Microcontrollers

Embedded Programming

Team Emertxe

Important Terms

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Important Terms

- Host:

  A system which is used to develop the target.

- Target:

  A system which is being developed for specific application.

- Cross Compiler:

  An application used to generated code for another architecture being in another architecture

Lets Start Coding

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Embedded Programming - Let's Start Coding

- Well, come on lets make our hand a bit dirty in embedded coding with the following code

Example

```
#include <stdio.h>

int main()
{
    int x = 20;

    printf("%d\n", x);

    return 0;
}
```

- Nice, but few questions here
  - Why did you write this code?

    Hmm, Just to print x to embedded programming
  - Fine, where are you planning to run this code?

    Of course on a embedded target!
  - Does it have a OS already running?

    Ooink, Hmm noo, may be …

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Embedded Programming - Let's Start Coding

- So questions raised in the previous slide has to be answered before we can start our code.
- The answers to these questions are little tricky and depends on
  - Complexity of the work you do
  - The requirement of the project

  and many other factors
- Now the scope of this module is to learn low level microcontroller programming which is non OS (called as bare metal)
- So let's rewrite the same example as shown in the next slide

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Embedded Programming - Let's Start Coding

Example

```
#include <stdio.h>

void main(void)
{
    int x = 20;

    printf("%d\n", x);
}
```

- The change you observe is **void main(void)**
- Why?
  - As mentioned generally the low end embedded system are non OS based
  - The code you write would be the first piece of code coming to existence
- Now, lets not take this too seriously. This could again depend the development environment
- There could be some startup codes, which would call the main

Example

```
#include <stdio.h>

void main(void)
{
    int x = 20;

    printf("%d\n", x);
}
```

- The next questions is, where are trying to print? On Screen?
  - Does your target support that?
  - Does your development environment support that?

- Now again, all these are depends on your target board and development environment
- Maaan, So many questions? Well, what should I write then?
  - Well that too depends on your target board!! 😜

- Well, my principle is simple. No matter on what type of board you work, the first code you write, should give you the confidence that you are on the right path.
- Try to identify the simplest possible interface which can be made work with lesser overhead, so that, we are sure about our setup like
  - Hardware is working
  - Toolchain setup is working
  - Connectivity between the host and target is established

  and so on.

- It is good to know what your target board is, what it contains by its architecture
- Board architecture generally gives you overview about your board and its peripheral interfaces
- In our case we will be using PICSimLab simulator board which is shown in the next slide

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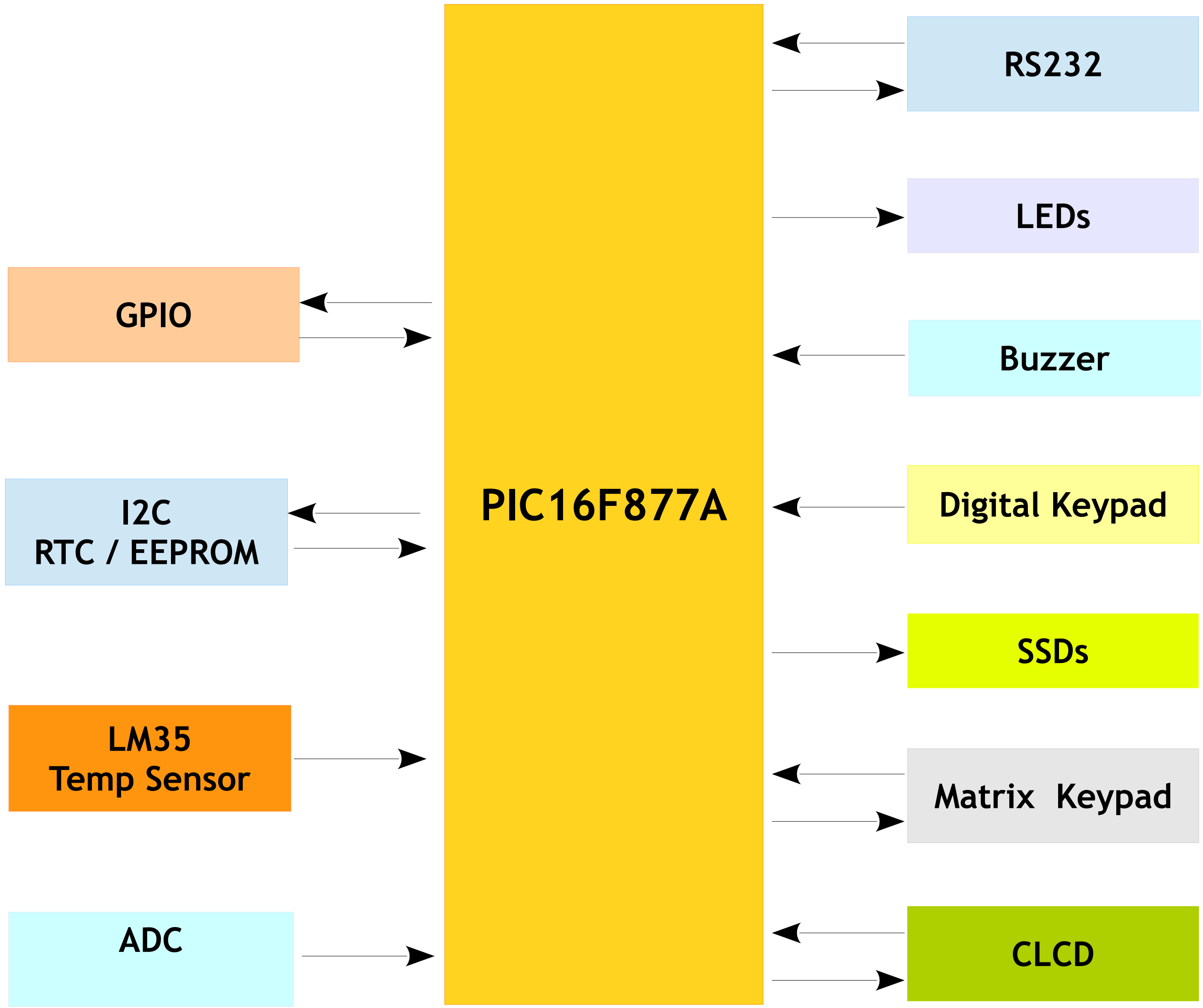
EP - Let's Start Coding – PICSimLab Architecture



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Embedded Programming - Let's Start Coding

- So from the architecture we come to know that the board has few LEDs, So why don't we start with it?

Example

```
#include <stdio.h>

void main(void)
{
    int led;

    led = 0;
}
```

- So simple right? Well I hope you know whats going happen with this code!!
- Any C programmer knows that the led is just a integer variable and we write just a value in it, hence no point in this code

Now what should we do?

- Hmm, refer next slide

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Embedded Programming - Let's Start Coding

- LED is an external device connected to microcontroller **port**
- A **port** is interface between the controller and external peripheral.
- Based on the controller architecture you will have **N** numbers of **ports**
- The target controller in PICGenios board is **PIC16F877A** from Microchip
- The next question arises is how do I know how many ports my target controller has?
  - From **Microcontroller Architecture** which will be detailed in the data sheet provided by the maker

- By reading the data sheet you come to know that there are 5 Ports
- Again a question. Where are the LEDs connected. You need the **Schematic** of the target board to know this.
- A **Schematic** is document which provides information about the physical connections on the hardware.
- From the schematic we come to know the the LEDs are connected to PORTB and PORTD
- Port is a peripheral and we need need to know on how to access and address. This info will be available in the data sheet in **PORTB, PORTD** and **Data Memory** sections

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Embedded Programming - Let's Start Coding

- From the section of PORTB it clear that there is 1 more register associated with it named, **TRISB**
- The TRISB register is very important for IO configuration. The value put in this register would decide pin direction as shown below

TRIS Register		PORT Register		Pin Direction
1	TRISx7	?	Rx7	Input
0	TRISx6	?	Rx6	Output
1	TRISx5	?	Rx5	Input
1	TRISx4	?	Rx4	Input
0	TRISx3	?	Rx3	Output
1	TRISx2	?	Rx2	Input
1	TRISx1	?	Rx1	Input
0	TRISx0	?	Rx0	Output

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Embedded Programming - Let's Start Coding

- So from previous slide its clear that we have to use the TRIS register to control the pin direction
- LEDs are driven by external source, so the port direction should be made as output
- In this case the LEDs are connected to the controller and will be driven by it
- Fine, what should write to the port to make it work?

  It depends on the hardware design.
- By considering all these point we can modify our code as shown in the next slide

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Embedded Programming - Let's Start Coding

Example

```
void main(void)
{
    /*
     * Defining a pointer to PORTB register at address 0x06,
     * pointing to 8 bit register. Refer data sheet
     */
    unsigned char *portb = (unsigned char *) 0x06;
    /*
     * Defining a pointer to PORTB tri-state register at address 0x86,
     * pointing to 8 bit register. Refer data sheet
     */
    unsigned char *trisb = (unsigned char *) 0x86;

    /* Setting the pin direction as output (0 - output and 1 - Input) */
    *trisb = 0x00;

    /*
     * Writing just a random value on the portb register where
     * LEDs are connected
     */
    *portb = 0x55;
}
```

- Hurray!!, we wrote our first Embedded C code for our target board
- Come on let's move forward, how do I compile this code?
- Obviously with a compiler!, Yes but a cross compiler since this code has to run on the target board.
- The target controller, as mentioned, is by Microchip. So we will be using **XC8 (Free Version)**
- You need to download it and install it in your system
  - You can use MPLABX

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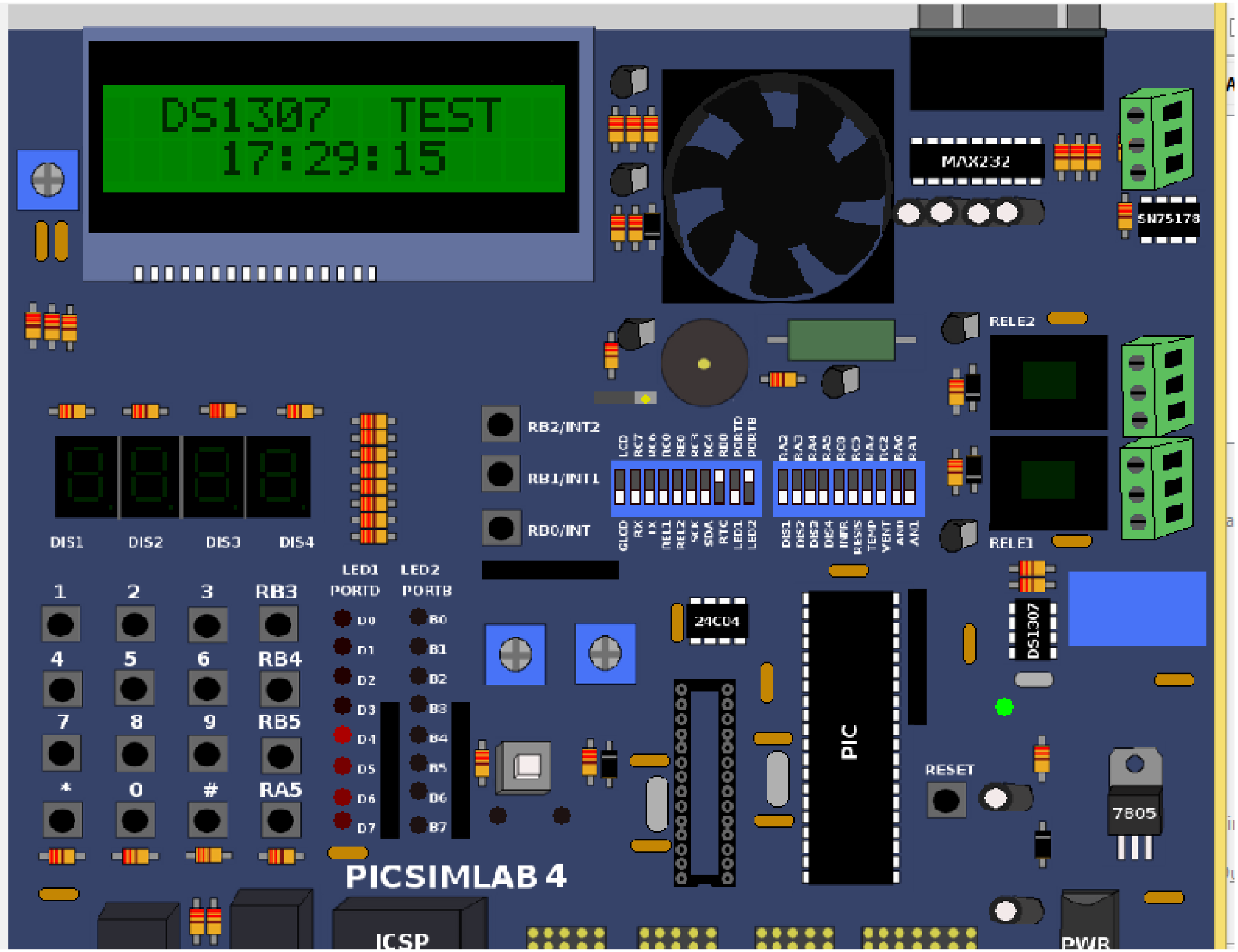
EP - Let's Start Coding –PICSimLab Board



- The thrill of having your first code working is different.
- But, this is just the beginning, you might like to design some good application based on your board
- Proceeding forward, the way how we wrote the code with indirect addressing would require good amount of time
- So it is common to use the definitions and libraries provided by the cross compiler to build our applications else we end up **“Reinventing the Wheel”**
- The same code can be re-written the the way provided in the next slide

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Embedded Programming - Let's Start Coding

Example

```
#include <xc8.h>

void main(void)
{
    /* Setting the pin direction as output (0 - output and 1 - Input) */
    TRISB = 0x00;

    /*
     * Writing just a random value on the data portb register where
     * LEDs are connected
     */
    PORTB = 0x55;
}
```

- So simple. Isn't it?

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Project Creation - Code Template

main.c

```
#include "main.h"

void init_config(void)
{
    /* Initilization Code */
}

void main(void)
{
    init_config();

    while (1)
    {
        /* Application Code */
    }
}
```

main.h

```
#ifndef MAIN_H
#define MAIN_H

#include <htc.h>

#endif
```

Lets Roll Out on Interfaces

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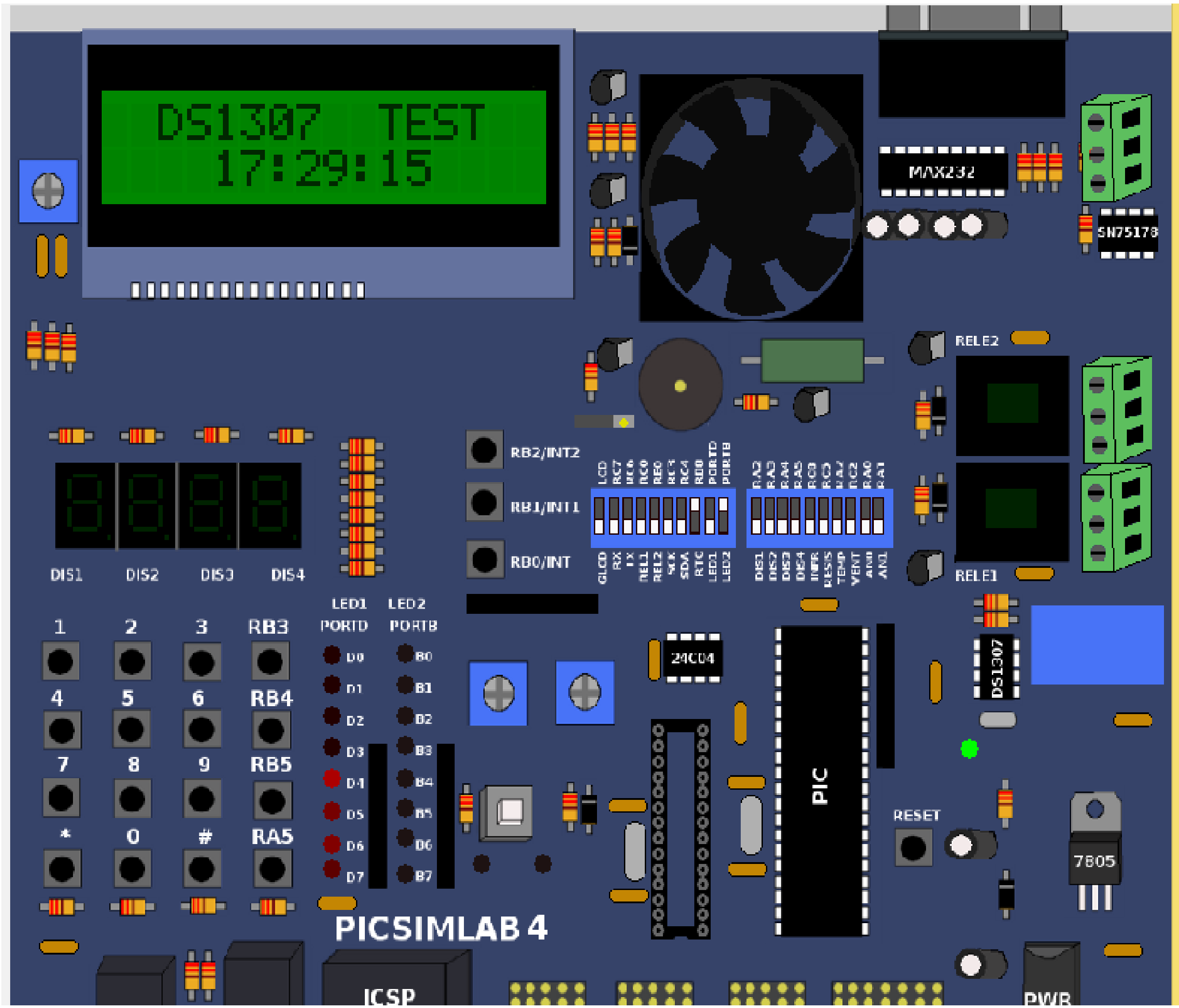
Lets Role Out on Interfaces



- LEDs
- Digital Keypad
- Interrupts
- Timers
- Clock I/O
- SSDs
- CLCD
- Matrix Keypad
- Analog Inputs

Light Emitting Diodes

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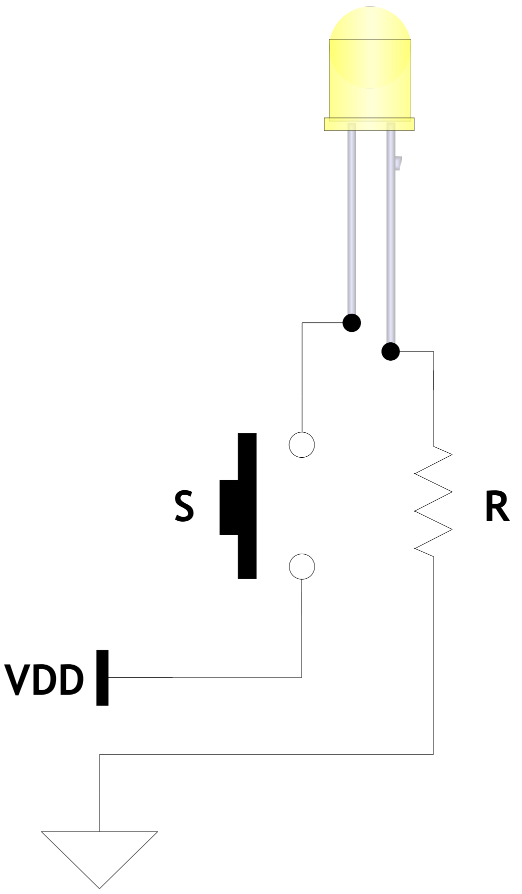
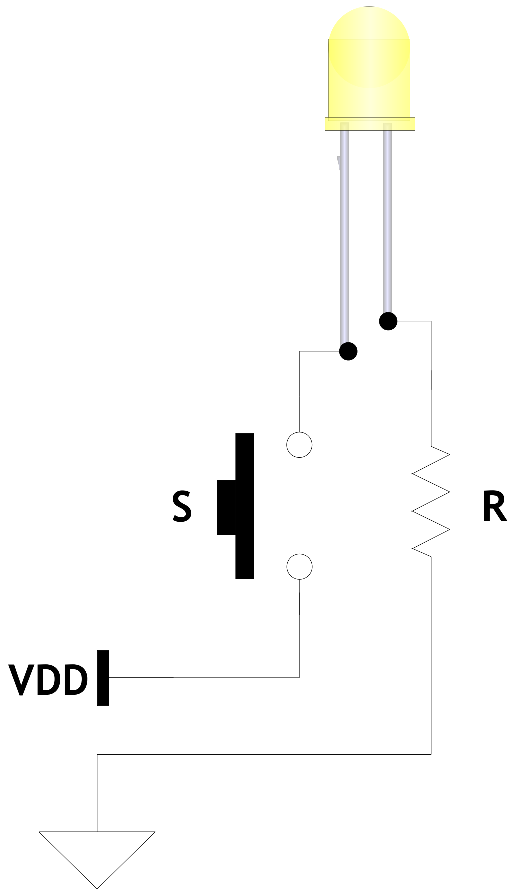
Interfaces – LEDs - Introduction

- Simplest device used in most on the embedded applications as feedback
- Works just like diodes
- Low energy consumptions, longer life, smaller size, faster switching make it usable in wide application fields like
  - Home lighting,
  - Remote Controls, Surveillance,
  - Displays and many more!!



Which side will work?



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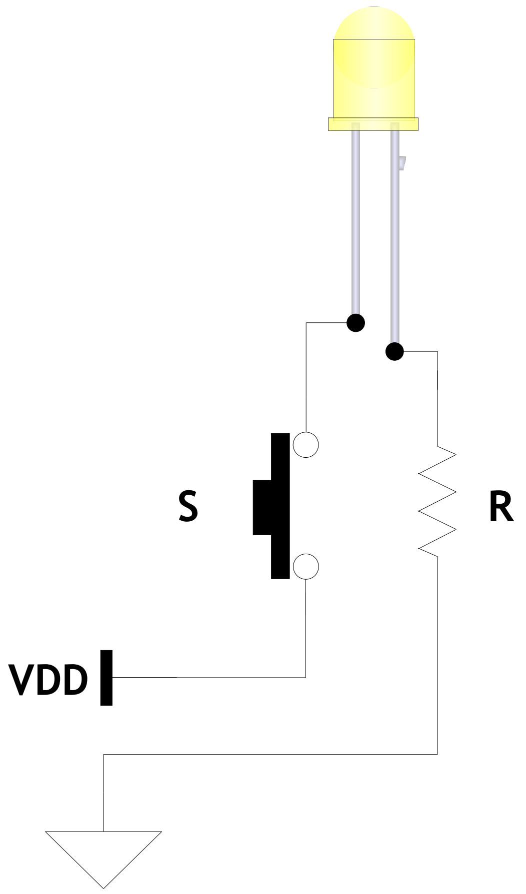
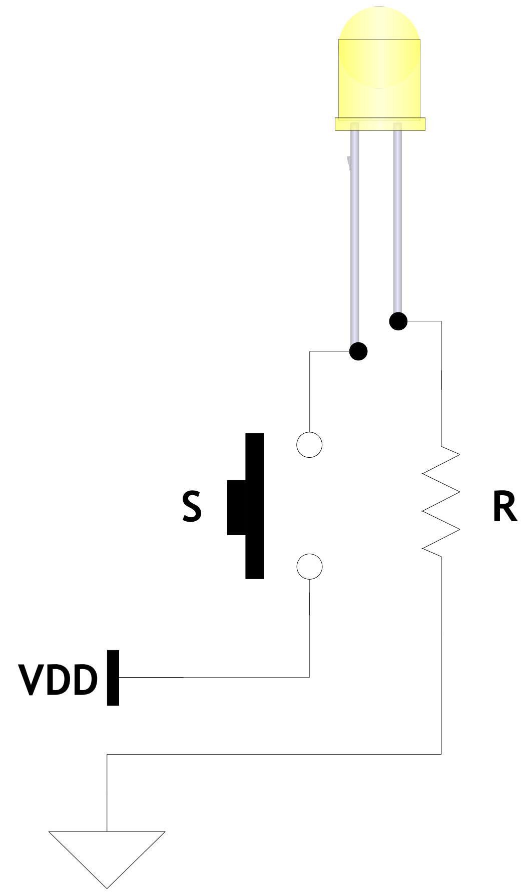
Interfaces – LEDs – Working Principle



Oops, wrong choice. Can you explain why?



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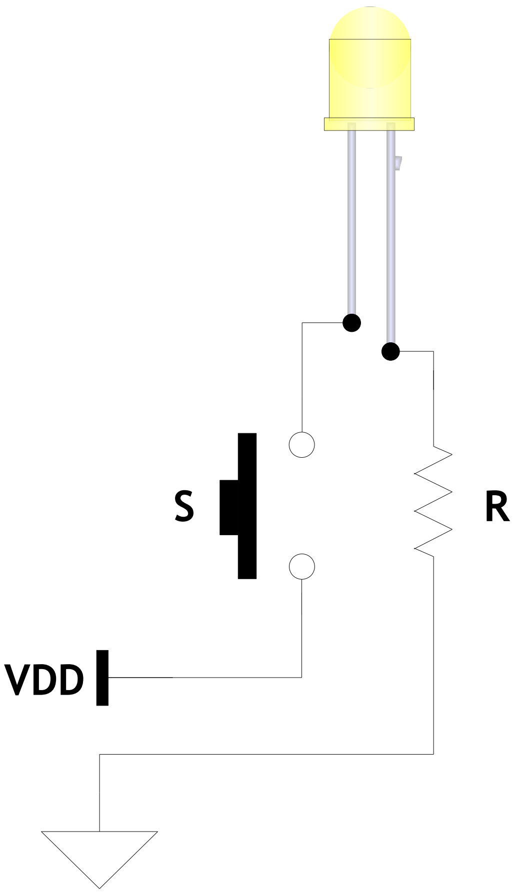
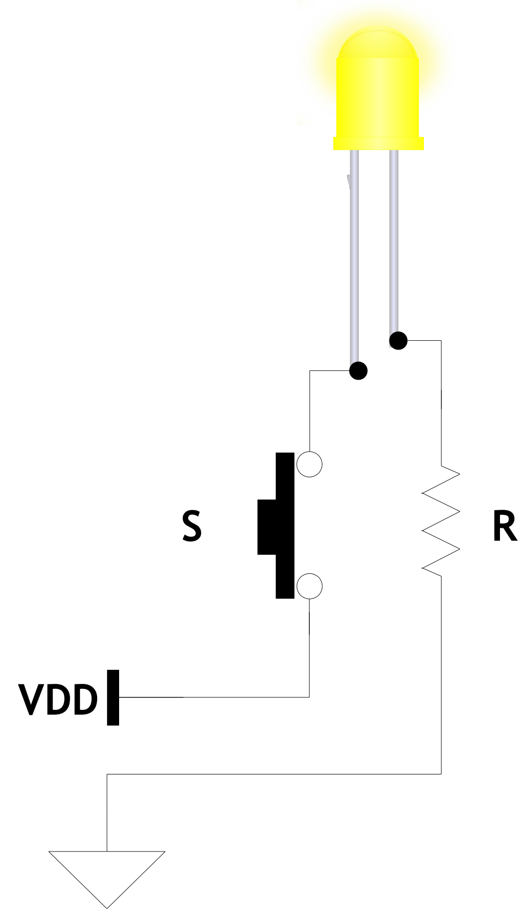
Interfaces – LEDs – Working Principle



Ooh, looks like you know the funda.



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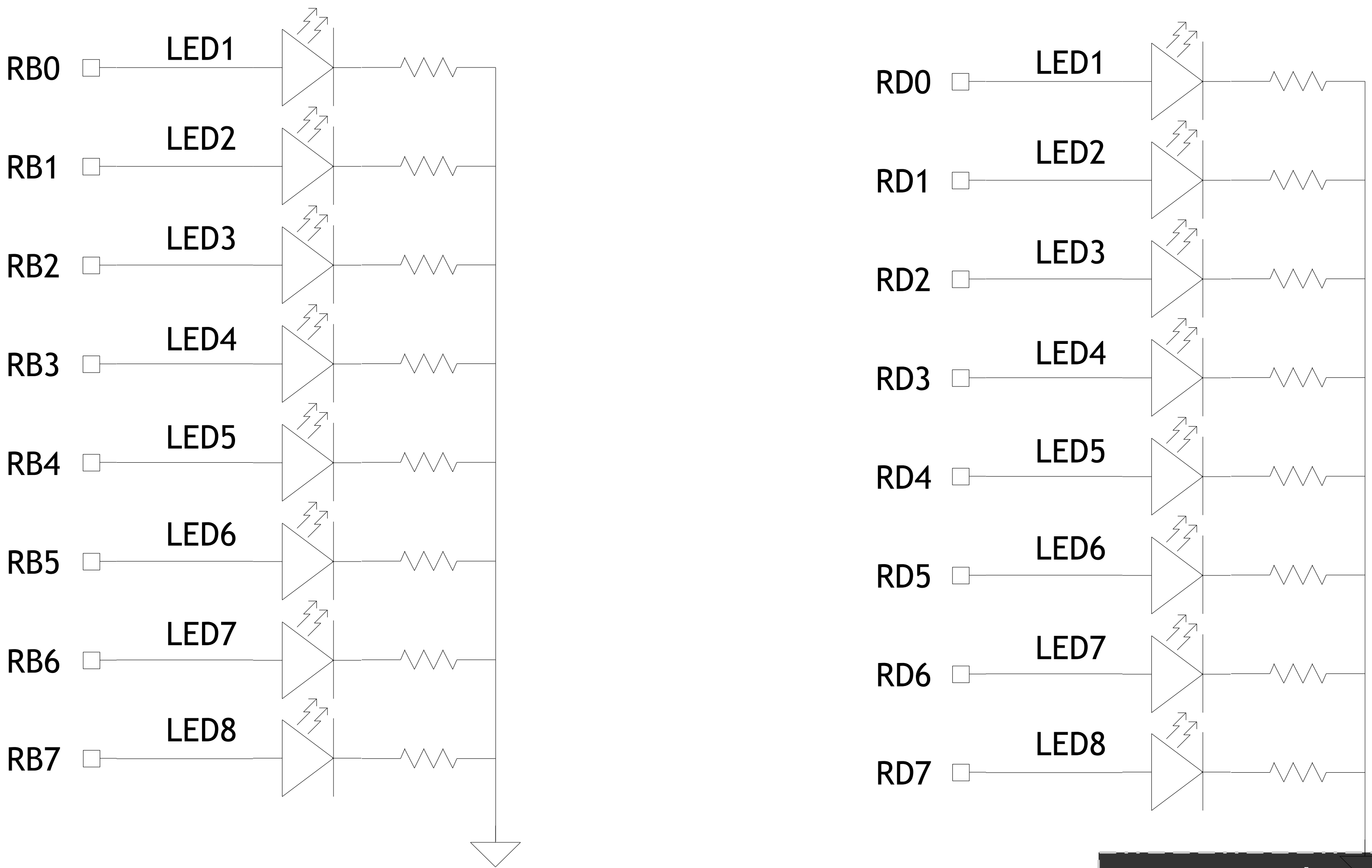
Interfaces – LEDs – Circuit on Board



Note: Make sure the DP switch its towards LEDs

Digital Keypad

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Interfaces – Digital Keypad

- Introduction
- Interfacing
- Input Detection
- Bouncing Effect
- Circuit on Board

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Interfaces – Digital Keypad - Introduction

- Provides simple and cheap interface
- Comes in different shapes and sizes
- Preferable if the no of user inputs are less
- Mostly based on tactile switches
- Some common application of tactile keys are
  - HMI
  - Mobile Phones
  - Computer Mouse etc,.

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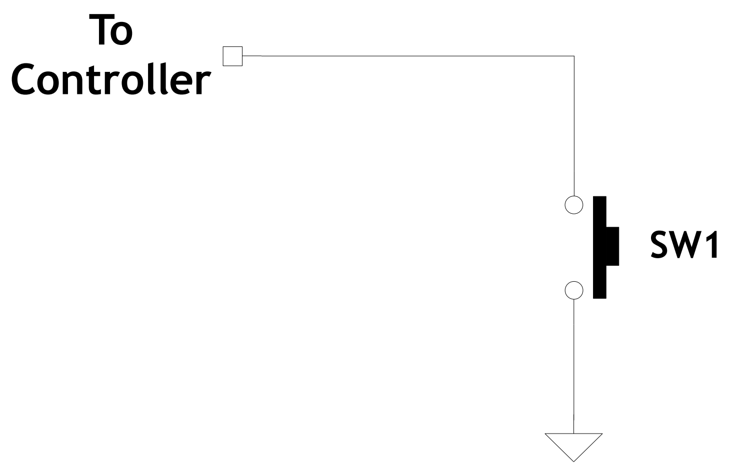
Interfaces – Digital Keypad - Tactile Switches

- Considering the below design what will be input to the controller if the switch is pressed?



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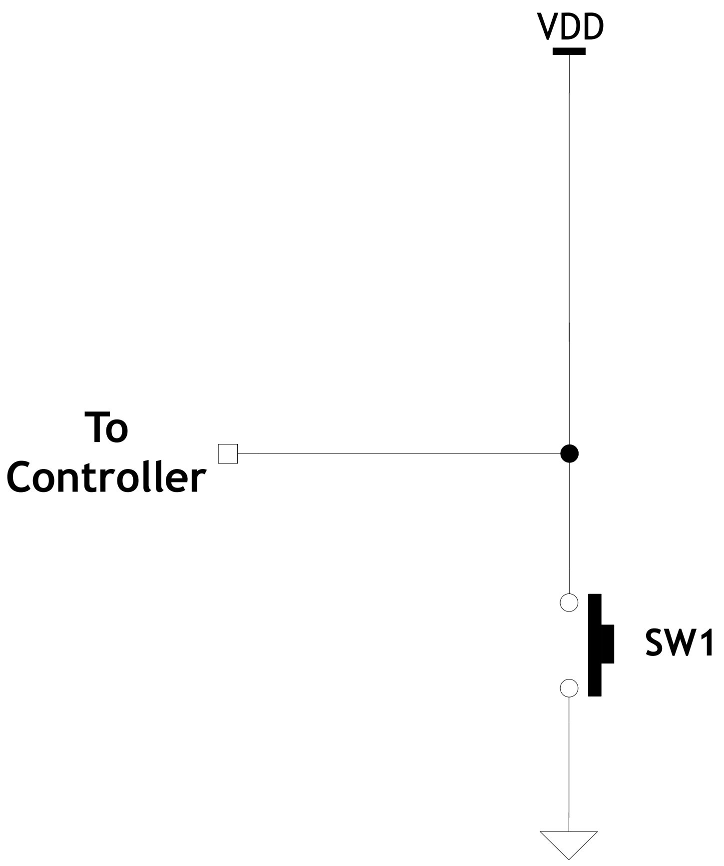
Interfaces – Digital Keypad - Tactile Switches

- Will this solve the problem which may arise in the design mentioned in previous slide?



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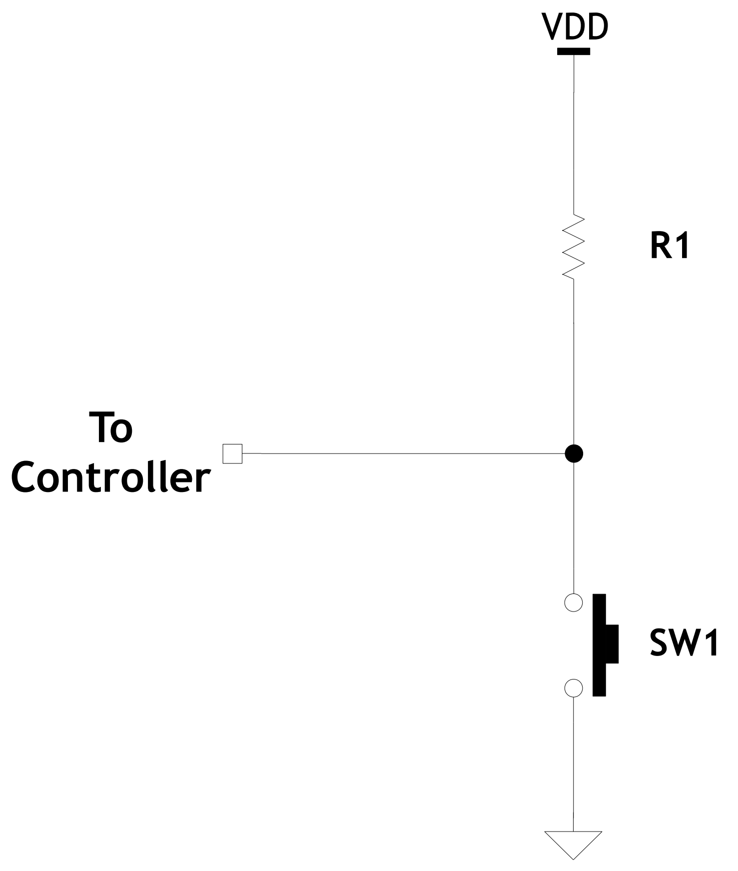
Interfaces – Digital Keypad - Tactile Switches

- Now will this solve the problem which may arise in the design mentioned in previous slides?



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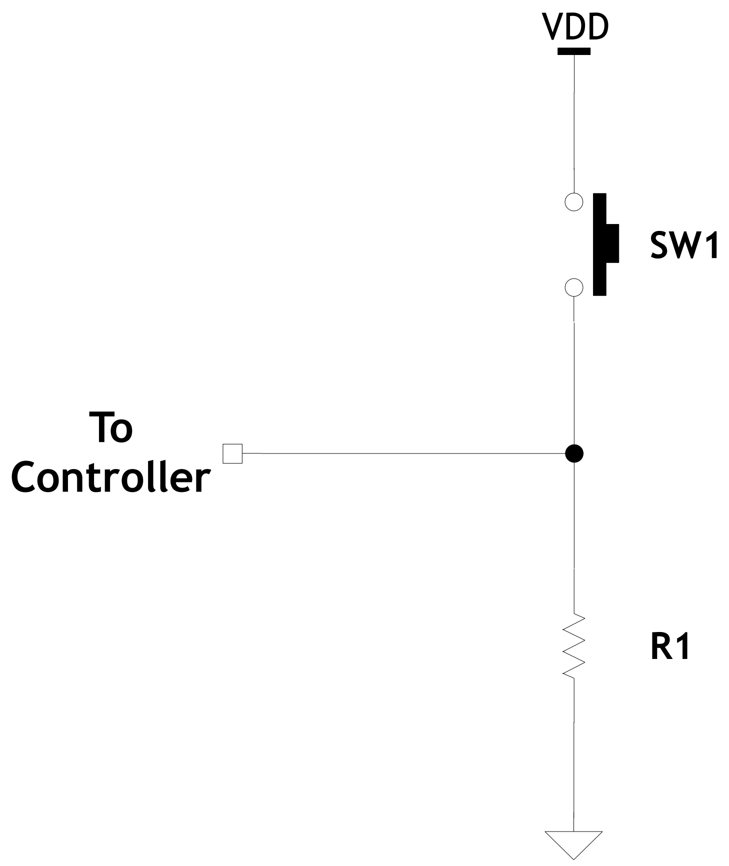
Interfaces – Digital Keypad - Tactile Switches

- What would you call the this design?
- Is there any potential problem?



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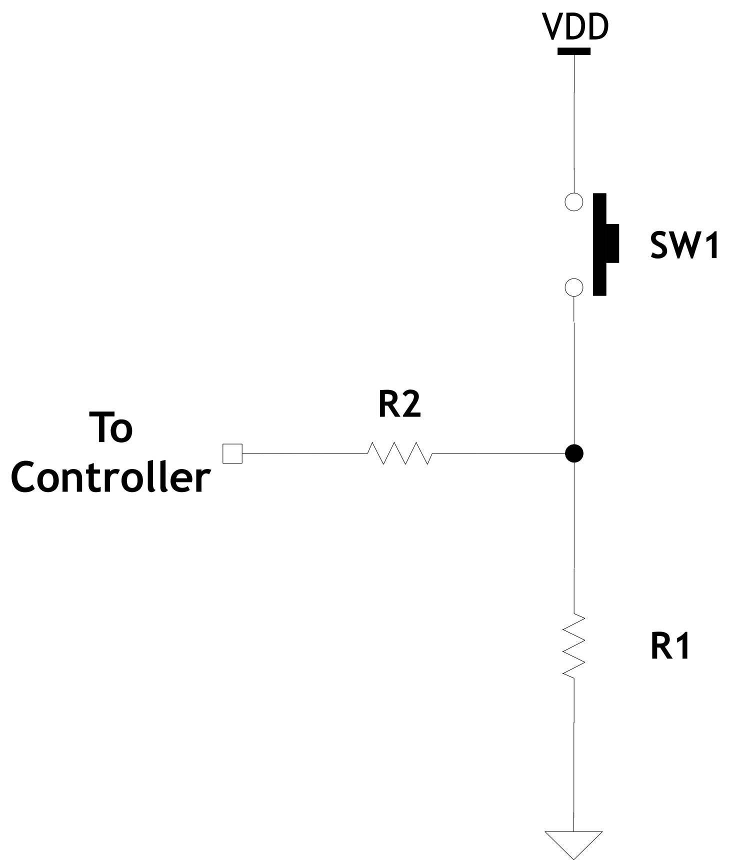
Interfaces – Digital Keypad - Tactile Switches

- What would you call the this design?
- Is there any potential problem?



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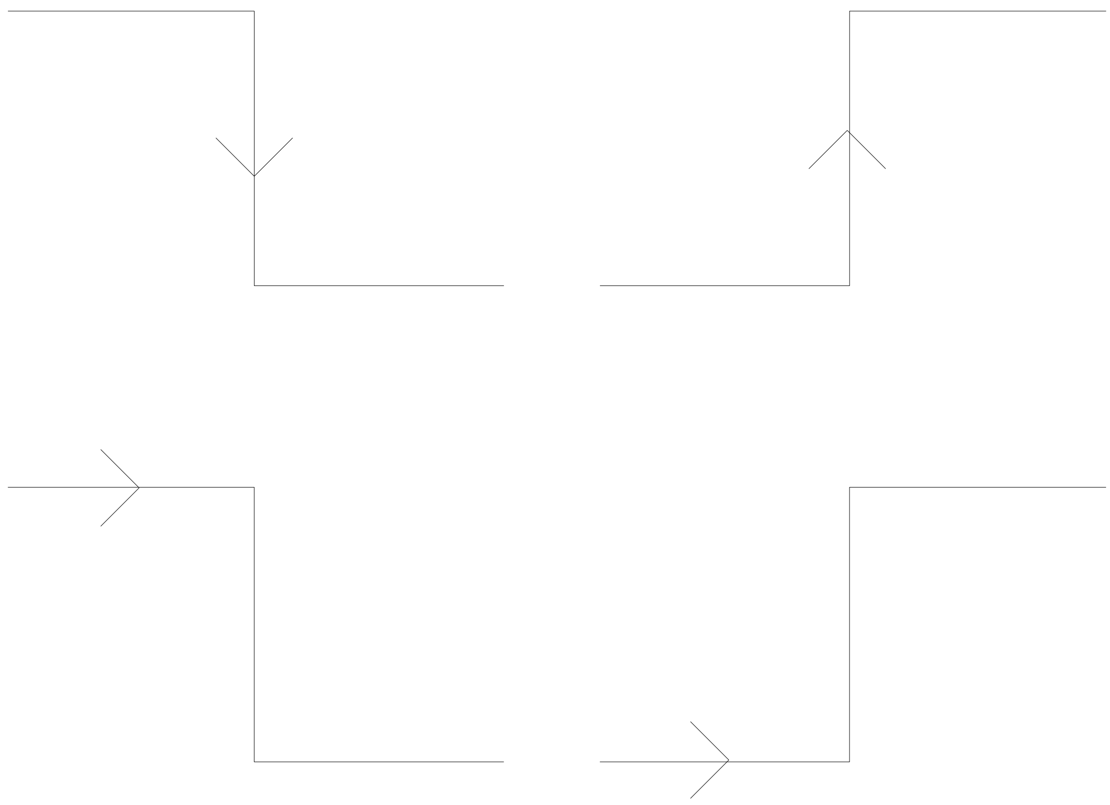
Interfaces – Digital Keypad - Triggering Methods



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Interfaces – Digital Keypad - Bouncing Effects

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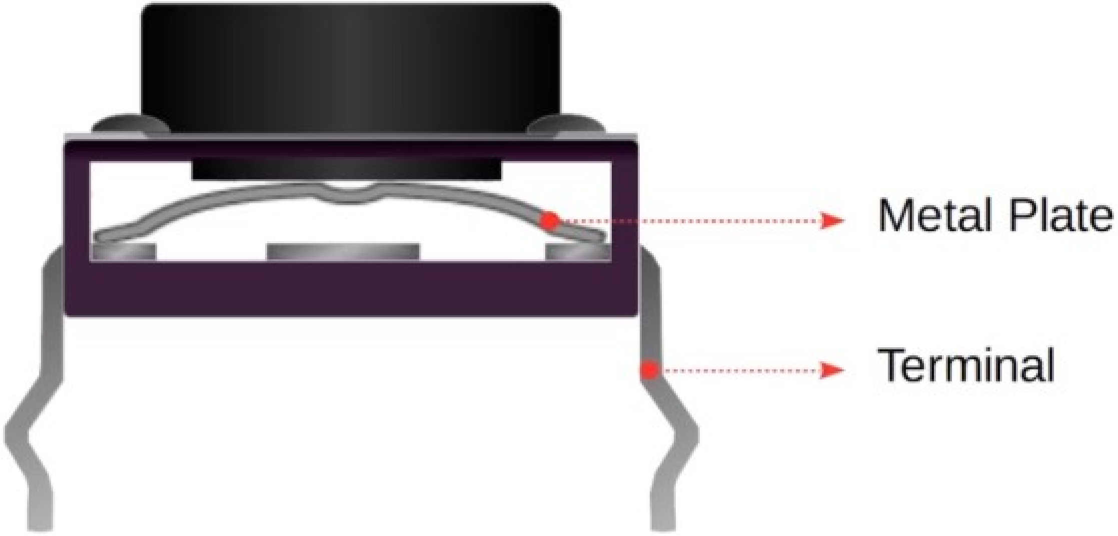
Interfaces – Tactile key - Bouncing Effects



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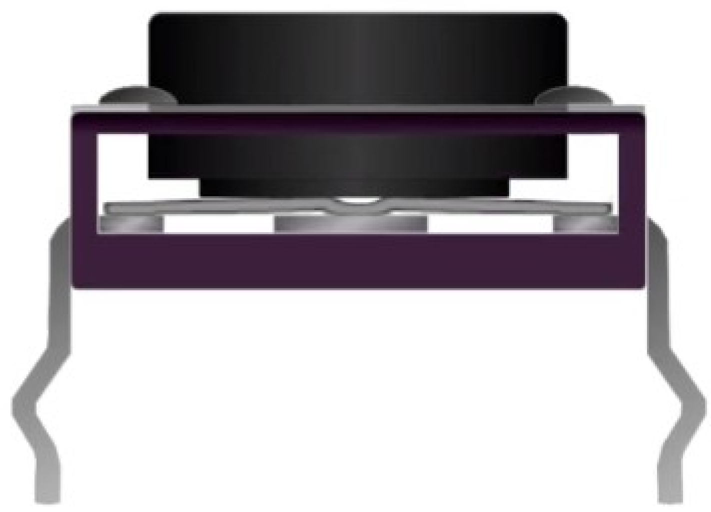
Interfaces – Tactile key - Bouncing Effects



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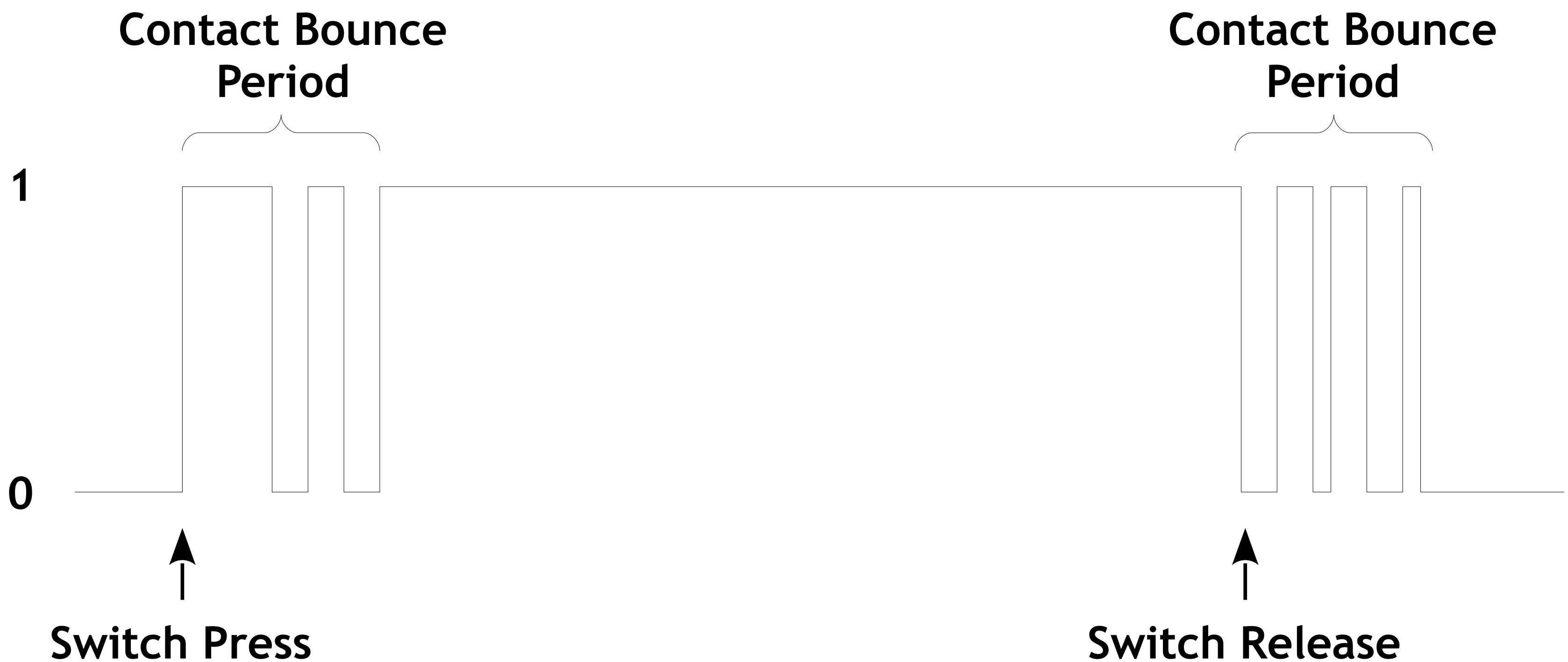
Interfaces – Digital Keypad - Bouncing Effects



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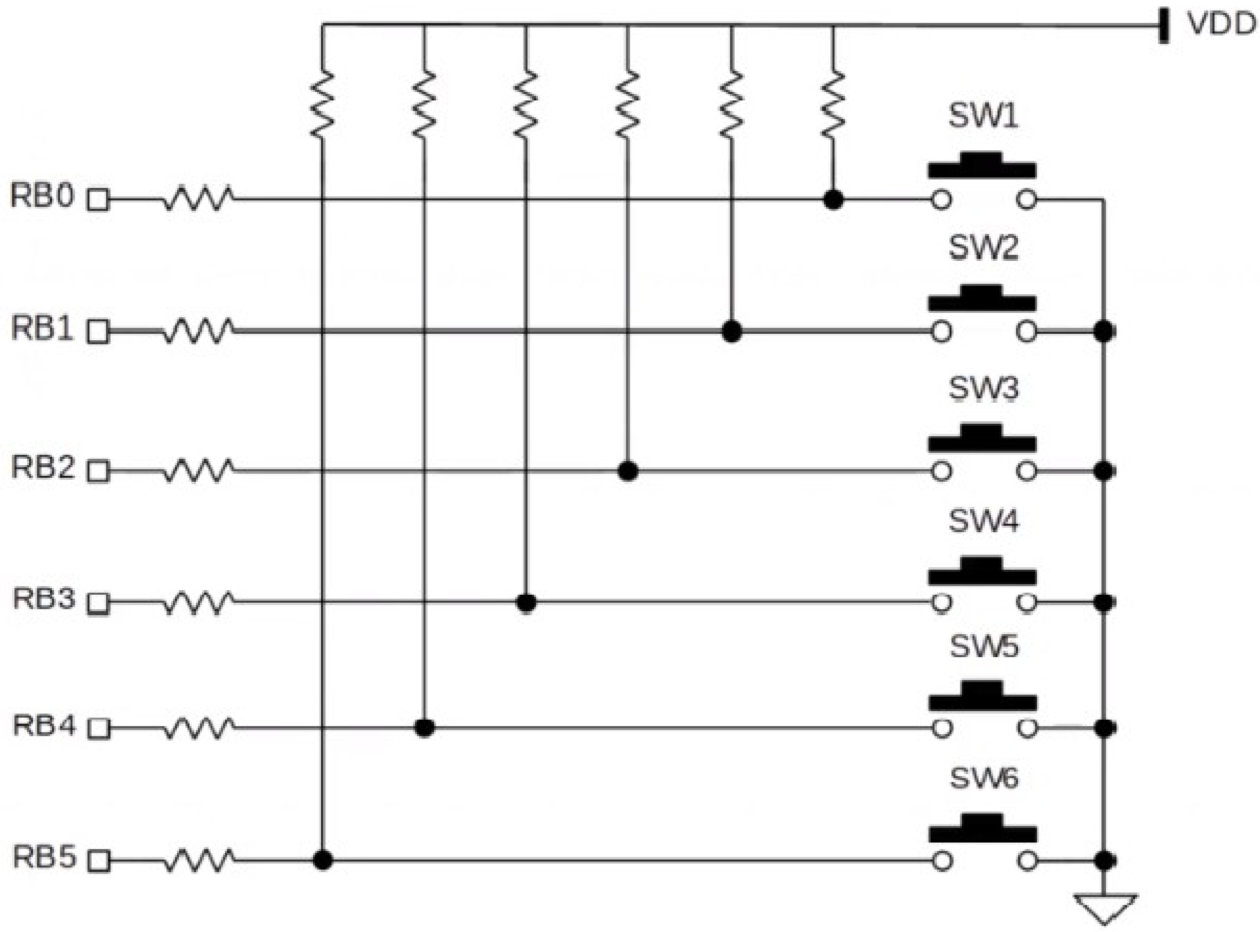
Interfaces – Digital Keypad - Circuit on Board



Interrupts

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Interrupts

- Basic Concepts
- Interrupt Source
- Interrupt Classification
- Interrupt Handling

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Interrupts - Basic Concepts

- An interrupt is a communication process set up in a microprocessor or microcontroller in which:
  - An internal or external device requests the MPU to stop the processing
  - The MPU acknowledges the request
  - Attends to the request
  - Goes back to processing where it was interrupted

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Interrupts - Sources

- External
- Internal

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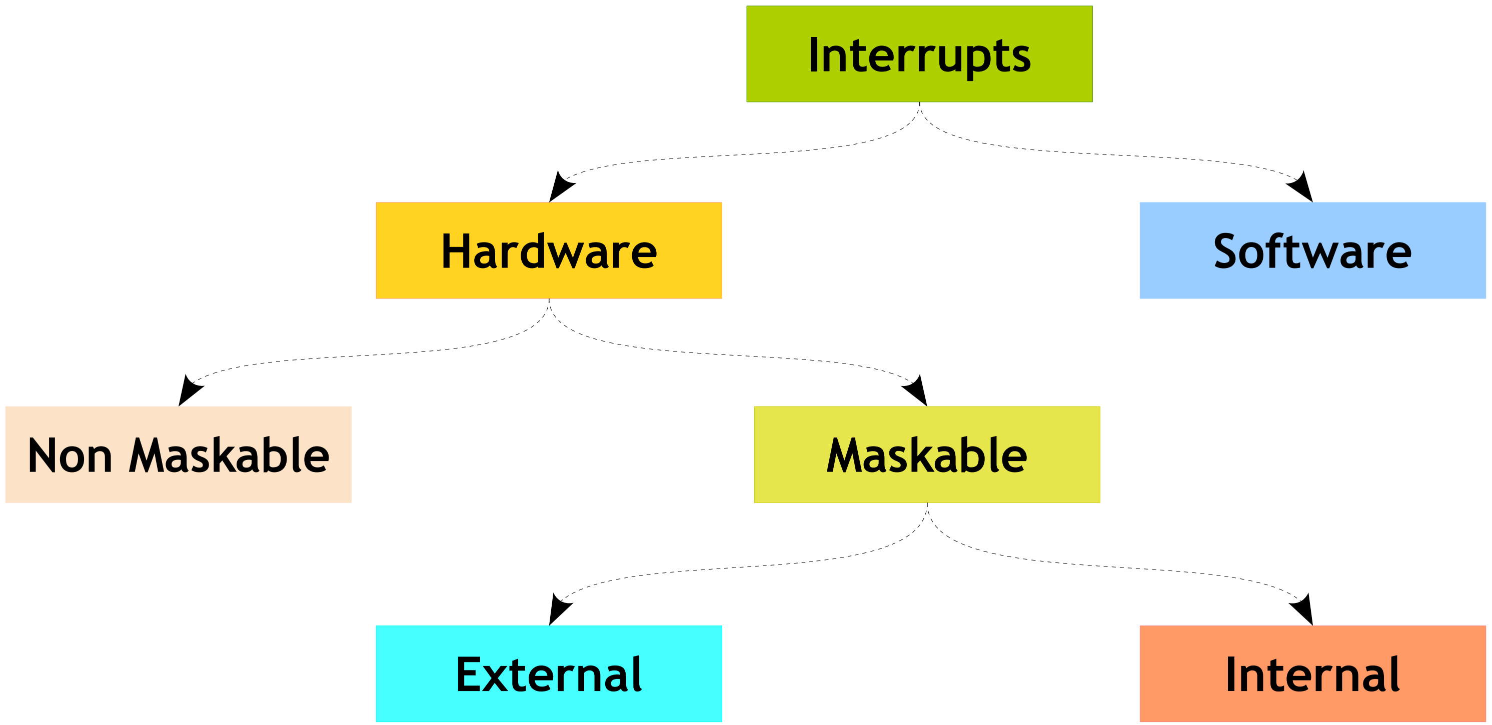
Interrupts - Classification



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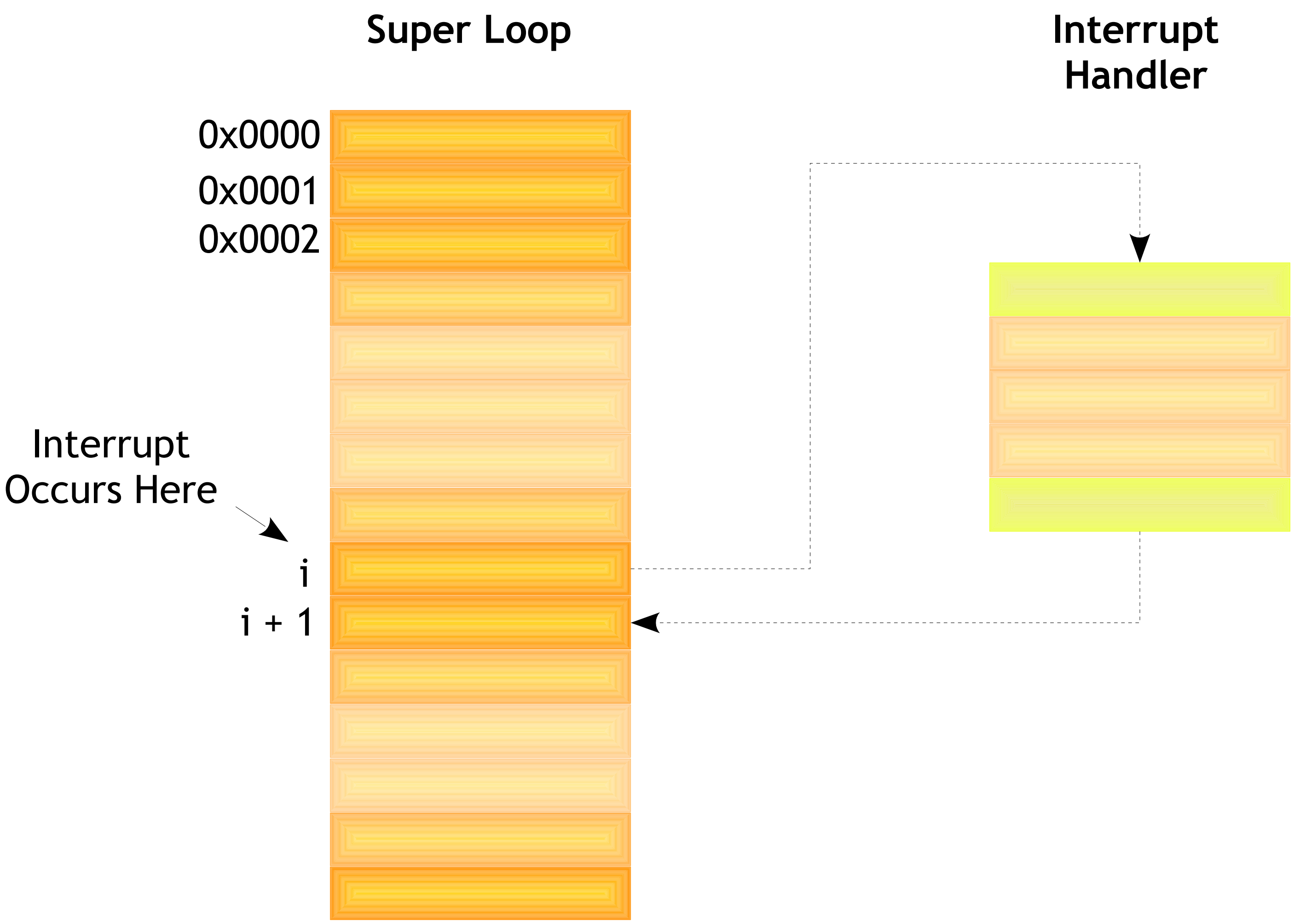
Interrupts - Handling



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Interrupts - Service Routine (ISR)

- Similar to a subroutine
- Attends to the request of an interrupting source
  - Clears the interrupt flag
  - Should save register contents that may be affected by the code in the ISR
  - Must be terminated with the instruction RETFIE
- When an interrupt occurs, the MPU:
  - Completes the instruction being executed
  - Disables global interrupt enable
  - Places the address from the program counter on the stack
- Return from interrupt

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Interrupts - Service Routine (ISR)

- What / What Not

Timers

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Timers - Introduction

- Resolution → Register Width
- Tick → Up Count or Down Count
- Quantum → System Clock settings
- Scaling → Pre or Post
- Modes
    - Counter
    - PWM or Pulse Generator
    - PW or PP Measurement etc.,
- Examples

Microcontrollers
Timers - Example

- Requirement – 5 pulses of 8 µsecs
- Resolution – 8 Bit
- Quantum – 1 µsecs
- General

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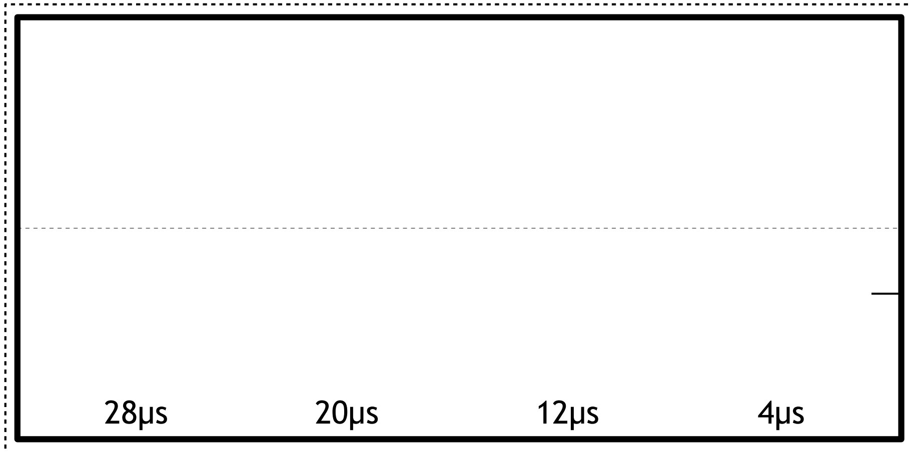
Timers - Example

Timer Register	252
Overflows	0



Character Liquid Crystal Display

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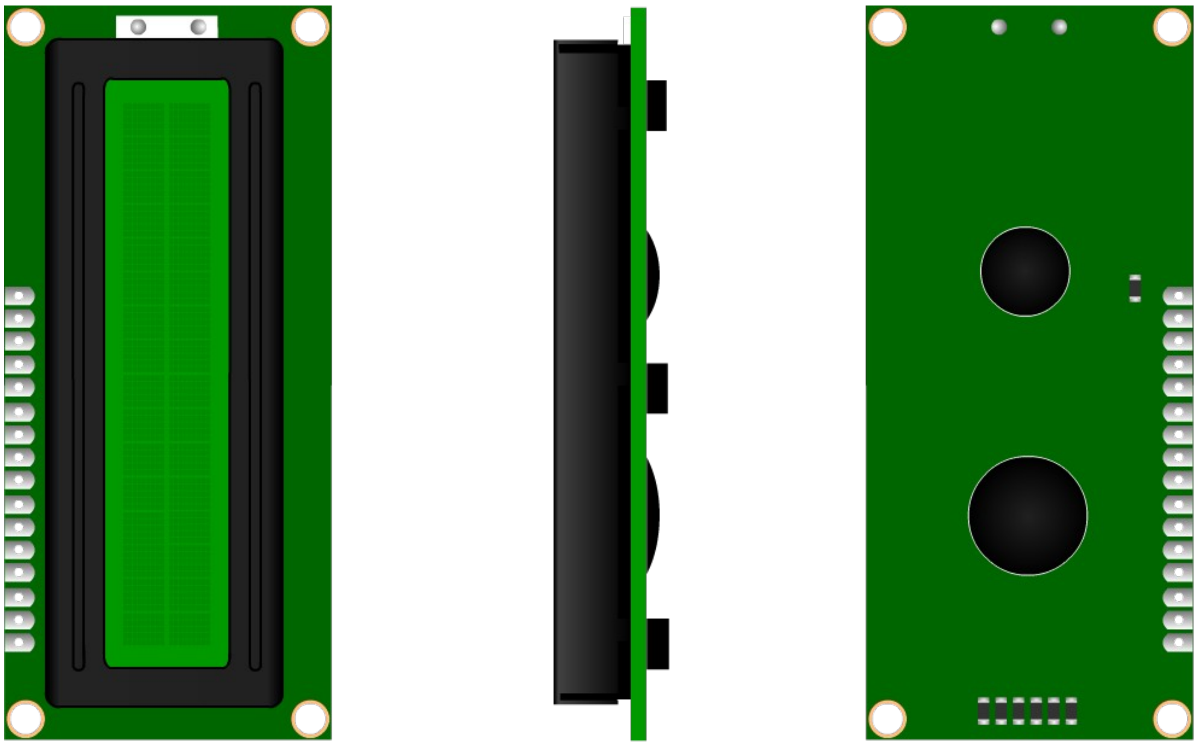
Interfaces – CLCD - Introduction

- Most commonly used display ASCII characters
- Some customization in symbols possible
- Communication Modes
  - 8 Bit Mode
  - 4 Bit Mode



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Vdd	Vdd	Vo	RS	R/W	E	D0	D1	D2	D3	D4	D5	D6	D7	A	K

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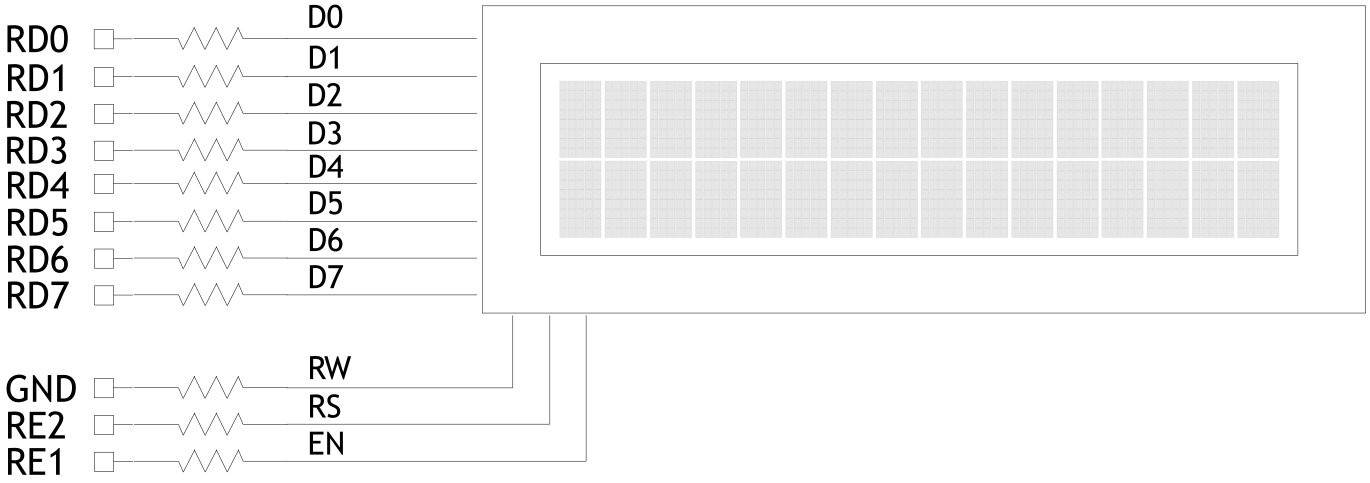
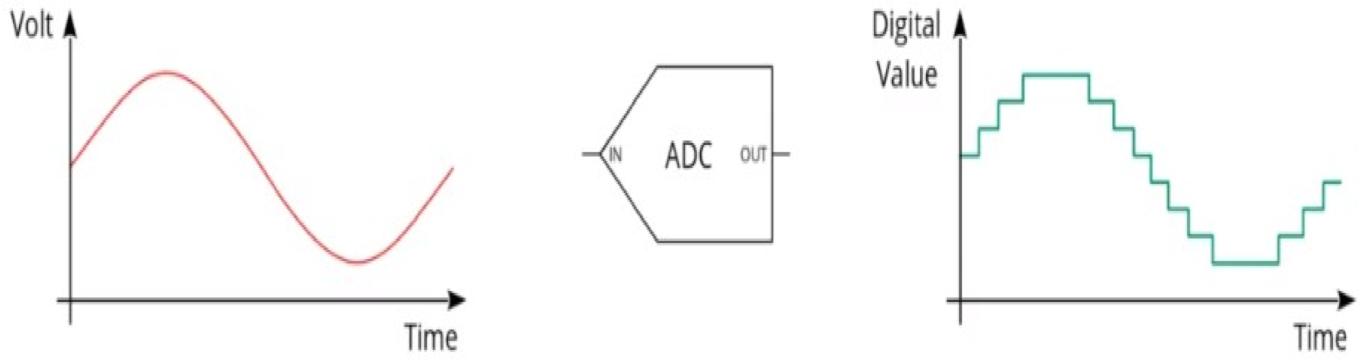
Interfaces – CLCD - Circuit on Board



Analog Inputs

ADC:
Analog to Digital Converter



- Types of ADCs:

1) Flash ADC
2) Pipelined
3) SAR
4) Dual-scope
5) Sigma delta

Microcontrollers
Analog Inputs - Introduction

- Sampling
- Nyquist Frequency
- Over Sampling
- Sampling Error
- Differential Non Linearity Error (DNL)
- Integral Non Linearity Error (INL)
- Quantization
- Quantization Errors
- Aliasing
- Channel
- Signal to Noise Ratio (SNR)
- Resolution
- Jitter
- Dither
- Noise
- Step Size
- Offset Error
- Acquisition Time
- Sample and Hold
- Reference Voltage
- Gain Error
- Full Scale
- Full Scale Range (FSR)
- Full Scale Error
- Non-Monotonicity Error
- Bandwidth
- Missing Codes
- Effective Number of Bits (ENOB)

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Analog Inputs - Introduction

- Resolution:

  → ADC Register Width

  → 8bit : 0 – 255

  → 10bit : 0 – 1023

  → 12bit : 0 – 4095

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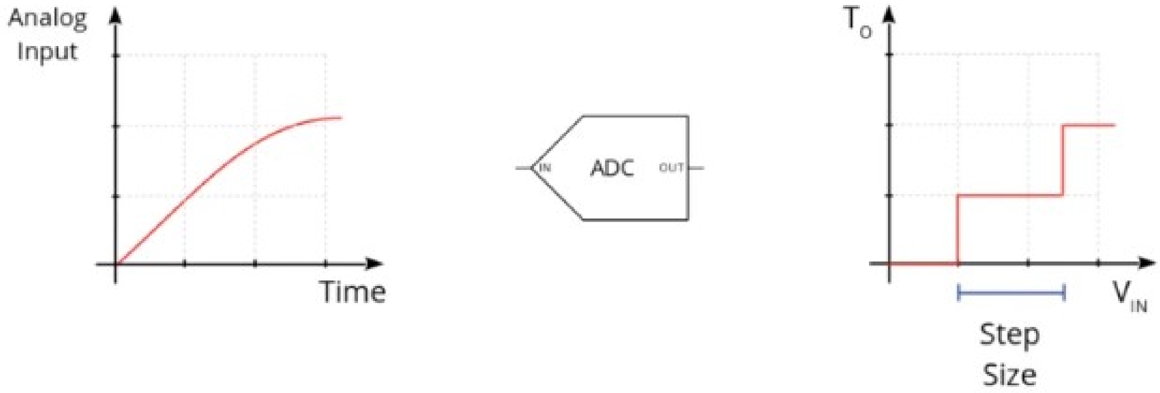
Analog Inputs - Introduction

- Step Size:(LSB)

  → Minimum change resolved

  step size = Input Range / 2 ^ (resolution)



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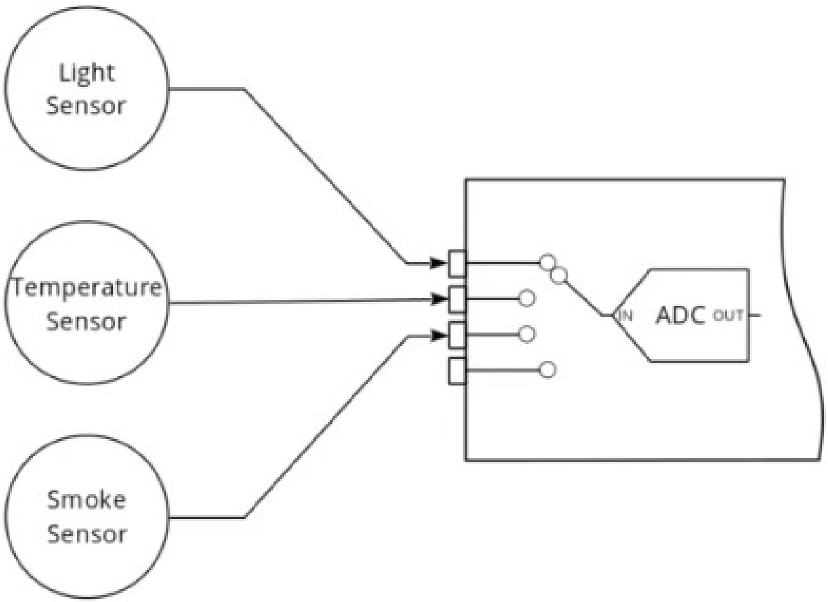
Analog Inputs - Introduction

- Full Scale Range (FSR):

  Max Representable Amplitude

- Channel:



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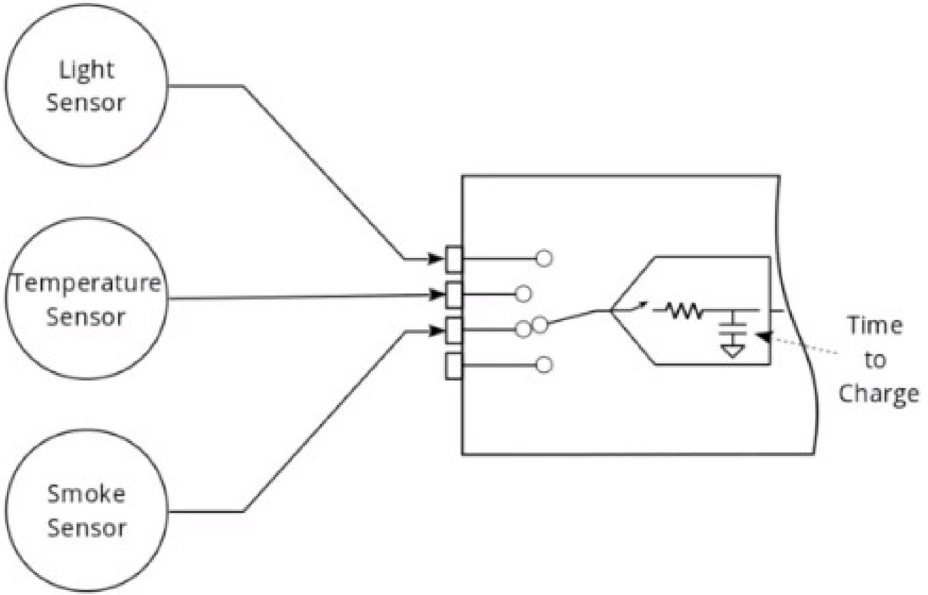
Analog Inputs - Introduction

- Acquisition Time:



Conversion Time:

Data Storage

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Data Storage - Introduction

- Mostly used in every Embedded System
- The size and component (memory) of storage depends upon the requirements
- Modern controllers has built in data storage
  - EEPROM
  - Data Flash etc.

Thank You