Using the Digital I/O interface of Microchip PIC18F Microcontrollers

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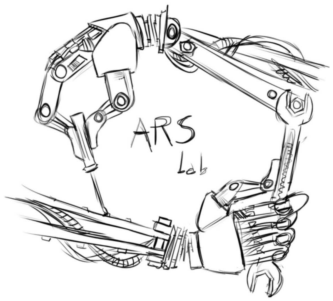

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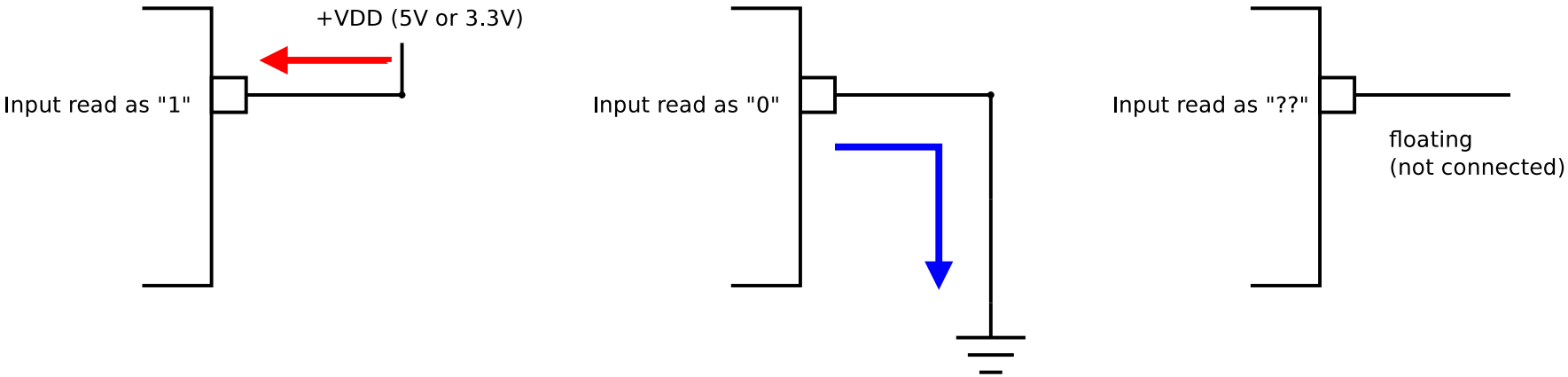
What is a “digital I/O interface”?

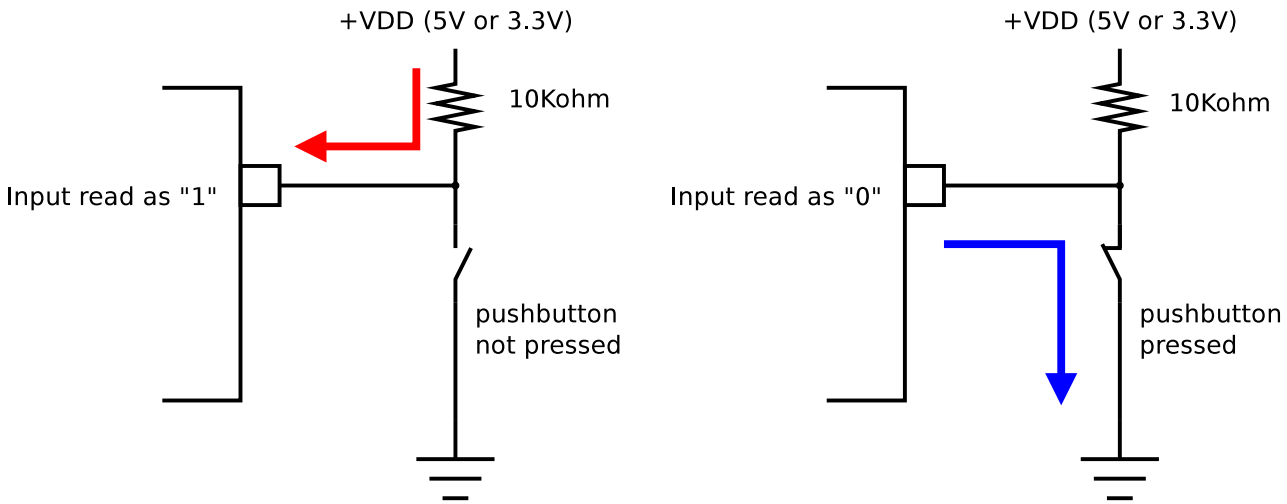
- It is an interface in which each electrical pin may have two states:
  - Logical `0` (it means 0V);
  - Logical `1` (it means 5V or 3.3V on the basis of the VDD);
- Each line can be programmer as:
  - an **output** (it “generates” current and can be used, for example, to lit a LED)
  - an **input** (it “receives” current and can be used, for example, to read a pushbutton)

Digital Input: Electrical consideration



- An **input** connected to **VDD** is read (by software) as “1”
- An **input** connected to **Ground** is read (by software) as “0”
- If the input is **floating** (not connected) the value read cannot be determined!

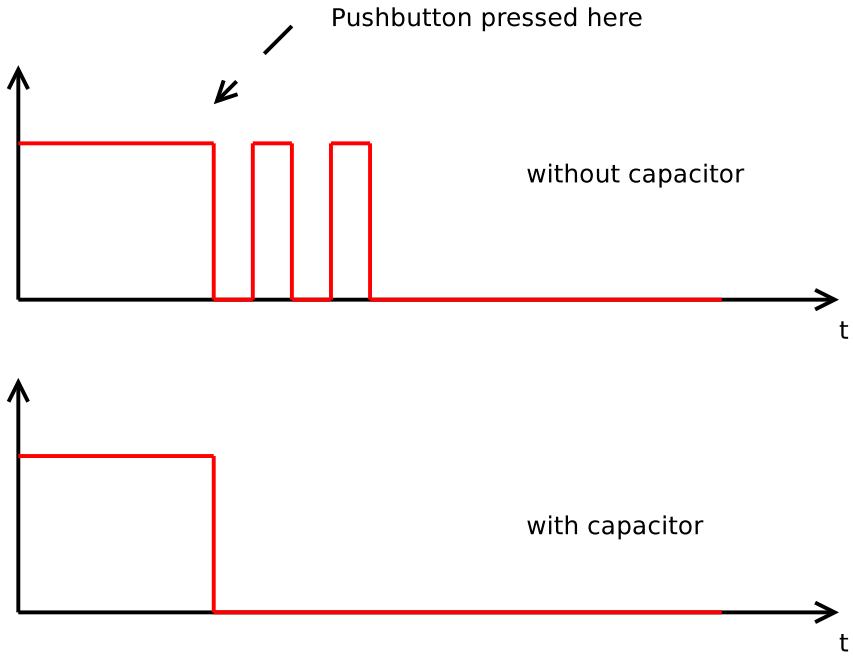
Digital Input: Connecting a pushbutton or a switch

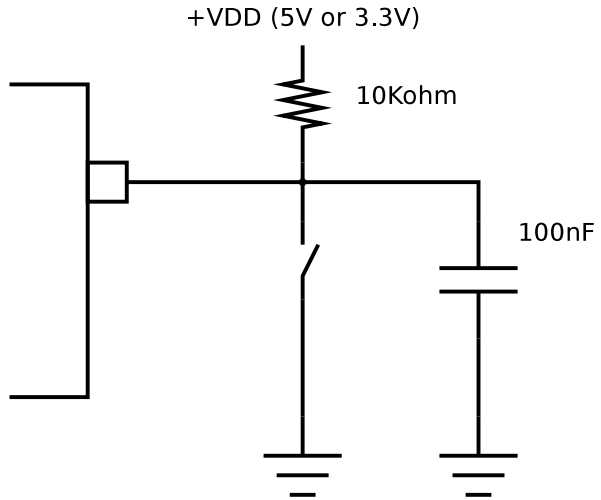


The typical connection of a switch or pushbutton is by means of a **“pull-up resistor”**, connected to VDD.

- When the pushbutton is **not pressed (open)**, the pin is connected to VDD through the resistor; **the valure read is “1”**
- When the pushbutton is **pressed (closed)**, the pin is connected directly to Ground through the button itself; **the value read is “0”**

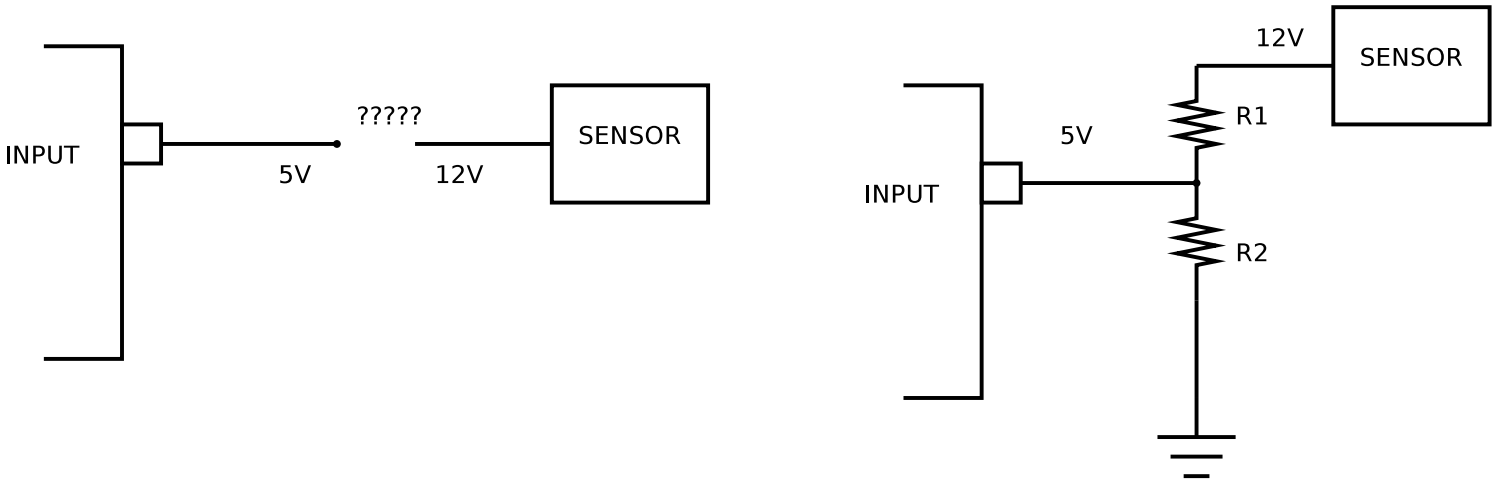
Pushbuttons and Digital Inputs: Bouncing problem!





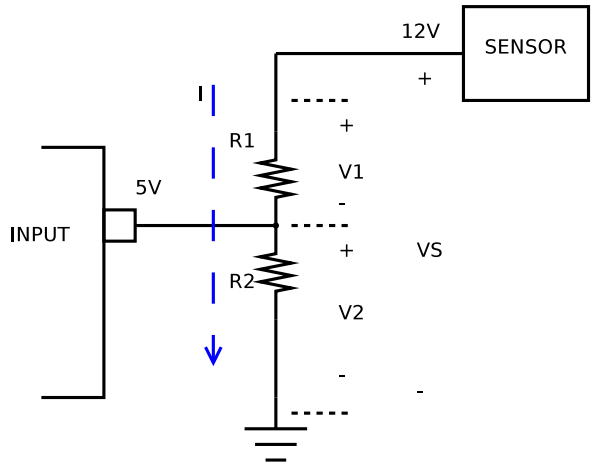
- Due to mechanical reasons, pushbuttons and switches (which have a spring inside) typically generate a **bouncing signal** when pressed or released.
- The bouncing signal is **read** by the software, thus causing malfunctioning.
- The solution is to **add a capacitor**, in parallel with the button, in order to **filter** the bouncing signal.

Industrial sensors and Digital Inputs: Voltage problem!



- Inputs can be also used to connect **digital sensors** (e.g. proximity sensors).
- However industrial sensors work using a voltage of 12V or 24V, thus they cannot be connected directly to the microcontroller pin.
- The solution is to employ a **voltage divider** in order to **convert** the sensor voltage to the microcontroller voltage.

Let's compute the voltage divider.

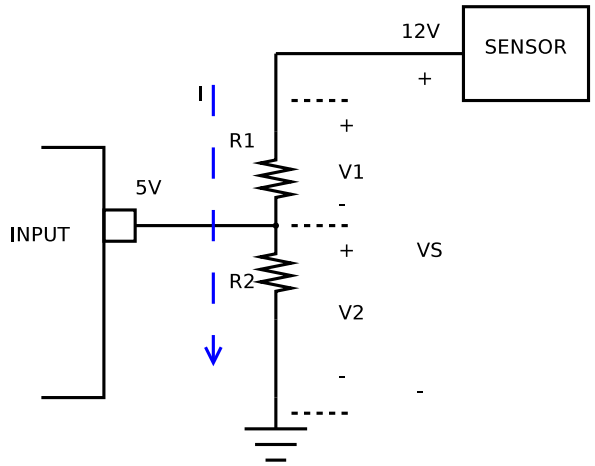


$$VS = V1 + V2 \qquad VS = 12 \qquad V2 = 5$$

$$V1 = R1 \cdot I \qquad V2 = R2 \cdot I \qquad VS = (R1 + R2) \cdot I$$

$$V2 = \frac{R2}{R1 + R2} \cdot VS$$

Let's compute the voltage divider.

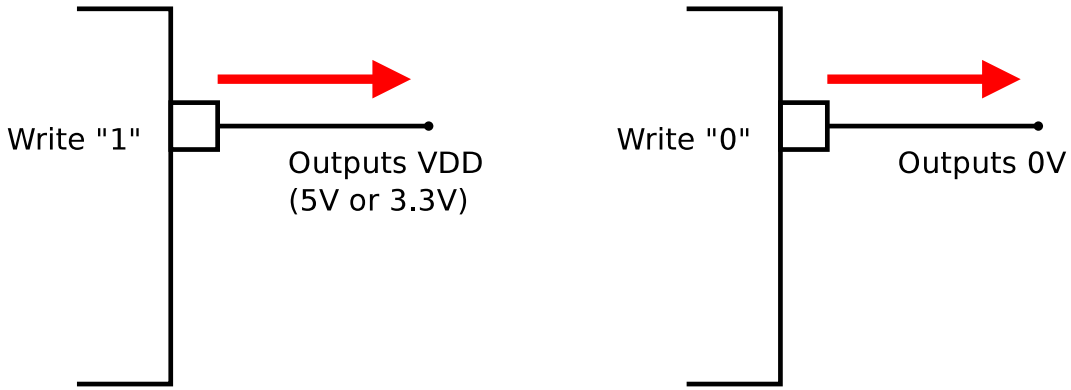


$$V2 = \frac{R2}{R1 + R2} \cdot VS \qquad VS = 12 \qquad V2 = 5$$

$$\frac{R2}{R1 + R2} = \frac{V2}{VS} = \frac{5}{12} = 0.41\overline{6}$$

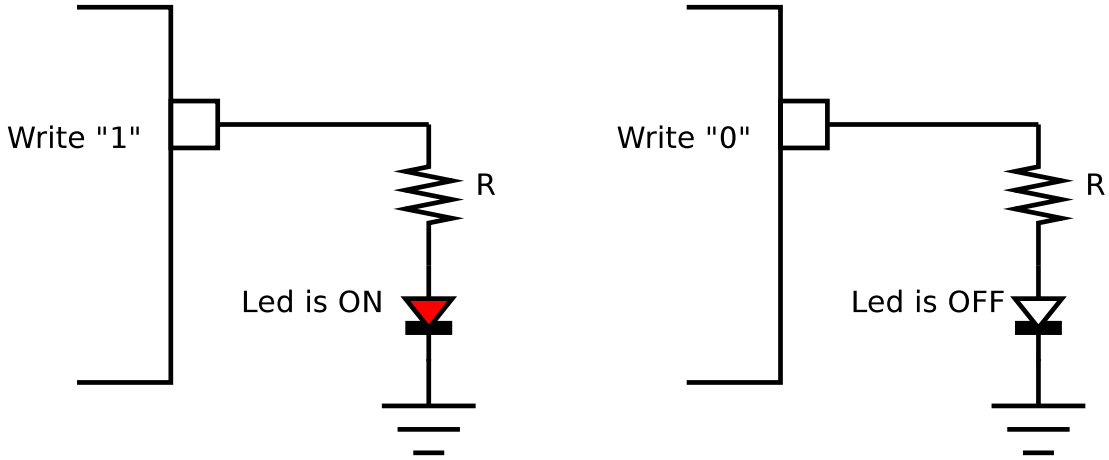
$$R1 = 15K\Omega \quad R2 = 10K\Omega \qquad \frac{R2}{R1 + R2} = \frac{10}{10 + 15} = 0.4$$

Digital Output: Electrical consideration



- Writing “1” implies to drive the **output** to generate **VDD**
- Writing “0” implies to drive the **output** to generate **0V**

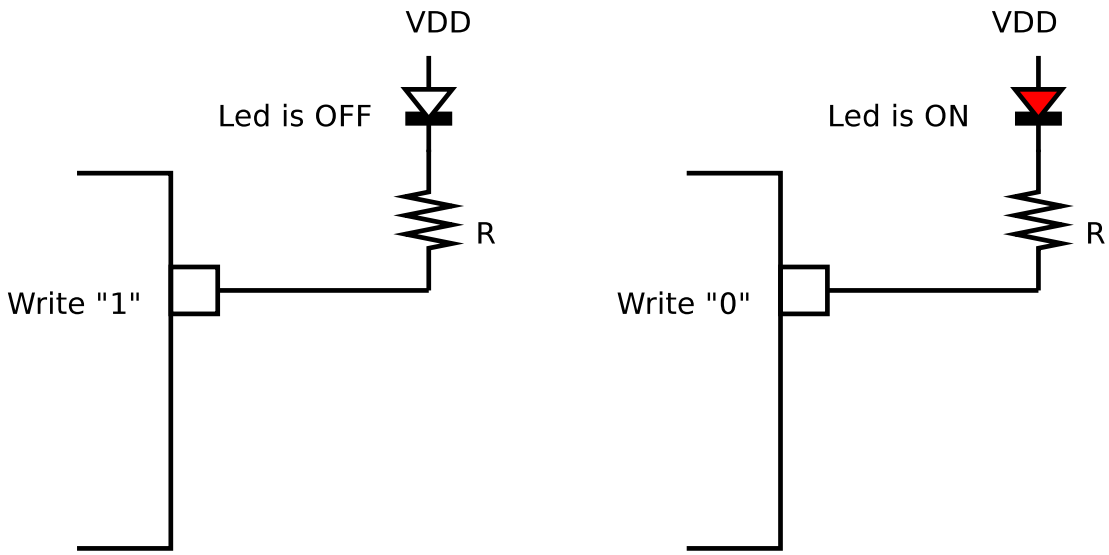
Digital Output: Connecting a LED



Using the PIN as **“current source”**

- Writing “1” turns on the LED
- Writing “0” turns off the LED

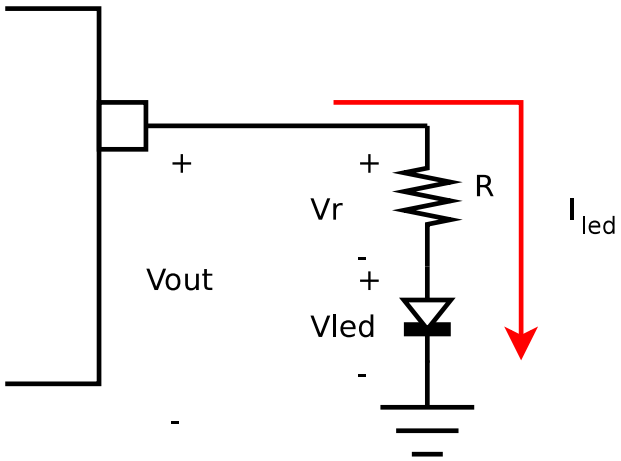
Digital Output: Connecting a LED



Using the PIN as **“current sink”**

- Writing “1” turns off the LED
- Writing “0” turns on the LED

Connecting a LED: calculating the limiting resistor

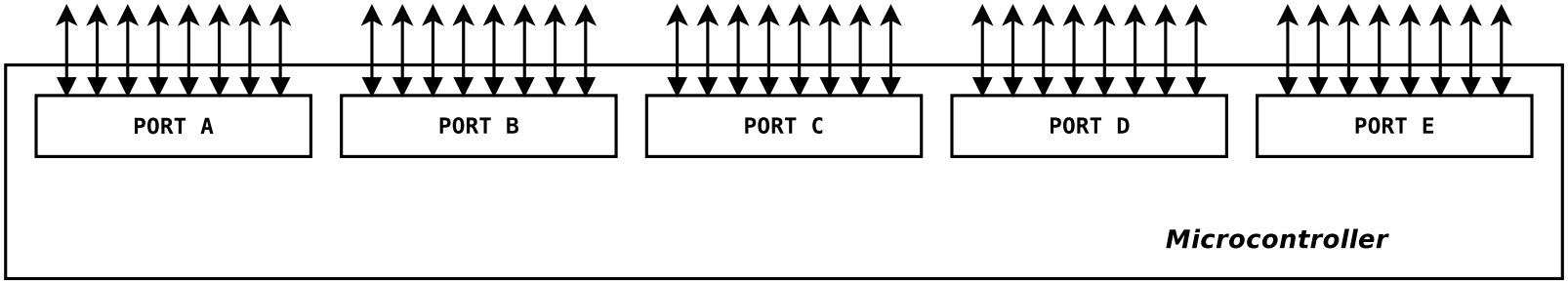


- I_{led} LED lit current (about 20mA)
- V_{led} LED lit voltage (1.2V for small red leds)

$$V_{out} = V_{led} + V_r \qquad V_r = R \cdot I_{led}$$

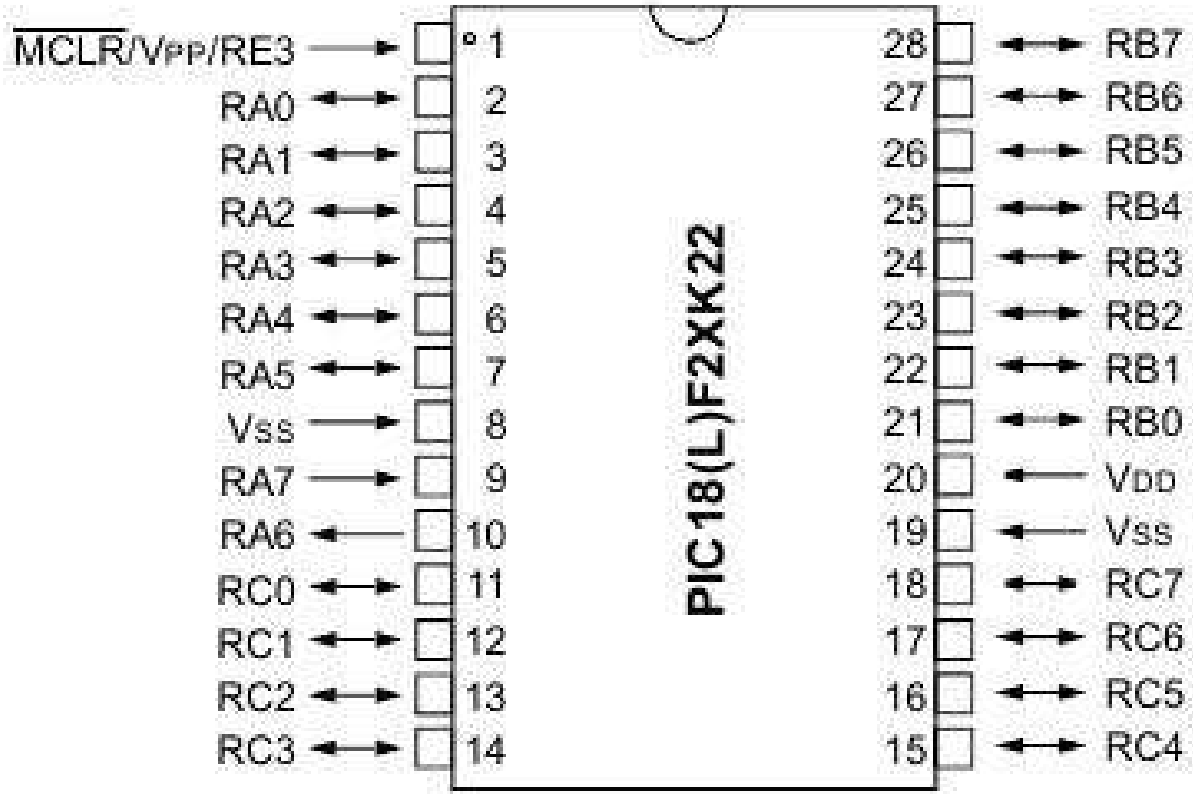
$$R = \frac{V_{out} - V_{led}}{I_{led}} = \frac{5 - 1.2}{0.02} = 190\Omega$$

The Digital Interface of PIC18



- MCUs of the PIC18 family have **5 digital ports**, called **PORT A**, **PORT B**, **...**, **PORT E**.
- Each port has **8 bits** and thus **8 electrical pins**
- Pins are referred as **R*xy***, where *x* is the port name (A, B, ..., E) and *y* is the bit (0, 1, ..., 7).
- As an example, the pin **RC3** is the bit 3 of the port C.
- However, not all bits are mapped to electrical pins. This is a choice "by-design".

The PINOUT of the PIC18F25K22 (again!)



Digital I/O and SFR

Each port *x* has three SFRs: **TRISx**, **PORTx** and **LATx**.

- **TRISx**: each bit of this SFR programs the relevant PIN as input or output:
  - A **0** means **output**
  - A **1** means **input**
- Example:
  - `TRISC = 0x30; // 0x30 = 0011 0000`
  - RC0 to RC3:**outputs**;
  - RC4, RC5: **inputs**;
  - RC6, RC7:**outputs**;

Digital I/O and SFR

Each port *x* has three SFRs: **TRISx**, **PORTx** and **LATx**.

- **LATx**: each bit of this SFR programs the **output status** of the relevant PIN (if it is programmed as output, otherwise it is ignored).
- Example:
  - `LATB = 0xe0; // 0xe0 = 1110 0000`
  - RB0 to RB4 output **0**;
  - RB5 to RB7 output **1**.

Digital I/O and SFR

Each port *x* has three SFRs: **TRISx**, **PORTx** and **LATx**.

- **PORTx**: each bit of this SFR reflects the **input status** of the relevant PIN (if the pin is configured as input, otherwise it replies the bit of the LATx register):
- Example:
  - Let us read, into `button` variable, the status of the RA5 input pin:
  - `int button = (PORTA & 0x20) != 0;`

Digital I/O and SFR: Summary

- **TRISx**: programs the relevant PIN as input or output:
  - A `0` means **output**
  - A `1` means **input**
- **LATx**: **output status** of the relevant PIN (if it is programmed as output, otherwise it is ignored).
- **PORTx**: **input status** of the relevant PINs (if the pin is configured as input, otherwise it replies the bit of the LATx register)

Bit Mask Operations

Bit Mask Operations

- To perform operations on a SFR we need to **manipulate single bits**
- Set (to 1) a specific bit.
- Clear (set to 0) a specific bit.
- “Toggle” a specific bit.
- Test a specific bit.
- These operations are performed using bit-mask

Setting a bit

- Make an **OR** operation with a constant bit pattern formed as follows:
  - The bit to be set is “1”
  - All the other bits are “0”
- Example: setting the bit 3 of the (8-bit) variable `A`:

A	B7	B6	B5	B4	B3	B2	B1	B0	OR
mask	0	0	0	0	1	0	0	0	=
A	B7	B6	B5	B4	1	B2	B1	B0	

```
A = A | 0x08;
A |= 0x08;
```

Clearing a bit

- Make an **AND** operation with a constant bit pattern formed as follows:
  - The bit to be cleared is “0”
  - All the other bits are “1”
- Example: clearing the bit 6 of the (8-bit) variable `A`:

A	B7	B6	B5	B4	B3	B2	B1	B0	AND
mask	1	0	1	1	1	1	1	1	=
A	B7	0	B5	B4	B3	B2	B1	B0	

```
A = A & 0xbf;
A &= 0xbf;
```

Toggling a bit

- Make an **XOR** operation with a constant bit pattern formed as follows:
  - The bit to be set is “1”
  - All the other bits are “0”
- Example: toggling the bit 4 of the (8-bit) variable `A`:

A	B7	B6	B5	B4	B3	B2	B1	B0	XOR
mask	0	0	0	1	0	0	0	0	=
A	B7	B6	B5	$\overline{B4}$	B3	B2	B1	B0	

```
A = A ^ 0x10;
A ^= 0x10;
```

Testing a bit

- Make an **AND** operation with a constant bit pattern formed as follows:
  - The bit to be tested is “1”
  - All the other bits are “0”
- Check if the result is zero or non-zero
- Example: testing the bit 5 of the (8-bit) variable `A`:

A	B7	B6	B5	B4	B3	B2	B1	B0	AND
mask	0	0	1	0	0	0	0	0	=
	0	0	B5	0	0	0	0	0	

```
if ((A & 0x20) != 0) ...   // non-zero
```

An Example

We have a circut where:

- A pushbutton is connected to RA3;
- A LED is connected to RB0.

Let us write a program that lits the LED with the pushbutton:

- First configure RA3 as **input** and RB0 as **output**;
- then use a continuous loop which copies RA3 to RB0.

An Example

The listing

```
main()
{
  TRISA |= 0x08; // RA3 as input

  TRISB &= 0xfe; // RB0 as output

  for (;;) { // loop forever
    if ((PORTA & 8) != 0) // read RA3
        LATB |= 1; // write ``1'' to RB0
    else
        LATB &= 0xfe; // write ``0'' to RB0
  }
}
```

Manipulating bits

Here we have statements like:

- `TRISB &= 0xfe;`
- `LATB |= 1;`

We manipulate the whole register (PORTA or LATB) but we are interested in a single bit!!

But each bit of a SFR has a specific meaning:

REGISTER 10-1: PORTX(1): PORTx REGISTER

R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x
Rx7	Rx6	Rx5	Rx4	Rx3	Rx2	Rx1	Rx0
bit 7							bit 0

Legend:		
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown
-n/n = Value at POR and BOR/Value at all other Resets		

bit 7-0 **Rx<7:0>:** PORTx I/O bit values(2)

Note 1: Register Description for PORTA, PORTB, PORTC and PORTD.

2: Writes to PORTx are written to corresponding LATx register. Reads from PORTx register is return of I/O pin values.

Manipulating bits

REGISTER 10-1: PORTX(1): PORTx REGISTER

R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x	R/W-u/x
Rx7	Rx6	Rx5	Rx4	Rx3	Rx2	Rx1	Rx0
bit 7							bit 0

Legend:		
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown
-n/n = Value at POR and BOR/Value at all other Resets		

bit 7-0 **Rx<7:0>:** PORTx I/O bit values(2)

Note 1: Register Description for PORTA, PORTB, PORTC and PORTD.

2: Writes to PORTx are written to corresponding LATx register. Reads from PORTx register is return of I/O pin values.

Each SFR is defined (in the compiler):

- As an integer variable (e.g. **`PORTA`**);
- As a `struct`, where the field are the single bits:
  - **`PORTAbits.RA3`** is the bit 3 of the SFR PORTA
  - **`LATBbits.LATB0`** is the bit 0 of the SFR LATB

The example becomes

The listing

```
main()
{
  TRISAbits.TRISA3 = 1;
  // RA3 as input

  TRISBbits.TRISB0 = 0;
  // RB0 as output

  for (;;) { // loop forever
    LATBbits.LATB0 = PORTAbits.RA3;
    // read RA3 and write to RB0
  }
}
```

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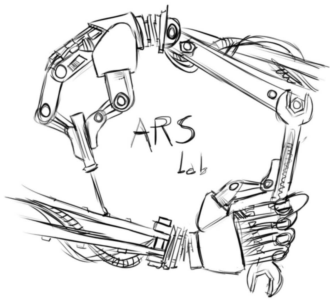

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