FIB
UNIVERSITAT POLITÈCNICA DE CATALUNYA
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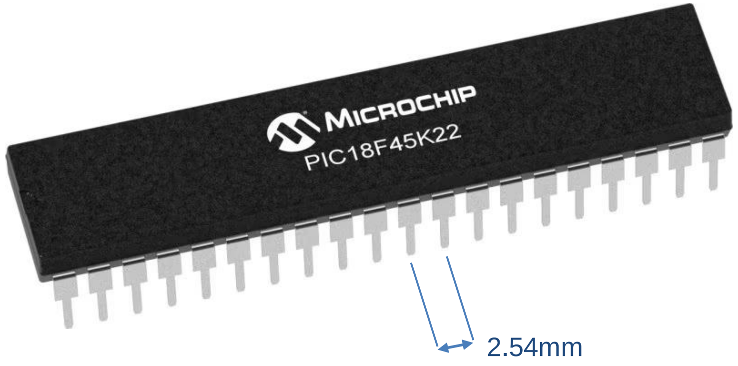
Computer interfacing (CI)

3. The physical interface. Digital I/O

3.1 The physical interface

The microcontrollers have a set of physical pins (grouped on ports: A, B, C…) in order to interface with the physical world.

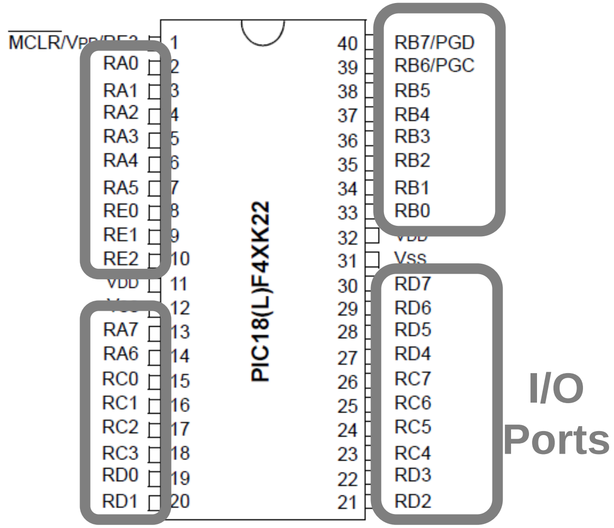
Here we can input or output data to/from our programmable systems.

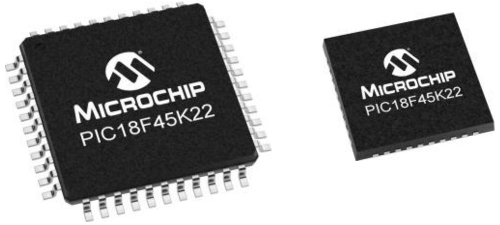


Physical pins consists on metallic pads, separated by 2.54mm (1/10th inch). This is the standard protoboard-compatible packaging.

There are other smaller packages (images not at scale) for industrial, wearable devices, etc.

40-PIN PDIP DIAGRAM





3.1 The physical interface

PORTA is an 8-bit wide, bidirectional port.

Pins RA6 and RA7 are multiplexed with the main oscillator pins. Pins RA<3:0> and RA5 can be used as analog or digital pins.
On a Power-on Reset, RA5 and RA<3:0> are configured as analog inputs and read as ‘0’.
RA4 is configured as a digital input.

PORTB is an 8-bit wide, bidirectional port.

All pins may be used as Digital or Analog Pins.

The pins RB<2:0> may be used for external interrupts (Int0, Int1 and Int2). Four of the PORTB pins (RB<7:4>) are individually configurable as interrupt-on-change pins

On a Power-on Reset, RB<5:0> are configured as analog inputs by default and read as ‘0’; RB<7:6> are configured as digital inputs.

3.1 The physical interface

PORTC is an 8-bit wide, bidirectional port.

Pins RC2 to RC7 can be used as analog inputs. On a Power-on Reset these pins are configured as analog and read ‘0’. RC0 and RC1 are by default digital inputs.

PORTD is an 8-bit wide, bidirectional port.

All 8 port-D pins can be used as analog inputs. On a Power-on Reset these pins are configured as analog and read ‘0’.

PORTE is a 4-bit wide, bidirectional port.

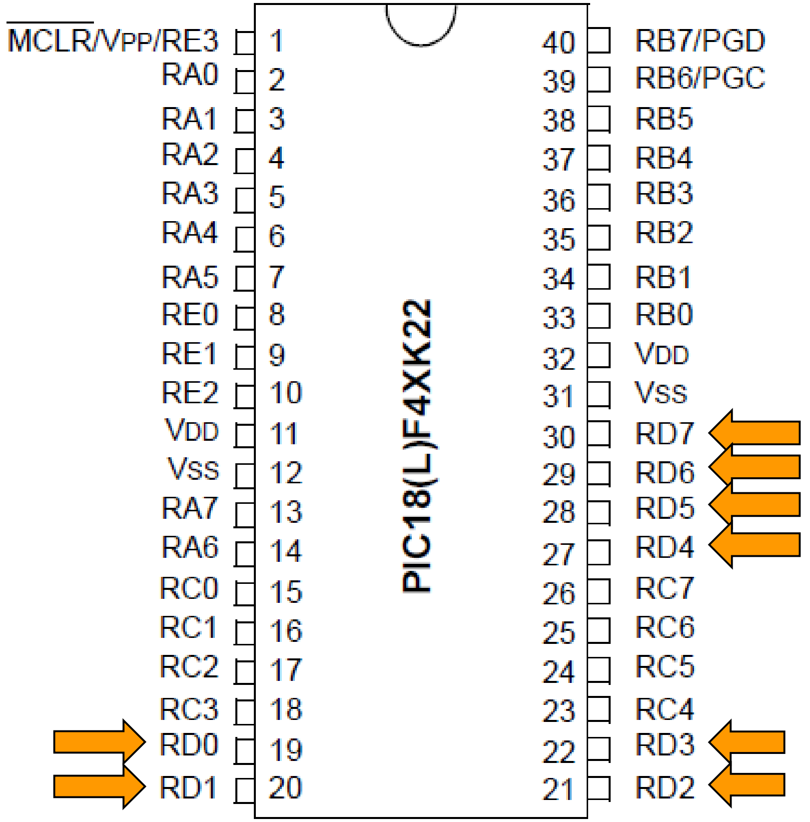
Pins RE0 to RE2 can be used as analog inputs. On a Power-on Reset these pins are configured as analog and read ‘0’.
RE3 shares function with MCLR (Master Clear = Reset), will avoid this pin.

3.1 The physical interface

- As seen, functions on Pins are multiplexed.

- There is a set of registers to configure the functionality of every Pin: Analog or Digital, peripheral, interrupt, input, output…
- There are PIC18 microcontrollers with up to 10 I/O ports.
- By default, pins are configured at power-on as Analog or Digital inputs to avoid damages on peripherals before our program starts!

- Exact **location** of pins can be found in the chip schematics (see example).
- **Functions** for all pins can be found in the device datasheet (see next page).



Example: PORTD pins RD{0..7}

3.1 The physical interface

Example. PORTA per pin functions (A0 to A3), table 10-1, datasheet page 128.

5 functions!

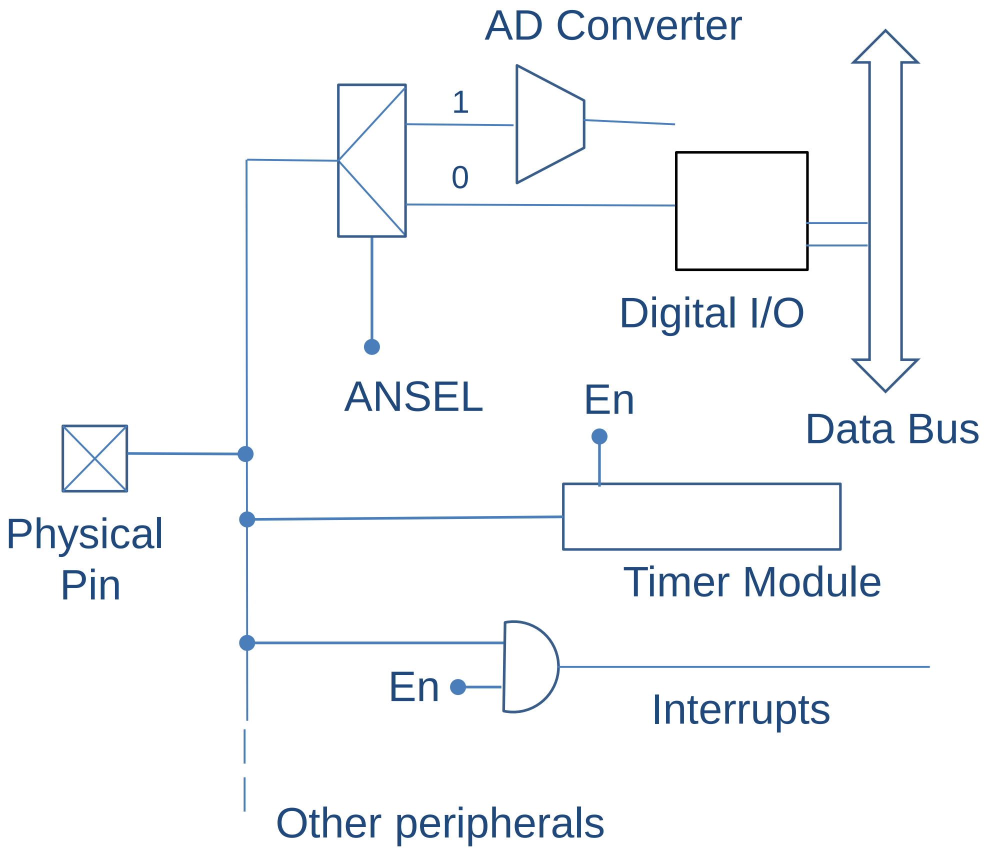
Pin Name	Function	TRIS Setting	ANSEL Setting	Pin Type	Buffer Type	Description
RA0/C12IN0-/AN0	RA0	0	0	O	DIG	LATA<0> data output; not affected by analog input.
		1	0	I	TTL	PORTA<0> data input; disabled when analog input enabled.
	C12IN0-	1	1	I	AN	Comparators C1 and C2 inverting input.
	AN0	1	1	I	AN	Analog input 0.
RA1/C12IN1-/AN1	RA1	0	0	O	DIG	LATA<1> data output; not affected by analog input.
		1	0	I	TTL	PORTA<1> data input; disabled when analog input enabled.
	C12IN1-	1	1	I	AN	Comparators C1 and C2 inverting input.
	AN1	1	1	I	AN	Analog input 1.
RA2/C2IN+/AN2/ DACOUT/VREF-	RA2	0	0	O	DIG	LATA<2> data output; not affected by analog input; disabled when DACOUT enabled.
		1	0	I	TTL	PORTA<2> data input; disabled when analog input enabled; disabled when DACOUT enabled.
	C2IN+	1	1	I	AN	Comparator C2 non-inverting input.
	AN2	1	1	I	AN	Analog output 2.
	DACOUT	x	1	O	AN	DAC Reference output.
	VREF-	1	1	I	AN	A/D reference voltage (low) input.
RA3/C1IN+/AN3/ VREF+	RA3	0		O	DIG	LATA<3> data output; not affected by analog input.
		1	0	I	TTL	PORTA<3> data input; disabled when analog input enabled.
	C1IN+	1	1	I	AN	Comparator C1 non-inverting input.
	AN3	1	1	I	AN	Analog input 3.
	VREF+	1	1	I	AN	A/D reference voltage (high) input.

3.2 The GPIO module

The GPIO (General Purpose Input-Output) manages the interface between the microcontroller: Data Bus, Peripherals, and the physical pins.

GPIO module functions:

- Electronic protection of the device.
- Multiplex of analog and digital functions.
- Arbitrate bidirectionality (data in-data out), configurable direction.
- Digital data buffering (keep the values).
- Provide registers for configuration (data, status, control…).



3.2 The GPIO module

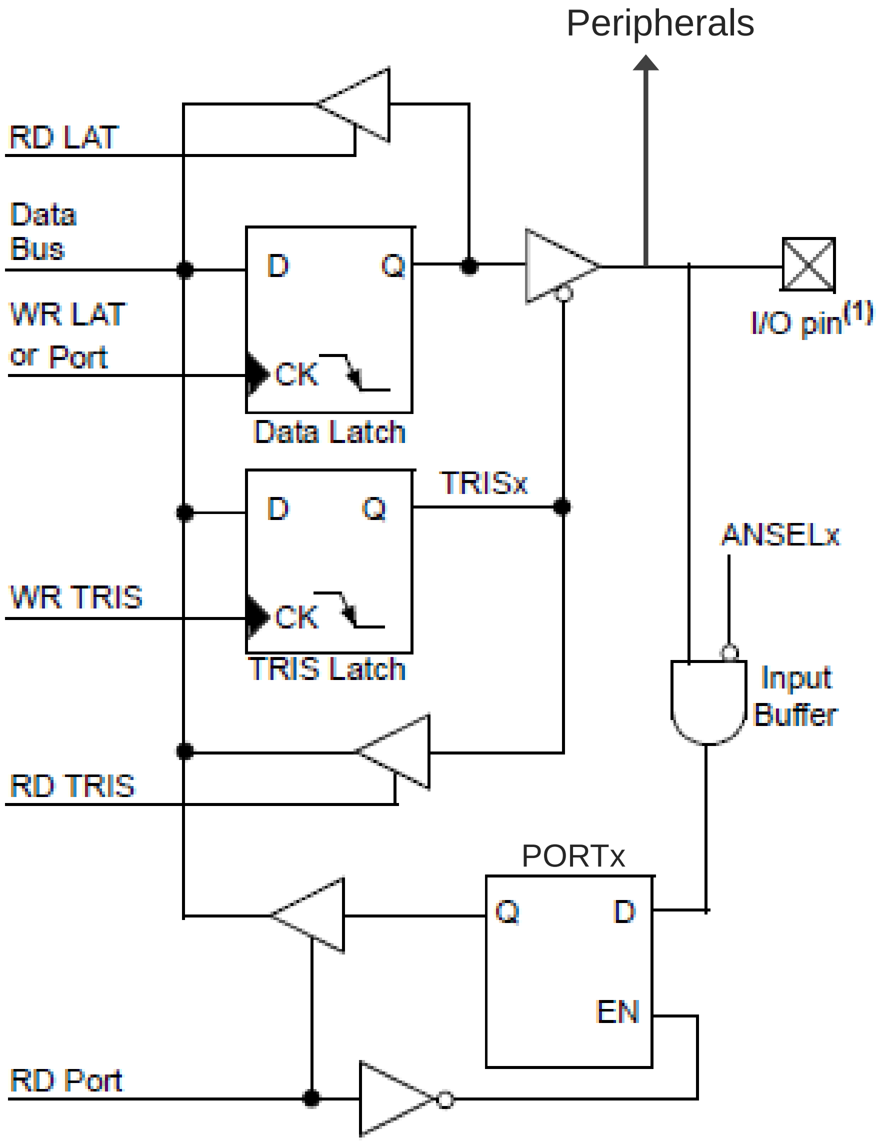
GPIO in the PIC18 device family (for every pin)

DIGITAL INTERFACE, Involved Registers:

- ANSELx register (analog/digital input control bit: 0 Digital, 1 Analog)
- TRISx register (data direction register: 1 Input, 0 Output)
- PORTx register (reads the levels on the pins of the device in digital mode)
- LATx register (latch output data in digital mode)

x = {A, B, C, D}

Peripherals (analog to digital converter, timers…) have individual activation pins.



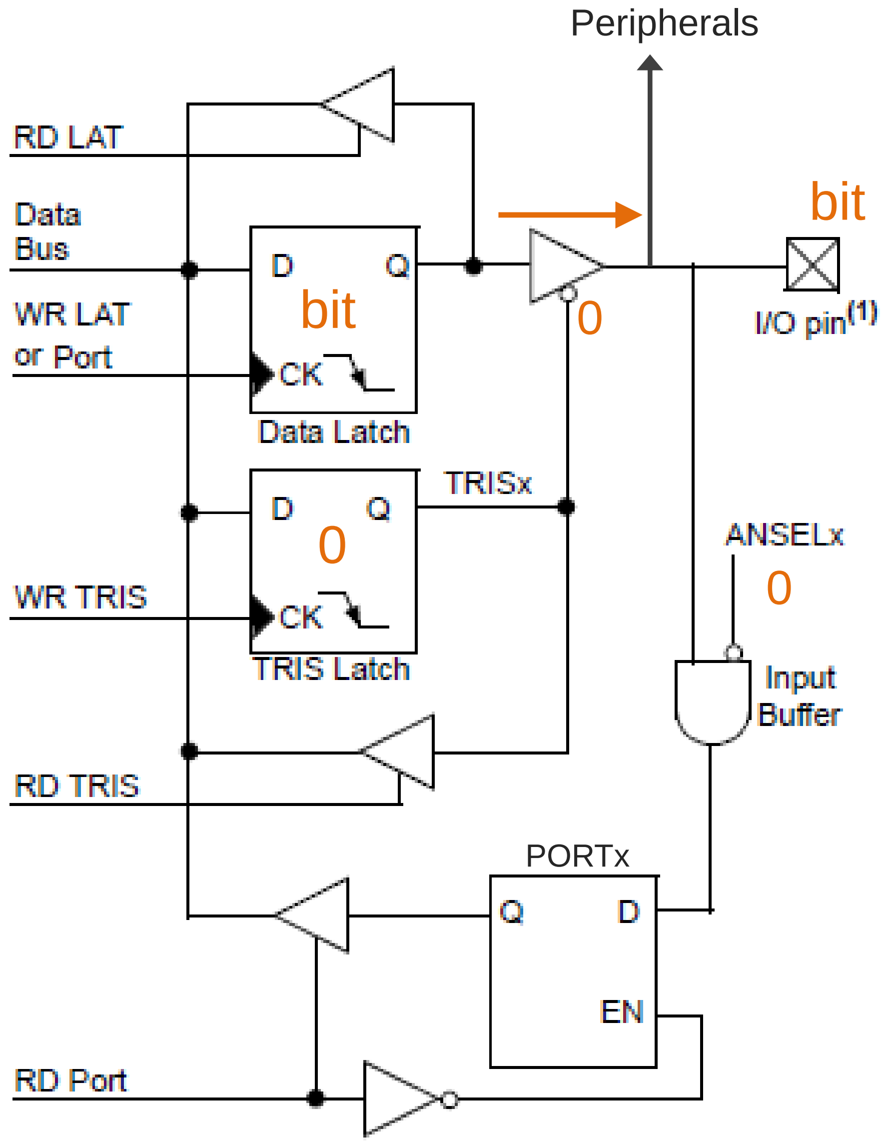
3.2 The GPIO module

Configuration for **output** digital data.

- ANSELx register = 0
- TRISx register = 0
- PORTx register not involved
- LATx register = data bit

Function:

LAT register stores the data bit (bit)
TRIS register stores the direction bit (0)
Tristate buffer (0-active), outputs the data bit to the I/O pin.



3.2 The GPIO module

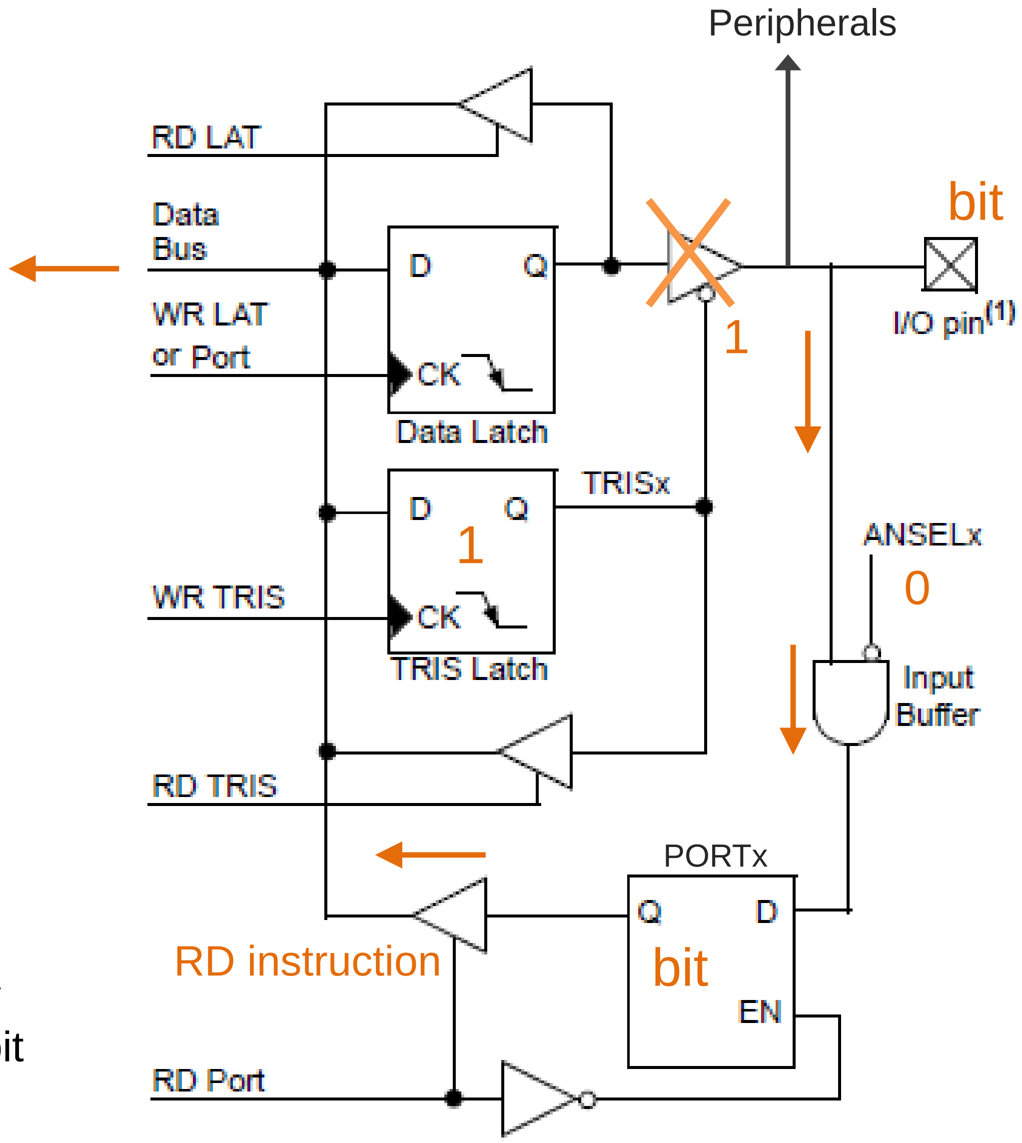
Configuration for **input** digital data.

- ANSELx register = 0
- TRISx register = 1
- PORTx register stores data on pin
- LATx register not involved

Function:

LAT register stores some data…
TRIS register stores the direction bit (1= input)
Tristate buffer (1-inactive) cuts its output.

PORT register continously loads data from the pin.
When there is a "Read" instruction from the adress mapped by the GPIO, PORTx stops sampling the Pin and the last stored bit passes to the data bus.



3.2 The GPIO module

GPIO in PIC18 configuration, digital usage coding examples:

Assembler programming

```
        #include <p18F45K22.inc>

        MOVLB 0xF; Set BSR for banked SFRs
        MOVLW 0xC0
        MOVWF ANSELA,1 ; A is DIGITAL
        CLRF ANSELB,1     ; B is DIGITAL
        SETF TRISA          ; A is INPUT
        CLRF TRISB          ; B is OUTPUT

Loop    MOVFF PORTA, PORTB
        GOTO Loop
        end
```

C programming

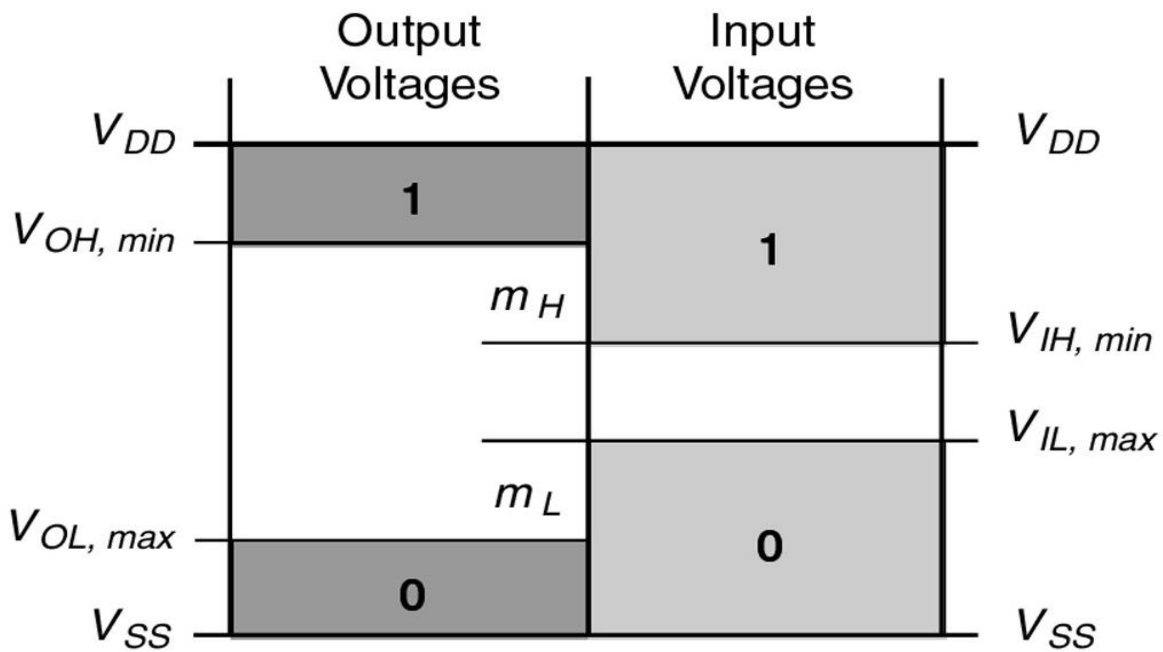
```
#include <p18f45k22.h>
#include "config.h"

void main()
{
   ANSELA = 0xC0;      // A5-A0:DIGITAL, A6,A7 OSC
   ANSELB = 0x00;      // B DIGITAL
   TRISA = 0xFF;        // PORTA INPUT
   TRISB = 0x00;        // PORTB OUTPUT

   while (1)
   {
     PORTB = PORTA;
    }
}
```

3.3 Electrical characteristics

DC Voltage: When using the digital interface on GPIO, what is a 0? What is a 1? It is the same a 0/1 on input or a 0/1 on output?

Some parameters to discuss:

- Vdd and Vss are the power supply voltages.
- The output voltage parameters are V_{OL} and V_{OH}
- The input voltage parameters are V_{IL} and V_{IH}
- Noise margins: m_H and m_L



3.3 Electrical characteristics

DC Current: what are the maximum current sourced or sunk by a physical pin?

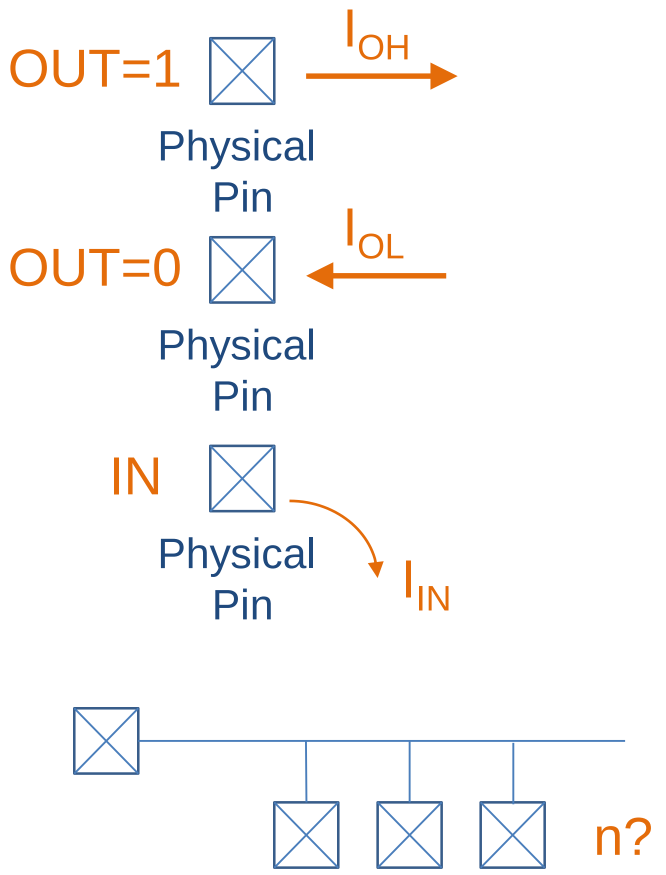
Some parameters to discuss:

- I_{OH} is the current *flowing out* of a *high output* (sourced)
- I_{OL} is the current *flowing in* to a *low output* (sunk)
- I_{IN} is the leakage current that flows into or out of an input pin.
- Static fanout for a device: number of inputs that can be connected to one output while preserving the required voltage margins:

  Static fanout for a low output is: $n_L = | I_{OL,max} | / | I_{In} |$

  Static fanout for a high output is: $n_H = | I_{OH,max} | / | I_{In} |$

  $n = \min [n_H, n_L]$
- Consider what is "dynamic fanout".



3.3 Electrical characteristics

Device's datasheet provides all the information about the discussed parameters.

Ambient temperature under bias	-40°C to +125°C
Storage temperature	-65°C to +150°C
Voltage on any pin with respect to V_{SS} (except V_{DD}, and $\overline{MCLR}$)	-0.3V to (V_{DD} + 0.3V)
Total power dissipation **(Note 1)**	1.0W
Maximum current out of V_{SS} pin (-40°C to +85°C)	300 mA
Maximum current out of V_{SS} pin (+85°C to +125°C)	125 mA
Maximum current into V_{DD} pin (-40°C to +85°C)	200 mA
Maximum current into V_{DD} pin (+85°C to +125°C)	85 mA
Input clamp current, I_{IK} ($V_I < 0$ or $V_I > V_{DD}$)	±20 mA
Output clamp current, I_{OK} ($V_O < 0$ or $V_O > V_{DD}$)	±20 mA
Maximum output current sunk by any I/O pin	25 mA
Maximum output current sourced by any I/O pin	25 mA
Maximum current sunk by all ports (-40°C to +85°C)	200 mA
Maximum current sunk by all ports (+85°C to +125°C)	110 mA
Maximum current sourced by all ports (-40°C to +85°C)	185 mA
Maximum current sourced by all ports (+85°C to +125°C)	70 mA

3.3 Electrical characteristics

Device’s datasheet provides all the information about the discussed parameters.

27.1 DC Characteristics: Supply Voltage, PIC18(L)F2X/4XK22

PIC18(L)F2X/4XK22				**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +125°C				
Param No.	**Symbol**	**Characteristic**		**Min**	**Typ**	**Max**	**Units**	**Conditions**
D001	VDD	**Supply Voltage**	PIC18LF2X/4XK22	1.8	—	3.6	V	
			PIC18F2X/4XK22	2.3	—	5.5	V	
D002	VDR	**RAM Data Retention Voltage**(1)		1.5	—	—	V	
D003	VPOR	**VDD Start Voltage** to ensure internal Power-on Reset signal		—	—	0.7	V	See section on Power-on Reset for details
D004	SVDD	**VDD Rise Rate** to ensure internal Power-on Reset signal		0.05	—	—	V/ms	See section on Power-on Reset for details
D005	VBOR	**Brown-out Reset Voltage**						
		BORV<1:0> = 11(2)		1.75	1.9	2.05	V	
		BORV<1:0> = 10		2.05	2.2	2.35	V	
		BORV<1:0> = 01		2.35	2.5	2.65	V	
		BORV<1:0> = 00(3)		2.65	2.85	3.05	V	

Note 1: This is the limit to which VDD can be lowered in Sleep mode, or during a device Reset, without losing RAM data.

3.3 Electrical characteristics

27.8 DC Characteristics: Input/Output Characteristics, PIC18(L)F2X/4XK22

DC CHARACTERISTICS			**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +125°C				
Param No.	**Symbol**	**Characteristic**	**Min**	**Typ†**	**Max**	**Units**	**Conditions**
	VIL	**Input Low Voltage**					
		I/O PORT:					
D140		with TTL buffer	—	—	0.8	V	4.5V ≤ VDD ≤ 5.5V
D140A			—	—	0.15 VDD	V	1.8V ≤ VDD ≤ 4.5V
D141		with Schmitt Trigger buffer	—	—	0.2 VDD	V	2.0V ≤ VDD ≤ 5.5V
		with I^{2}C levels	—	—	0.3 VDD	V	
		with SMBus levels	—	—	0.8	V	2.7V ≤ VDD ≤ 5.5V
D142		$\overline{\text{MCLR}}$, OSC1 (RC mode)(1)	—	—	0.2 VDD	V	
D142A		OSC1 (HS mode)	—	—	0.3 VDD	V	
	VIH	**Input High Voltage**					
		I/O ports:		—	—		
D147		with TTL buffer	2.0	—	—	V	4.5V ≤ VDD ≤ 5.5V
D147A			0.25 VDD + 0.8	—	—	V	1.8V ≤ VDD ≤ 4.5V
D148		with Schmitt Trigger buffer	0.8 VDD	—	—	V	2.0V ≤ VDD ≤ 5.5V
		with I^{2}C levels	0.7 VDD	—	—	V	
		with SMBus levels	2.1	—	—	V	2.7V ≤ VDD ≤ 5.5V
D149		$\overline{\text{MCLR}}$	0.8 VDD	—	—	V	
D150A		OSC1 (HS mode)	0.7 VDD	—	—	V	
D150B		OSC1 (RC mode)(1)	0.9 VDD	—	—	V	

3.3 Electrical characteristics

27.8 DC Characteristics: Input/Output Characteristics, PIC18(L)F2X/4XK22 (Continued)

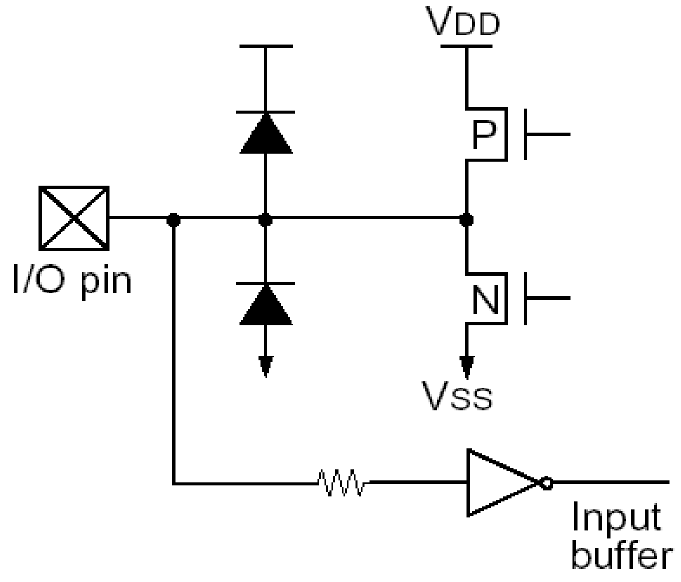
DC CHARACTERISTICS			**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +125°C				
Param No.	**Symbol**	**Characteristic**	**Min**	**Typ†**	**Max**	**Units**	**Conditions**
D159	VOL	**Output Low Voltage** I/O ports	—	—	0.6	V	IOL = 8 mA, VDD = 5V IOL = 6 mA, VDD = 3.3V IOL = 1.8 mA, VDD = 1.8V
D161	VOH	**Output High Voltage**(3) I/O ports	VDD - 0.7	—	—	V	IOH = 3.5 mA, VDD = 5V IOH = 3 mA, VDD = 3.3V IOH = 1 mA, VDD = 1.8V
D155	IIL	**Input Leakage I/O and MCLR**(2),(3) I/O ports and $\overline{MCLR}$					VSS ≤ VPIN ≤ VDD, Pin at high-impedance
			—	0.1	50	nA	≤ +25°C(4)
			—	0.7	100	nA	+60°C
			—	4	200	nA	+85°C
			—	35	1000	nA	+125°C

Homework:

- Identify in the tables the parameters: V_{OH}, V_{OL}, I_{OH}, I_{OL}, I_{IL}
- Calculate noise margins and static fanout.

3.3 Electrical characteristics

Protections on I/O Pins.



Simplified structure of an I/O pin.

Voltages (much) over V_{DD} or below V_{SS}, currents over I_{MAX} can destroy the pin or the device.
Aggregate currents over the maximum limits can overheat the device and destroy it.

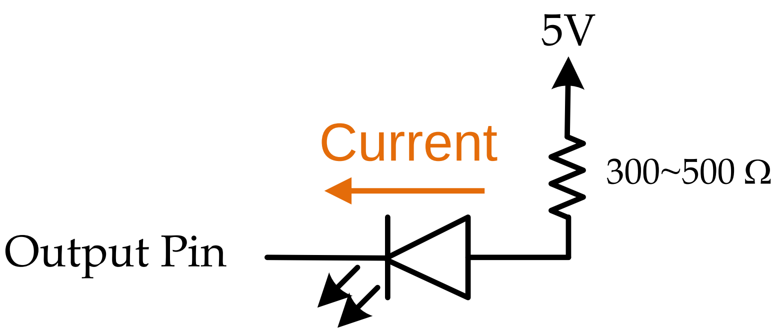
3.4 Common digital interfaces

Interfacing with LEDs (**Output**)

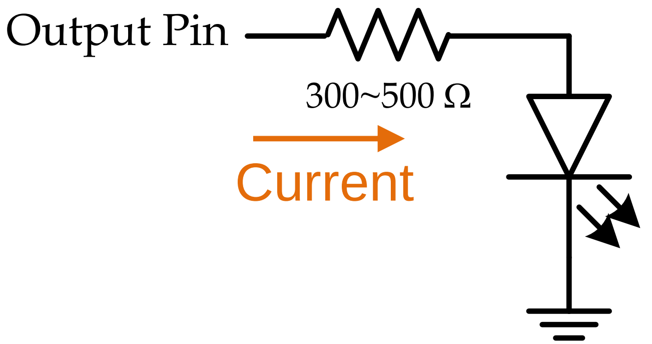
A LED emits light when current flows through it in the positive direction i.e. when the voltage on the anode side is made higher than the voltage on the cathode side.

The forward voltage across the LED is typically about 1.5 to 2 Volts.

We need to add a **resistor** to limit the current.



(a) low voltage on output pin lights LED



(b) high voltage on output pin lights LED

Example question: Using a 5-volt supply and assuming that the LED has a 2.0 V drop across it, what resistor value will limit the current to 10mA?

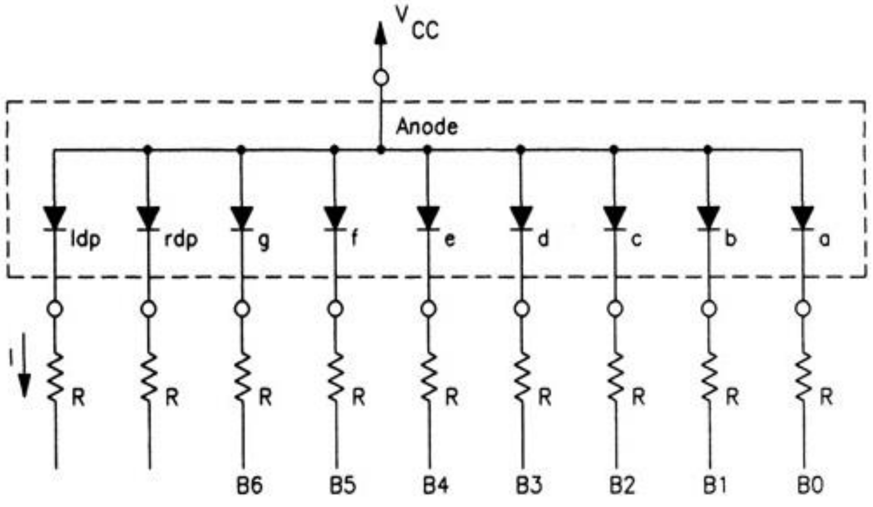
$5V = 2.0V + I_{Rx} \cdot Rx$; Setting I_{Rx} to 10mA the resistor Rx is solved to be 300 Ohm.

3.4 Common digital interfaces

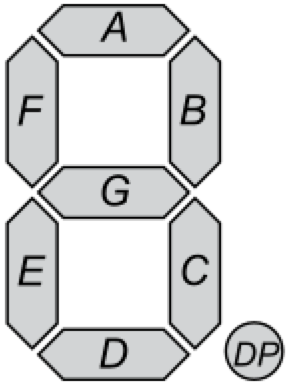
Seven Segment Displays (Output)

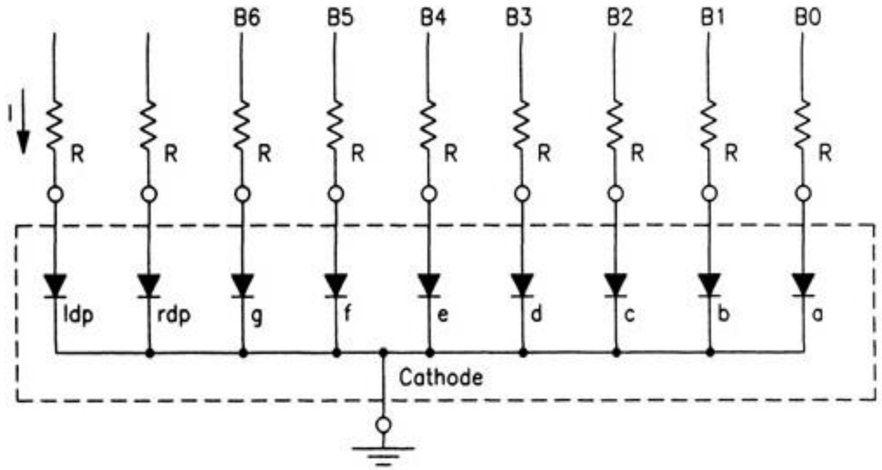
A Seven Segment Display is a group of LEDs used to display figures.
Every Segment (LED) will be managed by one digital out on the microcontroller.

Two possible configurations: Common Anode and Common Cathode



(a) Common Anode Connection
Current sinking when bit is low.

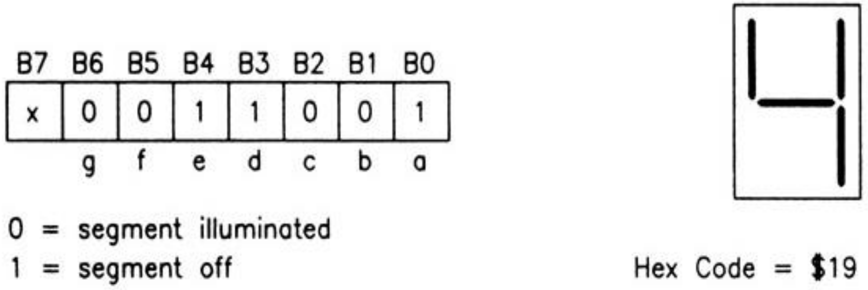




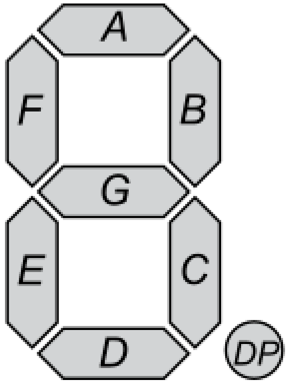
(b) Common Cathode Connection
Current sourcing when bit is high.

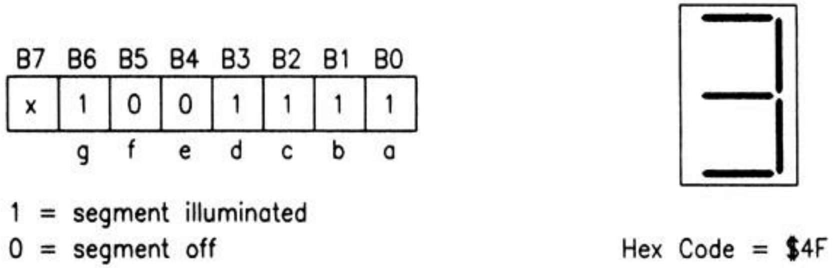
3.4 Common digital interfaces

Two possible configurations: Common Anode and Common Cathode



(a) Common Anode Example





(b) Common Cathode Example

Common Anode: sending a “0” will illuminate the segment.

Common Cathode: sending a “1” will illuminate the segment.

Example question: Write a void C function that displays a number (input parameter) in the Seven Segments Display assuming a Common Cathode configuration.

3.4 Common digital interfaces

DIP switches interface (INPUT)

DIP switches allow users to set some digital bits to the microcontroller.

Every input requires a pull-up or pull-down resistor to set a default value.

It is commonly used to define system configuration parameters or assign address when several identic systems lie on a bus.

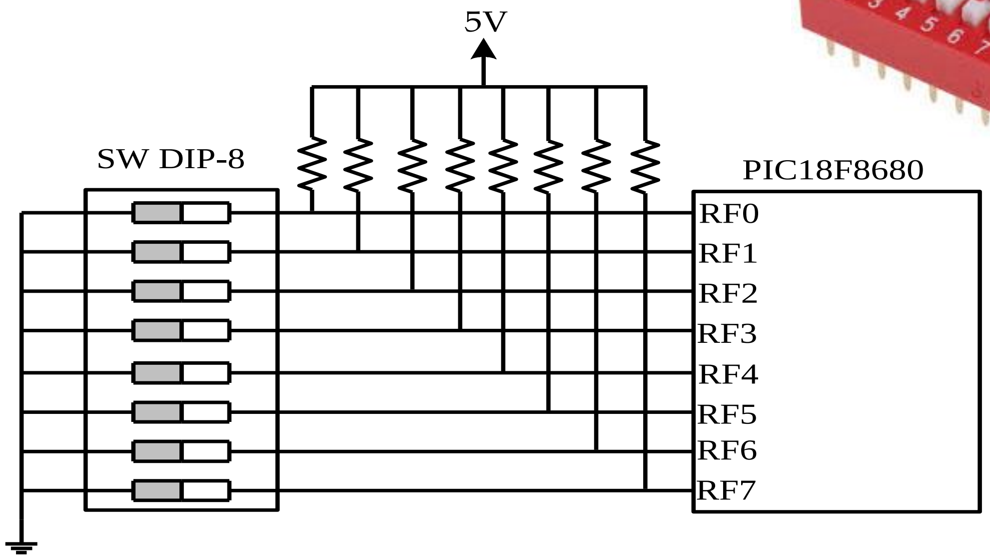


Figure 7.24b Connecting a set of eight DIP switches to port F of the PIC18F8680

Reading a byte from the DIP switches to WREG

```
movlw    0xFF          ; configure port for input
movwf    TRISD         ;  “
movf     PORTD,W       ; read portD
```

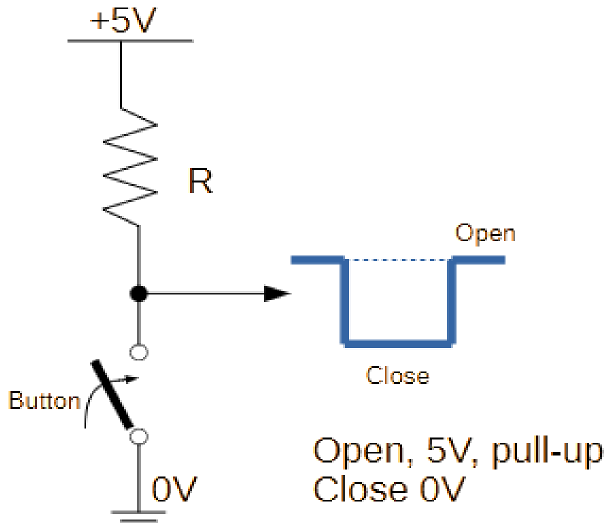
3.4 Common digital interfaces

Button interface (INPUT)

Buttons allow users to interact with a Microcontroller (polling, interrupt…)

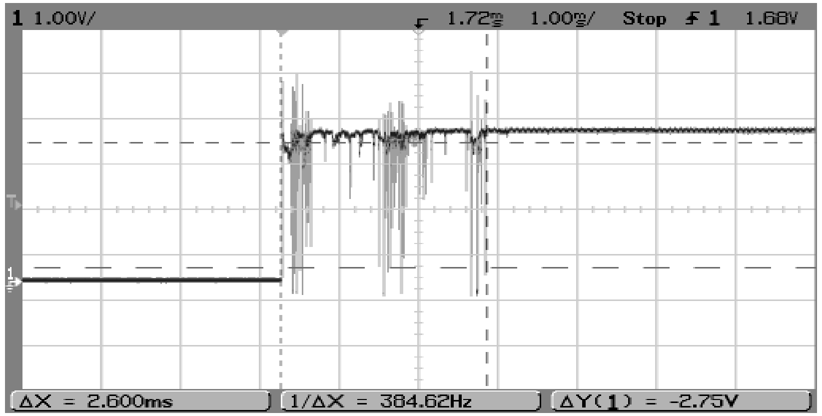
Every input requires a pull-up or pull-down resistor to set a default value.

Example: Button with pull-up (activation to 0)



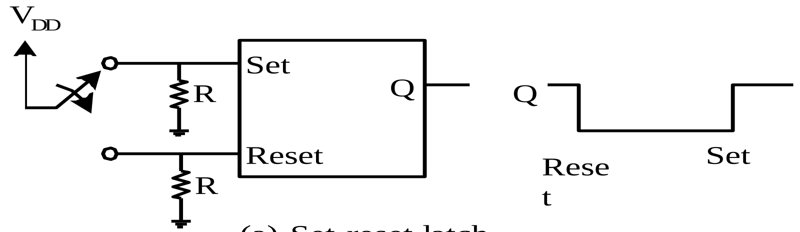
Main problem with push-buttons: bounce.

- When the button is moved (push, release), some noise appear due to metal elasticity, dust particles, etc.

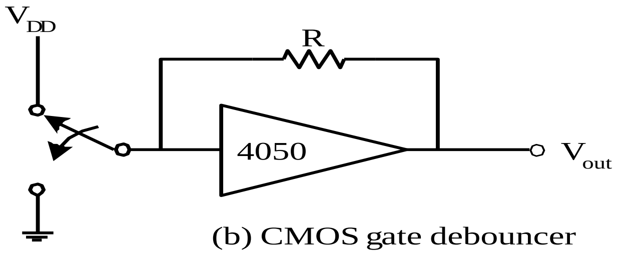


3.4 Common digital interfaces

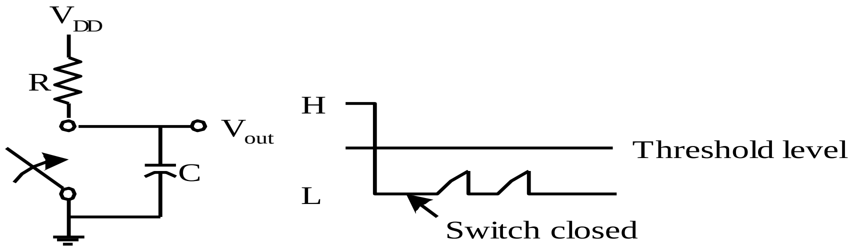
Some hardware debouncing techniques.



(a) Set-reset latch



(b) CMOS gate debouncer



(c) Integrating RC circuit debouncer

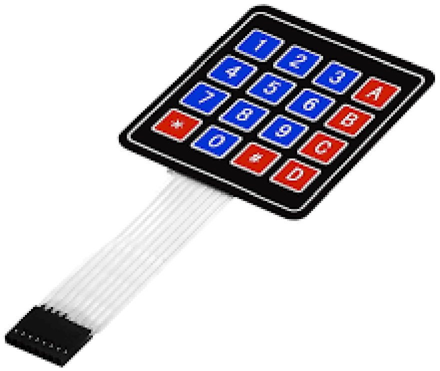
Software debouncing techniques.

The most used software debouncing technique is “wait and see”.

Pseudocode:

```
…
button_pressed = FALSE
if ( button == 1 )
{
        delay (10);
        if (button ==1 )
                button_pressed = TRUE;
}
…
```

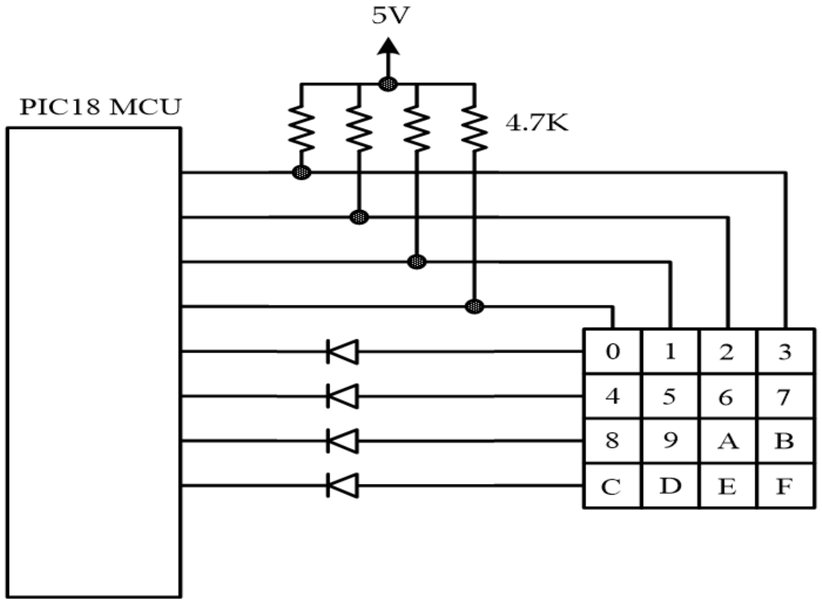
3.4 Common digital interfaces



Keypad and Keyboard (INPUT)

Membrane: A plastic or rubber membrane presses one conductor onto another.

Example: 16 key keypad connection to 8 pins



Capacitive: Two parallel plates. Pressing the plates changes the distance between the plates and changes the capacitance.

Mechanical: Two metal contacts are brought together to complete an electrical circuit.

Mechanical:

- Low cost and strength of construction. Most popular
- Human being cannot press and release the key switch 20 ms
- A debouncing process is required for correct operation

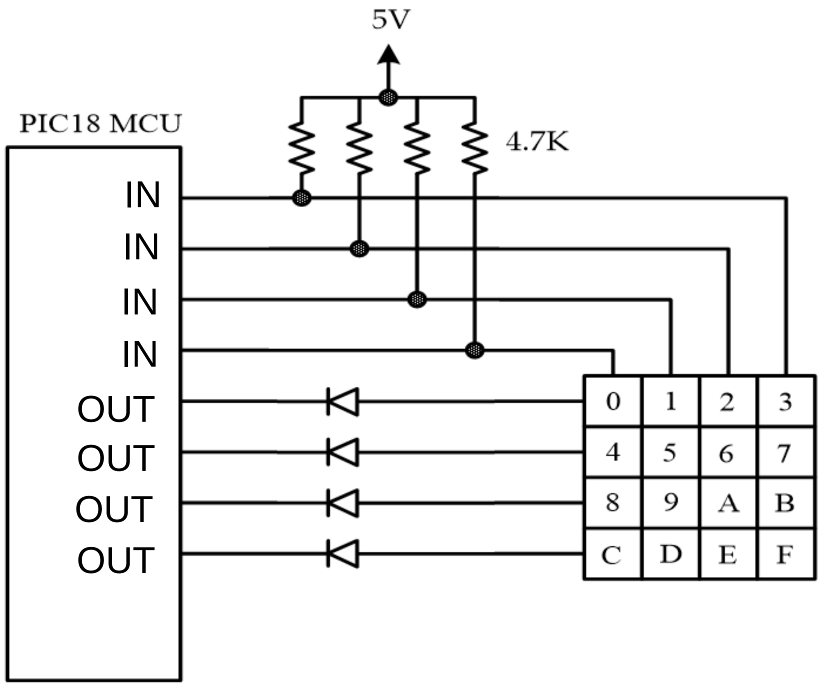
3.4 Common digital interfaces

Keypad and Keyboard (INPUT)

"Row-by-row" scan method:

- The row to be scanned is pulled to low. Other rows are pulled high.
- When a key is pressed, the corresponding row and column are shorted together and is detected low.
- Apply debouncing technique.
- Decode the key pressed.

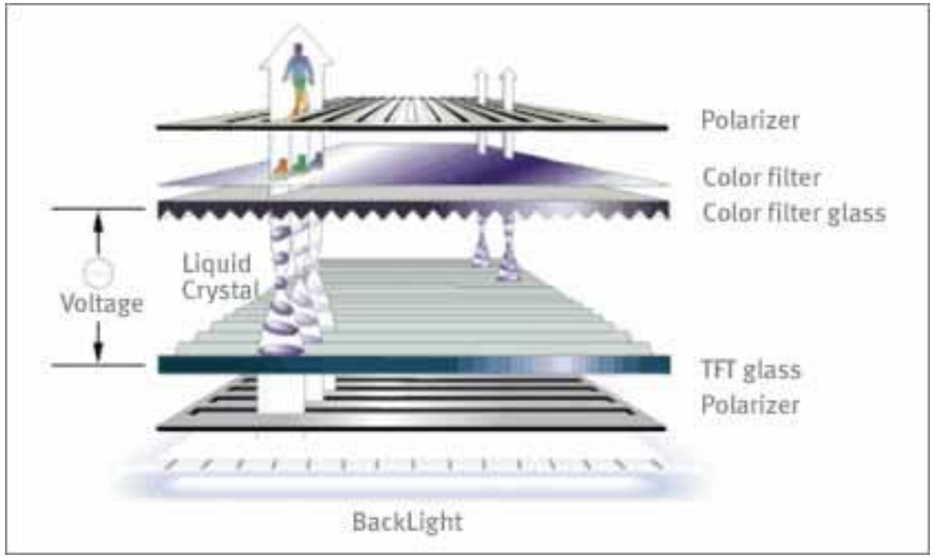
The diodes provide protection of accidental simultaneous press of multiple keys.

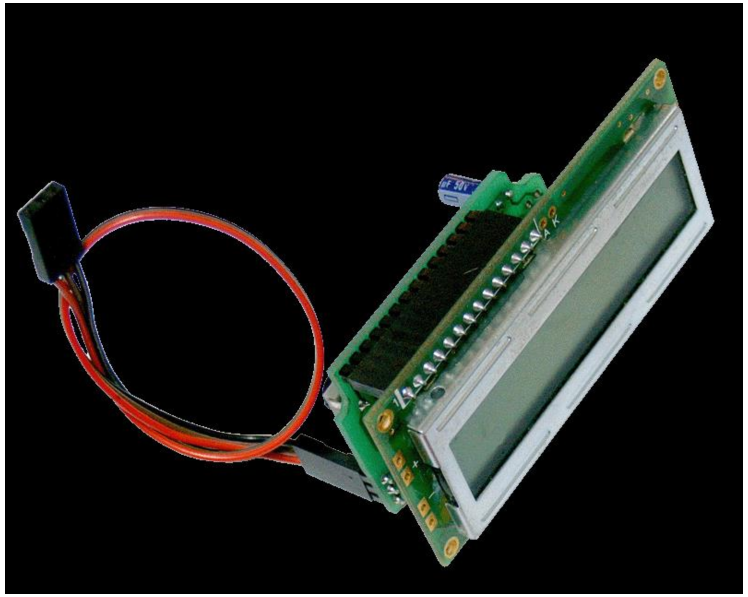


3.4 Common digital interfaces

LCD (OUTPUT)

Liquid Crystal Display. Typical use on calculators.





Addressed through a specific digital bus.

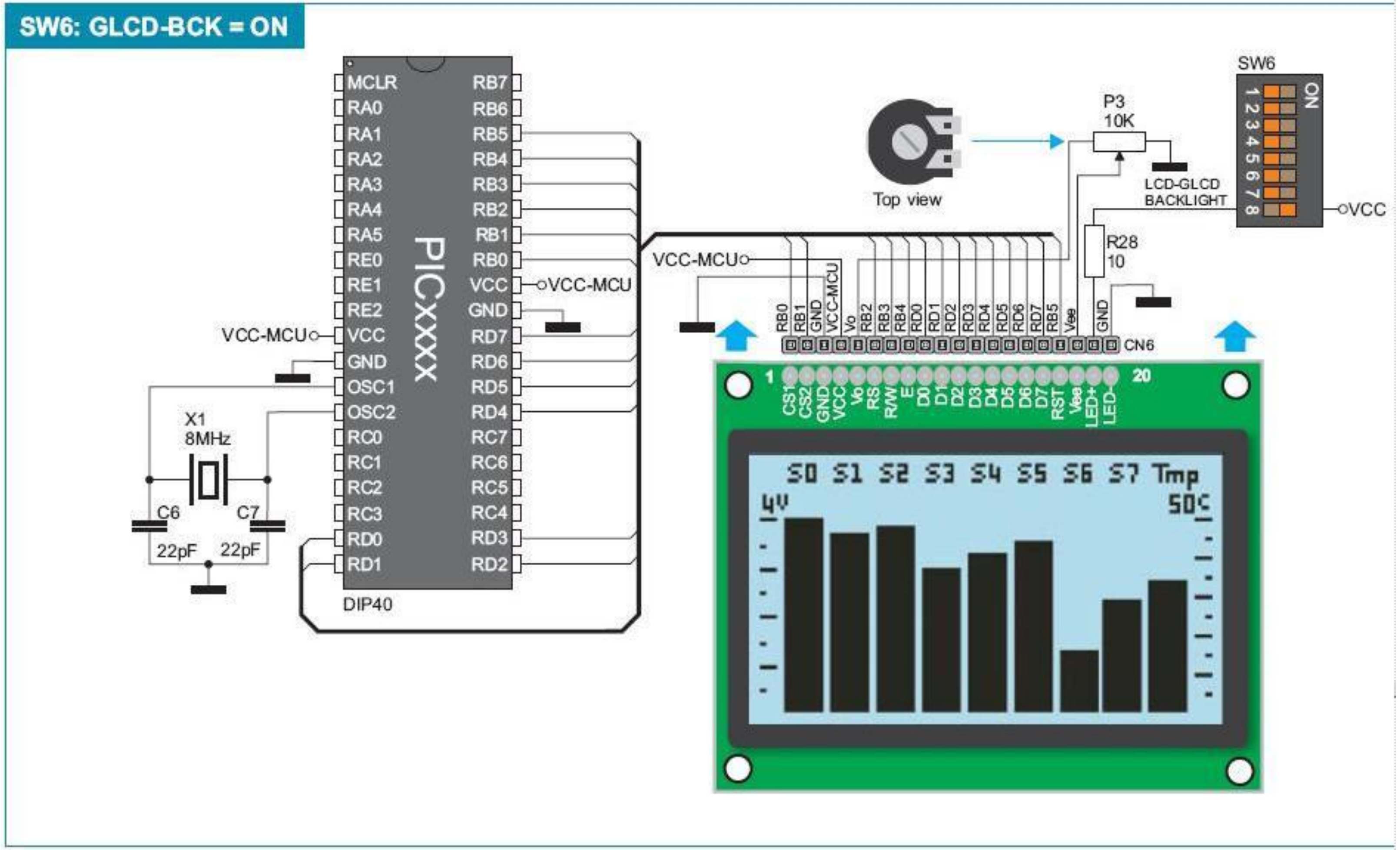
3.4 Common digital interfaces

GLCD (OUTPUT)

Graphic Liquid Crystal Display.

Typical use on calculators and device's displays like weather stations.

Will be used in the lab.

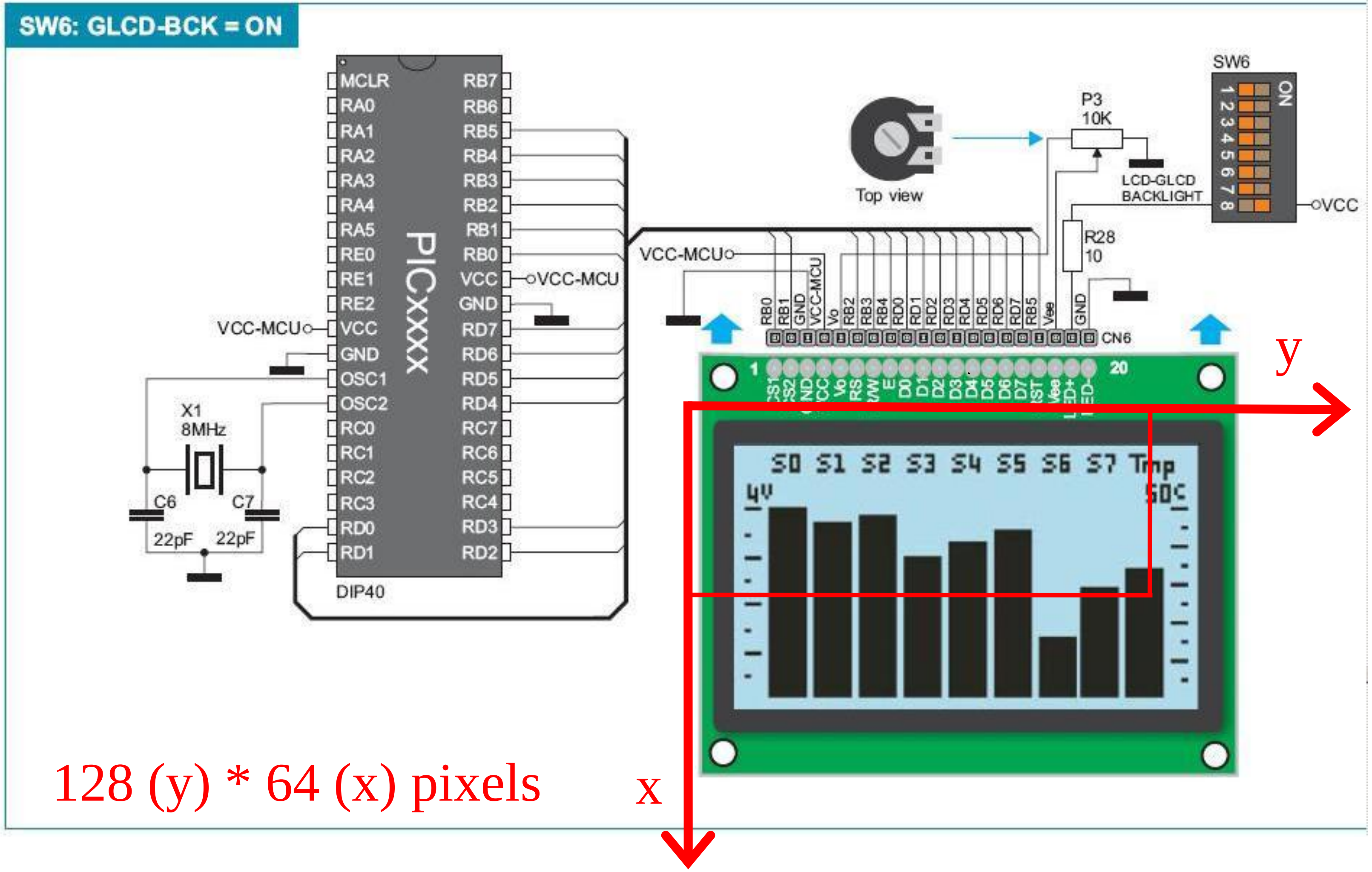


3.4 Common digital interfaces

GLCD (OUTPUT)

Pixel access in a x-y coordinate system.

128x64 pixel resolution.

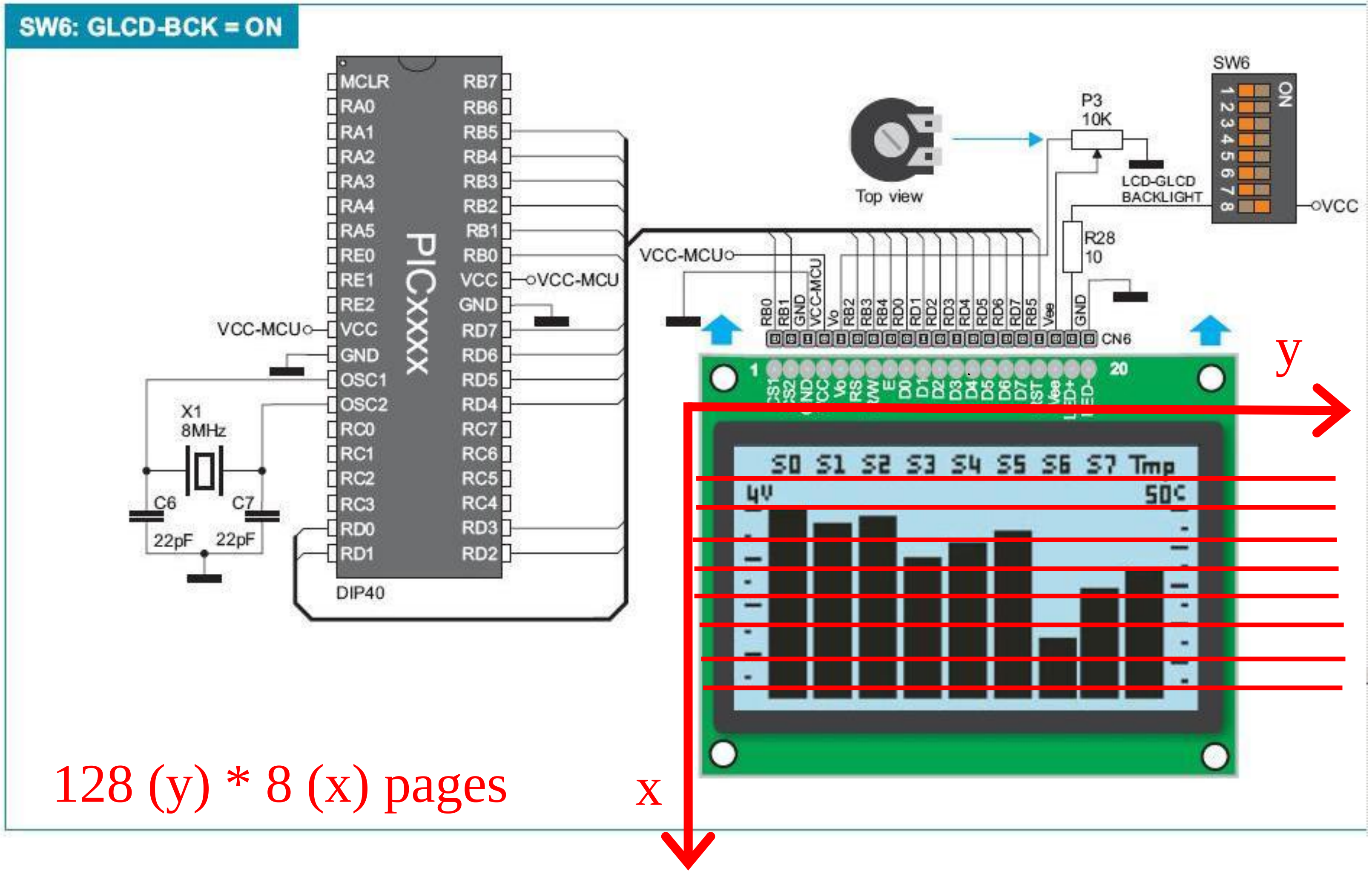


3.4 Common digital interfaces

GLCD (OUTPUT)

Pixel access in a x-y coordinate system.

X axis is organized in 8 pages, containing 8 pixels each.



3.4 Common digital interfaces

GLCD (OUTPUT)

Is controlled through a 10-bit parallel digital interface.

10 bit coded instructions are sent. Examples:

0 0 0 0 1 1 1 1 1 1 Display on

0 0 0 1 0 0 0 0 1 1 Y = 3

0 0 1 0 1 1 1 0 0 0 Page = 0

1 0 0 0 1 1 1 1 1 1 Set 6 bits on page 0

Instruction	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Function
Display on/off	L	L	L	L	H	H	H	H	H	L/H	Controls the display on or off. Internal status and display RAM data is not affected. L: OFF, H: ON
Set address (Y address)	L	L	L	H	Y address (0 - 63)						Sets the Y address in the Y address counter.
Set page (X address)	L	L	H	L	H	H	H	Page (0 - 7)			Sets the X address at the X address register.
Display start line (Z address)	L	L	H	H	Display start line (0 - 63)						Indicates the display data RAM displayed at the top of the screen.
Status read	L	H	Busy	L	On / Off	Reset	L	L	L	L	Read status. BUSY L: Ready H: In operation ON/OFF L: Display ON H: Display OFF RESET L: Normal H: Reset
Write display data	H	L	Write data								Writes data (DB0:7) into display data RAM. After writing instruction, Y address is increased by 1 automatically.
Read display data	H	H	Read data								Reads data (DB0:7) from display data RAM to the data bus.