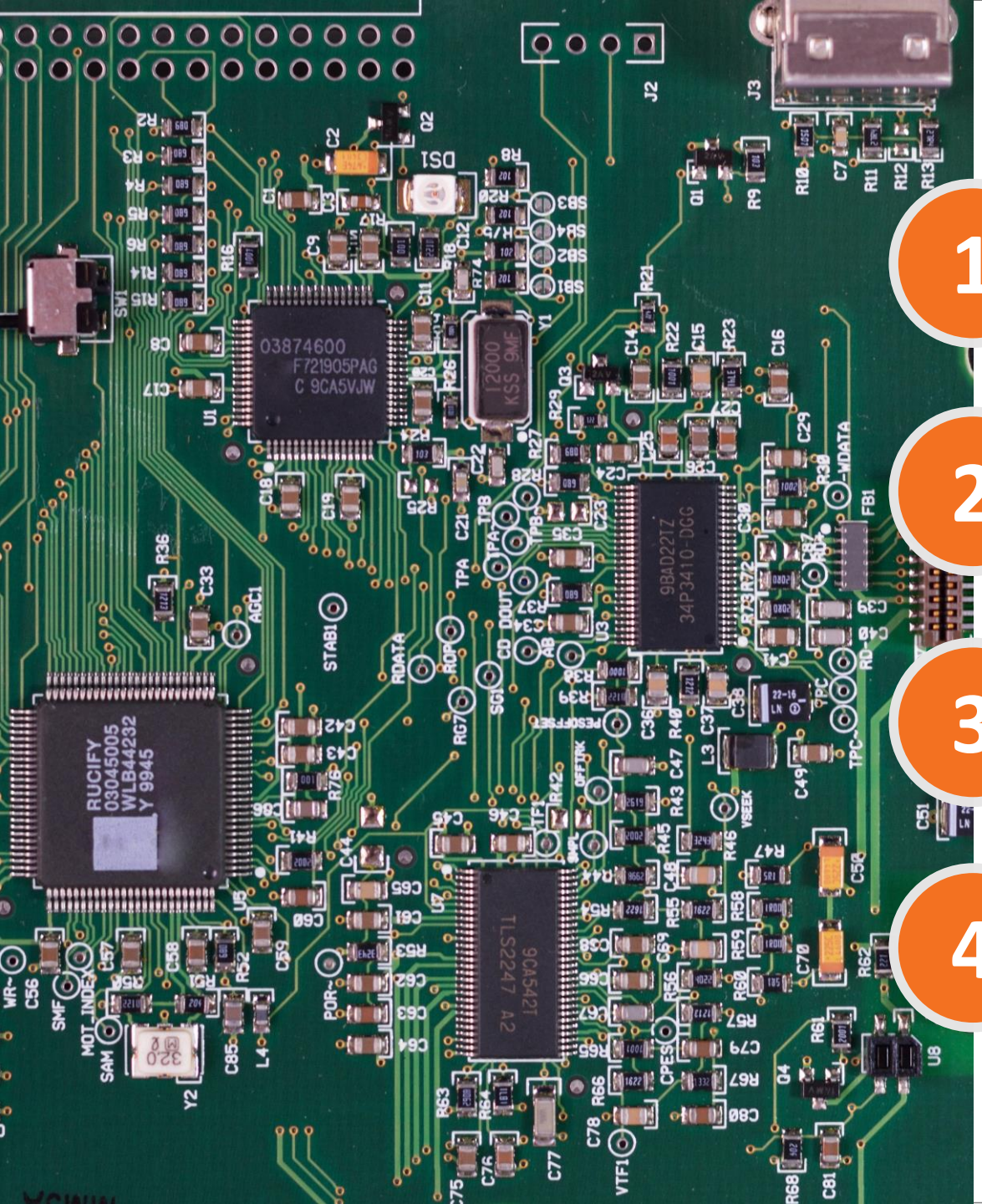
Lecture 04

# *Introduction to TM4C123 Microcontroller*

**MCT-238: Embedded Systems-I**



1. SELECTION OF MICROCONTROLLER
2. TM4C123 MICROCONTROLLER
3. TM4C123 MICROCONTROLLER PERIPHERALS
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# SELECTION OF MICROCONTROLLER

TM4C123 Microcontroller

# Introduction

## SELECTION OF MICROCONTROLLER

Cortex-M based microcontrollers integrate the ARM processor core with many peripheral modules, providing a highly capable single chip solution for different applications, including

- Motion control
- Medical instrumentation
- Test and measurement equipment
- Security and surveillance systems
- Factory automation
- Automotive and transportation
- Gaming
- Renewable energy

to name a few.

One of the fundamental operations in these applications is to perform digital actuation or control. Another important aspect is the availability of an interface allowing the user to interact with the system by configuring parameters and visualizing the system status.

Most of these requirements are fulfilled by using general purpose input-output (GPIO) interfacing.

# Factors

## SELECTION OF MICROCONTROLLER

Multiple factors are considered, while choosing a microcontroller and some of the important ones are listed below:

- Integration of essential interfaces on the microcontroller is one of the key factors when selecting a microcontroller.
- The execution speed and memory sizes are also important.
- The availability of low cost and user friendly evaluation platform is another important aspect
- Availability of economical programming and debugging tools is also highly critical, when selecting a microcontroller.
- In addition, the availability of an easy to use accompanying firmware as well as documentation for programming and debugging purposes can be highly beneficial.

The **TM4C123 microcontroller** (Cortex-M4F) from Texas Instruments is one of the most suitable choices, which provides the best compromise when considering the above-mentioned factors.

# CORTEX-M BASED TM4C123 MICROCONTROLLER

Key Features, Block Diagram, Minimum Connectivity, Hardware Development Board

# Key Features

## CORTEX-M BASED TM4C123 MICROCONTROLLER

The key features of the TM4C123 microcontroller are listed below.

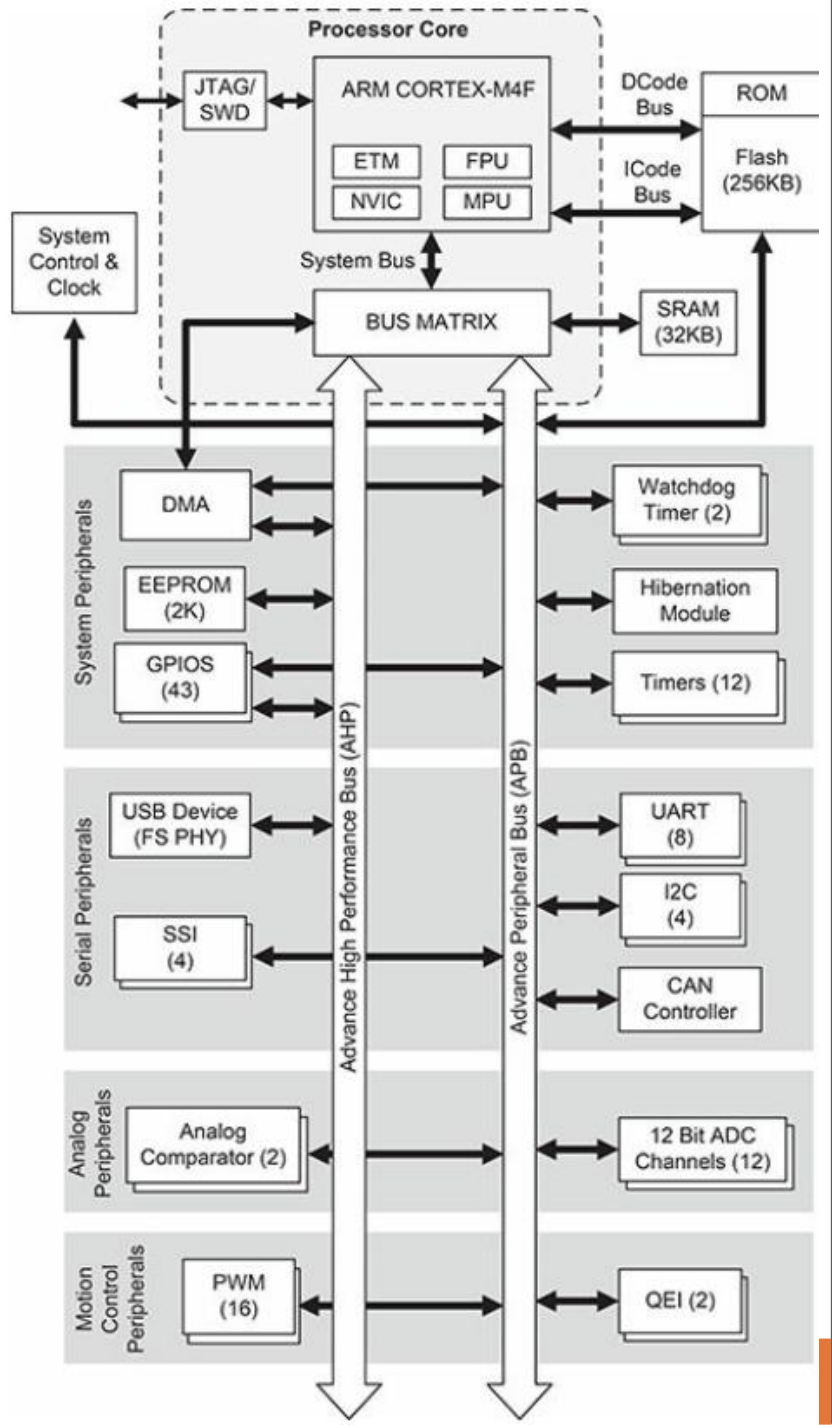
- **Clock frequency**: Processor clock frequency up to 80 MHz with floating point unit (FPU).
- **System timer SysTick**: SysTick is 24-bit, clear-on-write, decrementing timer. Its flexible control allows its use for the purpose of system time base generation.
- **Debugging interface** using JTAG/SWD: The TM4C123 microcontroller provides a JTAG and SWD (serial wire debug) based debugging interface for programming and debugging purpose
- **Nested vectored interrupt controller**: The NVIC along with Cortex-M processor can prioritize and handle the interrupts in handler mode. The CortexM4F processor in TM4C123 also supports the tail- chaining functionality that further reduces interrupt latency. A collection of 7 system exceptions and 65 peripheral interrupts are supported by TM4C123. The microcontroller supports 8 priority levels, which can be configured for these exceptions and interrupts

# TM4C123 Microcontroller Block Diagram

## CORTEX-M BASED TM4C123 MICROCONTROLLER

There are two important buses while interacting with microcontroller peripherals:

- The **advanced peripheral bus** (APB) is the low speed bus.
- The more complex advanced **high-performance bus** (AHB) gives improved performance than the APB bus and should be used for interfacing those peripherals, which require faster data transfer speeds.
- It should be noted that only the GPIO and direct memory access (DMA) modules have connectivity available to both the buses.



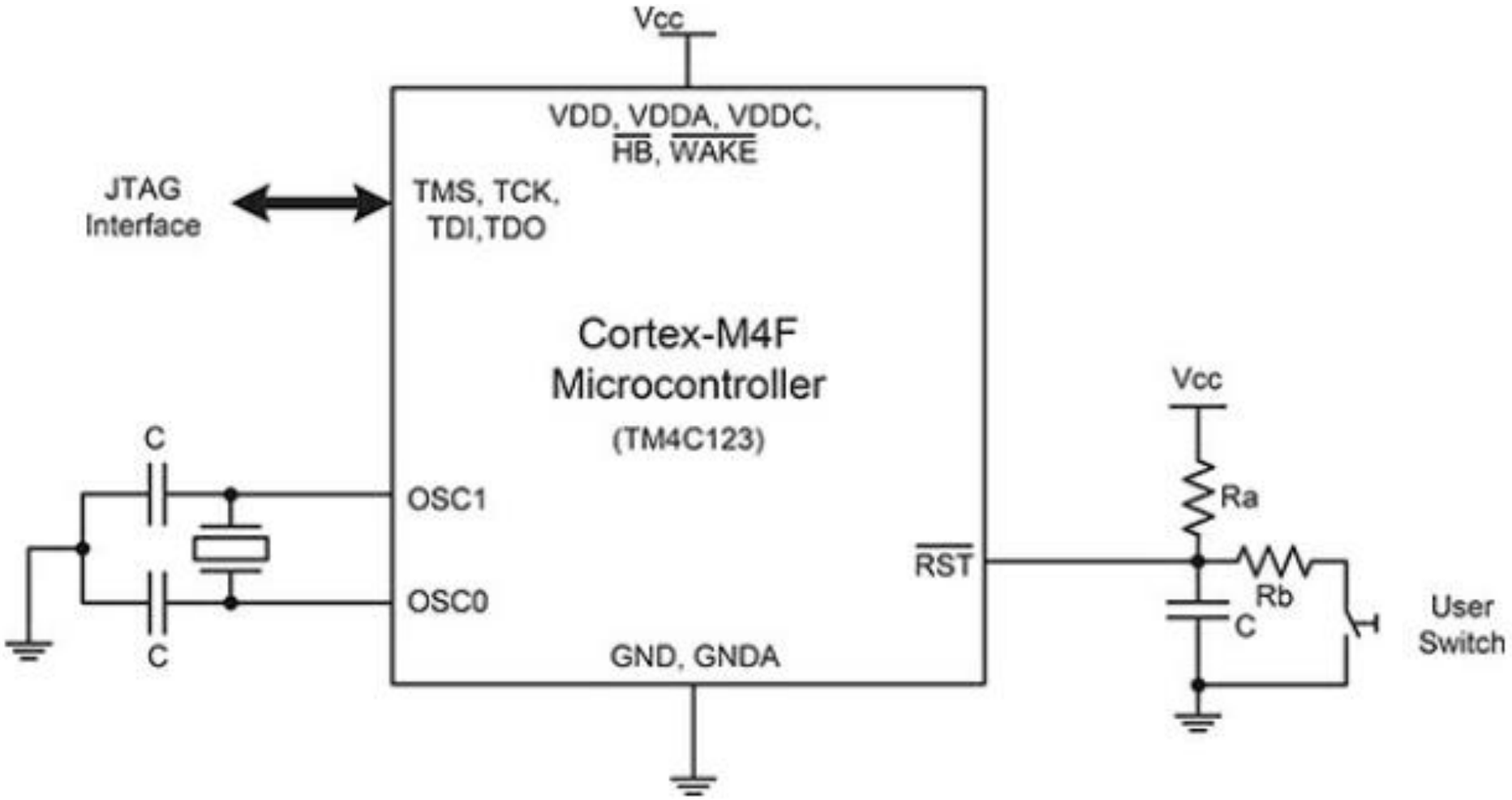
# Minimum Connectivity for TM4C123

## CORTEX-M BASED TM4C123 MICROCONTROLLER

- The TM4C123 microcontroller used in the hardware platform has a 64 pin package, of which 43 pins are available as GPIOs.
- Out of remaining 21 pins 13 are used for power supply connections and are labeled as VDD and GND.
- Four other pins are reserved for connecting external clock source connectivity.
- The remaining four pins are dedicated for reset, wakeup, hibernation, and an external battery connection.
- The programming and debugging interface, based on JTAG/SWD, of this microcontroller is multiplexed with GPIO pins.
- These GPIO pins are by default configured for the debugging functionality. Based on this fact, as a precautionary measure it is highly recommended that these GPIO pins should not be configured to be used as GPIOs.

# Minimum Connectivity for TM4C123

## CORTEX-M BASED TM4C123 MICROCONTROLLER



# Minimum Connectivity for TM4C123

## CORTEX-M BASED TM4C123 MICROCONTROLLER

A minimum wiring of the microcontroller is required for its proper functionality. In general, the following four hardware connections are required for proper functioning of the microcontroller

**Power supply**: A DC power supply of appropriate voltage level and current capacity needs to be connected to the Vcc and GND pins. It is a good practice to use bypass capacitors to filter any ripple or noise in the DC power supply.

**Clock source**: Each microcontroller requires a clock source for its proper working. A stable clock is also required for asynchronous communication interfaces.

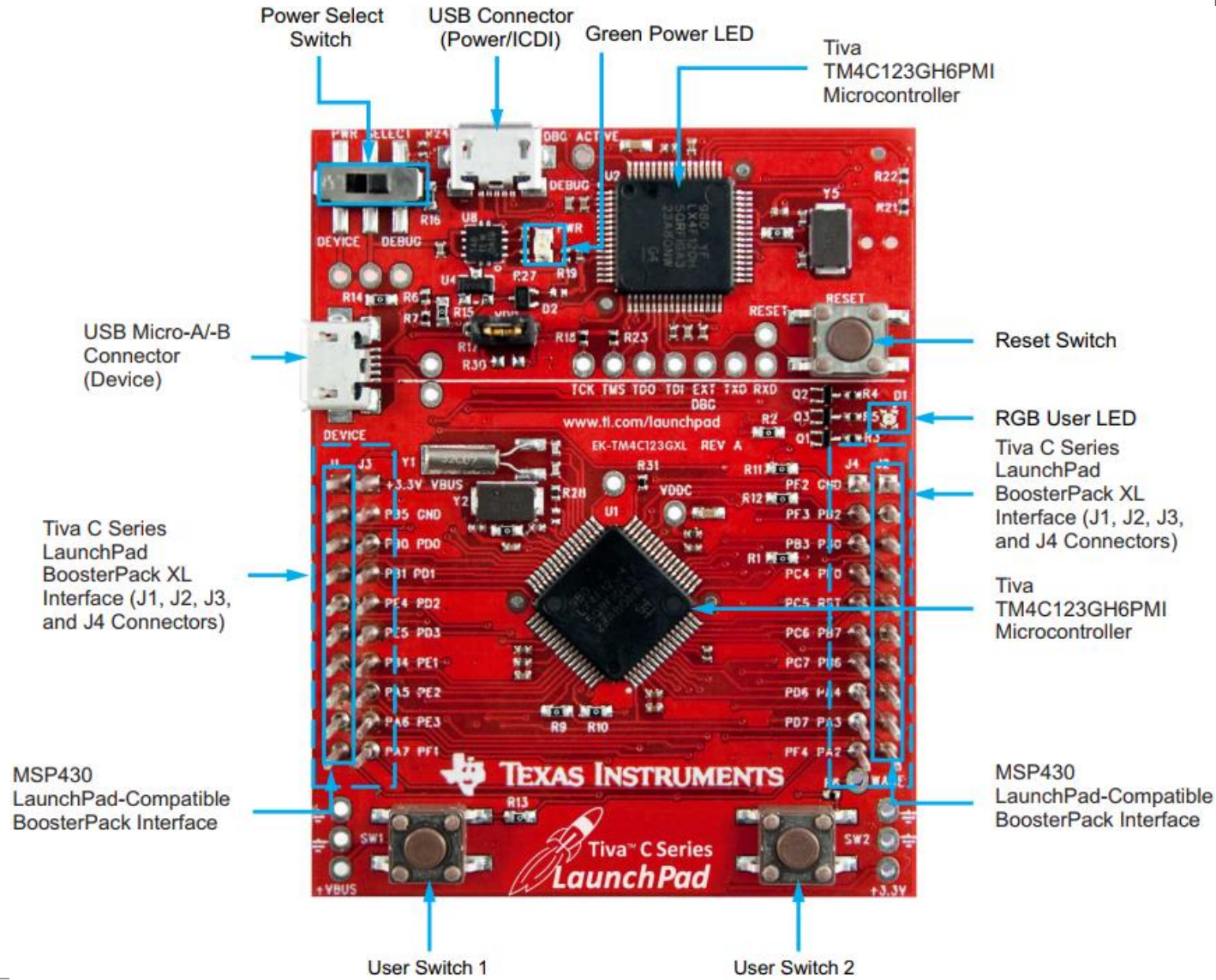
**Reset connection**: Each microcontroller has a reset pin for hardware reset capability. This pin should be wired according to the recommendation of the chip manufacturer for proper functioning.

**Programming and debugging**: Most of the microcontrollers have an on-chip program memory. To run the user program from the on-chip memory, a programming interface is required. In addition, for debugging the user program in real environment a debugging interface is also required. These two operations can be performed using a single interface. JTAG and serial wire debug are the two widely used programming and debugging interfaces and are also made available on the TM4C123 microcontroller.

# Hardware Development Board

## CORTEX-M BASED TM4C123 MICROCONTROLLER

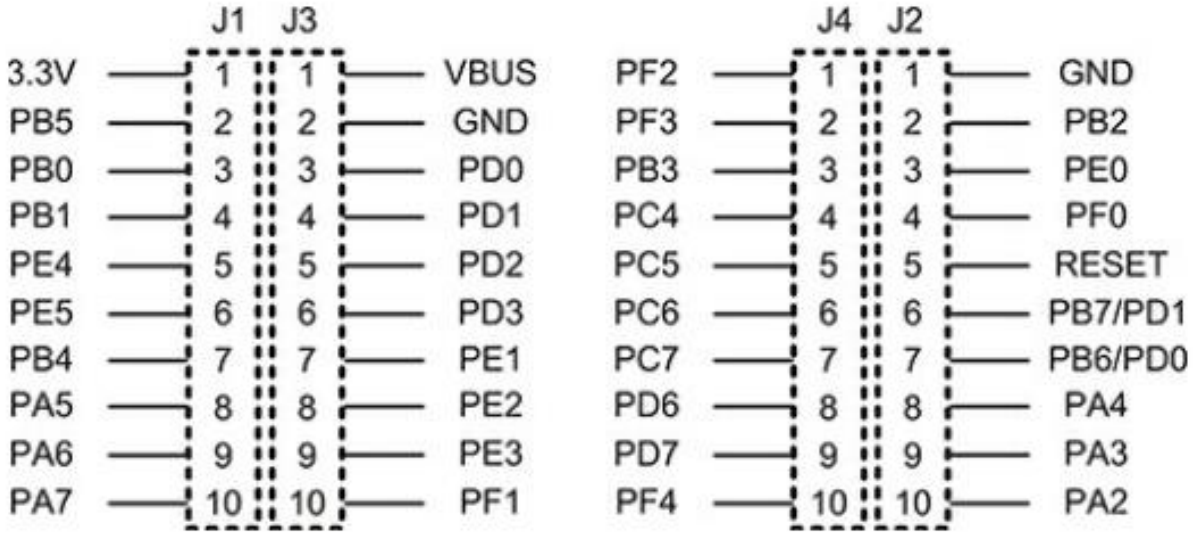
- The microcontroller platform used in this course is based on the Texas Instruments Tiva C series launchpad evaluation board.
- The development board is based on the TM4C123 microcontroller and provides **expansion headers** for peripheral interfacing.
- This platform is equipped with an on-board integrated **In-Circuit Debugging Interface** (ICDI), which allows programming and debugging of the TM4C123 microcontroller.
- There are two USB interfaces available on the board. 1. **Programming and Debugging mode**, 2. **Device Mode**
- There is a **selector switch** to select the board power source, which can be supplied from either of the two USB connectors.



# Hardware Development Board

## CORTEX-M BASED TM4C123 MICROCONTROLLER

- The ICDI is implemented using a dedicated microcontroller.
- The debugging interface on one side connects to the host computer using a USB link, while it connects to the TM4C123G microcontroller using JTAG/SWD interface on the other side.
- The interface with the external devices, using the available peripherals, can be implemented using the two expansion headers provided on the board.
- It should be noted that not all the GPIOs are available on the header pins.



# TM4C123 MICROCONTROLLER PERIPHERALS

Types of Microcontroller Peripherals, Alternate Functionality, and their Memory Map

# Introduction

## TM4C123 MICROCONTROLLER PERIPHERALS

The TM4C123 microcontroller is equipped with a variety of peripherals, which are integrated with the ARM Cortex-M core. The TM4C123 on chip peripherals can be categorized into the following four groups:

1. System Integration Peripherals
2. Timing Interfaces
3. Communication Interfaces
4. Analog Interfacing Peripherals

# 1. System Integration Peripherals

## TM4C123 MICROCONTROLLER PERIPHERALS

Different system integration peripherals include

- The **GPIOs** can be used for parallel interfacing. For example, external memory can be interfaced using parallel interface. In addition, the GPIO pins on TM4C123 can also be configured as interrupt inputs for external binary events.
- The **system clock management** module is responsible for generating clock for system as well as for other peripherals. It allows the user to run the system at different operating frequencies.
- In many battery-operated systems, the power conservation is of extreme importance. For that purpose, TM4C123G microcontroller has an integrated battery-backed **hibernation module** to efficiently keep the microcontroller in power down mode for reducing the power usage during intervals of inactivity
- **Direct Memory Access** method that allows an input/output (I/O) device to send or receive data directly to or from the main memory, bypassing the CPU to speed up memory operations. The process is managed by a chip known as a DMA controller

# 2. Timing Interfaces

## TM4C123 MICROCONTROLLER PERIPHERALS

The TM4C123 has 12 general purpose timers, two watchdog timers, and one systick timer.

- **Systick Timer**: It is integrated as part of the ARM processor core, while all other timers are integrated as peripheral modules.
- **General-purpose Timers**: Six 32-bit and six 64-bit timers that can be split into two 16-bit and 32-bit timers, respectively. Each timer can be used to configure as
  - Counter mode: to generate required amount of delay
  - Capture and compare mode: used to create periodic interrupts and measure period, pulse width, phase as well as frequency
- **Watchdog Timers**: There are two 32-bit watchdog timers that can be used for regaining system control.

# 3. Communication Interfaces

## TM4C123 MICROCONTROLLER PERIPHERALS

The TM4C123 has following serial communication interfacing peripherals.

- **UART**: 8 Universal Asynchronous Receiver/Transmitter (UART) interfaces, which can be used for asynchronous point to point serial communication between two devices. It allows simultaneous communication in both directions making its communication full-duplex.
- **SSI/SPI**: 4 Synchronous Serial Interfaces/Serial Peripheral Interface (SPI) which is also full-duplex.
- **I2C**: 4 I2C interfaces, which is a serial bus interface that can be used to connect multiple devices. The I2C bus is half-duplex.
- **CAN**: 2 CAN (controller area network) interfaces, commonly used in automotive and DCS
- **USB**: 1 USB device interface is also available on the TM4C123 microcontroller

# 4. Analog Interfacing Peripherals

## TM4C123 MICROCONTROLLER PERIPHERALS

- There are two 12-bit **analog-to-digital converters** (ADCs) available in TM4C123. The ADC is used for converting the analog signals to their digital equivalent, which is required for many data acquisition applications.
- In addition to ADCs, there are **analog comparators** available on the microcontroller. These analog comparators can be used for converting an analog signal to binary logical signal based on the thresholding principle. In addition, it can also be used for comparing two analog input signals.

# Summary TM4C123 Microcontroller Peripherals

| Peripheral | Description |
|---|---|
| GPIOs | 43 configurable pins for this purpose. |
| System Clock | 80 MHz maximum, can be configured arbitrarily using PLL |
| Hibernate | Operates in lower power mode using backup battery |
| UART | Eight UART modules with maximum baud rate of 10 Mbps |
| SPI | Four SPI modules with transmit & receive FIFOs |
| I2C | Four I2C bus interfaces configurable as master or slave |
| CAN | Two CAN modules supporting protocol versions 2.0 A/B |
| USB | One USB device interface |
| 32-bit Timers | Six 32-bit timers with each timer constructed from two 16-bit timers concatenated. Can be used as 16-bit timer |
| 64-bit Timers | Six 64-bit timers with each timer constructed from two 32-bit timers concatenated. Can be used as 32-bit timer |
| Watchdog Timers | Two watchdog 32-bit timer modules |
| ADC | Two analog to digital converters with 12-bit resolution |
| Comparators | Two analog comparators |
| QEI | Two quadrature encoder inputs |
| EEPROM | 2 KB on chip EEPROM for storing configuration and other data |

# Alternate Functionality

## TM4C123 MICROCONTROLLER PERIPHERALS

- Some of the GPIO pins are multiplexed for one or more alternate peripheral functionalities.
- These GPIO pins can be configured for one of the available alternate functions by using associated configuration registers
- In addition, the GPIO pin can be reconfigured to a different functionality at run time as well.

# Alternate Functionality on TM4C123 (Port A & B)

| Port Pin | Analog | Port control register GPIO_PCTL_R, configuration values for alternate function. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| PA0 | | U0Rx | | | | | | | CAN1Rx |
| PA1 | | U0Tx | | | | | | | CAN1Tx |
| PA2 | | | SPI0Clk | | | | | | |
| PA3 | | | SPI0CS | | | | | | |
| PA4 | | | SPI0Rx | | | | | | |
| PA5 | | | SPI0Tx | | | | | | |
| PA6 | | | | I2C1SCL | | M1PWM2 | | | |
| PA7 | | | | I2C1SDA | | M1PWM3 | | | |
| PB0 | USB0ID | U1Rx | | | | | | T2CC0 | |
| PB1 | USB0VBUS | U1Tx | | | | | | T2CC1 | |
| PB2 | | | | I2C0SCL | | | | T3CC0 | |
| PB3 | | | | I2C0SCL | | | | T3CC1 | |
| PB4 | AIN10 | | SPI2Clk | | M0PWM2 | | | T1CC0 | CAN0Rx |
| PB5 | AIN11 | | SPI2CS | | M0PWM3 | | | T1CC1 | CAN0Tx |
| PB6 | | | SPI2Rx | | M0PWM0 | | | T0CC0 | |
| PB7 | | | SPI2Tx | | M0PWM1 | | | T0CC1 | |

# Alternate Functionality on TM4C123 (Port C & D)

| Port Pin | Analog | Port control register GPIO_PCTL_R, configuration values for alternate function. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| PC0 | | TCK/ SWCLK | | | | | | T4CC0 | |
| PC1 | | TMS/ SWDIO | | | | | | T4CC1 | |
| PC2 | | TDI | | | | | | T5CC0 | |
| PC3 | | TDO/ SWO | | | | | | T5CC1 | |
| PC4 | C1- | U4Rx | U1Rx | | M0PWM6 | | IDX1 | WT0CC0 | U1RTS |
| PC5 | C1+ | U4Tx | U1Tx | | M0PWM7 | | PhA1 | WT0CC1 | U1CTS |
| PC6 | C0+ | U3Rx | | | | | PhB1 | WT1CC0 | USB0EPEN |
| PC7 | C0- | U3Tx | | | | | | WT1CC1 | USB0PFLT |
| PD0 | AIN7 | SPI3Clk | SPI3Clk | I2C3SCL | M0PWM6 | M1PWM0 | | WT2CC0 | |
| PD1 | AIN6 | SPI3CS | SPI1CS | I2C3SDA | M0PWM7 | M1PWM1 | | WT2CC0 | |
| PD2 | AIN5 | SPI3Rx | SPI1Rx | | M0FAULT0 | | | WT3CC0 | USB0EPEN |
| PD3 | AIN4 | SPI3Tx | SPI1Tx | | | | IDX0 | WT3CC0 | USB0PFLT |
| PD4 | USB0DM | U6Rx | | | | | | WT4CC0 | |
| PD5 | USB0DP | U6Tx | | | | | | WT4CC1 | |
| PD6 | | U2Rx | | | M0FAULT0 | | PhA0 | WT5CC0 | |
| PD7 | | U2Tx | | | | | PhB0 | WT5CC0 | NMI |

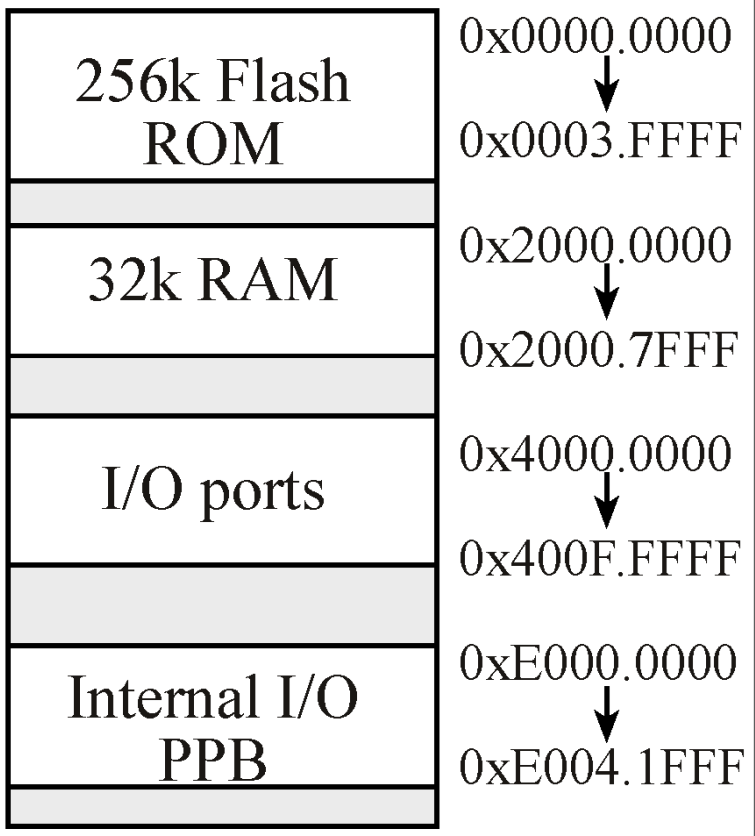
# Alternate Functionality on TM4C123 (Port E & F)

| Port Pin | Analog | Port control register GPIO_PCTL_R, configuration values for alternate function. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 14 |
| PE0 | AIN3 | U7Rx | | | | | | | | | |
| PE1 | AIN2 | U7Tx | | | | | | | | | |
| PE2 | AIN1 | | | | | | | | | | |
| PE3 | AIN0 | | | | | | | | | | |
| PE4 | AIN9 | U5Rx | | I2C2SCL | M0PWM4 | M1PWM2 | | | CAN0Rx | | |
| PE5 | AIN8 | U5Tx | | I2C2SDA | M0PWM5 | M1PWM3 | | | CAN0Tx | | |
| PF0 | | U1RTS | SPI1Rx | CAN0Rx | | M1PWM4 | PhA0 | T0CC0 | NMI | C0o | |
| PF1 | | U1CTS | SPI1Tx | | | M1PWM5 | PhB0 | T0CC1 | | C1o | TRD1 |
| PF2 | | | SPI1Clk | | M0FAULT0 | M1PWM6 | | T1CC0 | | | TRD0 |
| PF3 | | | SPI1CS | CAN0Tx | | M1PWM7 | | T1CC1 | | | TRClk |
| PF4 | | | | | | M1FAULT0 | IDX0 | T2CC0 | USB0EPEN | | |

# Peripherals on Memory Map

## TM4C123 MICROCONTROLLER PERIPHERALS

- The TM4C123 microcontroller is an ARM Cortex-M architecture which uses memory mapped peripherals.
- The microcontroller has a fixed memory map that provides up to 4 GB of addressable memory.
- Since TM4C123 microcontroller has 256 KB on-chip Flash (code) memory, the corresponding addressable range in code memory region is 0x00000000 to 0x0003FFFF.
- Similarly, the data memory (RAM) address range is 0x20000000 to 0x20007FFF, which shows that TM4C123 has 32 KB on-chip RAM.
- Address range 0x40000000 to 0x400FFFFF assigned to microcontroller peripherals and is allocated to different configuration, control, status, and data registers associated with that peripheral.



# Peripherals on Memory Map

## TM4C123 MICROCONTROLLER PERIPHERALS

| Start Address | End Address | Description |
|---|---|---|
| 0x0000.0000 | 0x0003.FFFF | On-chip Flash Memory |
| 0x2000.0000 | 0x2000.7FFF | On-chip SRAM |
| 0x4000.0000 | 0x4000.0FFF | Watchdog timer 0 |
| 0x4000.1000 | 0x4000.1FFF | Watchdog timer 1 |
| 0x4000.4000 | 0x4000.4FFF | GPIO Port A Registers APB bus |
| 0x4000.5000 | 0x4000.5FFF | GPIO Port B Registers APB bus |
| 0x4000.6000 | 0x4000.6FFF | GPIO Port C Registers APB bus |
| 0x4000.7000 | 0x4000.7FFF | GPIO Port D Registers APB bus |
| 0x4000.8000 | 0x4000.8FFF | SSI 0 or SPI 0 Interface |
| 0x4000.9000 | 0x4000.9FFF | SSI1 or SPI 1 Interface |
| 0x4000.A000 | 0x4000.AFFF | SSI 2 or SPI 2 Interface |
| 0x4000.B000 | 0x4000.BFFF | SSI 3 or SPI 3 Interface |
| 0x4000.C000 | 0x4000.CFFF | UART 0 Communication Interface |
| 0x4000.D000 | 0x4000.DFFF | UART 1 Communication Interface |
| ⋮ | ⋮ | ⋮ |
| 0x4001.3000 | 0x4001.3FFF | UART 7 Communication Interface |
| 0x4002.0000 | 0x4002.0FFF | I2C 0 Communication Bus |
| 0x4002.1000 | 0x4002.1FFF | I2C 1 Communication Bus |
| 0x4002.2000 | 0x4002.2FFF | I2C 2 Communication Bus |

| Start Address | End Address | Description |
|---|---|---|
| 0x4002.3000 | 0x4002.3FFF | I2C 3 Communication Bus |
| 0x4002.4000 | 0x4002.4FFF | GPIO Port E Registers APB bus |
| 0x4002.5000 | 0x4002.5FFF | GPIO Port F Registers APB bus |
| 0x4002.8000 | 0x4002.8FFF | PWM 0 module registers |
| 0x4002.9000 | 0x4002.9FFF | PWM 1 module registers |
| 0x4003.0000 | 0x4003.0FFF | 16/32-bit Timer 0 |
| ⋮ | ⋮ | ⋮ |
| 0x4003.5000 | 0x4003.5FFF | 16/32-bit Timer 5 |
| 0x4003.6000 | 0x4003.6FFF | 32/64-bit Timer 0 |
| 0x4003.7000 | 0x4003.7FFF | 32/64-bit Timer 1 |
| 0x4003.8000 | 0x4003.8FFF | ADC 0 |
| 0x4003.9000 | 0x4003.9FFF | ADC 1 |
| 0x4003.C000 | 0x4003.CFFF | Analog Comparators |
| 0x4004.0000 | 0x4004.0FFF | CAN 0 Controller |
| 0x4005.8000 | 0x4005.8FFF | GPIO Port A AHB bus |
| ⋮ | ⋮ | ⋮ |
| 0x4005.D000 | 0x4005.DFFF | GPIO Port F AHB bus |

# THANK YOU

Any Questions???