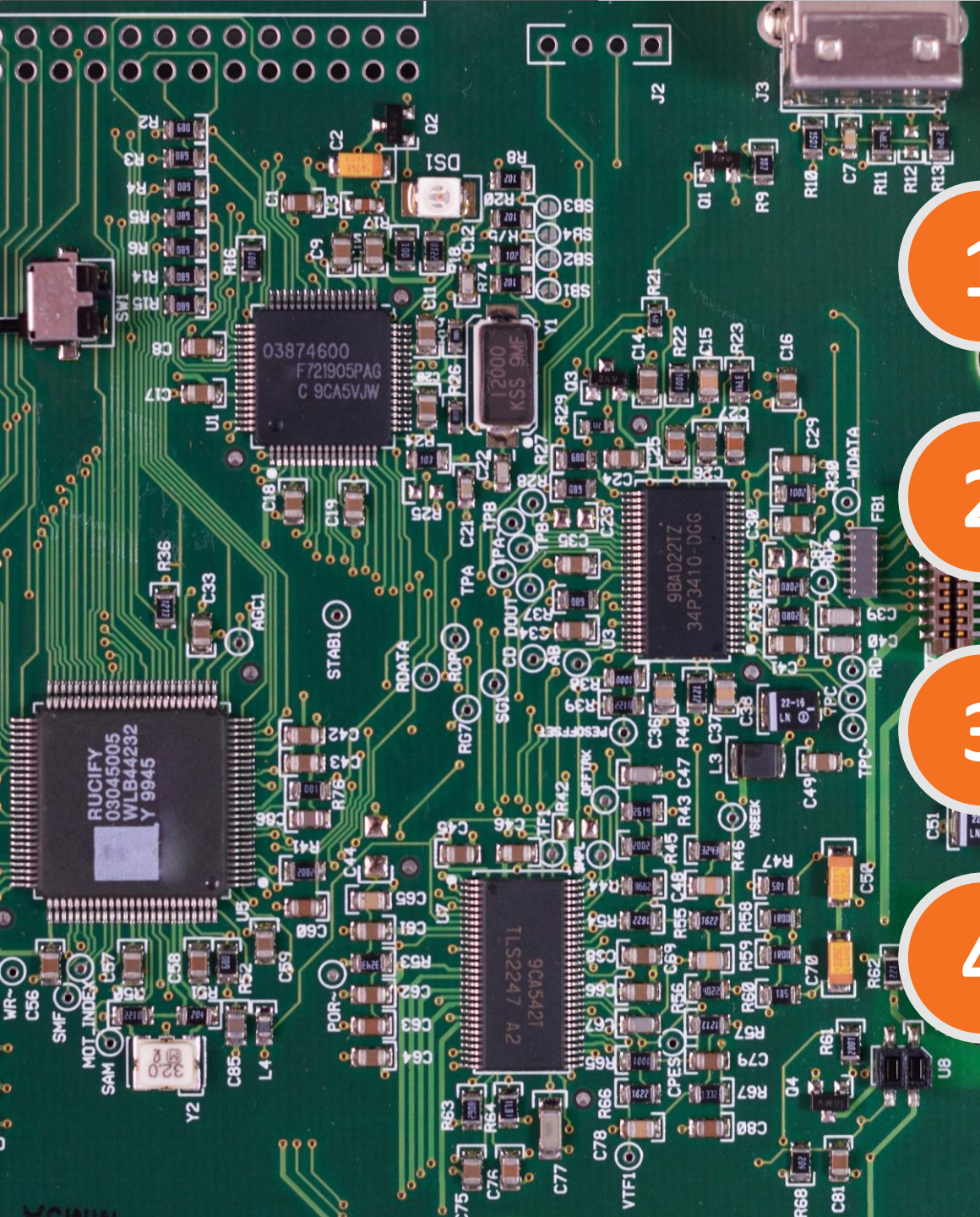




Lecture 04

Introduction to TM4C123 Microcontroller

MCT-236: Embedded Systems-I



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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
- Execution speed and memory sizes
- The availability of low cost and user-friendly evaluation platform
- Programming and debugging tools and documentation

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.

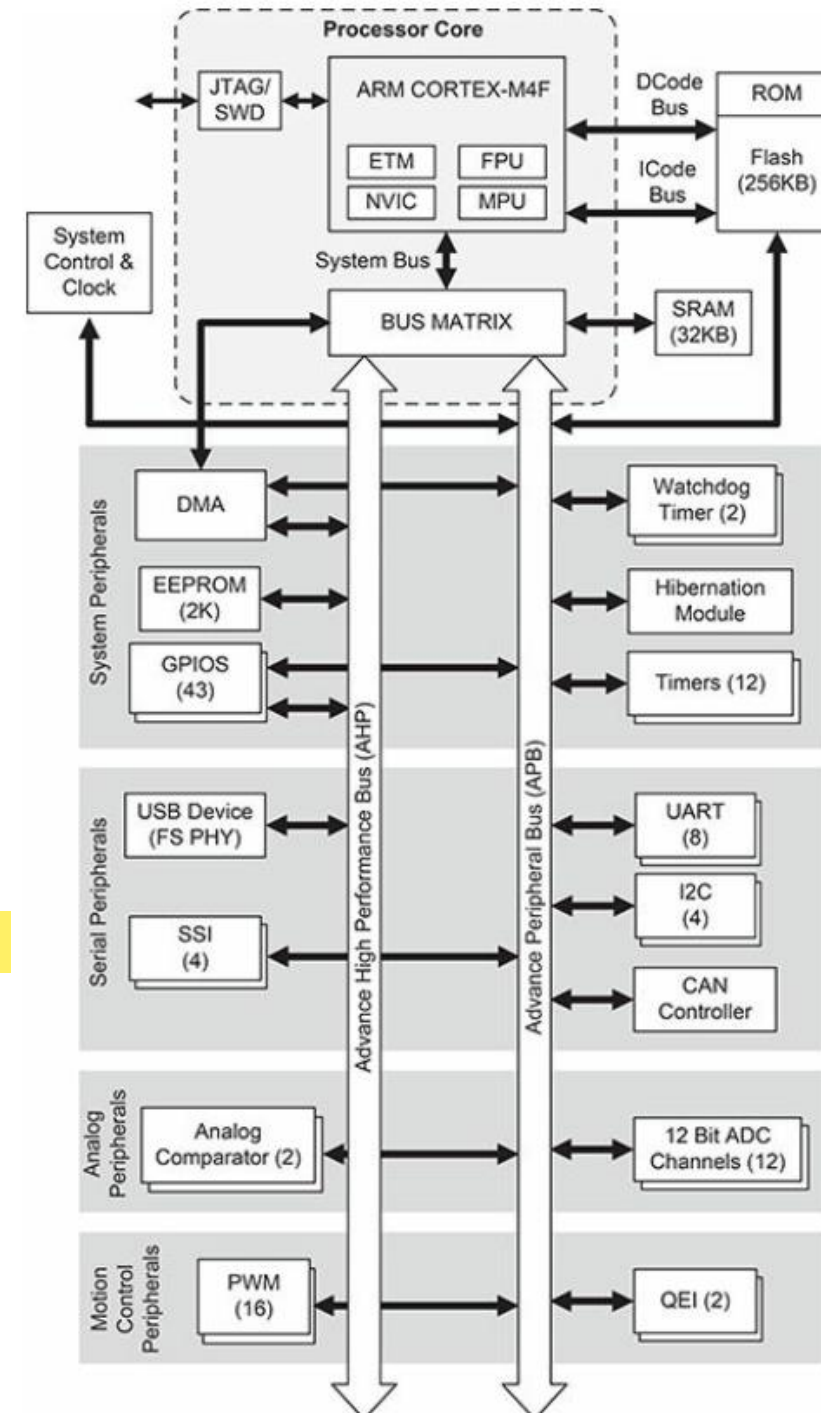
- **Clock frequency:** Processor clock frequency up to 80 MHz with floating point unit (FPU).
- **System timer SysTick:** SysTick is 24-bit, clear-on-write, decrementing timer. Its flexible control allows its use for the purpose of system time base generation.
- **Debugging interface** using JTAG/SWD: 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 with following addition:
 - supports the tail- chaining functionality to reduce interrupt latency
 - Supports 7 system exceptions and 65 peripheral interrupts
 - 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.



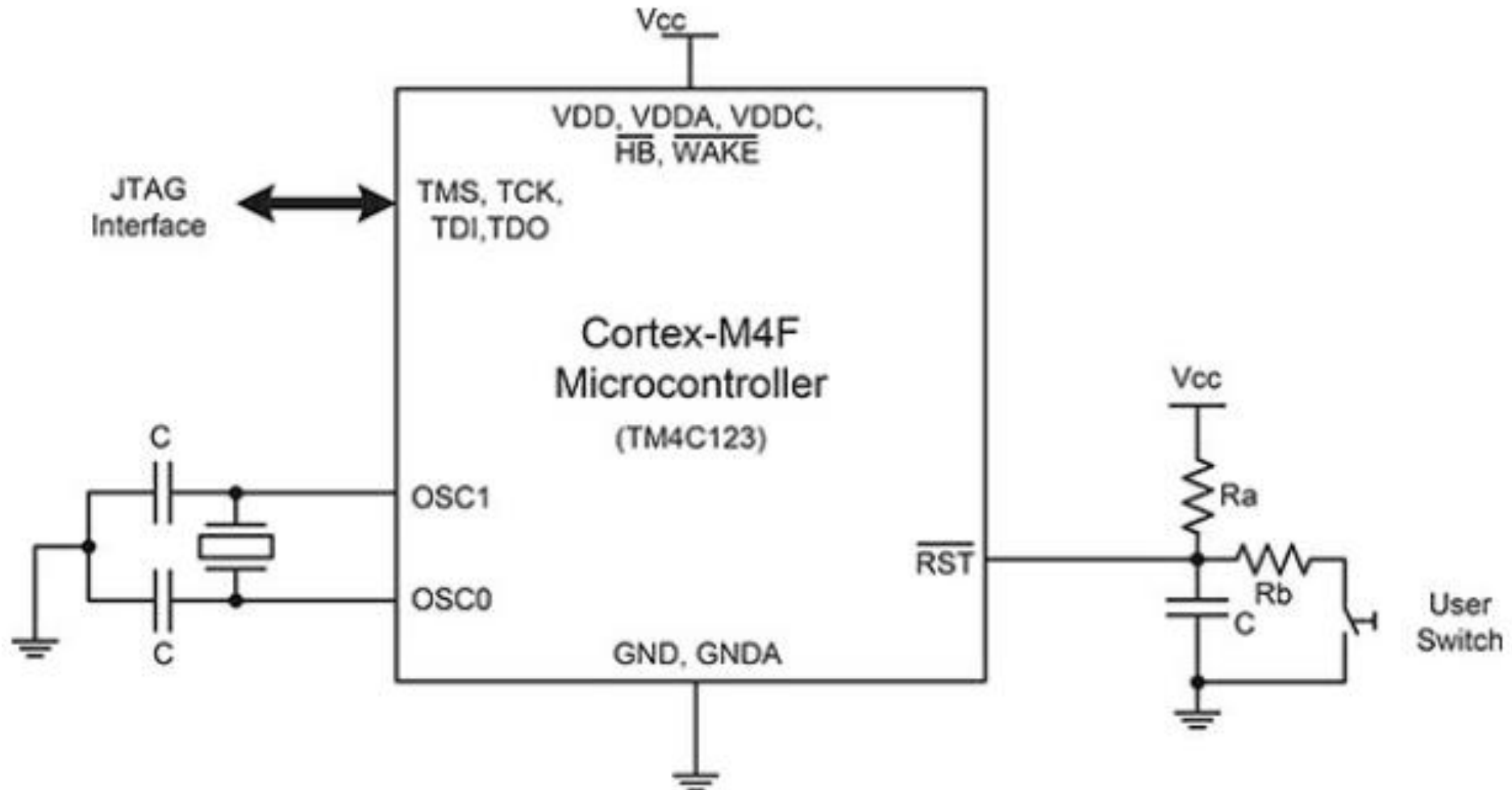
Minimum Connectivity for TM4C123

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.

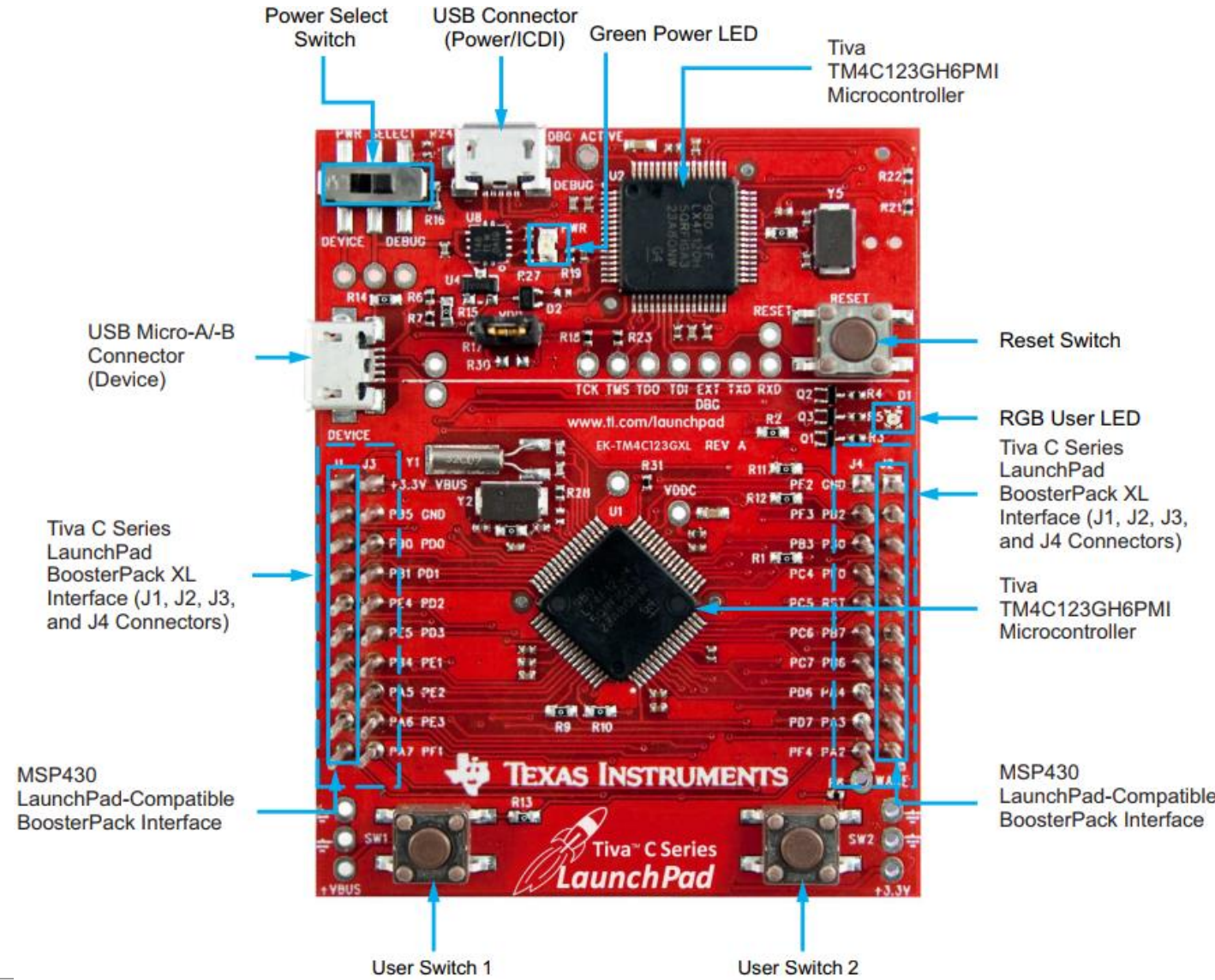
Reset connection: Each microcontroller has a reset pin for hardware reset capability. This pin should be wired according to the recommendation of the chip manufacturer for proper functioning.

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

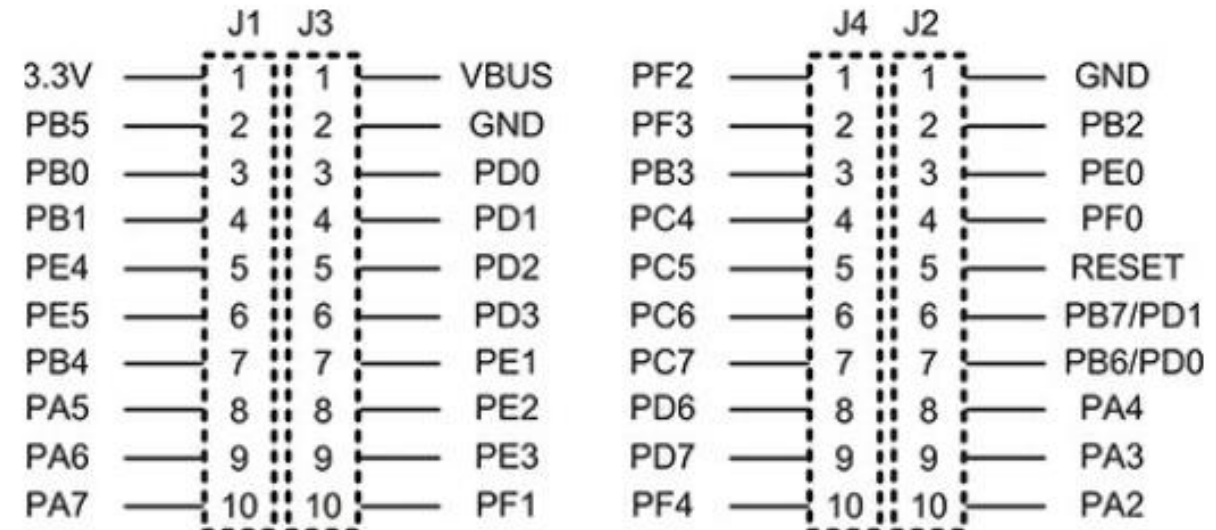
- The microcontroller platform used in this course is based on the Texas Instruments Tiva C series launchpad evaluation board.
- The development board is based on the TM4C123 microcontroller and provides **expansion headers** for peripheral interfacing.
- This platform is equipped with an on-board integrated **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

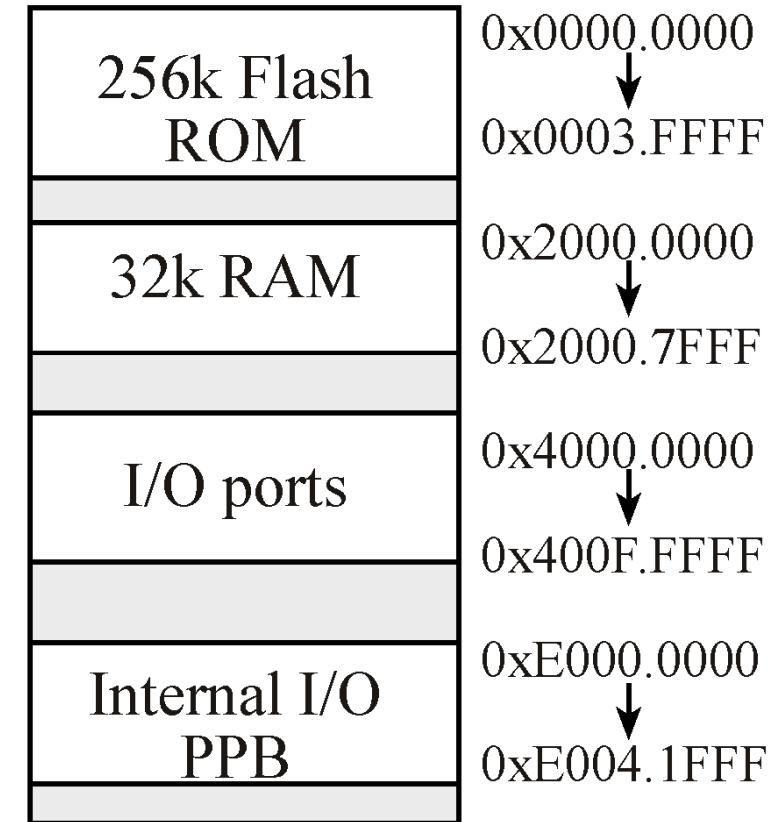
Alternate Functionality on TM4C123 (Port E & F)

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 0x400FFFFFFF 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	Start Address	End Address	Description
0x0000.0000	0x0003.FFFF	On-chip Flash Memory	0x4002.3000	0x4002.3FFF	I2C 3 Communication Bus
0x2000.0000	0x2000.7FFF	On-chip SRAM	0x4002.4000	0x4002.4FFF	GPIO Port E Registers APB bus
0x4000.0000	0x4000.0FFF	Watchdog timer 0	0x4002.5000	0x4002.5FFF	GPIO Port F Registers APB bus
0x4000.1000	0x4000.1FFF	Watchdog timer 1	0x4002.8000	0x4002.8FFF	PWM 0 module registers
0x4000.4000	0x4000.4FFF	GPIO Port A Registers APB bus	0x4002.9000	0x4002.9FFF	PWM 1 module registers
0x4000.5000	0x4000.5FFF	GPIO Port B Registers APB bus	0x4003.0000	0x4003.0FFF	16/32-bit Timer 0
0x4000.6000	0x4000.6FFF	GPIO Port C Registers APB bus	:	:	:
0x4000.7000	0x4000.7FFF	GPIO Port D Registers APB bus	0x4003.5000	0x4003.5FFF	16/32-bit Timer 5
0x4000.8000	0x4000.8FFF	SSI 0 or SPI 0 Interface	0x4003.6000	0x4003.6FFF	32/64-bit Timer 0
0x4000.9000	0x4000.9FFF	SSI1 or SPI 1 Interface	0x4003.7000	0x4003.7FFF	32/64-bit Timer 1
0x4000.A000	0x4000.AFFF	SSI 2 or SPI 2 Interface	0x4003.8000	0x4003.8FFF	ADC 0
0x4000.B000	0x4000.BFFF	SSI 3 or SPI 3 Interface	0x4003.9000	0x4003.9FFF	ADC 1
0x4000.C000	0x4000.CFFF	UART 0 Communication Interface	0x4003.C000	0x4003.CFFF	Analog Comparators
0x4000.D000	0x4000.DFFF	UART 1 Communication Interface	0x4004.0000	0x4004.0FFF	CAN 0 Controller
:	:	:	0x4005.8000	0x4005.8FFF	GPIO Port A AHB bus
0x4001.3000	0x4001.3FFF	UART 7 Communication Interface	:	:	:
0x4002.0000	0x4002.0FFF	I2C 0 Communication Bus	0x4005.D000	0x4005.DFFF	GPIO Port F AHB bus
0x4002.1000	0x4002.1FFF	I2C 1 Communication Bus			
0x4002.2000	0x4002.2FFF	I2C 2 Communication Bus			



THANK YOU

Any Questions???