX / TX</i>     | one receive wire, one transmit wire, independent of each other  |
| Devices      | <i>2</i>           | a receiver and a transmitter  |
| Speed        | <i>115 KB/s</i>    | usually a maximum baud rate of 115200 is used   |





# Usage

- print debug information
- device console
- RP2040 has two USART devices







# Embassy API

for RP2040, synchronous

```
pub struct Config {  
    pub baudrate: u32,  
    pub data_bits: DataBits,  
    pub stop_bits: StopBits,  
    pub parity: Parity,  
    pub invert_tx: bool,  
    pub invert_rx: bool,  
    pub invert_rts: bool,  
    pub invert_cts: bool,  
}
```

```
pub enum DataBits {  
    DataBits5,  
    DataBits6,  
    DataBits7,  
    DataBits8,  
}
```

```
pub enum StopBits {  
    STOP1,  
    STOP2,  
}
```

```
pub enum Parity {  
    ParityNone,  
    ParityEven,  
    ParityOdd,  
}
```

```
1 use embassy_rp::uart::Config as UartConfig;  
2 let config = UartConfig::default();  
3  
4 // use UART0, Pins 0 and 1  
5 let mut uart = uart::Uart::new_blocking(p.UART0, p.PIN_0, p.PIN_1, config);  
6 // write  
7 uart.blocking_write("Hello World!\r\n".as_bytes());  
8  
9 // read 5 bytes  
10 let mut buf = [0; 5];  
11 uart.blocking_read(&mut buf);
```



# Embassy API

for RP2040, asynchronous

```
1  use embassy_rp::uart::Config as UartConfig;
2
3  bind_interrupts!(struct Irqs {
4      UART0_IRQ => BufferedInterruptHandler<UART0>;
5  });
6
7  let config = UartConfig::default();
8
9  // use UART0, Pins 0 and 1
10 let mut uart = uart::Uart::new(p.UART0, p.PIN_0, p.PIN_1, Irqs, p.DMA_CH0, p.DMA_CH1, config);
11
12 // write
13 uart.write("Hello World!\r\n".as_bytes()).await;
14
15 // read 5 bytes
16 let mut buf = [0; 5];
17 uart.read(&mut buf).await;
```



# SPI

Serial Peripheral Interface



# Bibliography

for this section

## 1. **Raspberry Pi Ltd**, *RP2040 Datasheet*

- Chapter 4 - *Peripherals*
  - Chapter 4.4 - *SPI*

## 2. **Paul Denisowski**, *Understanding SPI*



# SPI

a.k.a *spy*

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





# Wires

3 + n

- **MOSI** - **M**ain **O**ut **S**ub **I**n - carries data from the **main** to the **subs**
- **MISO** - **M**ain **I**n **S**ub **O**ut - carries data from the active **sub** to the **main**
- **CLK** - Clock - the clock signal generated by the **main**, **subs** sample and write data to the bus only on the clock edge
- **CS\*** - **C**hip **S**elect - not actually part of SPI, one wire / sub, activates **one sub at a time**
  - inactive subs have to disconnect from the **MOSI** and **MISO** lines





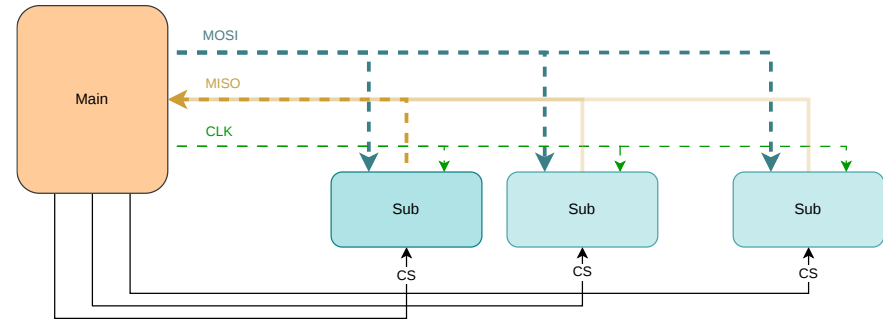
# Transmission Example

1. **main** activates the sub device
  - sets the **CS** signal to **LOW**
2. at the same time
  - **main** puts the first bit on the **MOSI** line
  - **sub** puts the first bit on the **MISO** line
3. **main** starts the clock
4. at the *rising edge*
  - **main** reads the data from the **MISO** line
  - **sub** reads the data from the **MOSI** line
5. on the *falling edge*
  - **main** puts the next bit on the **MOSI** line
  - **sub** puts the next bit on the **MISO** line
6. repeat 4 and 5 until **main** decides to stop the clock

## SPI Signals



## SPI Network





# SPI Modes

when data is read and written

| Mode | CPOL | CPHA |
|------|------|------|
| 0    | 0    | 0    |
| 1    | 0    | 1    |
| 2    | 1    | 0    |
| 3    | 1    | 1    |



defines when the data bit is read

0: *rising edge*

1: *falling edge*

defines when the data is written to the line

0: when **CS** *activates* or *clock edge*

1: on *clock edge* (depends on **CPOL** )





# Transmission Example

one main, two subs



1. **main** activates the CS pin of **sub 1**
2. **main** writes the first bit on MOSI, **sub 1** writes the first bit on MISO
3. **main** starts the clock
4. **main** and **sub 1** send the rest of the bits
5. **main** stops the clock
6. **main** deactivates the CS pin of **sub 1**
7. **main** activates the CS pin of **sub 2**
8. **main** writes the first bit on MOSI, **sub 2** writes the first bit on MISO
9. **main** starts the clock
10. **main** and **sub 2** send the rest of the bits
11. **main** stops the clock
12. **main** deactivates the CS pin of **sub 2**



# Daisy Chaining

using several SPI devices together

1. **main** activates all the **subs**

2. on the clock edge

- **main** sends data to **sub 1**
- **sub 1**<sup>[1]</sup> sends data to **sub 2**
- ...
- **sub n-1** sends data to **sub n**
- **sub n** sends data to **main**

1. usually **subs** send the previous data bit received from **main** to the **next sub** ←

activate all the **sub** devices





# Facts

|              |                                |  |
|--------------|--------------------------------|--|
| Transmission | <i>duplex</i>                  | data must be sent in both directions at the same time  |
| Clock        | <i>synchronized</i>            | the <b>main</b> and <b>sub</b> use the same clock, there is no need for clock synchronization      |
| Wires        | <i>MISO / MOSI / CLK / CS</i>  | different read and write wires, a clock wire and an <i>optional</i> chip select wire for every sub |
| Devices      | <i>1 main<br/>several subs</i> | a receiver and a transmitter   |
| Speed        | <i>no limit</i>                | does not have any limit, it is limited by the <b>main</b> clock and the electronics wirings        |



# Usage

- EEPROMs / Flash (usually in *QSPI* mode)
  - Raspberry Pi Pico has its 2MB Flash connected using *QSPI*
- sensors
- small displays
- RP2040 has two SPI devices





# Embassy API

for RP2040, synchronous

```
pub struct Config {  
    pub frequency: u32,  
    pub phase: Phase,  
    pub polarity: Polarity,  
}
```

```
pub enum Phase {  
    CaptureOnFirstTransition,  
    CaptureOnSecondTransition,  
}
```

```
pub enum Polarity {  
    IdleLow,  
    IdleHigh,  
}
```

```
1  use embassy_rp::spi::Config as SpiConfig;  
2  let mut config = SpiConfig::default();  
3  config.frequency = 2_000_000;  
4  
5  let miso = p.PIN_12;  
6  let mosi = p.PIN_11;  
7  let clk = p.PIN_10;  
8  let mut spi = Spi::new_blocking(p.SPI1, clk, mosi, miso, config);  
9  
10 // Configure CS  
11 let mut cs = Output::new(p.PIN_X, Level::Low);  
12  
13 cs.set_low();  
14 let mut buf = [0x90, 0x00, 0x00, 0xd0, 0x00, 0x00];  
15 spi.blocking_transfer_in_place(&mut buf);  
16 cs.set_high();
```



# Embassy API

for RP2040, asynchronous

```
1  use embassy_rp::spi::Config as SpiConfig;
2  let mut config = SpiConfig::default();
3  config.frequency = 2_000_000;
4
5  let miso = p.PIN_12;
6  let mosi = p.PIN_11;
7  let clk = p.PIN_10;
8  let mut spi = Spi::new(p.SPI1, clk, mosi, miso, p.DMA_CH0, p.DMA_CH1, config);
9
10 // Configure CS
11 let mut cs = Output::new(p.PIN_X, Level::Low);
12
13 cs.set_low();
14 let tx_buf = [1_u8, 2, 3, 4, 5, 6];
15 let mut rx_buf = [0_u8; 6];
16 spi.transfer(&mut rx_buf, &tx_buf).await;
17 cs.set_high();
```



# Sensors

Analog and Digital Sensors



# Bibliography

for this section

**BOSCH**, *BMP280 Digital Pressure Sensor*

- Chapter 3 - *Functional Description*
- Chapter 4 - *Global memory map and register description*
- Chapter 5 - *Digital Interfaces*
  - Subchapter 5.3 - *SPI 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





# BMP280 Digital Pressure Sensor

schematics



Datasheet



# BMP280 Digital Pressure Sensor

## registers map

| Register Name     | Address     | bit7             | bit6 | bit5 | bit4        | bit3         | bit2 | bit1      | bit0        | Reset state  |      |
|-------------------|-------------|------------------|------|------|-------------|--------------|------|-----------|-------------|--------------|------|
| temp_xlsb         | 0xFC        | temp_xlsb<7:4>   |      |      |             | 0            | 0    | 0         | 0           | 0x00         |      |
| temp_lsb          | 0xFB        | temp_lsb<7:0>    |      |      |             |              |      |           |             | 0x00         |      |
| temp_msb          | 0xFA        | temp_msb<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]      |      |      | osrs_p[2:0] |              |      | mode[1:0] |             | 0x00         |      |
| status            | 0xF3        |                  |      |      |             | measuring[0] |      |           |             | im_update[0] | 0x00 |
| reset             | 0xE0        | reset[7:0]       |      |      |             |              |      |           |             | 0x00         |      |
| id                | 0xD0        | chip_id[7:0]     |      |      |             |              |      |           |             | 0x58         |      |
| calib25...calib00 | 0xA1...0x88 | calibration data |      |      |             |              |      |           |             | individual   |      |

|            |                    |                  |                   |                |                  |           |            |
|------------|--------------------|------------------|-------------------|----------------|------------------|-----------|------------|
| Registers: | Reserved registers | Calibration data | Control registers | Data registers | Status registers | Revision  | Reset      |
|            | do not write       | read only        | read / write      | read only      | read only        | read only | write only |

Datasheet



# Reading from a digital sensor

using synchronous/asynchronous SPI to read the `press_lsb` register of BMP280



```
1  const REG_ADDR: u8 = 0xf8;
2
3  // enable the sensor
4  cs.set_low();
5
6  // buffer[2]: the address and "empty" value
7  let mut buf = [(1 << 7) | reg, 0x00];
8  spi.blocking_transfer_in_place(&mut buf);
9
10 // disable the sensor
11 cs.set_high();
12
13 // use the value
14 let pressure_lsb = buf[1];
```

```
1  const REG_ADDR: u8 = 0xf8;
2
3  // enable the sensor
4  cs.set_low();
5
6  // two buffers[2], writing and reading
7  let tx_buf = [(1 << 7) | REG_ADDR, 0x00];
8  let mut rx_buf = [0u8; 2];
9  spi.transfer(&mut rx_buf, &tx_buf).await;
10
11 // disable the sensor
12 cs.set_high();
13
14 // use the value
15 let pressure_lsb = rx_buf[1];
```



# Writing to a digital sensor

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



```
1  const REG_ADDR: u8 = 0xf4;
2
3  // see subchapters 3.3.2, 3.3.1 and 3.6
4  let value = 0b100_010_11;
5
6  // enable the sensor
7  cs.set_low();
8
9  // buffer[2]: the address and "empty" value
10 let mut buf = [!(1 << 7) & reg, value];
11 spi.blocking_transfer_in_place(&mut buf);
12
13 // disable the sensor
14 cs.set_high();
```

```
1  const REG_ADDR: u8 = 0xf4;
2
3  // see subchapters 3.3.2, 3.3.1 and 3.6
4  let value = 0b100_010_11;
5
6  // enable the sensor
7  cs.set_low();
8
9  // two buffers[2], writing and reading (ignored)
10 let tx_buf = [!(1 << 7) & REG_ADDR, value];
11 let mut rx_buf = [0u8; 2];
12 spi.transfer(&mut rx_buf, &tx_buf).await;
13
14 // disable the sensor
15 cs.set_high();
```



# Conclusion

we discussed about

- Direct Memory Access
- Buses
  - Universal Asynchronous Receiver and Transmitter
  - Serial Peripheral Interface
- Analog and Digital Sensors