Microcontrollers

Empedded Programming - RL-eCee Dev Board

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

Workspace Creation

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Workspace Creation

- For better data organization lets create some project working directories
- Please follow the below steps

Step 1

```
user@user:~] cd
```

Step 2

```
user@user:~] mkdir -p ECEP/Microcontrollers/ClassWork
```

Step 3

```
user@user:~] cd ECEP/Microcontrollers/ClassWork
```

Lets Start Coding

Microcontrollers
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 say hello world 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

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

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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 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.

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Embedded Programming - Let's Start Coding

- 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 RL-eCee development board which is shown in the next slide

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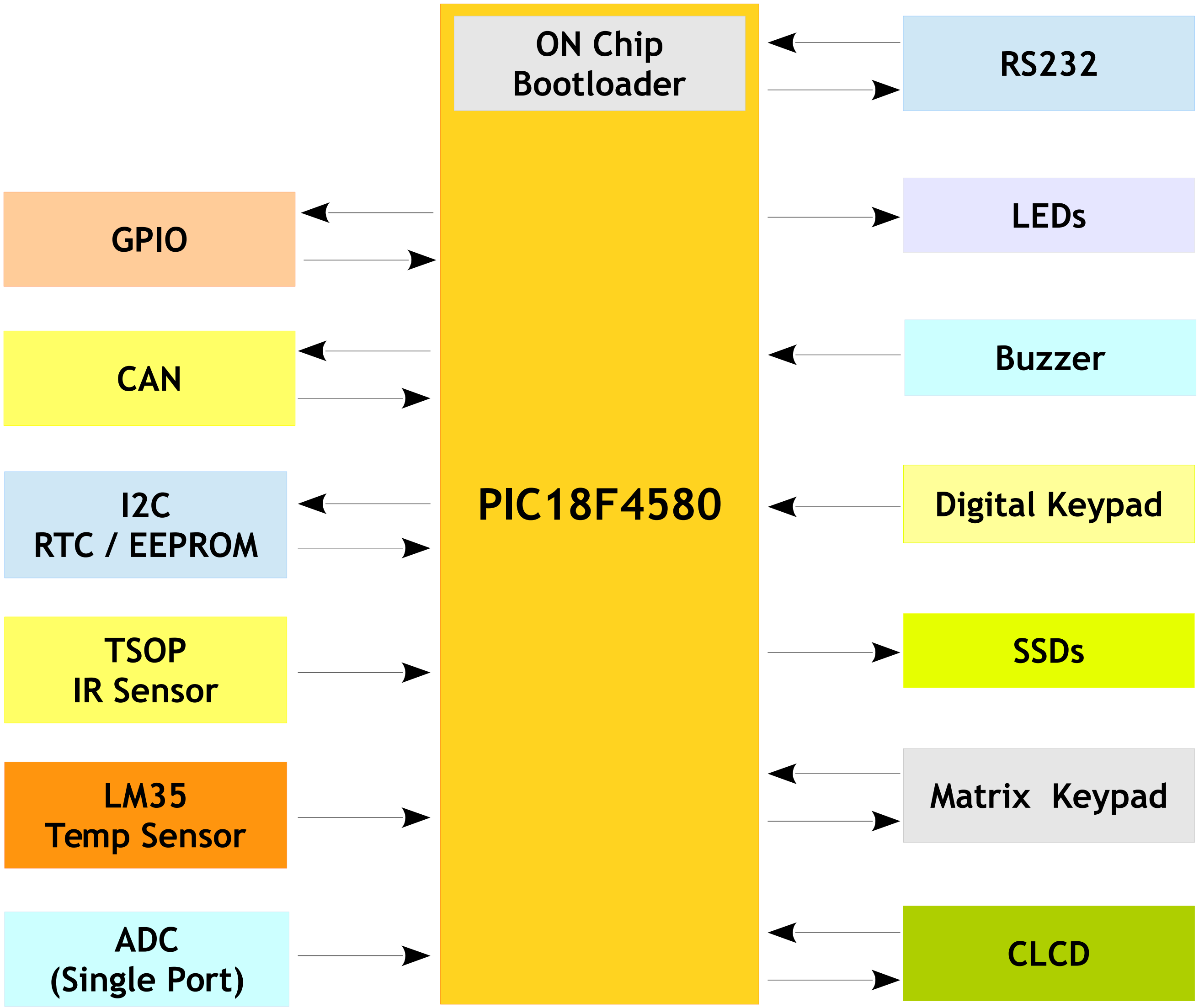
EP - Let's Start Coding – RL-eCee Architecture



- 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 RL-eCee board is **PIC18F4580** 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
- Port is a peripheral and we need need to know on how to access and address. This infos will be available in the data sheet in **PORTB** and **Data Memory** sections

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Embedded Programming - Let's Start Coding

- From the section of PORTB it clear that there are 2 more registers associated with it named, **TRISB** and **LATB**
- 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

- 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

Example

```
void main(void)
{
    /*
     * Defining a pointer to PORTB data latch register at address 0xF8A,
     * pointing to 8 bit register. Refer data sheet
     */
    unsigned char *latb = (unsigned char *) 0x0F8A;
    /*
     * Defining a pointer to PORTB tri-state register at address 0xF93,
     * pointing to 8 bit register. Refer data sheet
     */
    unsigned char *trisb = (unsigned char *) 0x0F93;

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

    /*
     * Writing just a random value on the data latch register where
     * LEDs are connected
     */
    *latb = 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
  - In Windows you can use MPLABX
  - In Linux, the simplest would be command line

- There some assumptions made here like
  - You should know how to interface your board with the Host System
  - How to power up the target board
  - Procedure on how to transfer the code into the target board

  and so on...
- All these might be available on the **User Manual** of the target board

- Assuming you are using Linux it can be compiled as shown below

Compile like

```
user@user:~] xc8 --ROM=0-3000 --chip=18f4580 main.c
```

or

Compile like

```
user@user:~] /<path>/xc8 --ROM=0-3000 --chip=18f4580 main.c
```

- The output of the compilation would be many intermediate files, but we will be interested in file name **main.hex**

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EP - Let's Start Coding – Hex Download

- As a last step we need to dump the **main.hex** to the target board.
- Sometimes we need a separate hardware to do this (typically depends on the target board design)
- RL-eCee board comes the microcontroller dumped with a serial boot loader in it
- So we need a system with a Serial Port or a USB to serial adapter from hardware prospective
- We will be using tiny boot loader software to transfer the code to the target
- Refer the next slide for the downloading steps

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EP - Let's Start Coding – Hex Download

Download like

```
user@user:~] tinybldlin.py --port /dev/ttyUSB0 --file main.hex
```

or

Download like

```
user@user:~] <path>/tinybldlin.py --port /dev/<device_file> --file main.hex
```

- The LEDs on the board should glow alternately
- Ooops!, where are the LEDs on board?

  Know your target board too!!. Refer next slide

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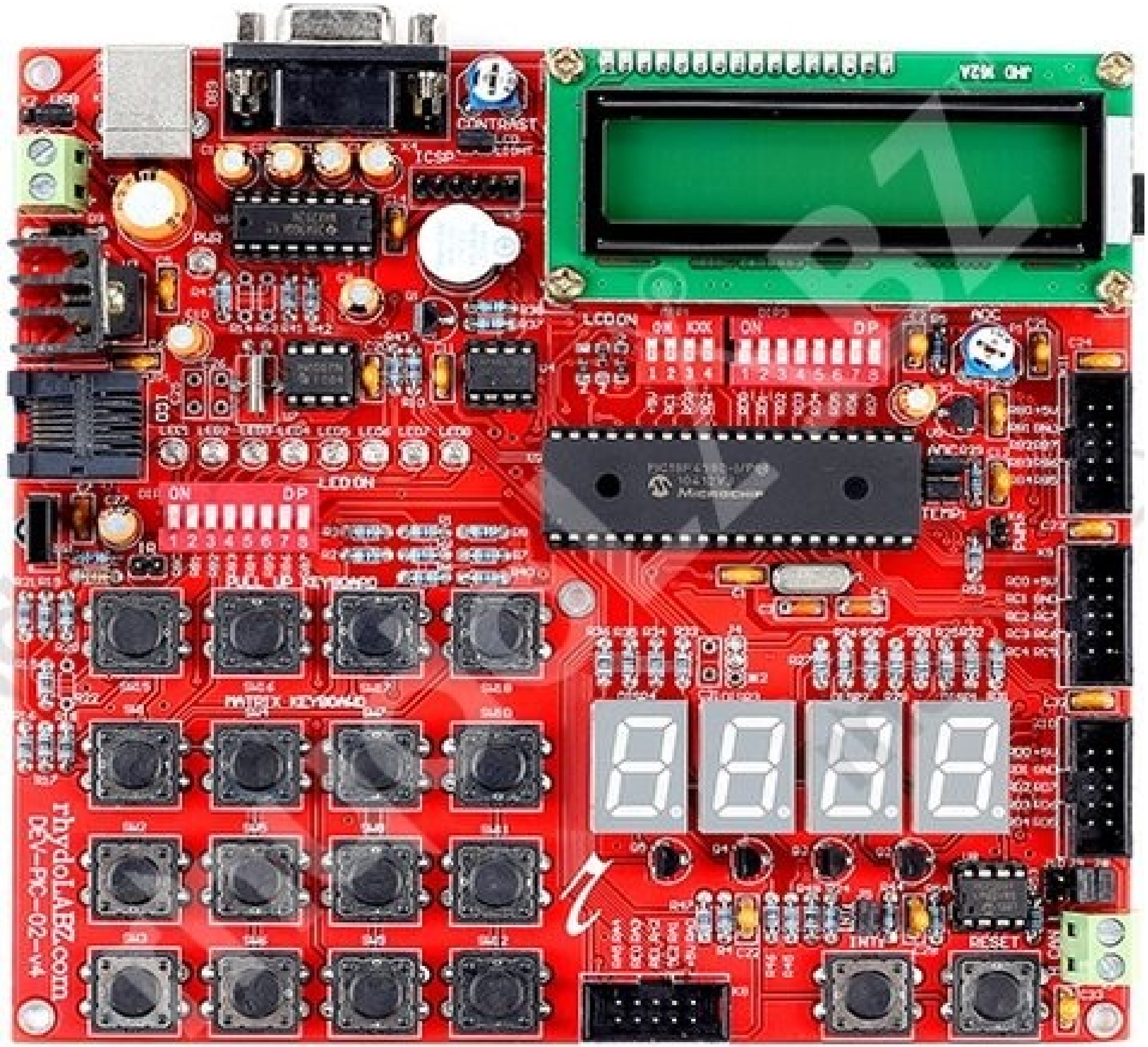
EP - Let's Start Coding – RL-eCee Dev Board



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Embedded Programming - Let's Start Coding

- 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

```c
#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 latch register where
     * LEDs are connected
     */
    LATB = 0x55;
}
```

- So simple. Isn't it?

Project Creation

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Project Creation - Code Organization

- Please organize the code as shown below to increase productivity and modularity
- Every .c file should have .h file

```
#include "supporting_file.h"

void function_1(void)
{
        /* Function Code */
}
```

modules.c

```
#include "main.h"

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

void main(void)
{
    init_config();

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

main.c

```
#ifndef MAIN_H
#define MAIN_H

#include <htc.h>

#endif
```

main.h

```
#ifndef SUPPORTING_FILE_H
#define SUPPORTING_FILE_H

#endif
```

modules.h

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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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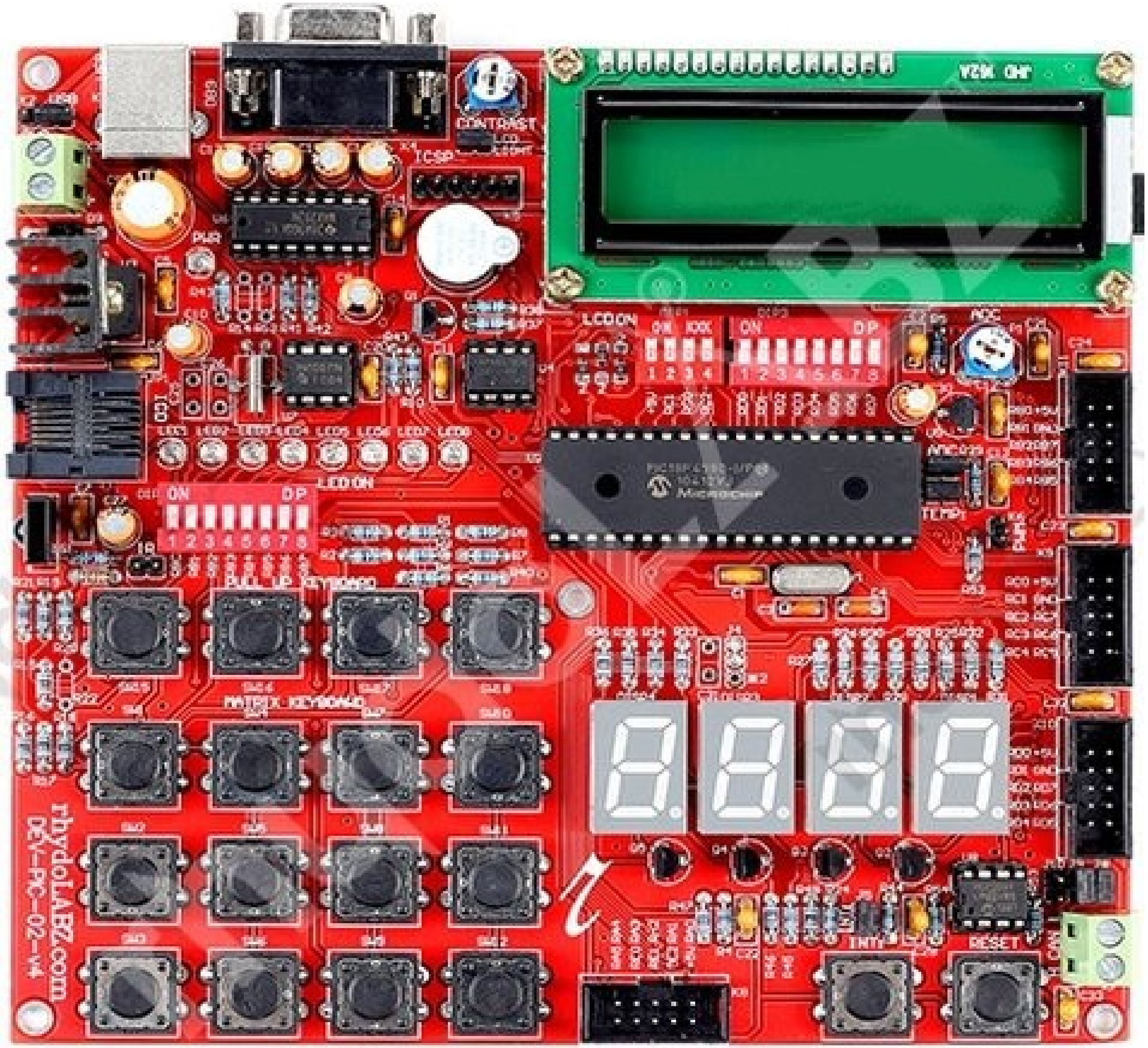
Lets Role Out on Interfaces



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

Light Emitting Diodes

Microcontrollers
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!!

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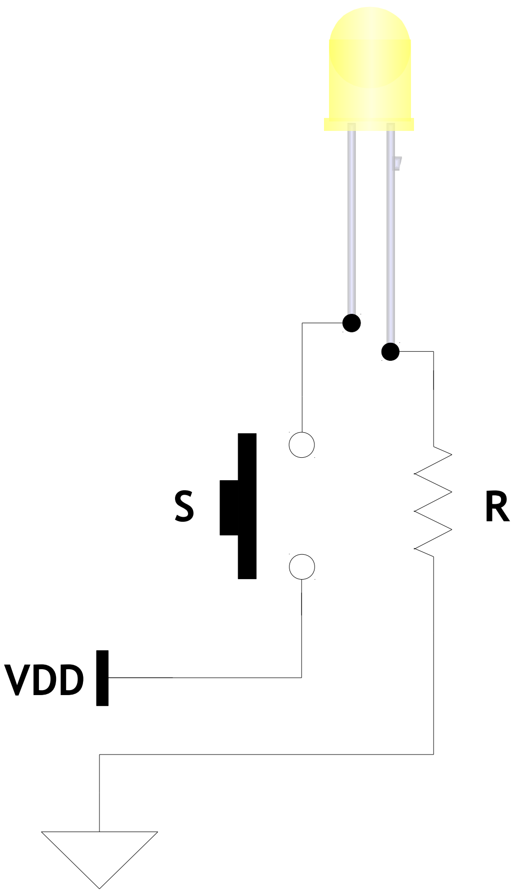
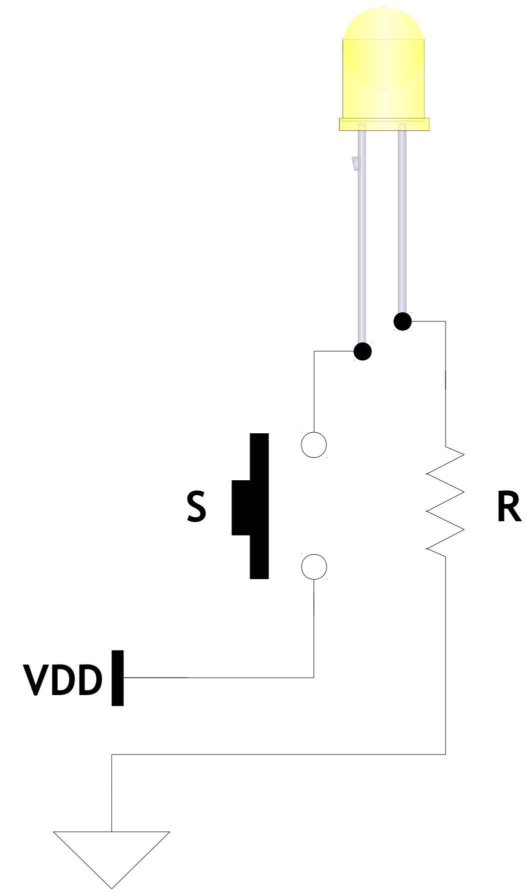
Interfaces – LEDs – Working Principle



Which side will work?



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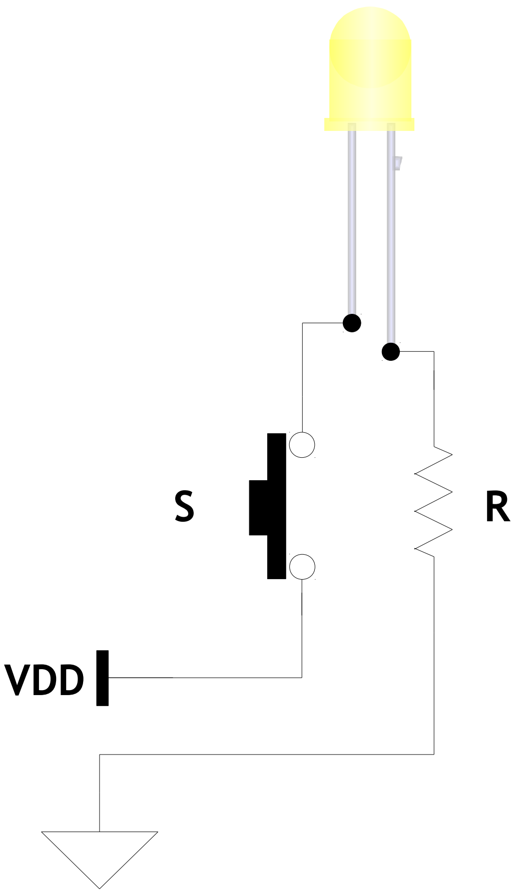
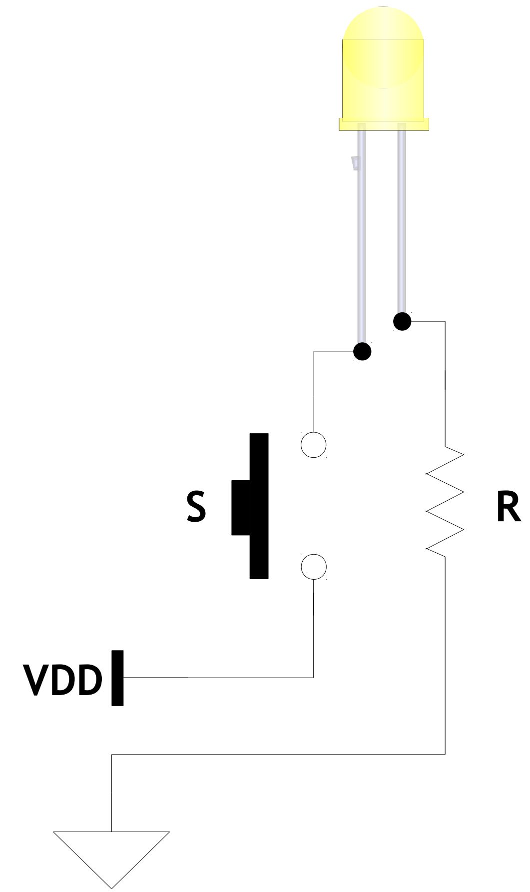
Interfaces – LEDs – Working Principle



Oops, wrong choice. Can you explain why?



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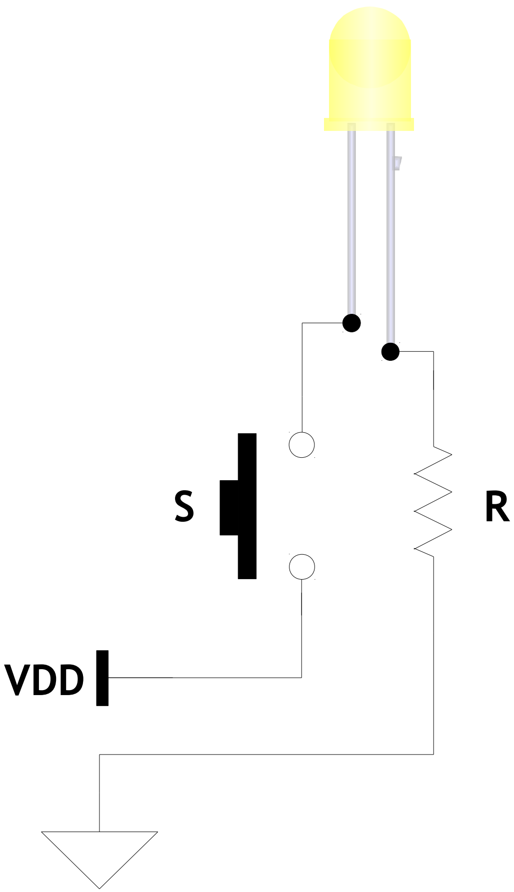
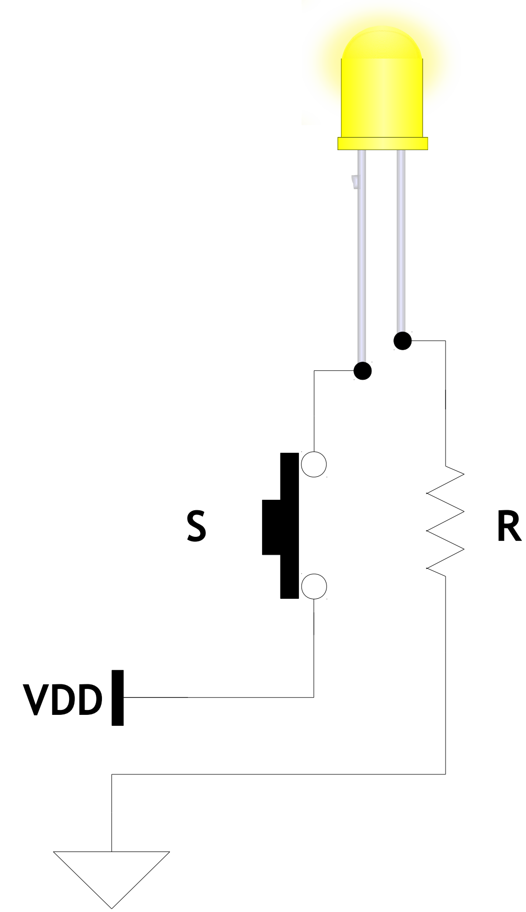
Interfaces – LEDs – Working Principle



Ooh, looks like you know the funda.



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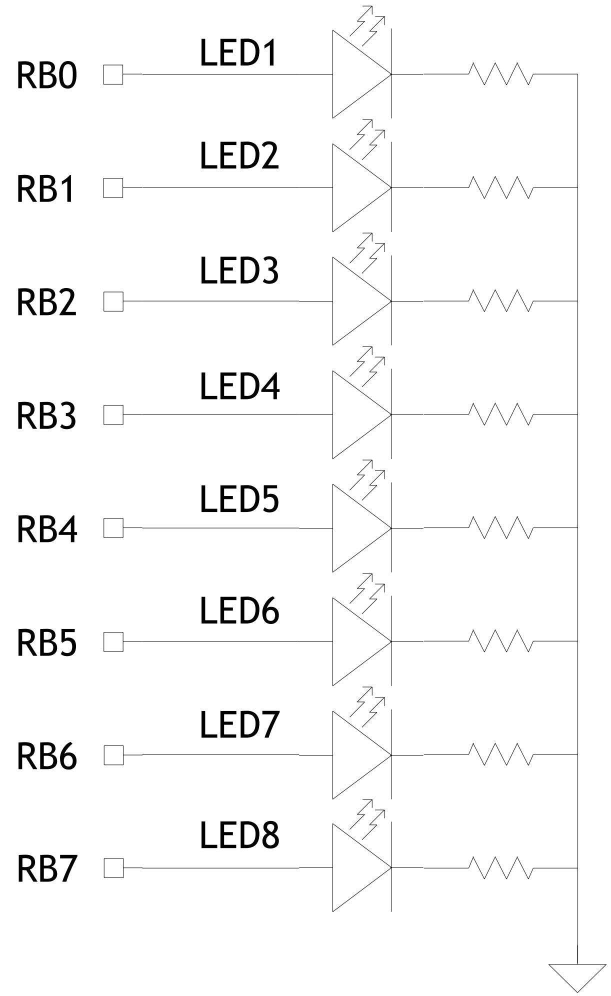
Interfaces – LEDs – Circuit on Board



Note: Make sure the DP switch its towards LEDs

Digital Keypad

Microcontrollers
Interfaces – Digital Keypad

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

Microcontrollers

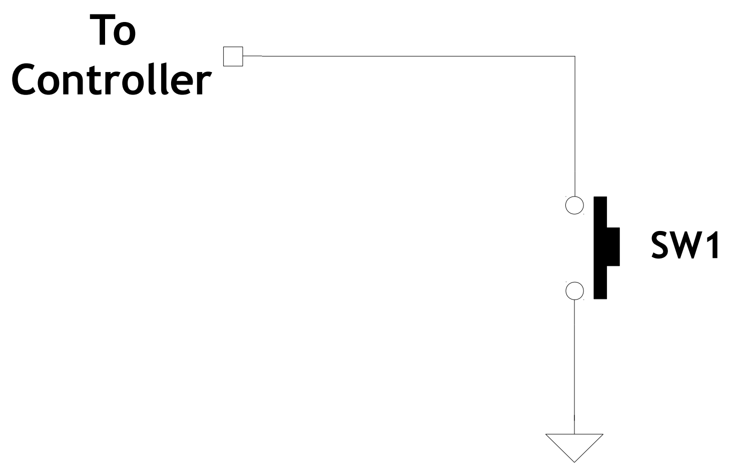
Interfaces – Digital Keypad - Introduction

- 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,.

Microcontrollers

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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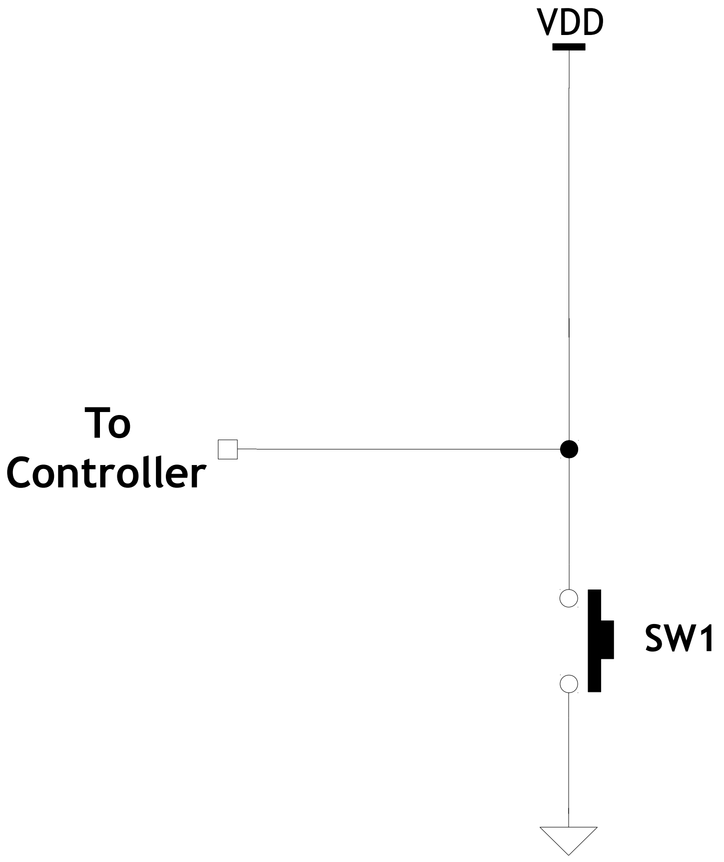
Microcontrollers
Interfaces – Digital Keypad - Tactile Switches

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



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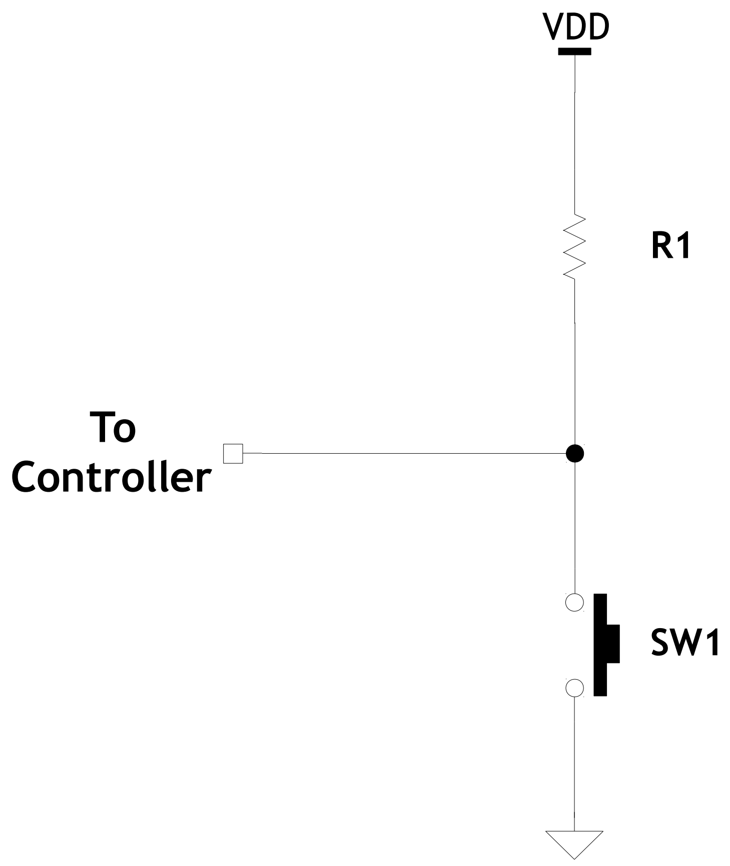
Interfaces – Digital Keypad - Tactile Switches

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



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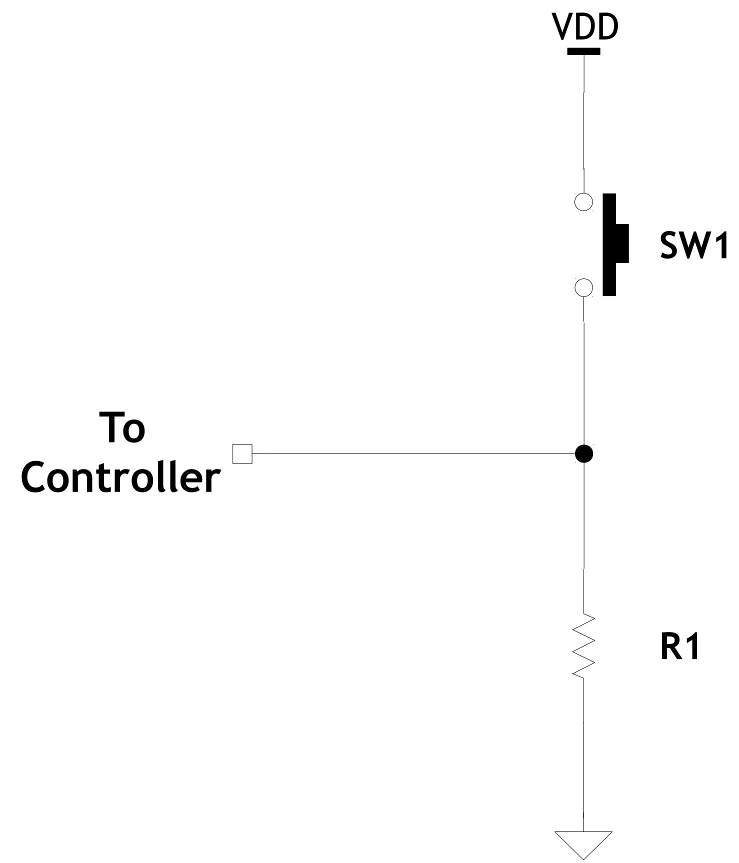
Interfaces – Digital Keypad - Tactile Switches

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



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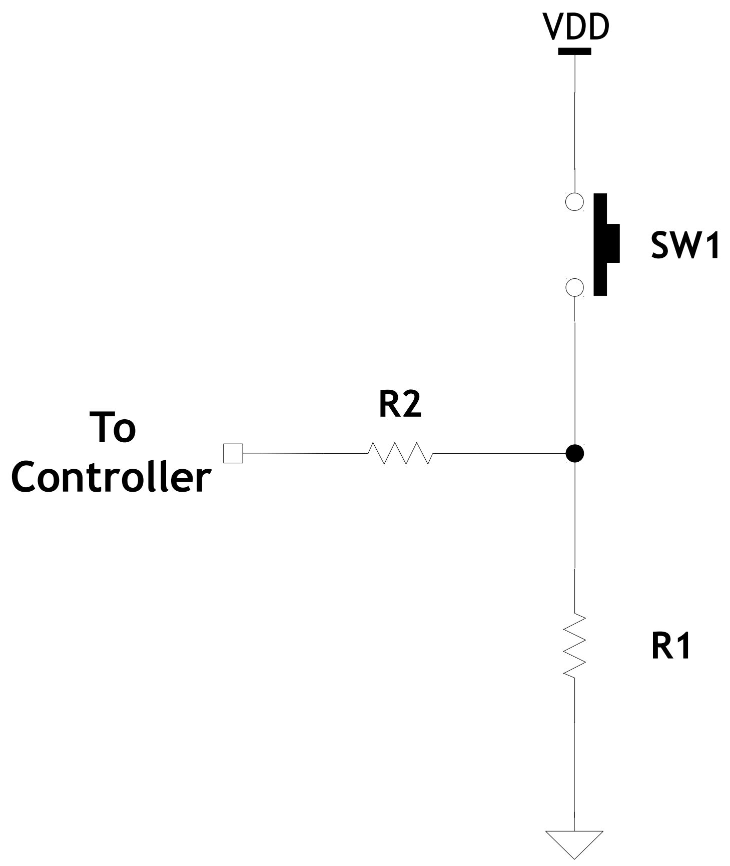
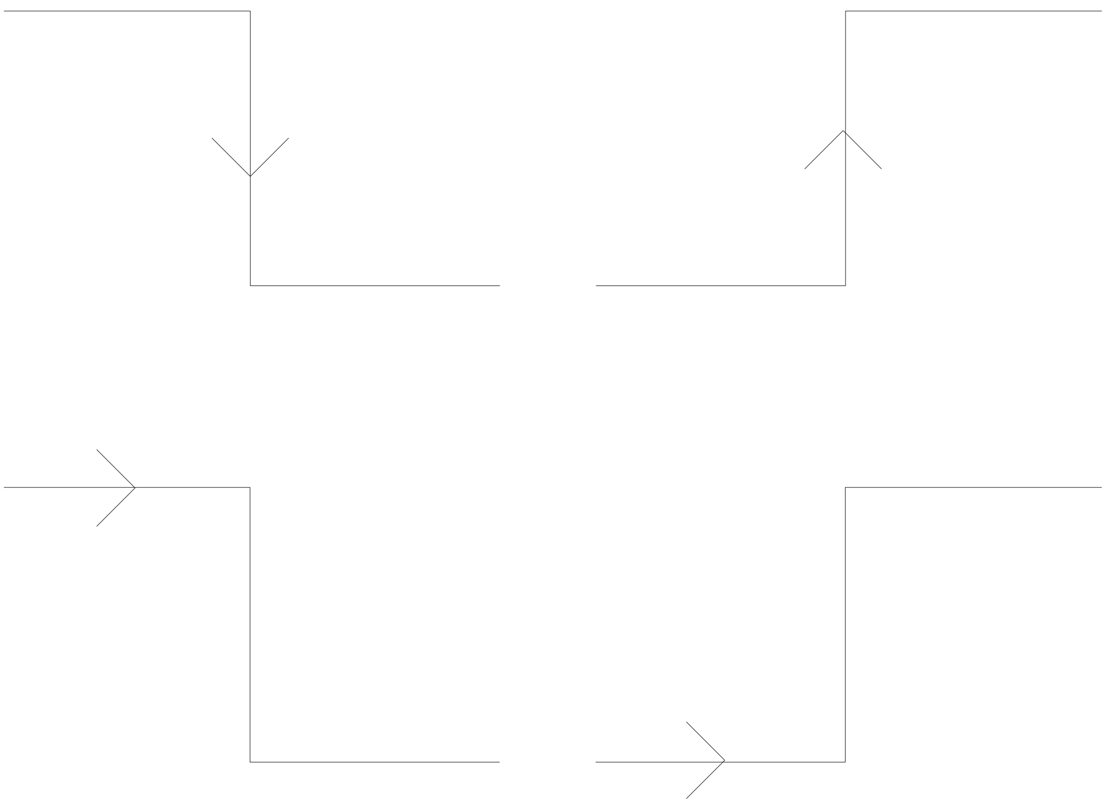
Interfaces – Digital Keypad - Tactile Switches

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





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Interfaces – Digital Keypad - Bouncing Effects

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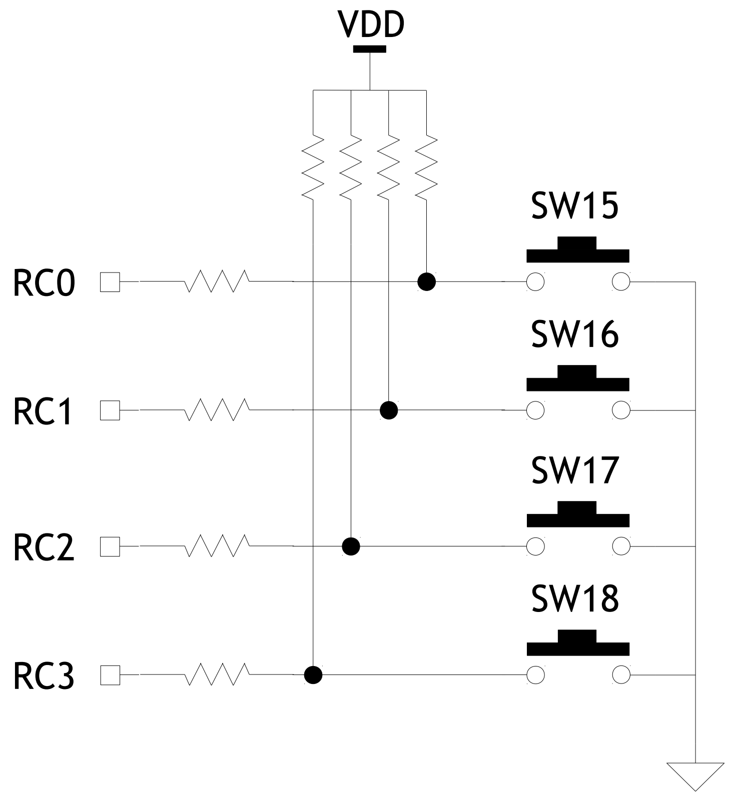
Interfaces – Digital Keypad - Circuit on Board



Interrupts

Microcontrollers
Interrupts

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

- 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
- Polling

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Interrupts - Interrupt vs Polling

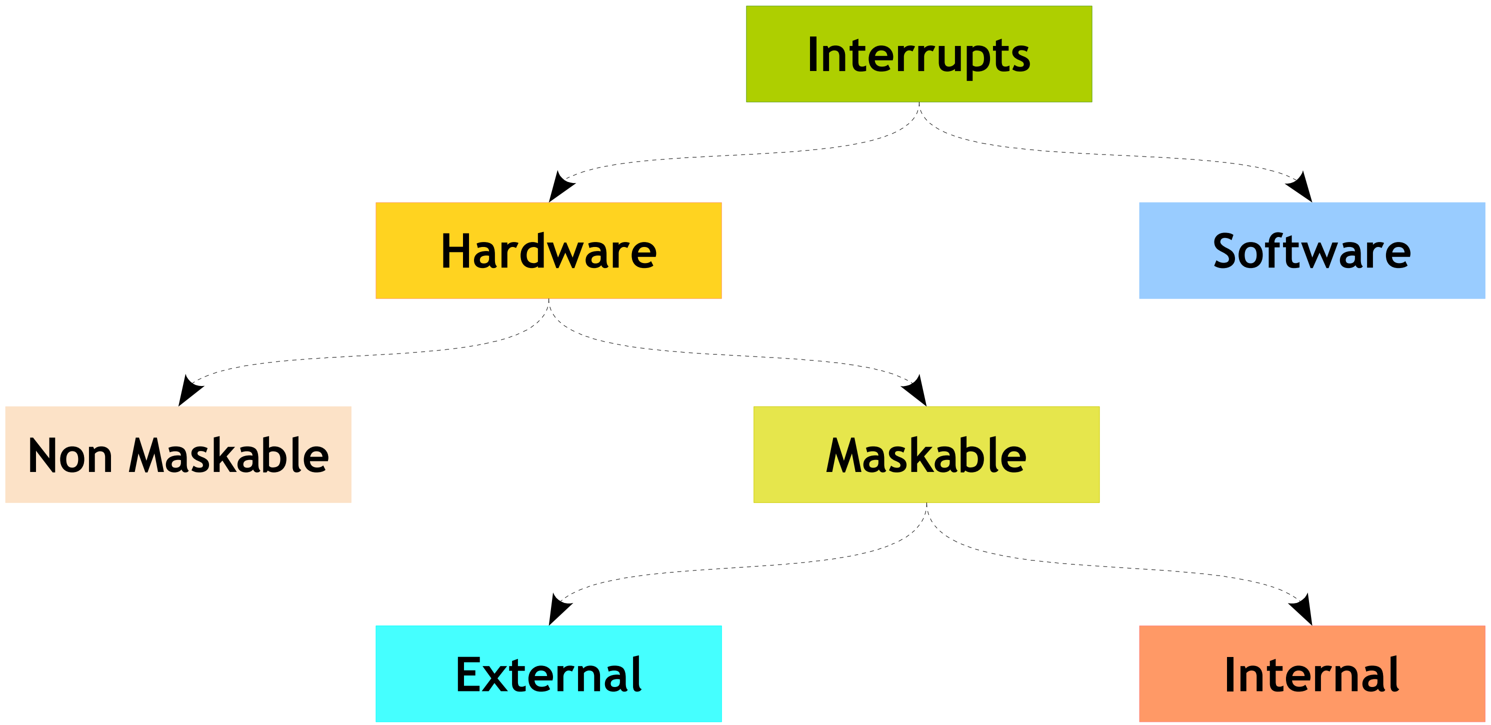
- Loss of Events
- Response
- Power Management

Microcontrollers

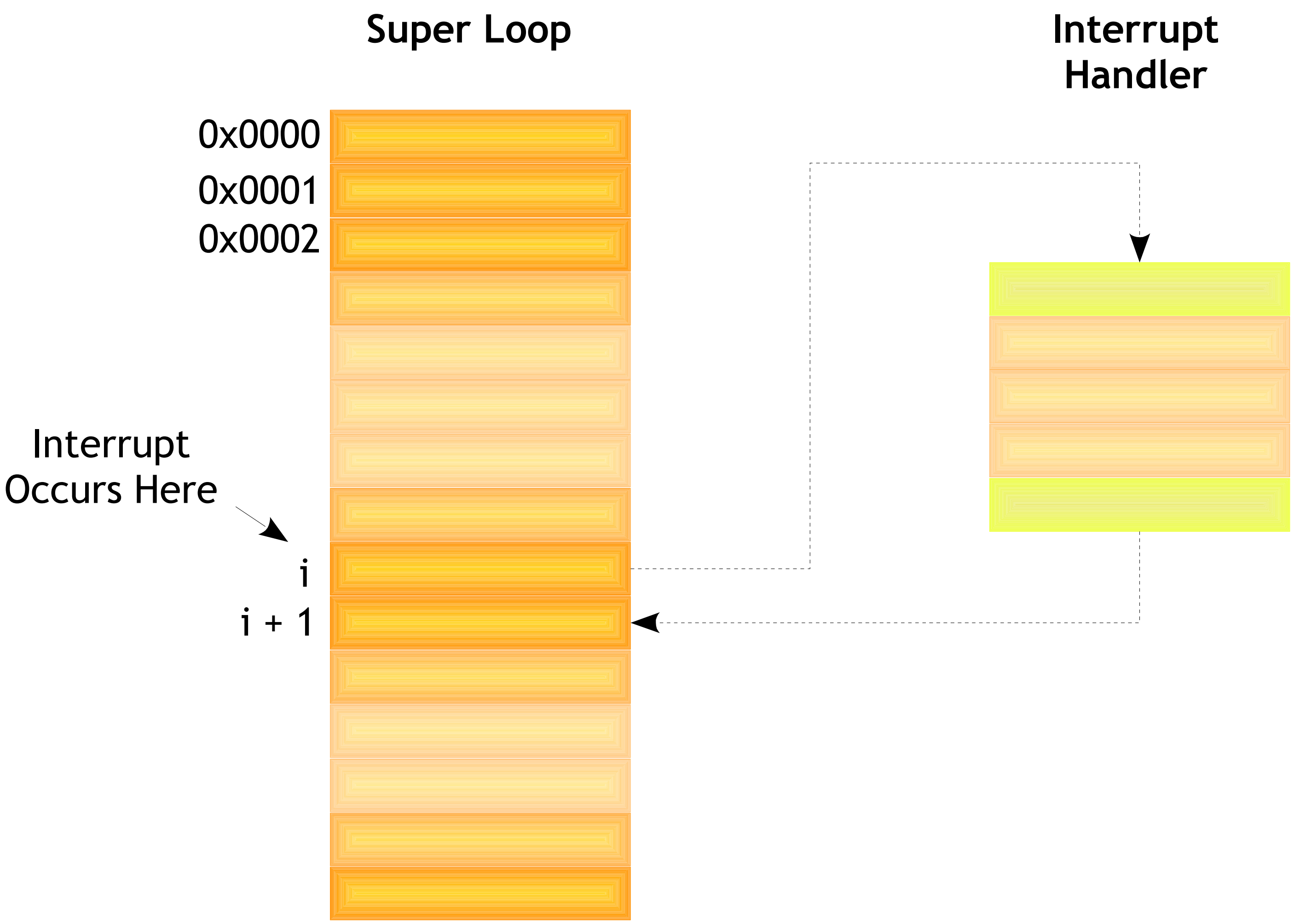
Interrupts - Sources

- External
- Timers
- Peripherals

Microcontrollers
Interrupts - Classification



Microcontrollers
Interrupts - Handling



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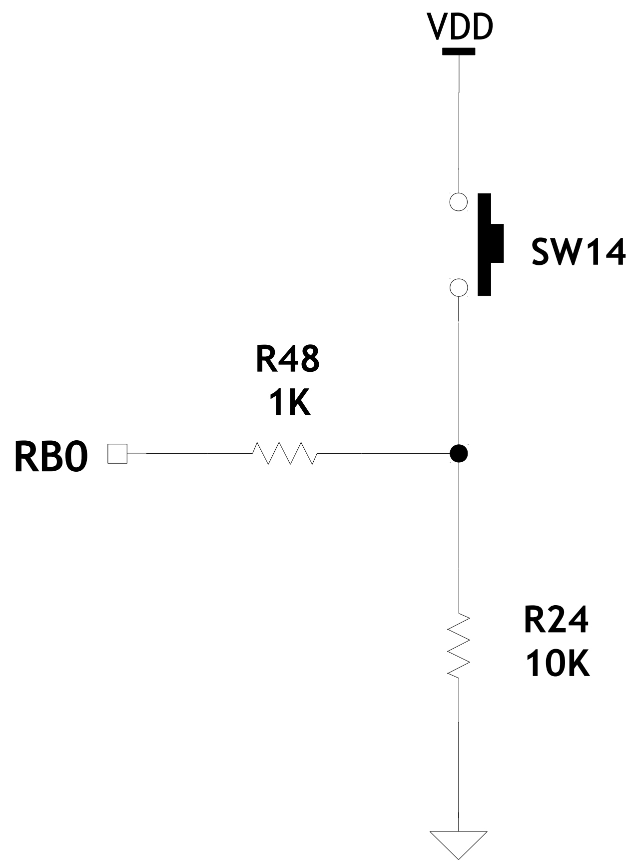
Interrupts - Service Routine (ISR)

- 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

- What / What Not

- Latency is determined by:
  - Instruction time (how long is the longest)
  - How much of the context must be saved
  - How much of the context must be restored
  - The effort to implement priority scheme
  - Time spend executing protected code

Microcontrollers
Interrupts - External Interrupt – Circuit on Board



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Interrupts - External Interrupt - Example

Example

```c
#include <xc8>

static void init_config(void)
{
    init_external_interrupt();
}

void main(void)
{
    unsigned char i;
    init_config();

    while (1)
    {
        while (!glow_led)
        {
            if (SWITCH == 1)
                glow_led = 1;

            for (i = 10000; i--; );
        }
        if (glow_led)
            LED = 0;
    }
}
```

```c
bit glow_led;

void interrupt external_pin(void)
{
    if (INTFLAG)
    {
        glow_led = 1;
        INTFLAG = 0;
    }
}
```

Timers

Microcontrollers

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

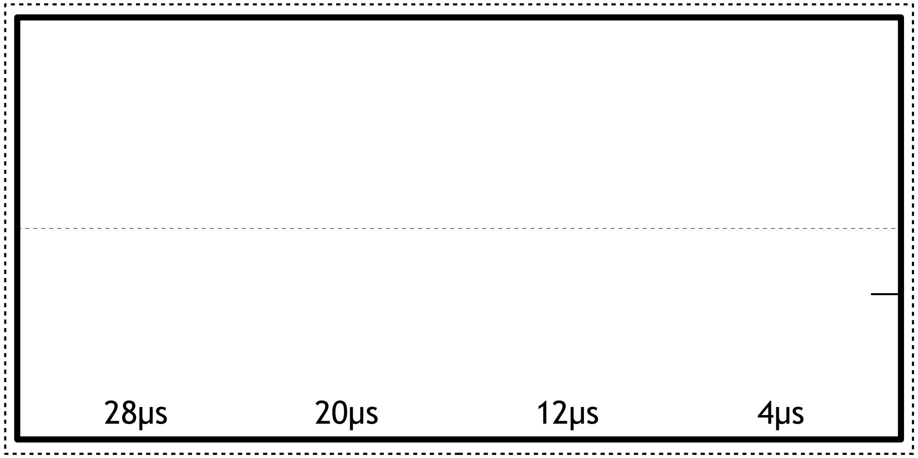
Microcontrollers

Timers - Example

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

Microcontrollers
Timers - Example

Timer Register	252
Overflows	0

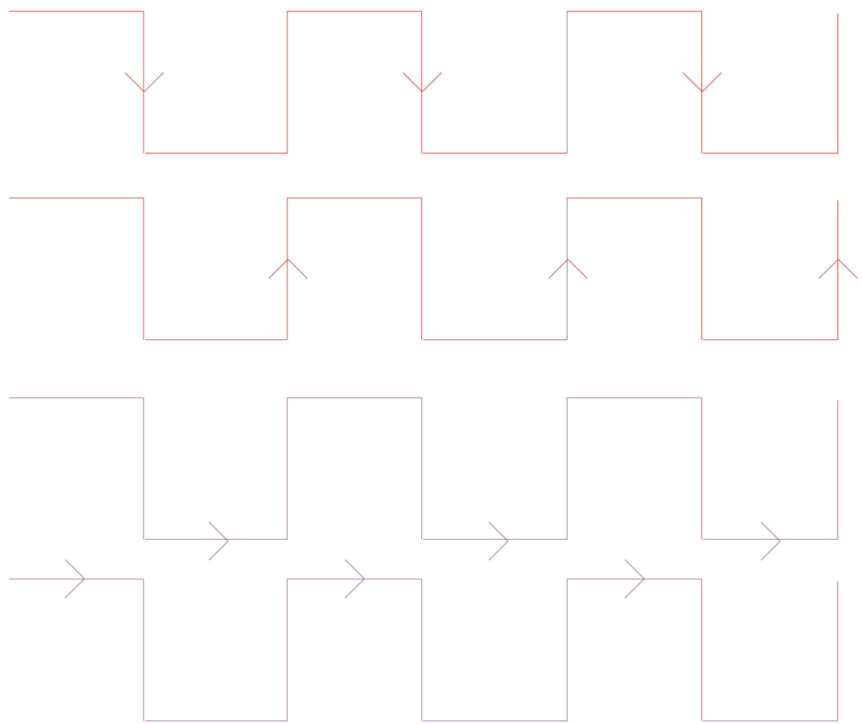


Clock I/O

Microcontrollers
Clock I/O - Introduction

- Most peripheral devices depends on Clocking
- Controllers have to generate clock to communicate with the peripherals
- Some of the Controllers internal peripherals work on external clocking provided at it pins

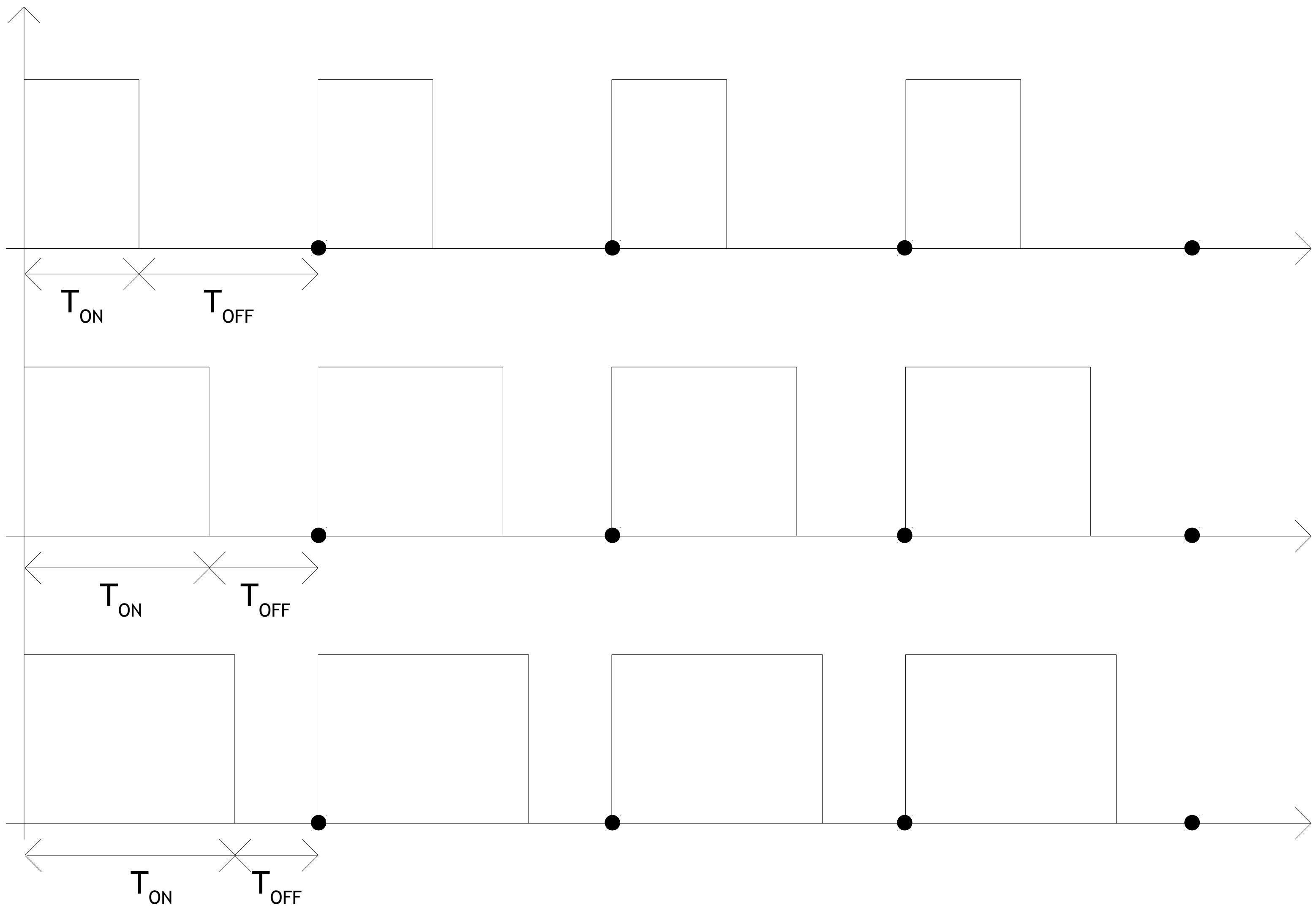
- The activity on the devices could be on
  - Edges
  - Levels



Microcontrollers
Clock I/O - PWM

- Sometimes called as PDM (Pulse Duration Modulation)
- A technique used to vary the active time vs inactive time in a fixed period.
- Mostly used to control the average voltage of the Load connected.
- Used in wide applications like Motor Controls, Lamp Dimmers, Audio, Power Controls and many more..

Microcontrollers
Clock I/O - PWM

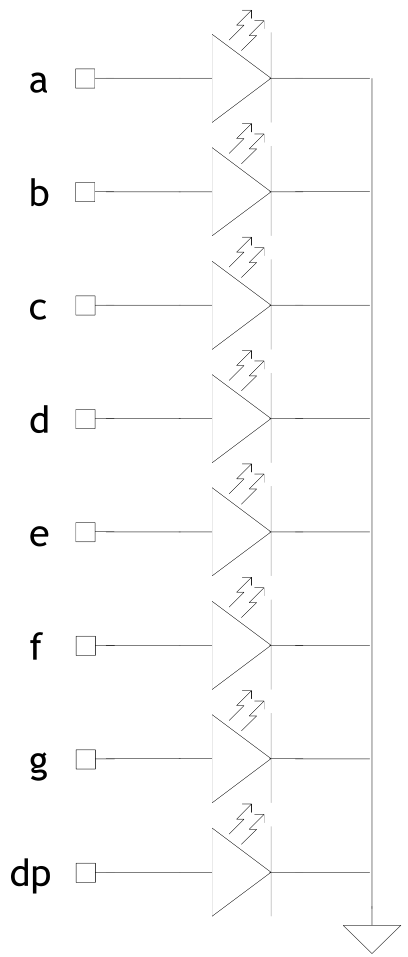


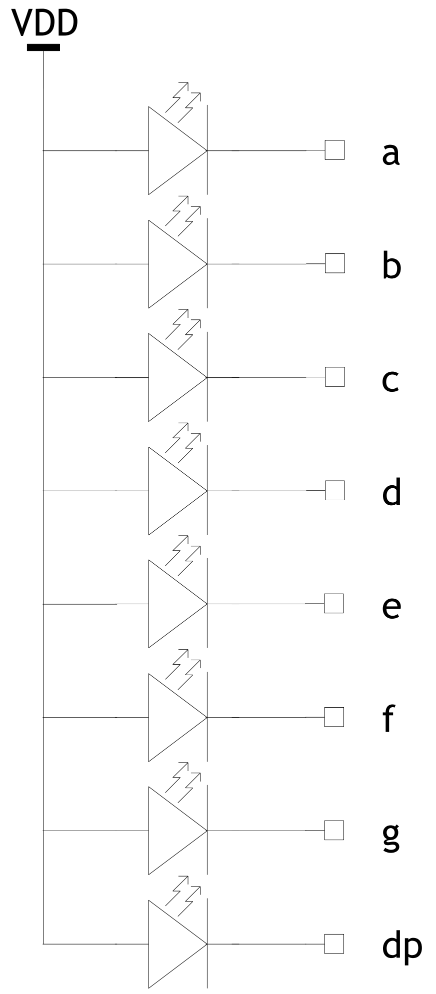
Seven Segment Displays

Microcontrollers
Interfaces – SSDs - Introduction

- Array of LEDs connected internally
- Possible configurations are common cathode and common anode
- Very good line of sight
- Used in many applications

Microcontrollers
Interfaces – SSDs – Introduction - Design



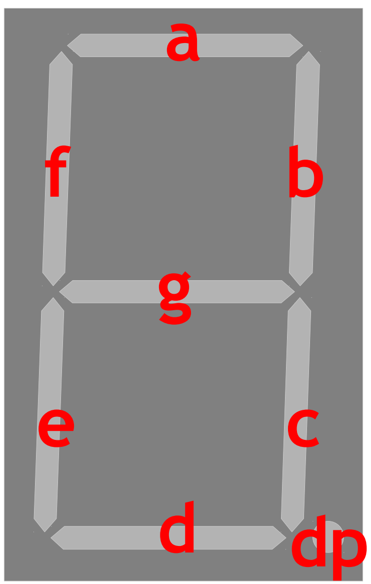


Microcontrollers

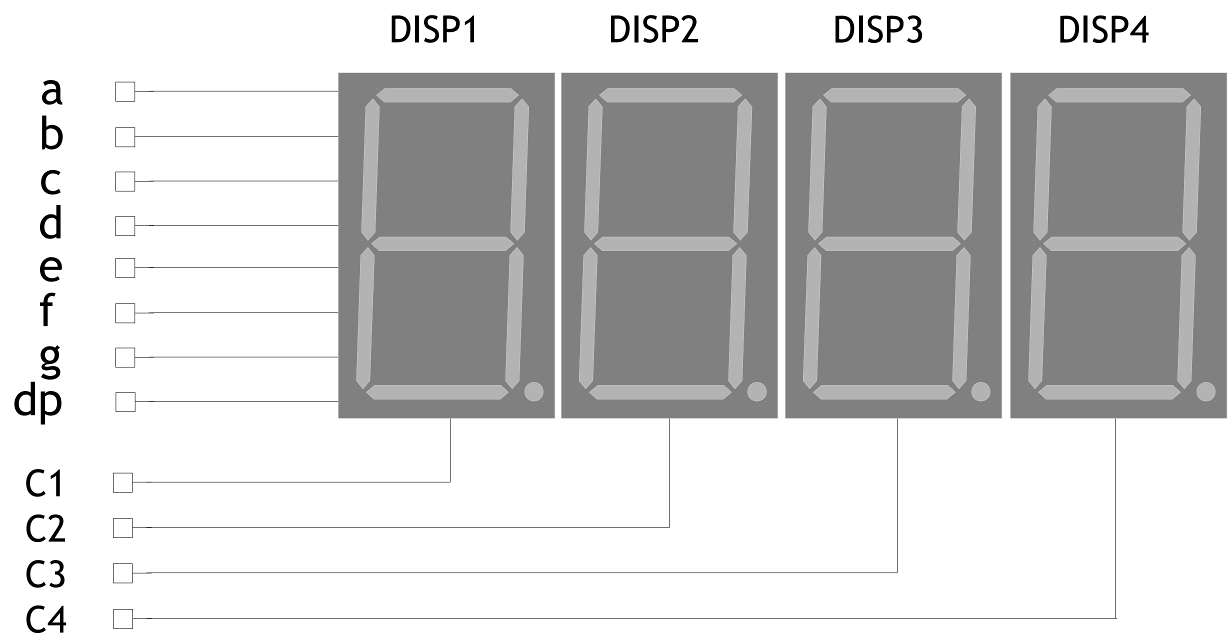
Interfaces – SSDs - Example

- Assuming a common anode display, what will the output for provided table?

Data								Control			
a	b	c	d	e	f	g	dp	C1	C2	C3	C4
0	0	1	0	0	1	0	1	0	1	0	0
0	1	0	0	1	0	0	1	0	0	1	0



Segment Map

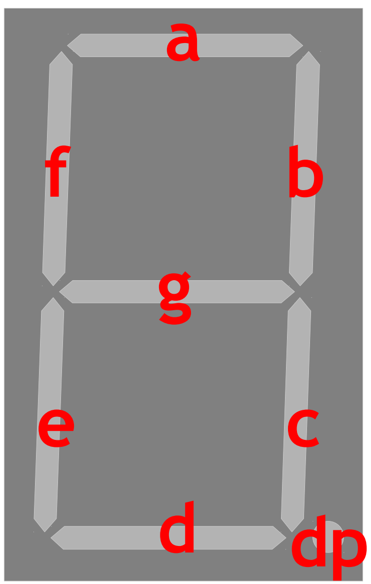


Microcontrollers

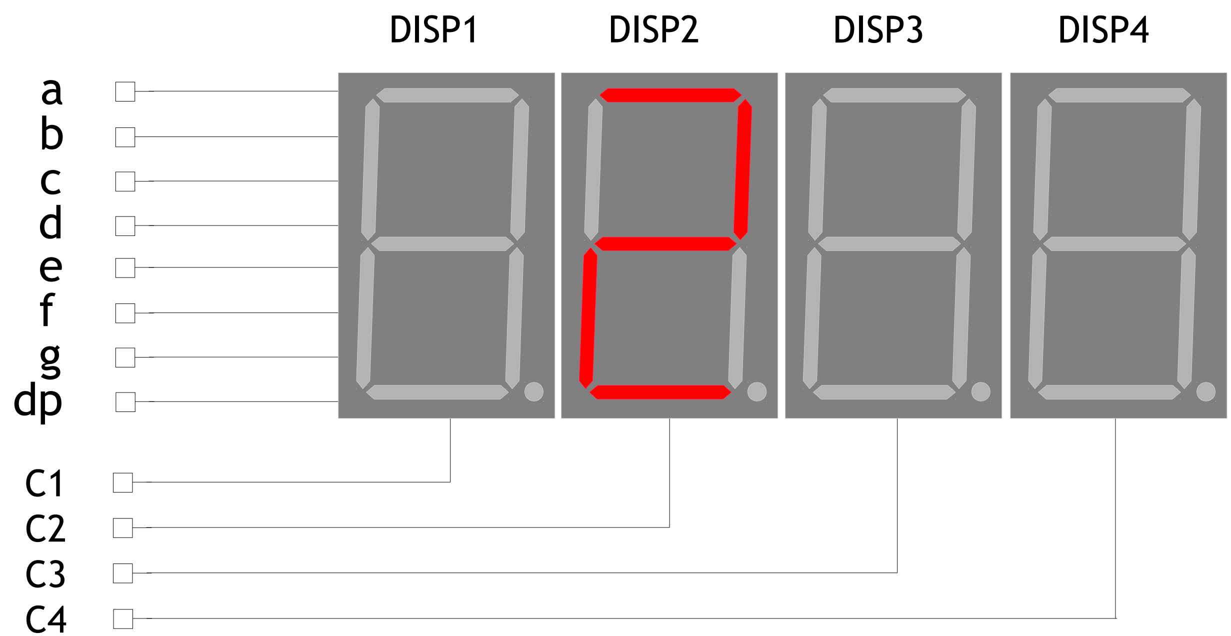
Interfaces – SSDs - Example

- Assuming a common anode display, what will the output for provided table?

Data								Control			
a	b	c	d	e	f	g	dp	C1	C2	C3	C4
0	0	1	0	0	1	0	1	0	1	0	0



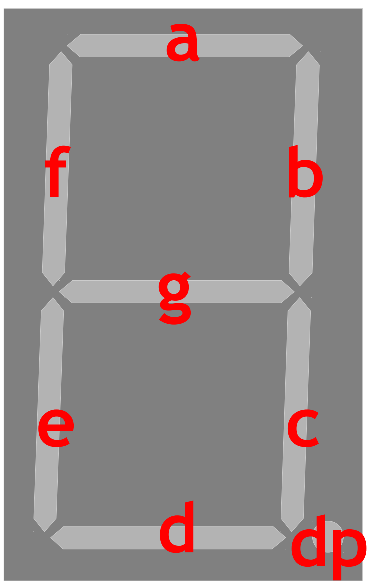
Segment Map



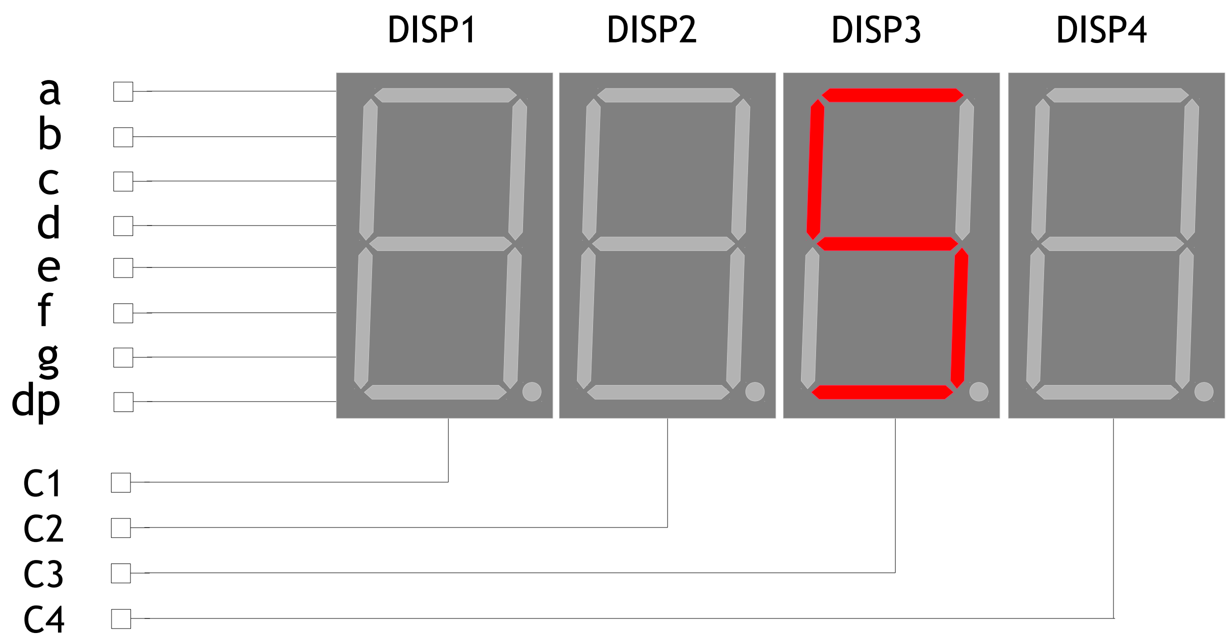
Microcontrollers
Interfaces – SSDs - Example

- Assuming a common anode display, what will the output for provided table?

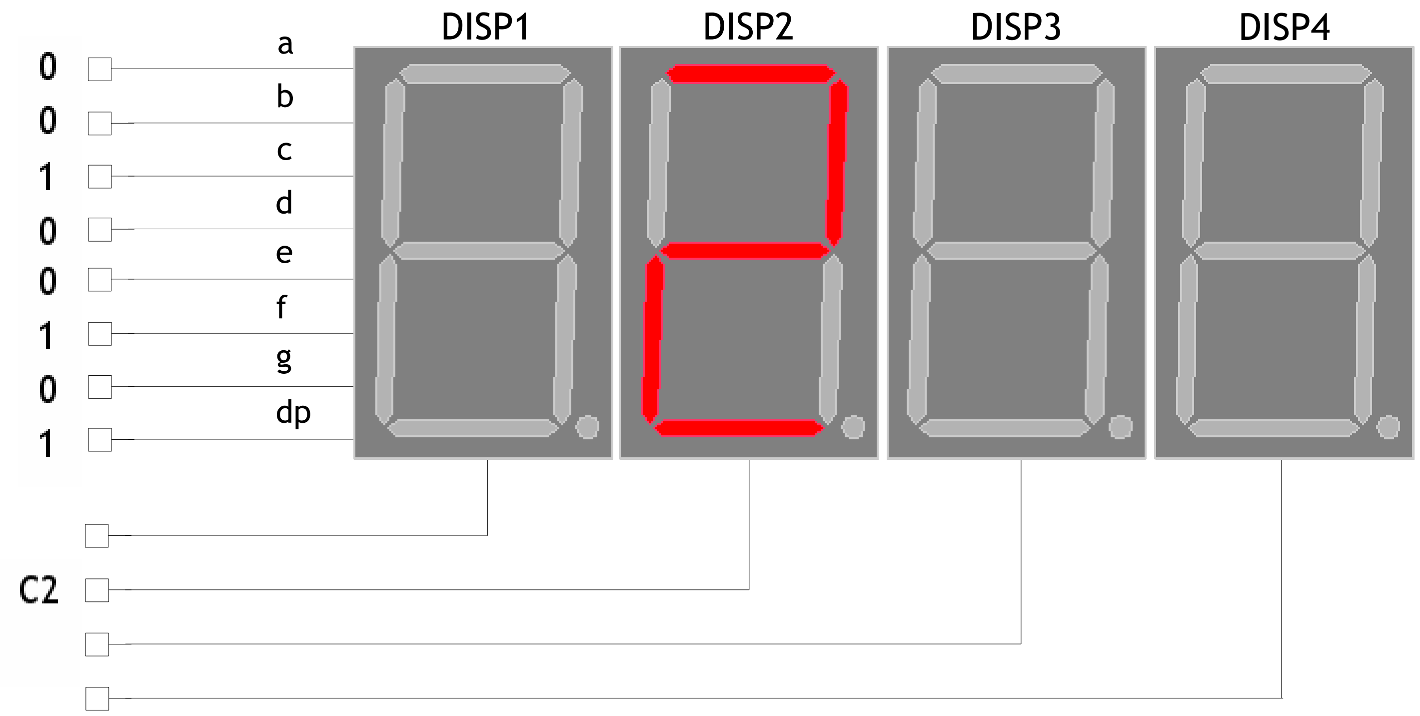
Data								Control			
a	b	c	d	e	f	g	dp	C1	C2	C3	C4
0	1	0	0	1	0	0	1	0	0	1	0



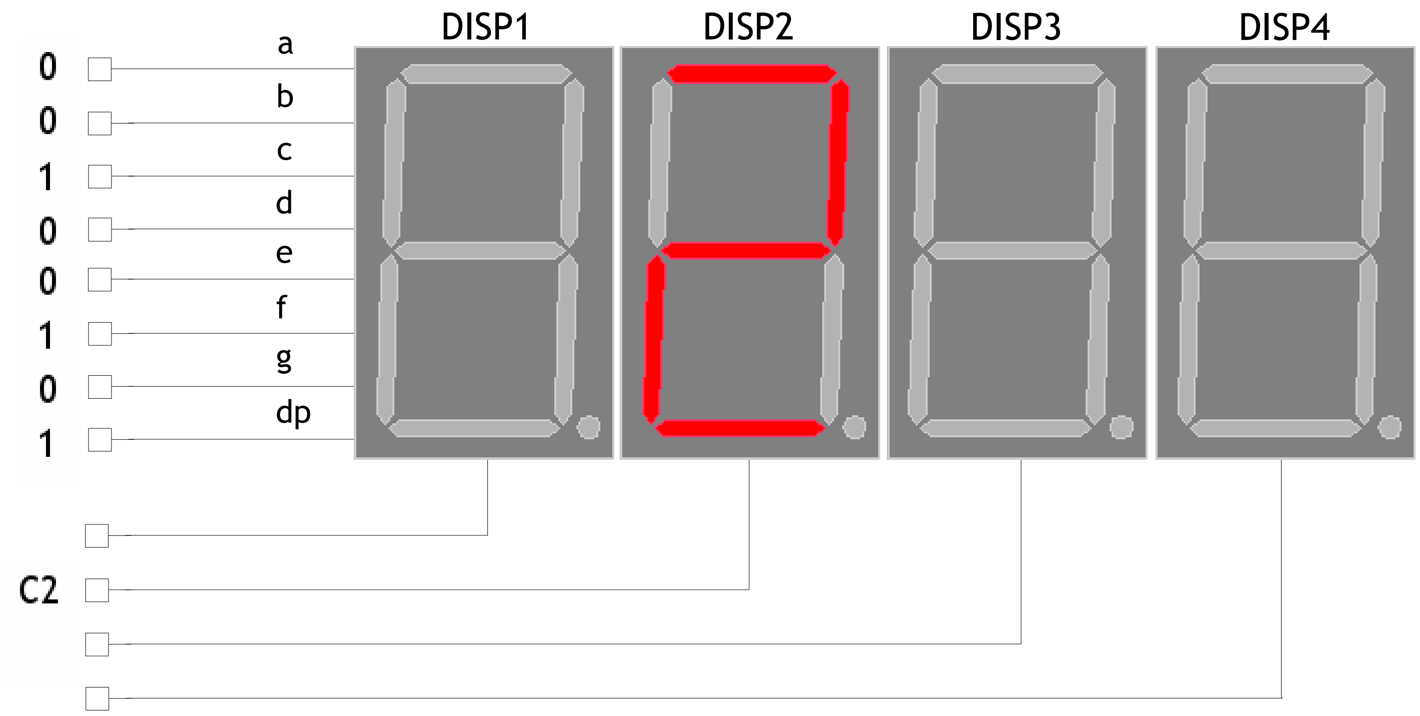
Segment Map



Microcontrollers
Interfaces – SSDs – Multiplexing

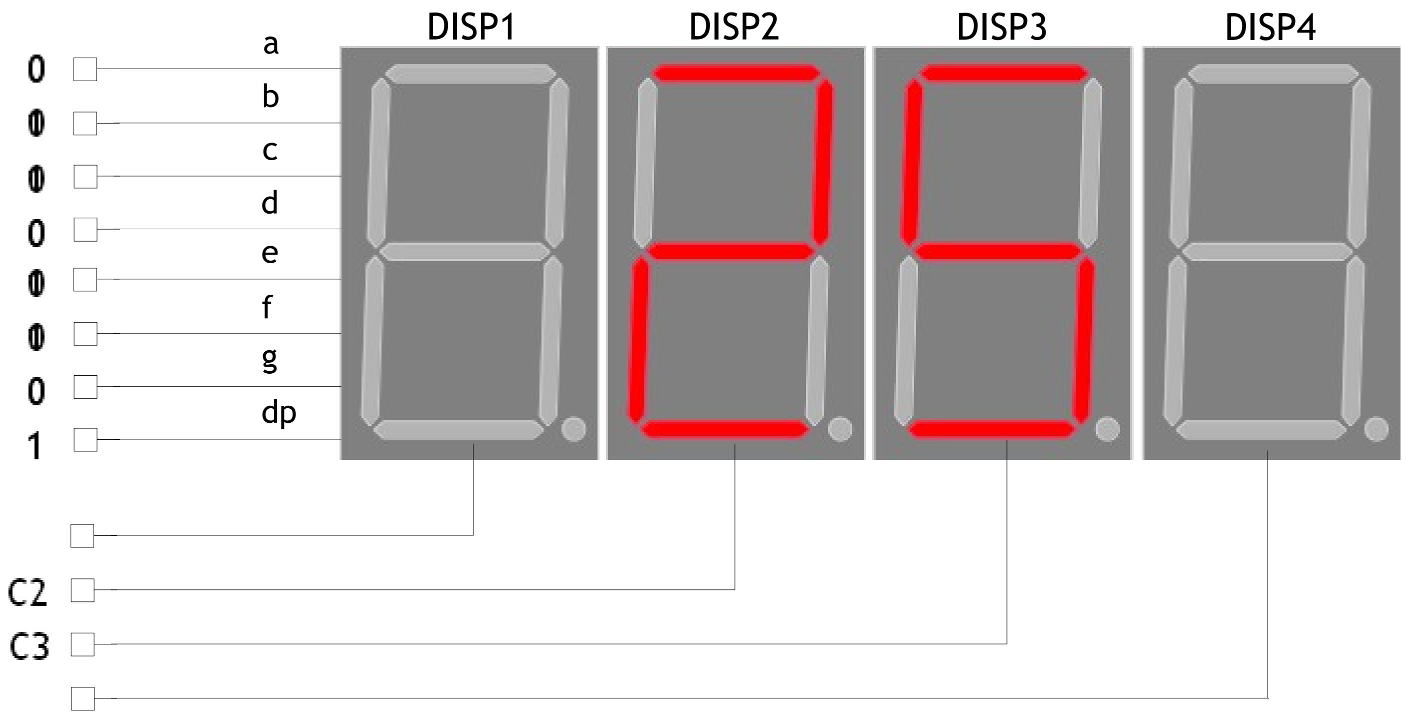


Microcontrollers
Interfaces – SSDs – Multiplexing



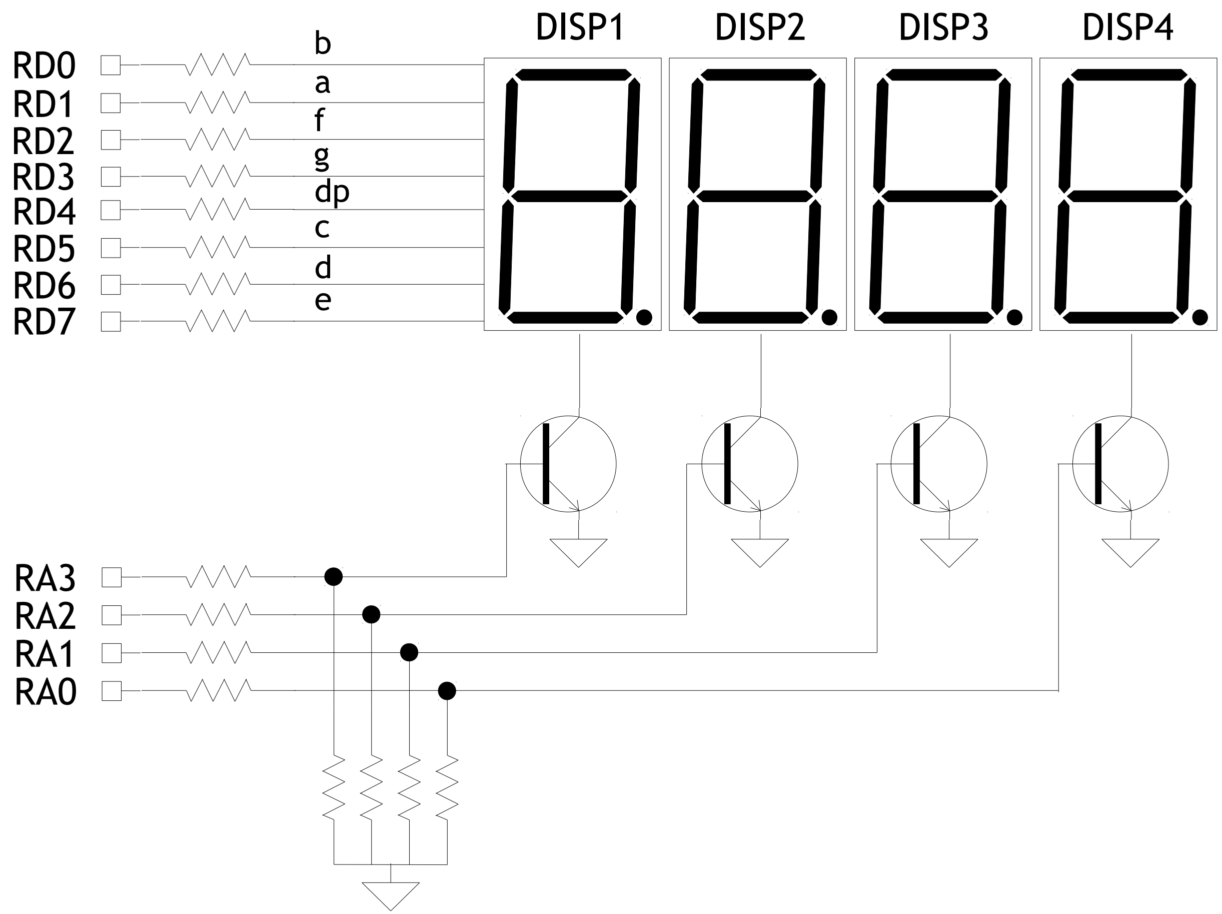
Microcontrollers

Interfaces – SSDs – Multiplexing



Microcontrollers

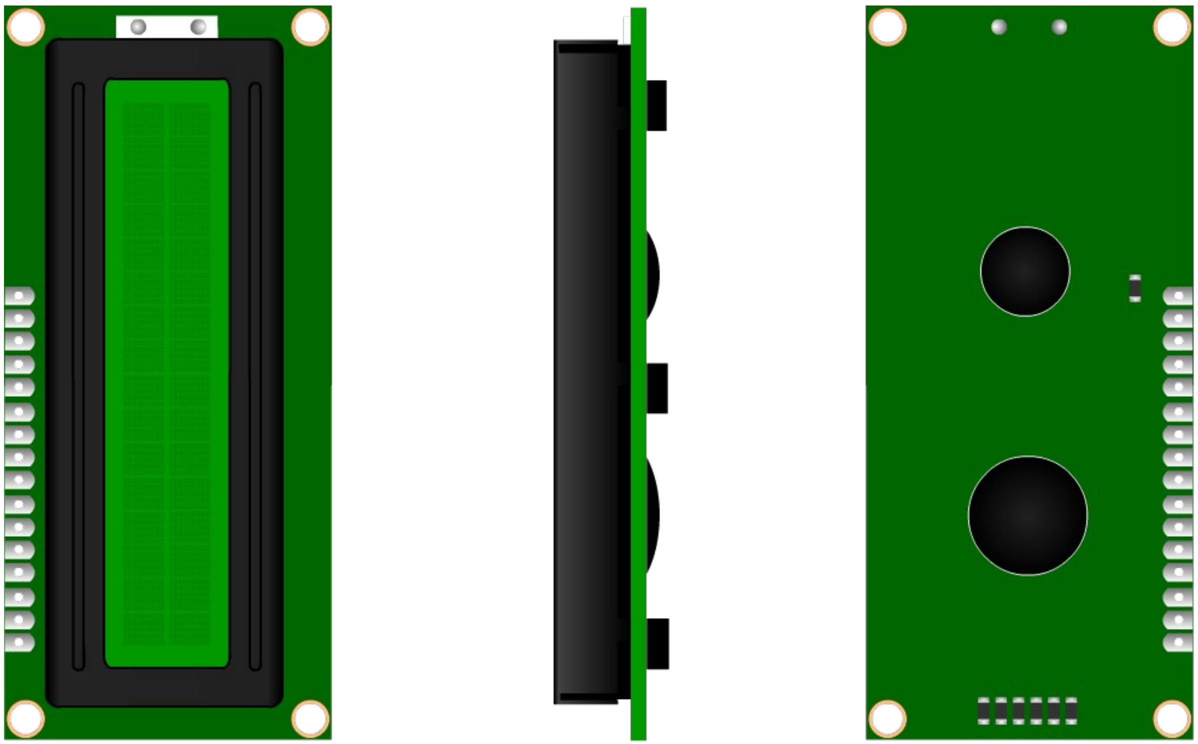
Interfaces – SSDs - Circuit on Board



Character Liquid Crystal Display

Microcontrollers
Interfaces – CLCD - Introduction

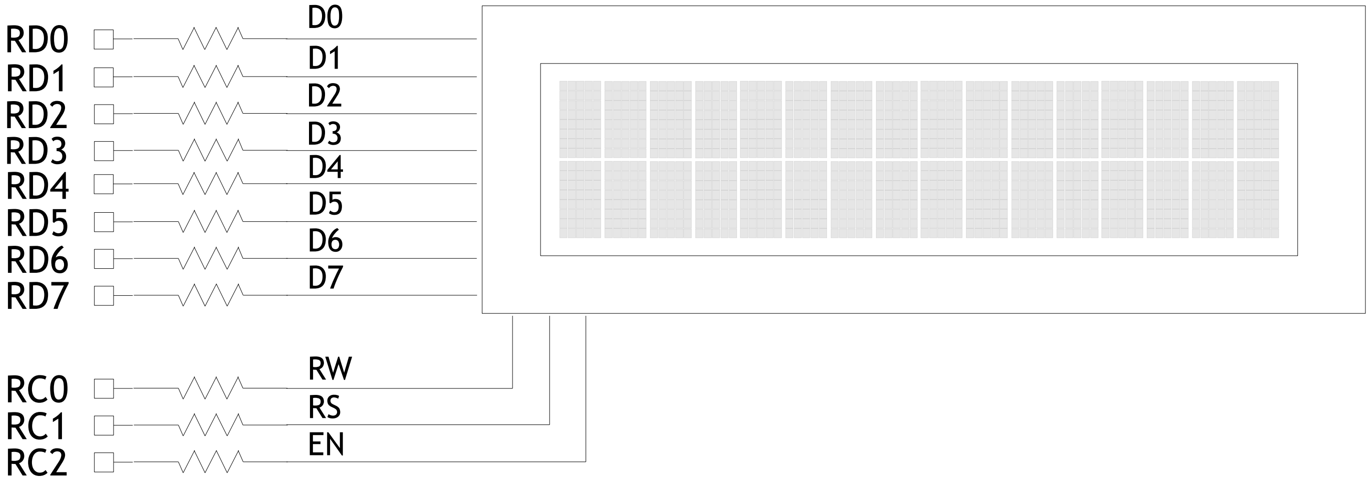
- Most commonly used display ASCII characters
- Some customization in symbols possible
- Communication Modes
  - 8 Bit Mode
  - 4 Bit Mode



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

Microcontrollers

Interfaces – CLCD - Circuit on Board



Matrix Keypad

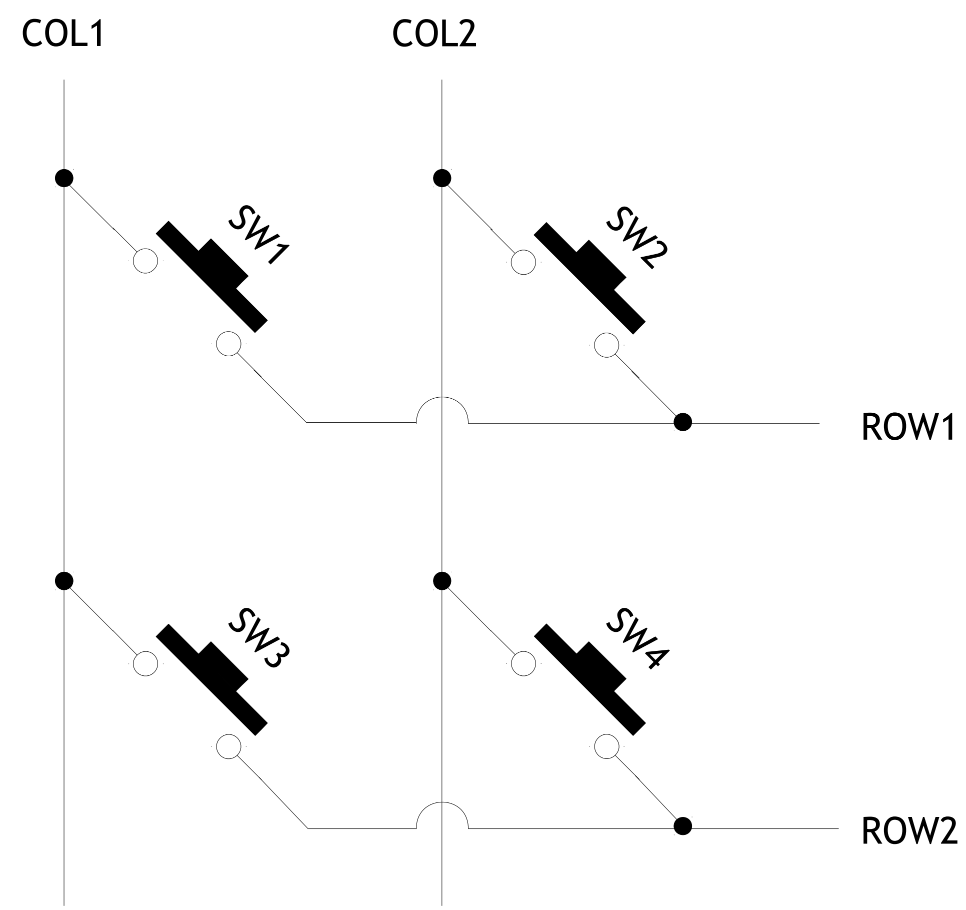
Microcontrollers

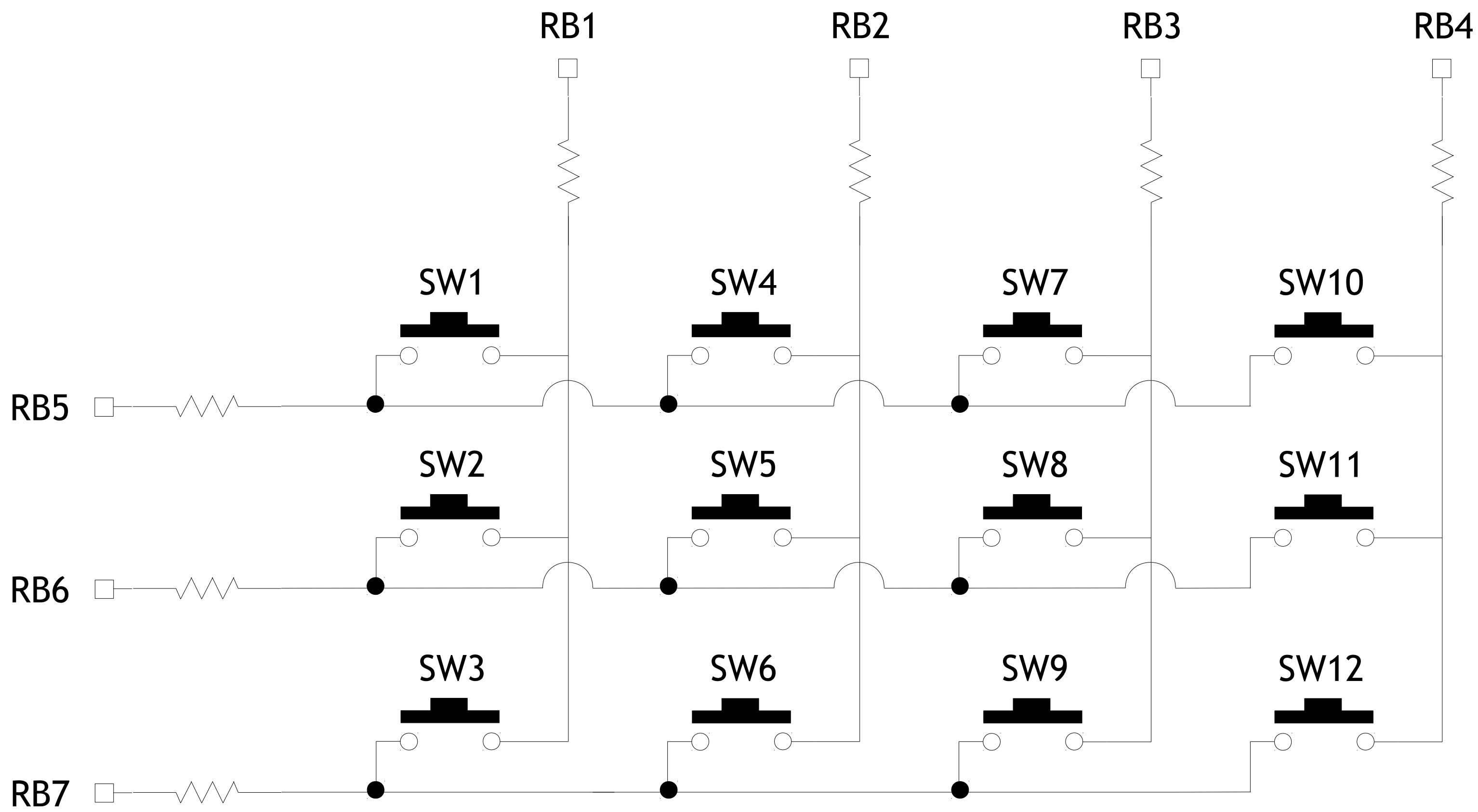
Interfaces – Matrix Keypad - Introduction

- Used when the more number of user inputs is required and still want to save the some controller I/O lines
- Uses rows and columns concept
- Most commonly used in Telephonic, Calculators, Digital lockers and many more applications

Microcontrollers

Interfaces – Matrix Keypad - Example





RB1
RB2
RB3
RB4
SW1
SW4
SW7
SW10
RB5
SW2
SW5
SW8
SW11
RB6
SW3
SW6
SW9
SW12
RB7

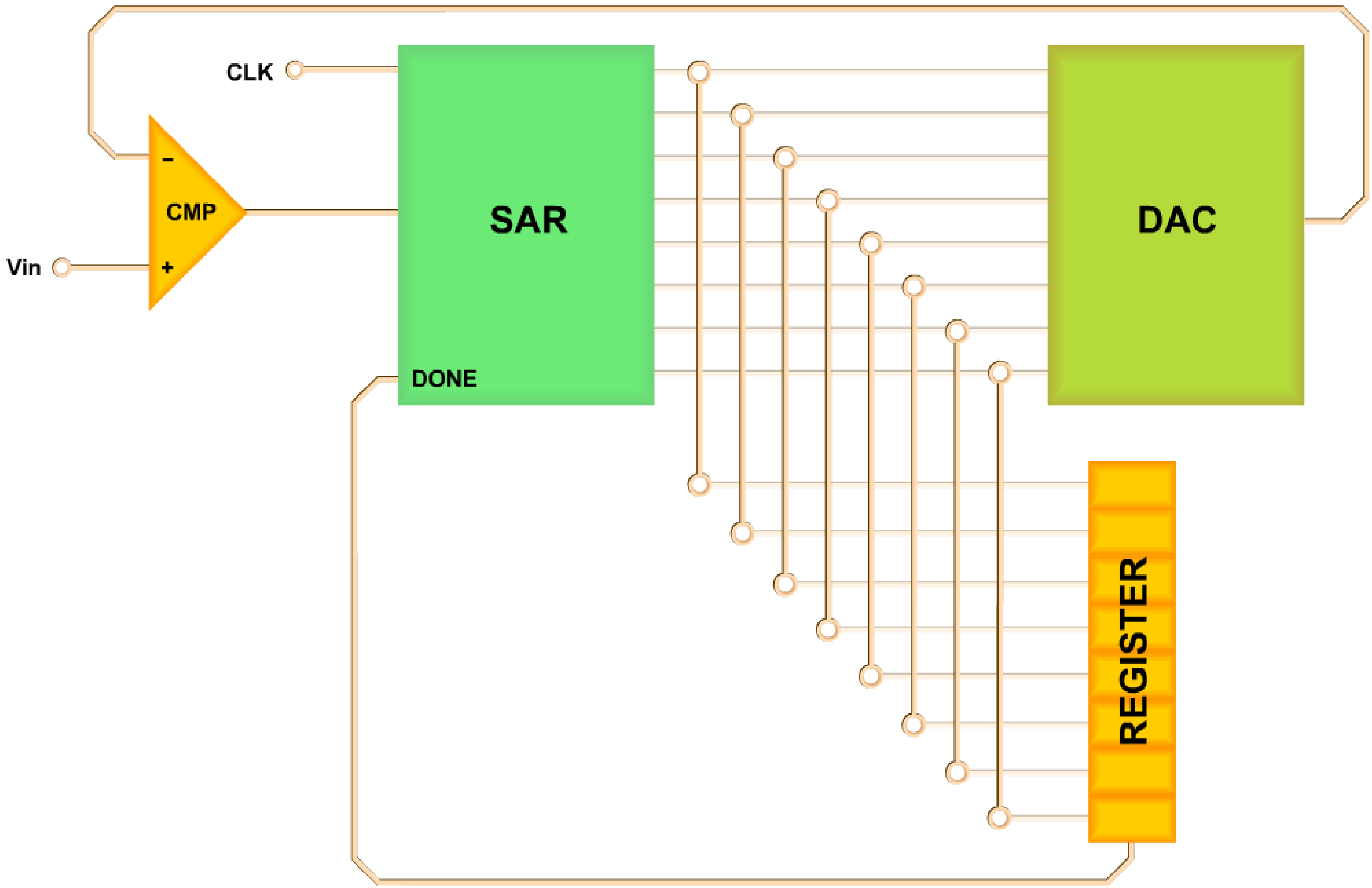
Analog Inputs

Microcontrollers

Analog Inputs - Introduction

- Very important peripheral in embedded systems for real time activities
- Multiplexed with normal GPIO
- Comes with different resolutions

Microcontrollers
Analog Inputs - SAR



Data Storage

Microcontrollers
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