

UART & SPI

Lecture 6

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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

- Chapter 2 *System Description*
 - Chapter 2.5 *DMA*



DMA

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

 \triangle 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



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





aka serial port

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



Transmission example



UART Device

properties

the number of bits
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

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



$$baud_{rate} = rac{f_{clock}}{divider imes (1 + payload_{bits} + parity_{bits} + stop_{bits})}$$

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 everybit
- 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 everybit
- 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
Clock elecrical signal data	b7 \ b6 \ B5 \ b4 \ b3 \ b2	2 \ b1 \ b0 \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	
elecrical signal data	/ b7 \(b6 \) B5 \(b4 \) b3 \(b2 \) Start \(\) payload	2 \(\text{b1 \(\text{b0 \(\text{p} \)}\) \(\text{parity} \) \(\text{stop} \)	\[\] \[\]
elecrical signal data	/ b8 \ b7 \ b6 \ B5 \ b4 \ b3	3 \ b2 \ b1 \ b0 \ p \ / parity\(stop \)	\[\(\lambda\)\[\lambda\)





using the 8N1 data format

Back to back



With delay







Transmission	duplex	data can be sent in both directions at the same time
Clock	independent	there is no clock sent between the two devices, the receiver has to synchronize its clock with the transmitter to be able to correctly read the received data
Wires	RX/TX	one receive write, one transmit wire, independent of each other
Devices	2	a receiver and a transmitter
Speed	115 KB/s	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 invert_cts: bool,
}
```

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

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

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

```
use embassy_rp::uart::Config as UartConfig;
let config = UartConfig::default();

// use UARTO, Pins 0 and 1
let mut uart = uart::Uart::new_blocking(p.UARTO, p.PIN_0, p.PIN_1, config);
// write
uart.blocking_write("Hello World!\r\n".as_bytes());

// read 5 bytes
let mut buf = [0; 5];
uart.blocking_read(&mut buf);
```

Embassy API



for RP2040, asynchronous

```
use embassy rp::uart::Config as UartConfig;
     bind interrupts!(struct Irgs {
         UART0 IRQ => BufferedInterruptHandler<UART0>;
     });
 6
     let config = UartConfig::default();
 8
     // use UARTO, Pins 0 and 1
     let mut uart = uart::Uart::new(p.UART0, p.PIN_0, p.PIN_1, Irqs, p.DMA_CH0, p.DMA_CH1, config);
10
11
12
     // write
13
     uart.write("Hello World!\r\n".as_bytes()).await;
14
15
     // read 5 bytes
16
     let mut buf = \lceil 0; 5 \rceil;
     uart.read(&mut buf).await;
17
```



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 Main Out Sub In carries data from the main to the subs
- MISO Main In Sub Out 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



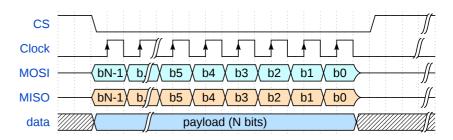


Transmission Example

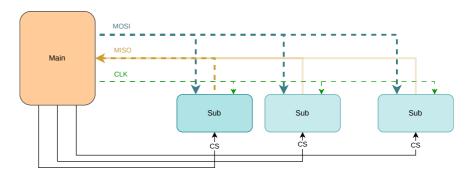
- 1. **main** activates the sub device
 - sets the CS signal to LOW
- 2. at the same time
 - main puts the first bit on the MOSI line
 - sub puts the first bit on the MISO line
- 3. **main** starts the clock
- 4. at the rising edge
 - main reads the data from the MISO line
 - **sub** reads the data from 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	СРНА
0	0	0
1	0	1
2	1	0
3	1	1





defines when the data is written to the line

CPHA Clock phase

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^[1] sends data to **sub** 2
 - **-** ...
 - sub n-1 sends data to sub n
 - **sub n** sends data to **main**
- usually subs send the previous data bit received from main to the next sub ←



activate all the **sub** devices









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



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







for RP2040, synchronous

cs.set high();

16

```
pub struct Config {
                                           pub enum Phase {
                                                                                     pub enum Polarity {
  pub frequency: u32,
                                            CaptureOnFirstTransition,
                                                                                       IdleLow,
  pub phase: Phase,
                                            CaptureOnSecondTransition,
                                                                                       IdleHigh,
  pub polarity: Polarity,
     use embassy rp::spi::Config as SpiConfig;
     let mut config = SpiConfig::default();
     config.frequency = 2 000 000;
     let miso = p.PIN 12;
     let mosi = p.PIN 11;
     let clk = p.PIN 10;
     let mut spi = Spi::new blocking(p.SPI1, clk, mosi, miso, config);
 9
     // Configure CS
     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);
```

Embassy API



for RP2040, asynchronous

```
use embassy rp::spi::Config as SpiConfig;
     let mut config = SpiConfig::default();
     config.frequency = 2 000 000;
     let miso = p.PIN_12;
     let mosi = p.PIN 11;
     let clk = p.PIN 10;
     let mut spi = Spi::new(p.SPI1, clk, mosi, miso, p.DMA CH0, p.DMA CH1, config);
 9
     // Configure CS
10
     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];
     let mut rx_buf = [0_u8; 6];
15
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









schematics









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_x	lsb<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]		mod	e[1:0]	0x00
status	0xF3		measuring[0] im_update[0]						0x00	
reset	0xE0	reset[7:0]					0x00			
id	0xD0	chip_id[7:0]					0x58			
calib25calib00	0xA10x88	calibration data				individual				

Registers:

Type:

Calibration Control Data Reserved **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 SPI to read the press_lsb register of BMP280



```
const REG_ADDR: u8 = 0xf8;

// enable the sensor
cs.set_low();

// buffer[2]: the address and "empty" value
let mut buf = [(1 << 7) | reg, 0x00];
spi.blocking_transfer_in_place(&mut buf);

// disable the sensor
cs.set_high();

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

```
const REG ADDR: u8 = 0xf8;
      // enable the sensor
      cs.set low();
      // two buffers[2], writing and reading
      let tx buf = \lceil (1 \ll 7) \mid REG ADDR, 0 \times 00 \rceil;
      let mut rx buf = \lceil 0u8; 2 \rceil;
      spi.transfer(&mut rx buf, &tx buf).await;
10
      // disable the sensor
11
12
      cs.set high();
13
14
      // use the value
      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



```
const REG_ADDR: u8 = 0xf4;

// see subchapters 3.3.2, 3.3.1 and 3.6

let value = 0b100_010_11;

// enable the sensor
cs.set_low();

// buffer[2]: the address and "empty" value
let mut buf = [!(1 << 7) & reg, value];
spi.blocking_transfer_in_place(&mut buf);

// disable the sensor
cs.set_high();</pre>
```

```
const REG ADDR: u8 = 0xf4;
      // see subchapters 3.3.2, 3.3.1 and 3.6
      let value = 0b100 010 11;
      // enable the sensor
      cs.set low();
      // two buffers[2], writing and reading (ignored)
      let tx buf = \lceil !(1 \ll 7) \& REG ADDR, value \rceil;
10
      let mut rx buf = \lceil 0u8; 2 \rceil;
11
12
      spi.transfer(&mut rx buf, &tx buf).await;
13
14
      // disable the sensor
      cs.set high();
```

Conclusion

we discussed about

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