SAMD21 ARM Cortex-M0+ Microcontroller & MCC Harmony

SMA2001-MCC

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

CAE Taiwan
Microchip Technology Inc.

March 31, 2023

Class Objectives

- **When you finish this course, you will be able to:**
  - Be familiar with MPLAB X IDE and MCC Harmony
  - Understand how to configure and use the SAMD21 series peripherals.
- **There have two level course included.**
  - Major course : General study of basic features.
  - Appendix : Advance features and appendix.

Major Course (1/3)

- SAMD21 ARM Cortex-M0+ Microcontroller Introduction
- MPLAB® X IDE, MCC Harmony and Development Tools Introduction
- SAMD21 EVB APP045 v4.20 Introduction
- Getting Started with First Project
  - 💻 Lab0 First Project
- MPLAB® Code Configurator Harmony Interface introduction
  - 🎯 Study Advanced Features
- PORT I/O Architecture
  - 💻 Lab1 PORT Output
  - 💻 Lab2 PORT Input and Output
- Timer/Counter, TC Architecture
  - 💻 Lab3 TC Timer Method Polling
  - 💻 Lab4 TCs Timer Method Polling

Major Course (2/3)

- NVIC Architecture
  - 💻 Lab5 TC Timer Method Interrupt Callback
  - 💻 Lab6 TCs Timer Method Interrupt Callback
  - 🎯 Study Advanced Features
- Clock System Architecture
  - 💻 Lab7 System Clock XOSC32K
  - 💻 Lab8 System Clock DFLL48M
- Pin Multiplexer (PINMUX)
- SERCOM - UART Architecture
  - 💻 Lab9 SERCOM - UART Tx Polling
  - 💻 Lab10 SERCOM - UART TxRx Interrupt Callback
  - 💻 Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

Major Course (3/3)

- High Speed ADC Architecture
  - Lab12 ADC Polling Software Trigger
- ADC Interrupt Callback and Pin Scan
  - Lab13 ADC Pin Scan
- TCC – PWM Architecture
  - Lab14 TCC NPWM
  - Lab15 TCC NPWM ADC Duty Control
  - Lab16 TCC NPWM Auto Duty Control
- SERCOM-SPI (OLED SSD1306)
  - Lab17 SERCOM - SPI SSD1306 OLED

SAMD21 ARM Cortex-M0+ Microcontroller Introduction

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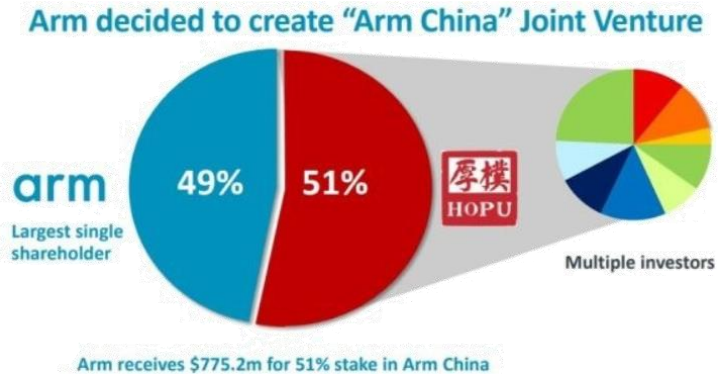
ARM’s history

- **ARM**, previously **A**dvanced **R**ISC **M**achine, is a family of reduced instruction set computing (RISC) architectures for computer processors. Arm Holdings develops the architecture and licenses it to other companies, who design their own products that implement systems-on-chips (SoC) and systems-on-modules (SoM).
- SoftBank complete acquisition of ARM Holdings on September 5, 2016 (GMT) for a total acquisition price approximately USD 31.0 billion or JPY 3.3 trillion.
- SoftBank confirmed on June 4, 2018 that Arm Limited agreed sell a majority stake in its Chinese subsidiary Arm Technology (China) Co., Ltd. Under the terms of the Transaction, Arm will sell 51% of its equity interest in Arm China for USD 775.2 million to the Direct Investors.
- On 13 September 2020, it was announced that Nvidia would buy Arm from SoftBank for $40 billion, subject to regulatory approval, with the latter acquiring a 10% share in Nvidia.

SoftBank

ARM® | arm



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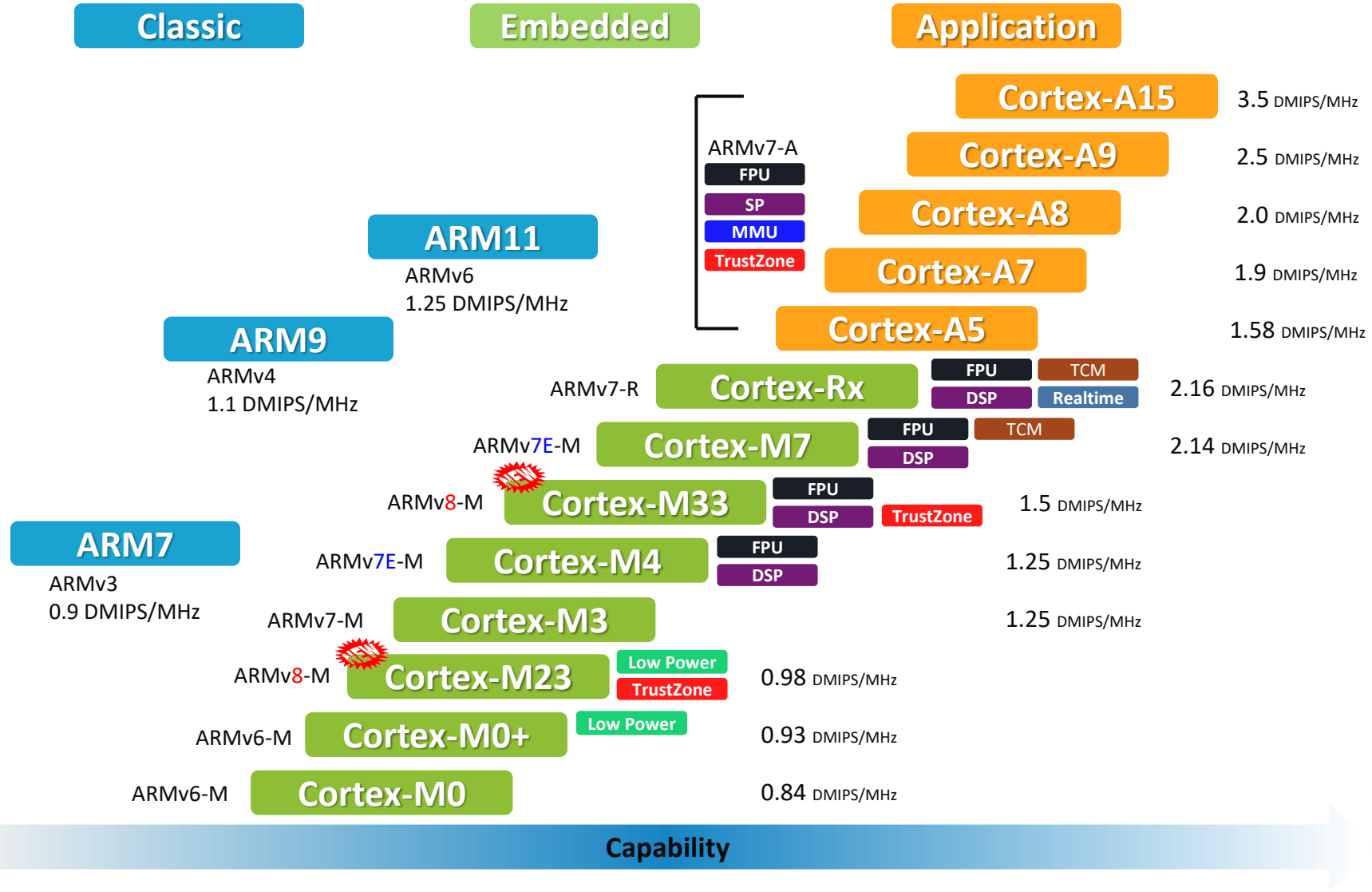
ARM in Partnership

ARM core MCU/MPU brief



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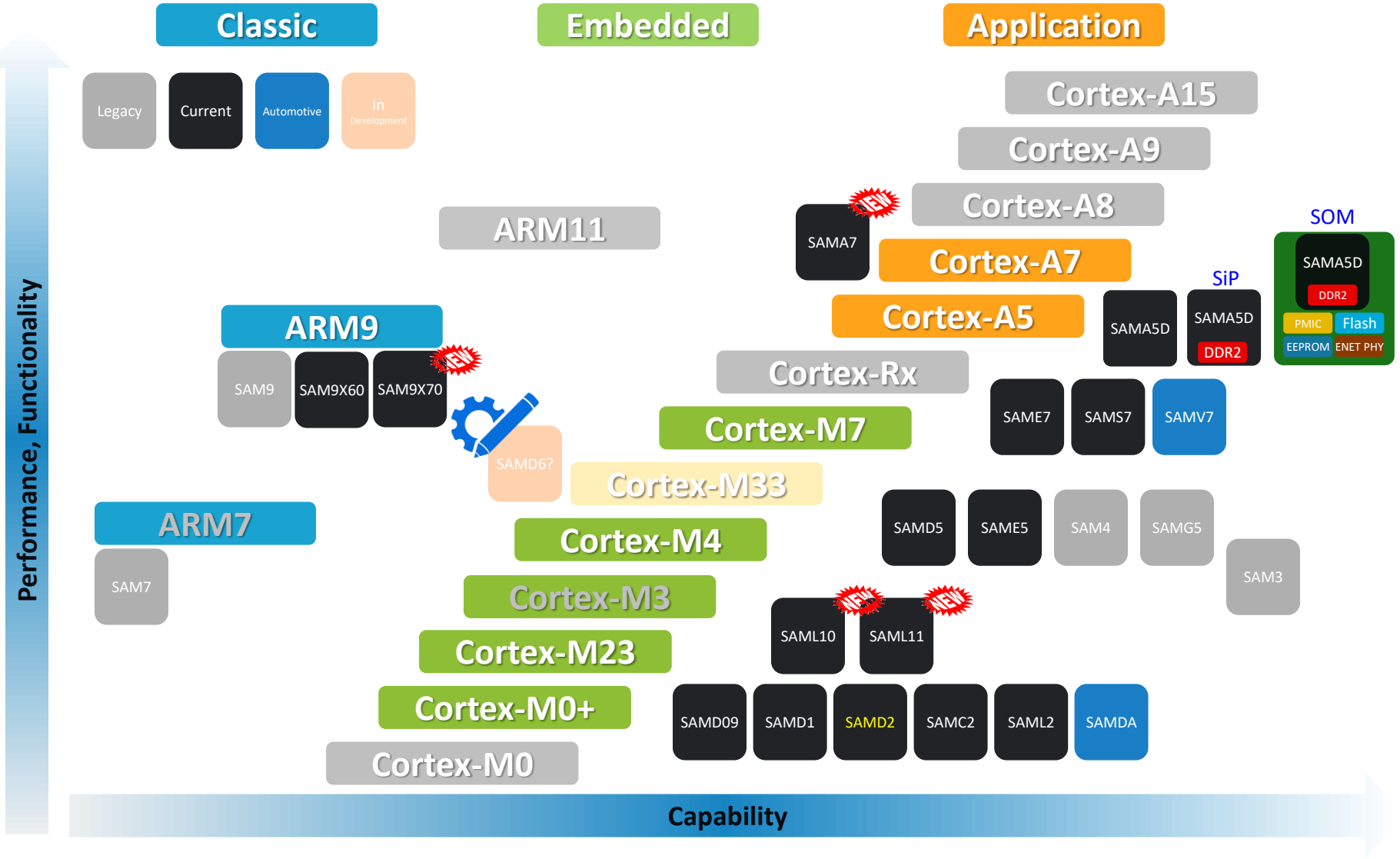
ARM core MCU/MPU success

Microchip ARM Core Products



Microchip Cortex-M MCU Series

- **Microchip 32 Bits (ARM core) MCU include below series :**
- **Cortex-M0+**
  - SAMD09/SAMD1x
    - Low pin count, high c/p.
  - SAMD2x
    - Rich peripheral.
  - SAMC2x
    - Support 5V and CAN bus.
  - SAML2x
    - Lowest power consumption and peripheral.
  - SAMDAx
    - Automotive certificated.
- **Cortex-M3, Cortex-M4 (Legacy)**
  - SAM3x, SAM4x, SAMG5x.

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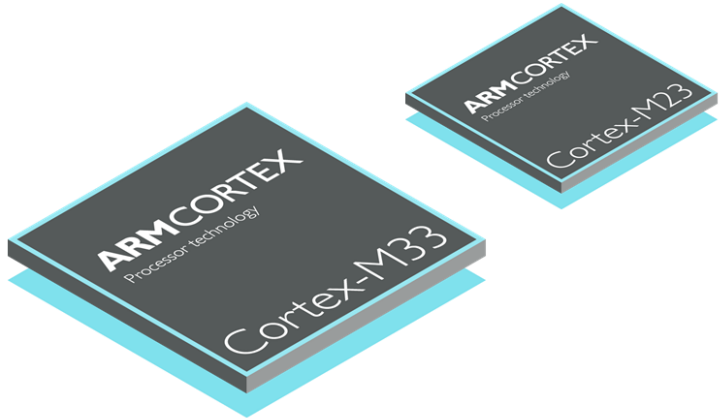
Microchip Cortex-M MCU Series (cont.)

- **Cortex-M4 (New generation)**
  - SAMD5x
    - Support float point FPU, crypto engine, USB , low power.
  - SAME5x
    - FPU, crypto engine, USB, Ethernet, CAN-FD, Low power.
- **Cortex-M23**
  - SAML1x
    - Very low power, support TrustZone.
- **Cortex-M33 (Coming soon)**
  - SAMD6x
    - High performance, support TrustZone.



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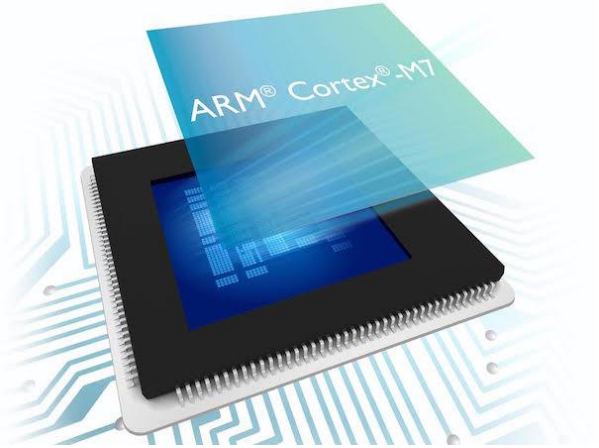
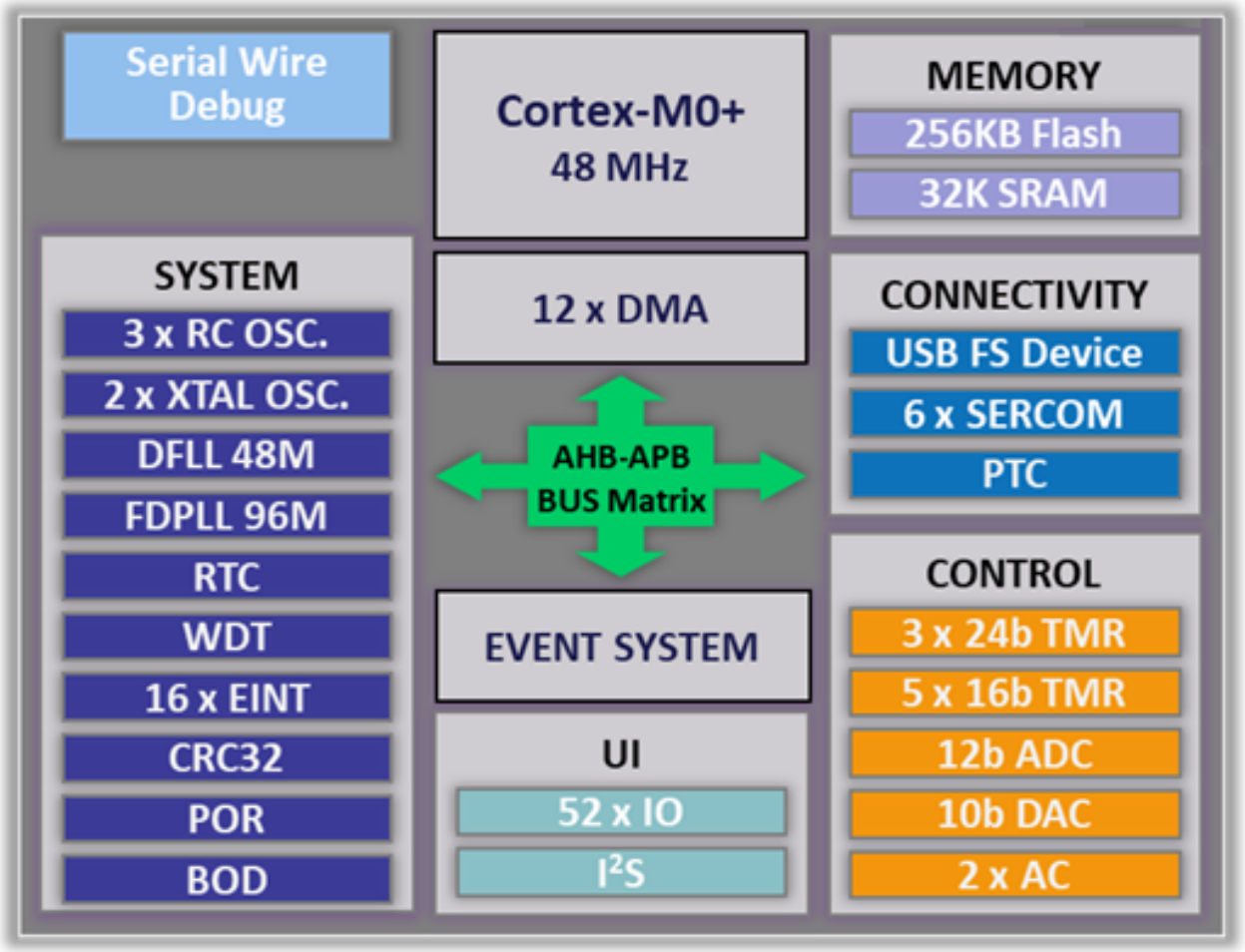
Microchip Cortex-M MCU Series (cont.)

- **Cortex-M7**
  - SAMS7x
    - High performance, rich peripheral.
  - SAME7x
    - Ethernet support, CAN-FD support.
  - SAMV7x
    - Ethernet support, CAN-FD support, automotive certificated.



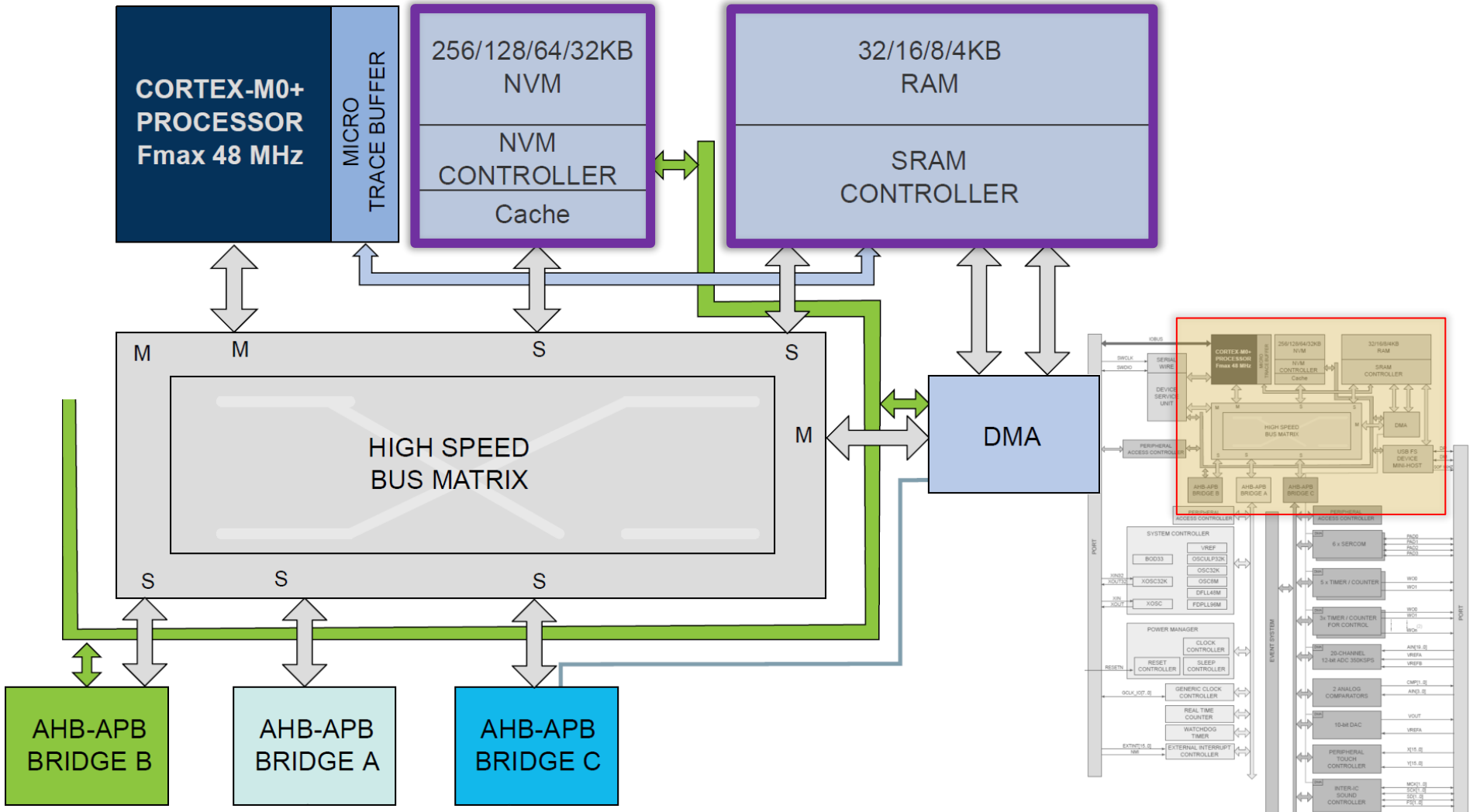
SAMD21 Block Diagram

- The SAMD21 is a series of low-power microcontrollers using the ARM® Cortex® M0+ processor (Cortexv6-M)。
- Maximum frequency of 48MHz and reach 2.46 CoreMark®/ MHz。
- All devices include intelligent and flexible peripherals, Event System for inter-peripheral signaling, and support for capacitive touch button, slider and wheel user interfaces。



Architecture

- Cortex M0+ is Von Neumann architecture, RISC



Architecture

- Cortex M0/M0+ Von Neumann

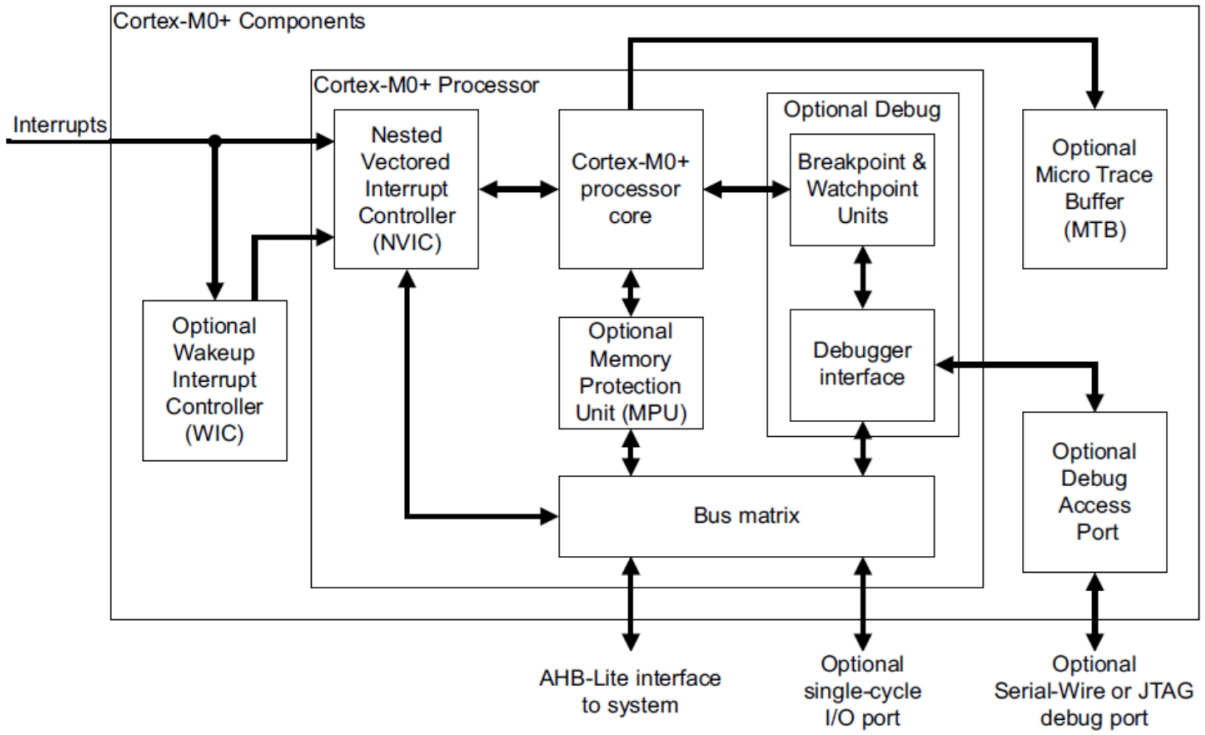


Figure 1-1 Cortex-M0+ implementation

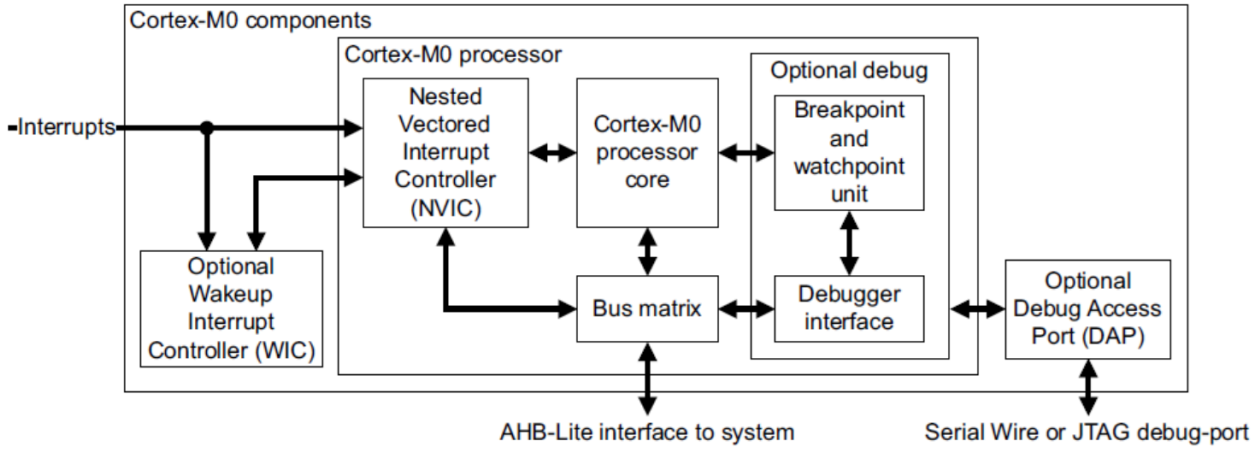


Figure 1-1 Cortex-M0 implementation

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Architecture

- Cortex M3 Harvard

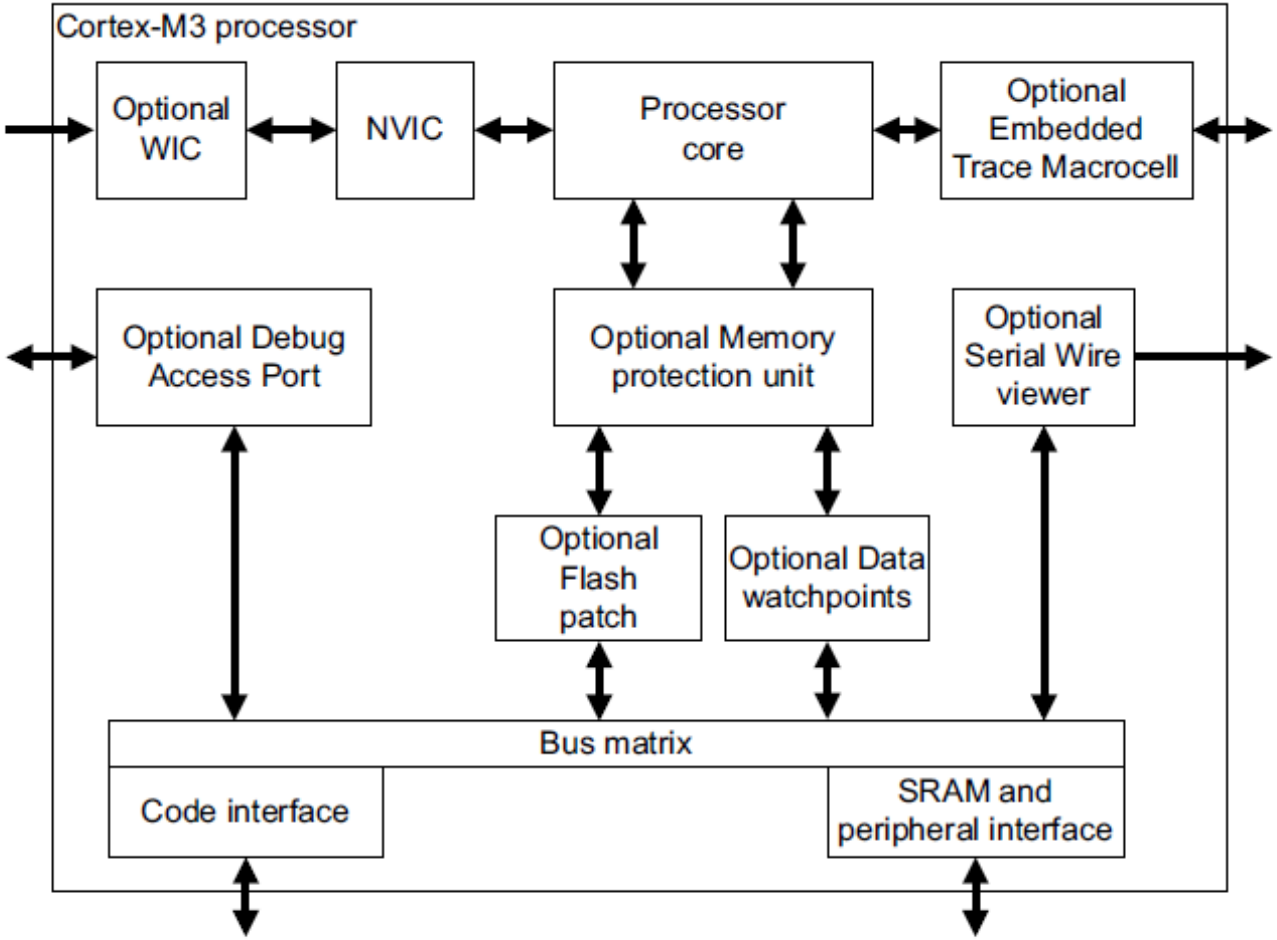

Figure 1-1 Cortex-M3 implementation

Architecture

ARM Cortex-M instruction variations

Arm Core	Cortex M0[2]	Cortex M0+[3]	Cortex M1[4]	Cortex M3[5]	Cortex M4[6]	Cortex M7[7]	Cortex M23[8]	Cortex M33[12]	Cortex M35P	Cortex M55
ARM architecture	ARMv6-M[9]	ARMv6-M[9]	ARMv6-M[9]	ARMv7-M[10]	ARMv7E-M[10]	ARMv7E-M[10]	ARMv8-M Baseline[15]	ARMv8-M Mainline[15]	ARMv8-M Mainline[15]	Armv8.1-M
Computer architecture	Von Neumann	Von Neumann	Von Neumann	Harvard	Harvard	Harvard	Von Neumann	Harvard	Harvard	Harvard
Instruction pipeline	3 stages	2 stages	3 stages	3 stages	3 stages	6 stages	2 stages	3 stages	3 stages	4 to 5 stages
Thumb-1 instructions	Most	Most	Most	Entire	Entire	Entire	Most	Entire	Entire	Entire
Thumb-2 instructions	Some	Some	Some	Entire	Entire	Entire	Some	Entire	Entire	Entire
Multiply instructions 32x32 = 32-bit result	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Multiply instructions 32x32 = 64-bit result	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Divide instructions 32/32 = 32-bit quotient	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Saturated instructions	No	No	No	Some	Yes	Yes	No	Yes	Yes	Yes
DSP instructions	No	No	No	No	Yes	Yes	No	Optional	Optional	Optional
Single-Precision (SP) Floating-point instructions	No	No	No	No	Optional	Optional	No	Optional	Optional	Optional
Double-Precision (DP) Floating-point instructions	No	No	No	No	No	Optional	No	No	No	Optional
Half-Precisions (HP)	No	No	No	No	No	No	No	No	No	Optional
TrustZone instructions	No	No	No	No	No	No	Optional	Optional	Optional	Optional
Co-processor instructions	No	No	No	No	No	No	No	Optional	Optional	Optional
Helium technology	No	No	No	No	No	No	No	No	No	Optional
Interrupt latency (if zero-wait state RAM)	16 cycles	15 cycles	23 for NMI 26 for IRQ	12 cycles	12 cycles	12 cycles 14 worst case	15 no security ext 27 security ext	12 no security ext ?? security ext	TBD	TBD

Link : https://en.wikipedia.org/wiki/ARM_Cortex-M

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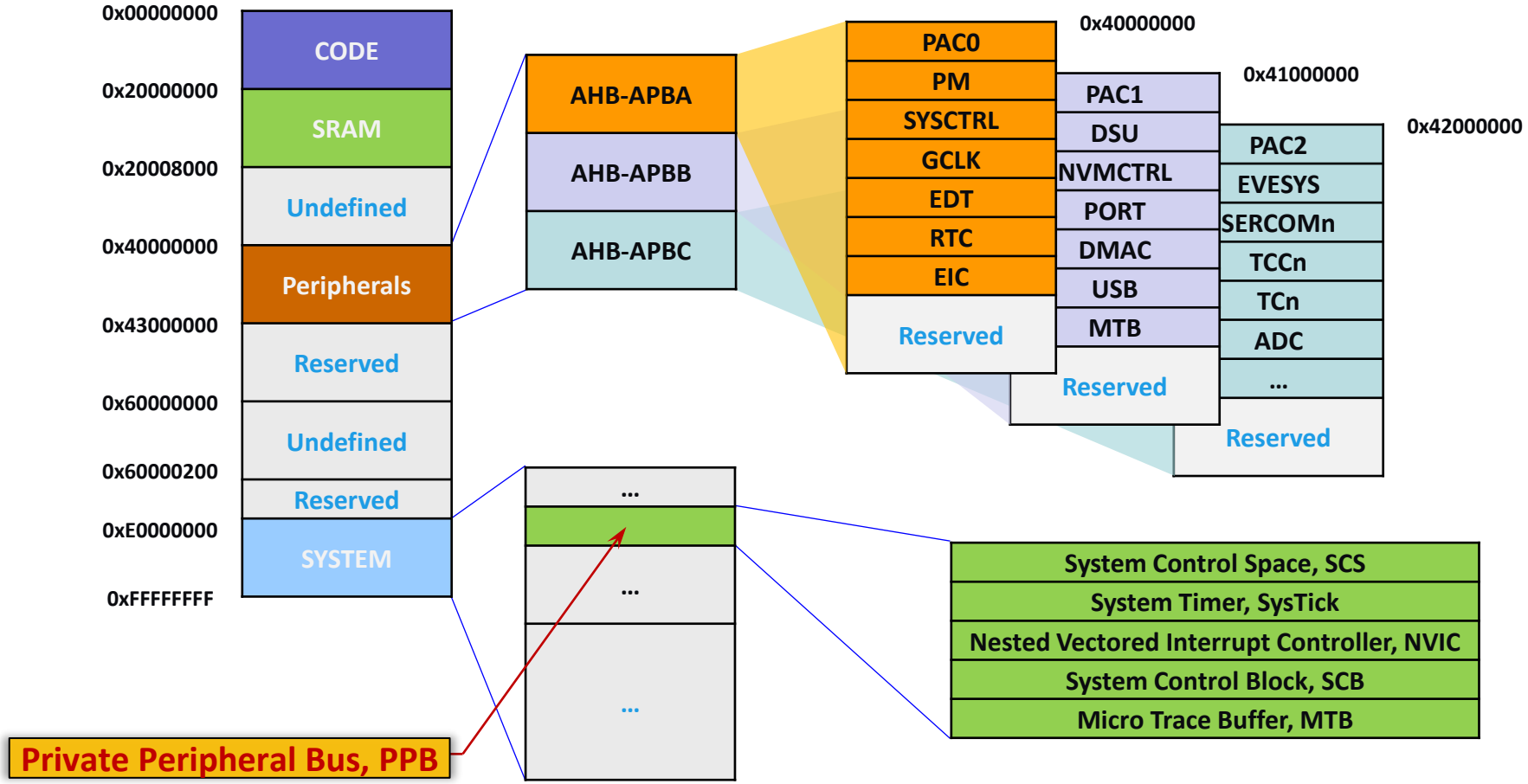
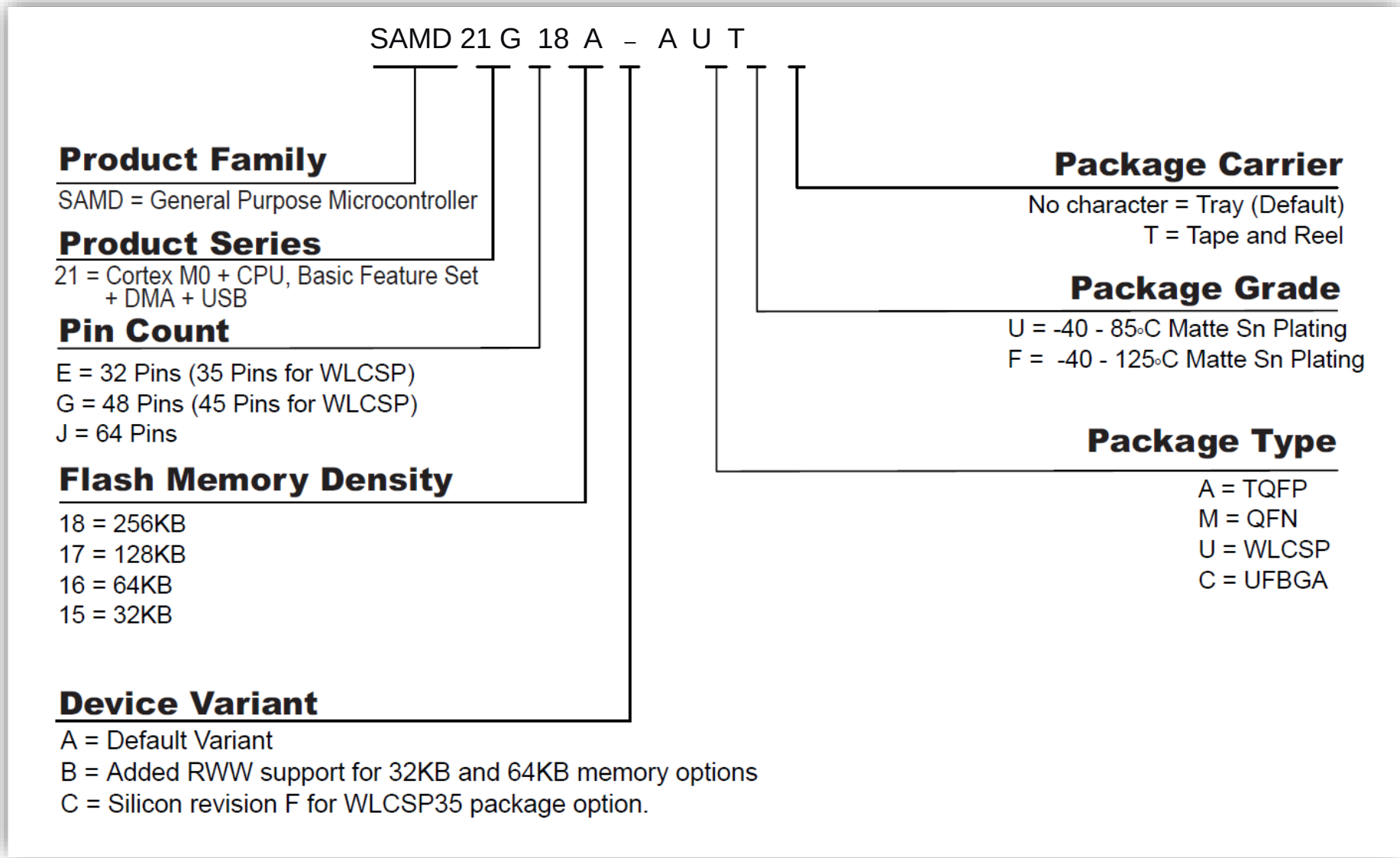
SAMD21 Memory

- Up to 256KB Flash and 32KB SRAM



Part Number


SAMD 21 G 18 A – A U T
Product Family
SAMD = General Purpose Microcontroller
Product Series
21 = Cortex M0 + CPU, Basic Feature Set + DMA + USB
Pin Count
E = 32 Pins (35 Pins for WLCSP)
G = 48 Pins (45 Pins for WLCSP)
J = 64 Pins
Flash Memory Density
18 = 256KB
17 = 128KB
16 = 64KB
15 = 32KB
Device Variant
A = Default Variant
B = Added RWW support for 32KB and 64KB memory options
C = Silicon revision F for WLCSP35 package option.
Package Carrier
No character = Tray (Default)
T = Tape and Reel
Package Grade
U = -40 - 85°C Matte Sn Plating
F = -40 - 125°C Matte Sn Plating
Package Type
A = TQFP
M = QFN
U = WLCSP
C = UFBGA

Soft Request In this Course

- **MPLAB® X IDE v6.05** https://www.microchip.com/mplab/mplab-x-ide
- **MPLAB® XC32 v4.21** https://www.microchip.com/mplab/compilers
- **MPLAB® Code Configurator v5.3.0**
- **MPLAB® MCC Harmony Framework (From X IDE MCC Harmony Content Manager)**
  - csp v3.16.0
  - Harmony-services v1.2.0
  - Quick_docs v1.6.0
  - dev_packs v3.15.1
- **SAMD21 DFP v3.6.144 (Device Family Pack) (From X IDE > Tools > Packs)**
- **CMSIS v5.8.0 (Common Microcontroller Software Interface Standard)**
- **SNAP tool packs v1.14.1052**

(Lasted Update : 2023/03/30)

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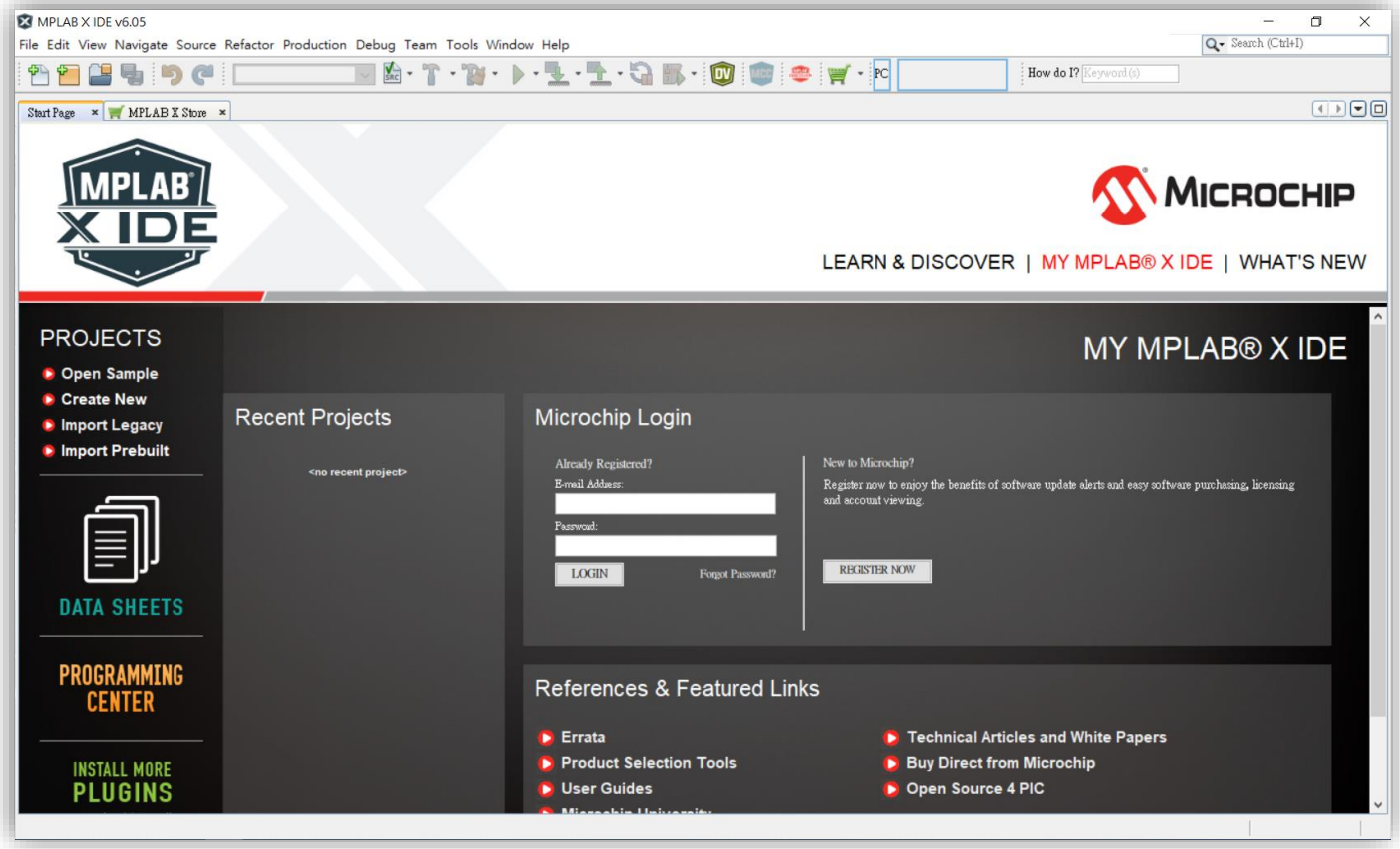
MPLAB® X IDE, MCC Harmony and Development Tools Introduction

All in One Development

MPLAB® X IDE

- **New generation integrated Development Tools, Support PIC, dsPIC, AVR, CEC and SAM Series MCU/MPU, Provide Plug-in function to extend more advance function. Java Based, Cross platform, Current version is v6.05.**

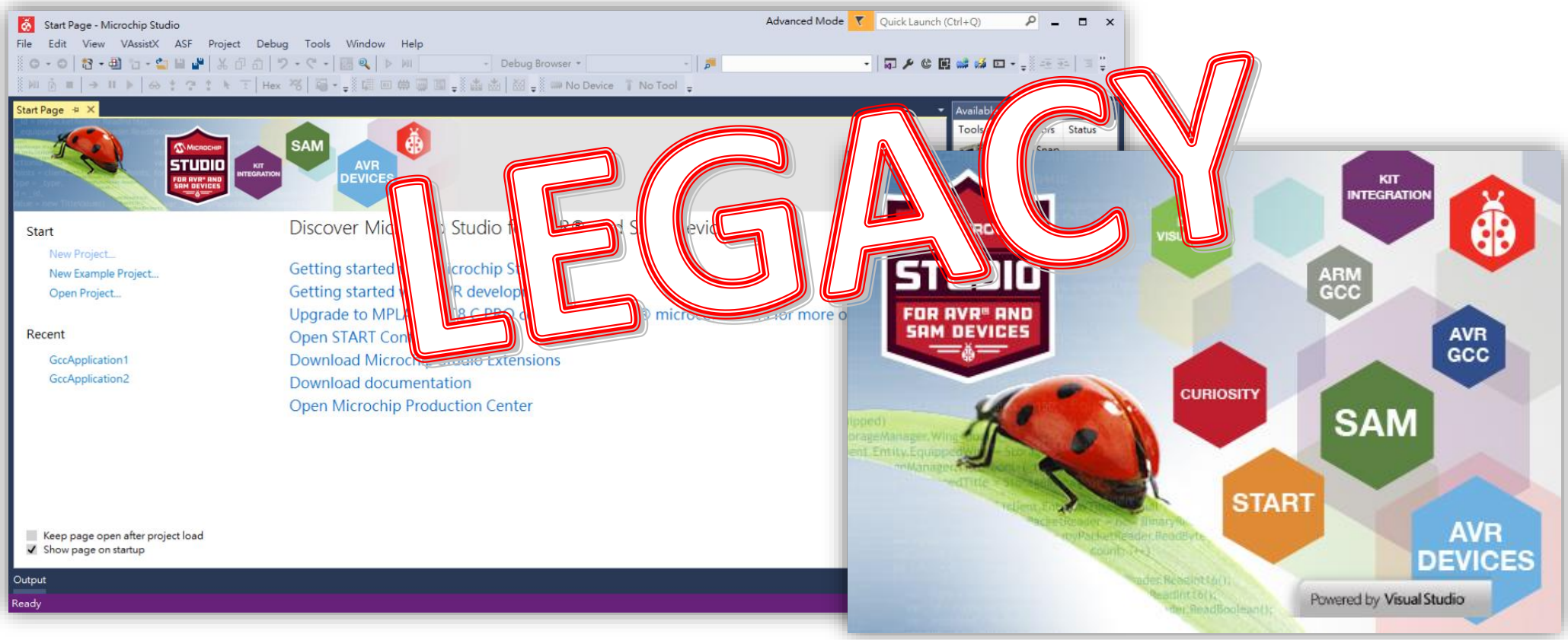


MICROCHIP

AVR/SAM Series Development

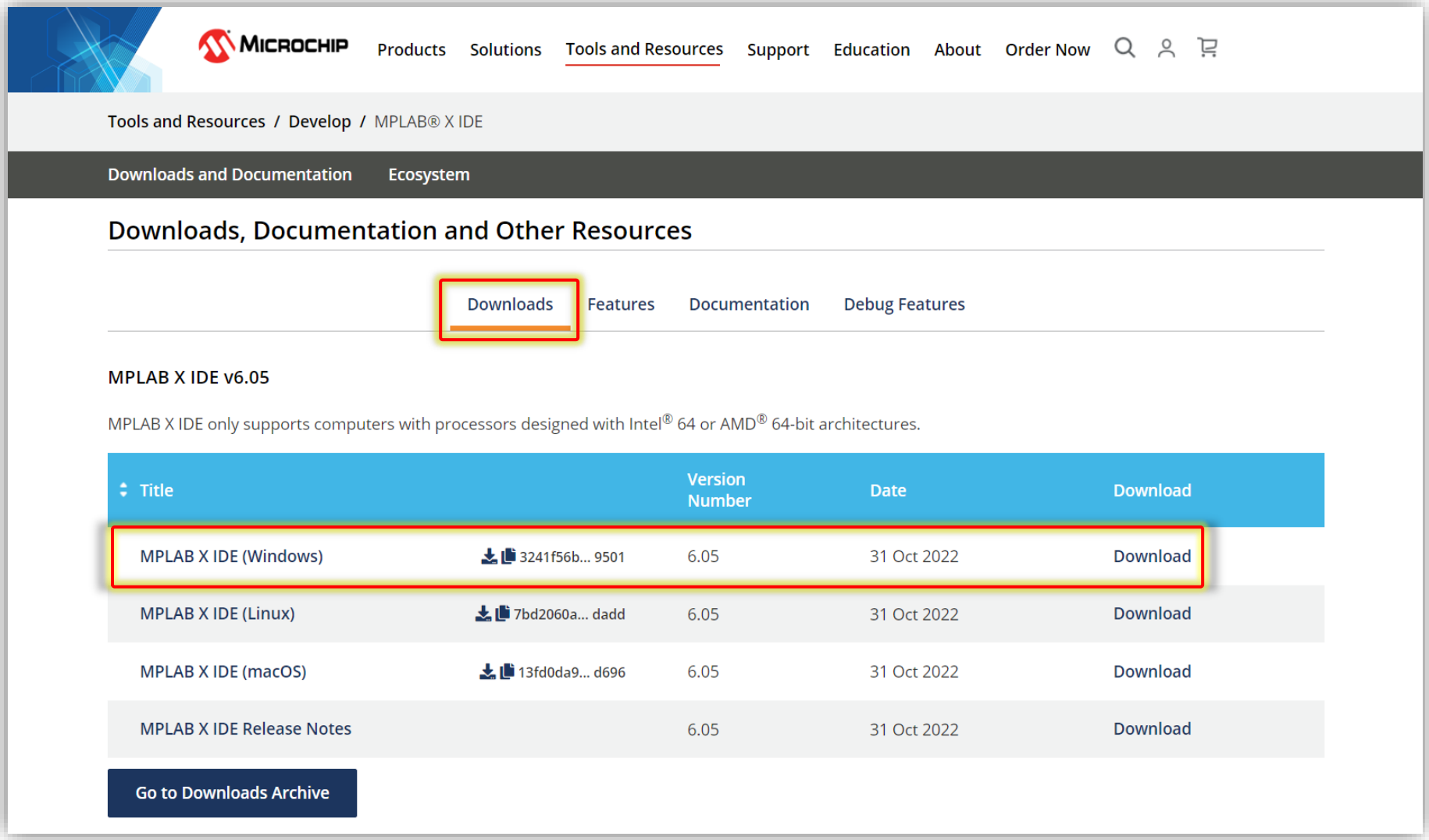
Atmel Studio 7 → Microchip Studio

- **New generation integrated Development Tools, Support AVR, SAM Series MCU/MPU, Current version is v7.0.2594.**
- **The GCC compilers already include support AVR/SAM series.**



Official Site Download Page

www.microchip.com/mplabX



MICROCHIP

Programmer/Debugger

PICkit 4 (Part No. PG164140)

- **The MPLAB® PICkit™ 4 In-Circuit Debugger/Programmer allows fast and easy debugging and programming of all PIC®, dsPIC®, AVR, SAM and CEC flash microcontrollers.**
- **Features**
  - Matches silicon clocking speed.
  - Target voltage of 1.20V to 5.5V.
  - Can supply up to 50mA of power to the target.
  - Minimal current consumption at <100µA from target.
  - Portable USB-powered and RoHS-compliant.
  - 8-pin single in-line header.
  - Backward compatible for demo boards, headers and target systems using 2-wire JTAG and ICSP.
  - Option to be self-powered from the target (2.7V to 5.5V).

$76.99

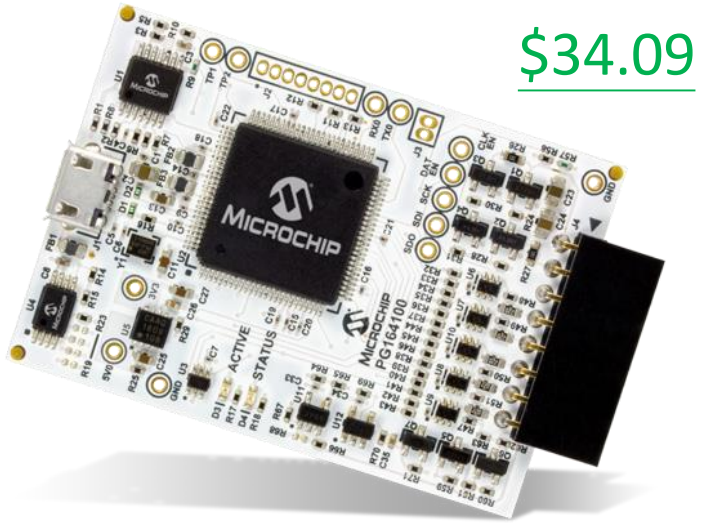
MICROCHIP

Programmer/Debugger

MPLAB SNAP (Part No. PG164100)

- **The MPLAB® SNAP In-Circuit Debugger/Programmer allows fast and easy debugging and programming of most PIC®, dsPIC®, AVR, SAM and CEC flash microcontrollers.**
- **Features**
  - Affordable performance
  - Matches silicon clocking speed
  - Target voltage of 1.20V to 5.5V
  - Portable USB-powered
  - CE and RoHS-compliant
  - 8-pin single in-line header
  - Backward compatible for demo boards, headers and target systems using 2-wire JTAG and ICSP

$34.09



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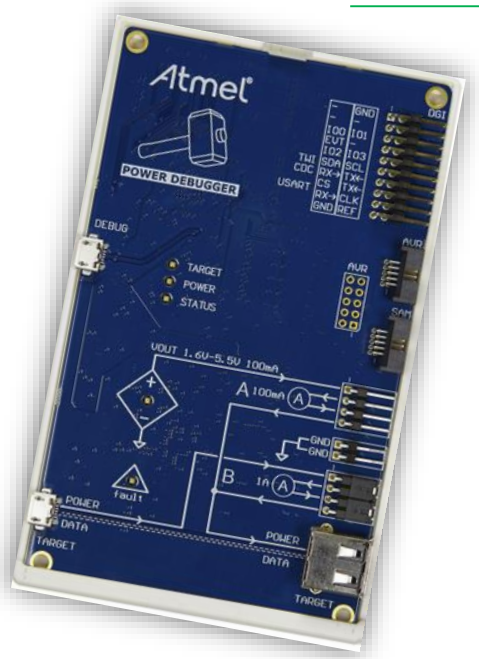
Programmer/Debugger

Power Debugger (Part No. atpowerdebugger)

- **Simultaneous debug & power measurement**
  - Debugging over CMSIS-DAP
  - Extended to support SWO trace, same as Atmel-ICE
- **Two independent channels for power measurements**
  - Channel A for high accuracy, lower currents
  - Channel B for higher currents with lower resolution
- **CDC virtual COM port**
- **DGI for streaming application & power data**
  - Open specification, docs provided
- **Provides target power, 1.6 – 5.5V, up to 100mAStatus LEDs for debugging & target supply**

$252.99



MICROCHIP

Programmer/Debugger

Atmel-ICE (Part No. ATATMEL-ICE)

- **Supports programming and debugging all Cortex-M based SAM, AVR and UC3 based parts**
  - Programming/ Debugging AVR/SAM MCU/CPU over JTAG, SD, PDI, SPI, TPI and aWire etc.
  - Target operating voltage range 1.62V to 5.5V
  - ITM serial trace support on Cortex-M based SAM MCUs
- **Supported in Atmel Studio, IAR, Keil and more**
  - Any IDE that supports the CMSIS-DAP protocol can support Atmel-ICE
- **3 different editions**
  - USD 71.99 - Low cost PCBA only
  - USD 114.99 - Basic edition with most common cables
  - USD 160.99 - Including all cables and adapters

$177.09

Programmer/Debugger

Debug Adapter Board (Part No. AC102015)

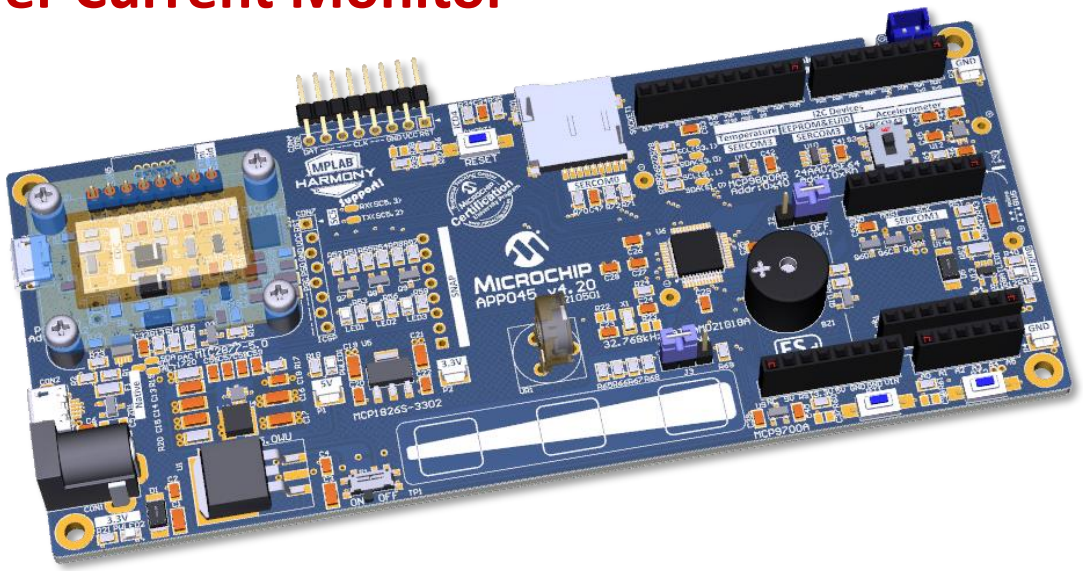
- **The Debug Adapter Board Gives ICD 4 / PICkit 4 cable compatibility with Atmel-ICE, Power Debugger and J-Link style connectors.**
  It supports JTAG, SWD and ICSP
  protocols in multiple connector formats.
- **Package Contents**
  - Debugger Adapter Board
  - Cable, FEMALE FLAT RIBBON IDC CONNECTOR, 15CM
  - Cable, FEMALE FLAT RIBBON IDC CONNECTOR, 12CM
  - 8 CONDUCTOR MODULAR CABLE, 6"
  - Cable, HCSD Dual Row Socket IDC Assembly 14pin (7 ea) 10"

$47.29

SAMD21 EVB
APP045 v4.2 ES.d Introduction

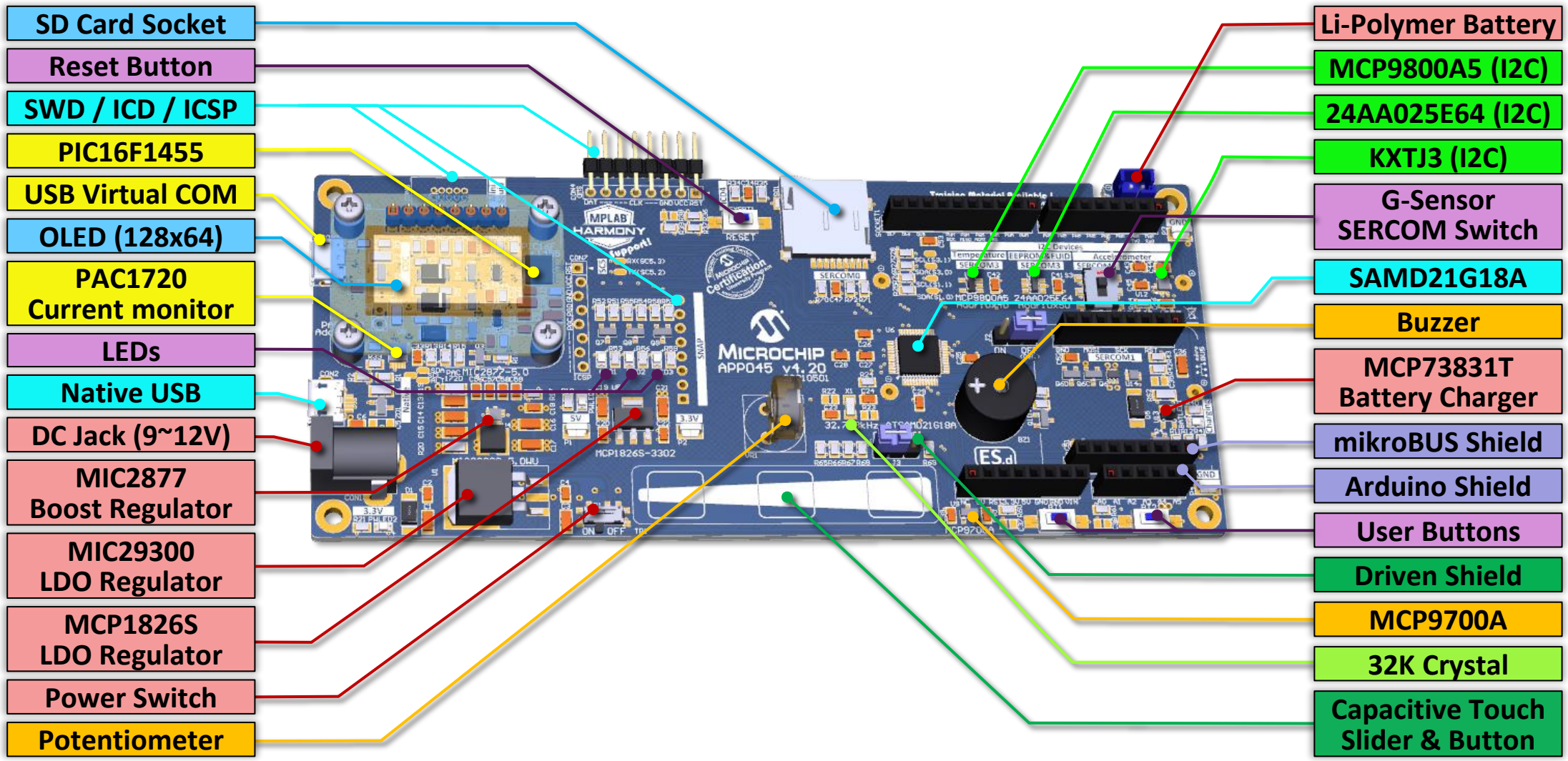
APP045 v4.2 ES.d Features

- On board SAMD21G18A 32Bit ARM Cortex M0+ Microcontroller
- Support plugged MPLAB SNAP external programmer/debugger
- Onboard USB CDC Virtual COM Port and Power Current Monitor
- Multiple Power Supply Source
- Support Li-on Battery, boost and charger
- 2 x Buttons, 3 x LEDs
- 1 x I2C Temperature Sensor
- 1 x I2C EEPROM with Unique ID
- 1 x I2C Accelerometer
- 1 x MicroSD Socket (SPI interface)
- 1 x SPI OLED (128 x 64, SSD1306 Compliant)
- 1 x Potentiometer, Analog Temperature Sensor and Buzzer
- 1 x Capacitive QTouch® Slider & Buttons with Driven Shield
- 1 x mikroBUS™ Click Board Socket
- 1 x Arduino® Shield Socket (Arduino M0 Pro board Compliant)

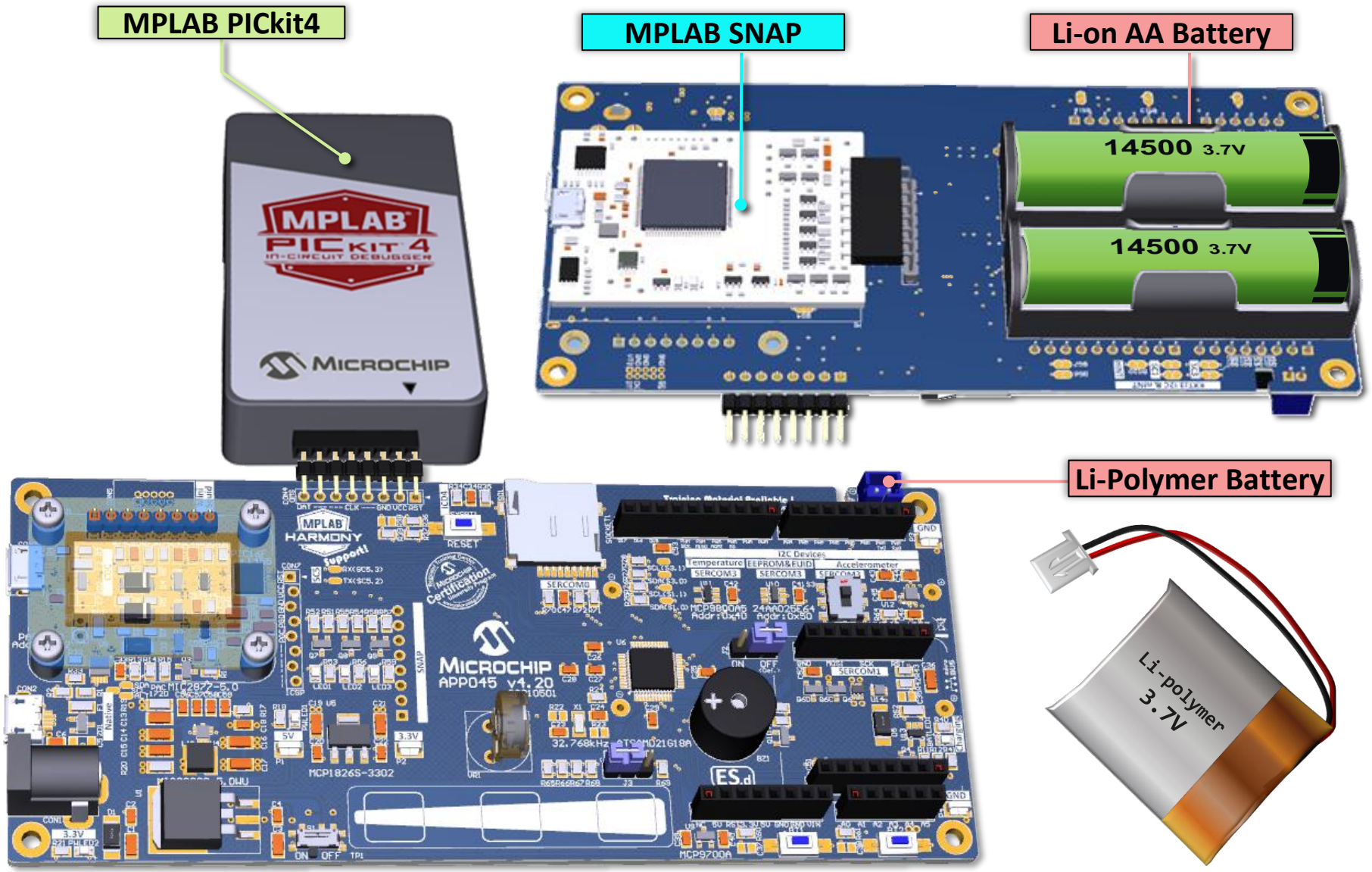


MICROCHIP

APP045 v4.2 ES.d Overview



APP045 v4.2 ES.d Programmer and Debugger



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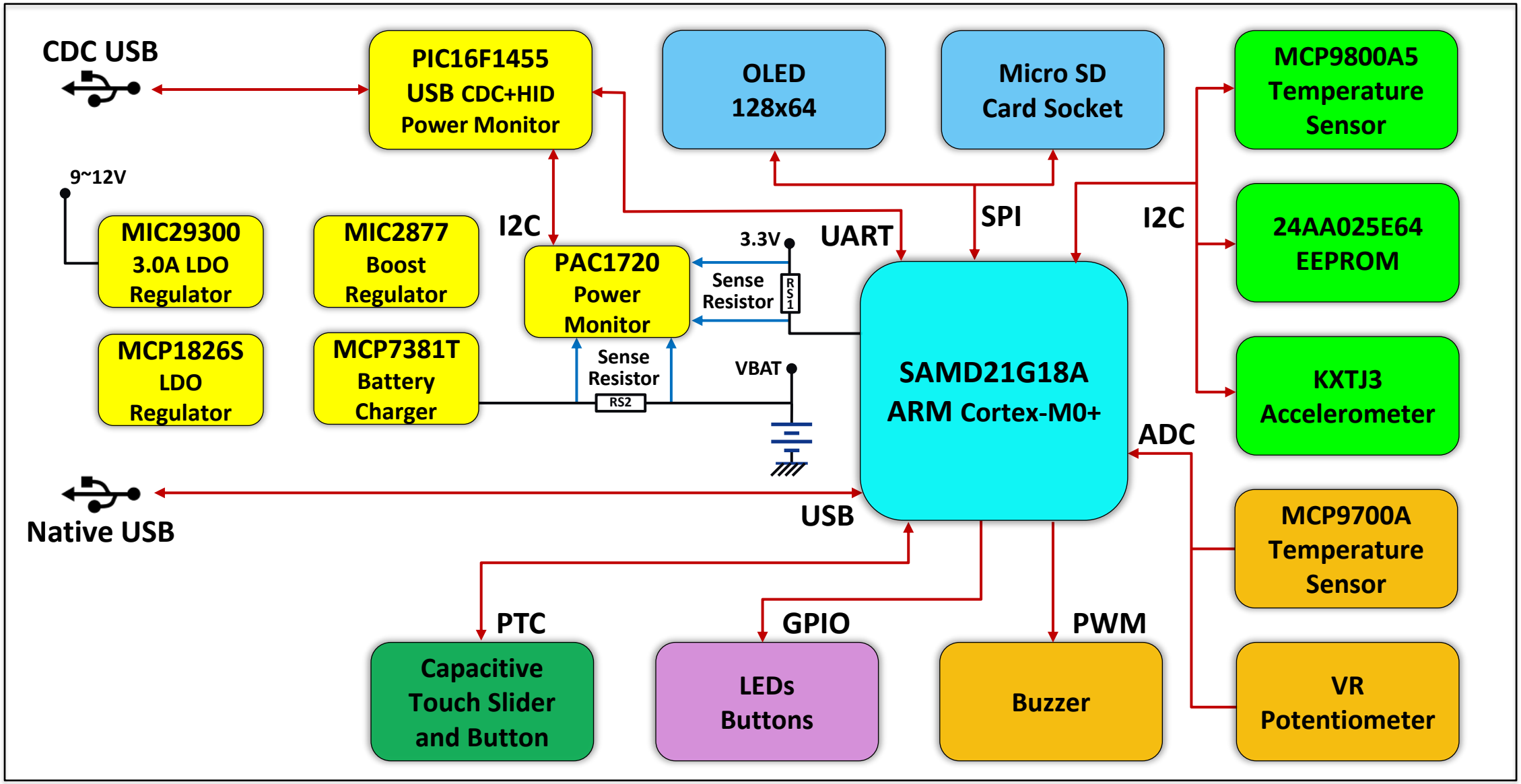
APP045 v4.2 ES.d Block Diagram



Getting Started with First Project

Lab0 First Project

- Try to create your first project to use MPLAB X IDE.
- Learn how to use edit, build, project manager, debug and programming functions.

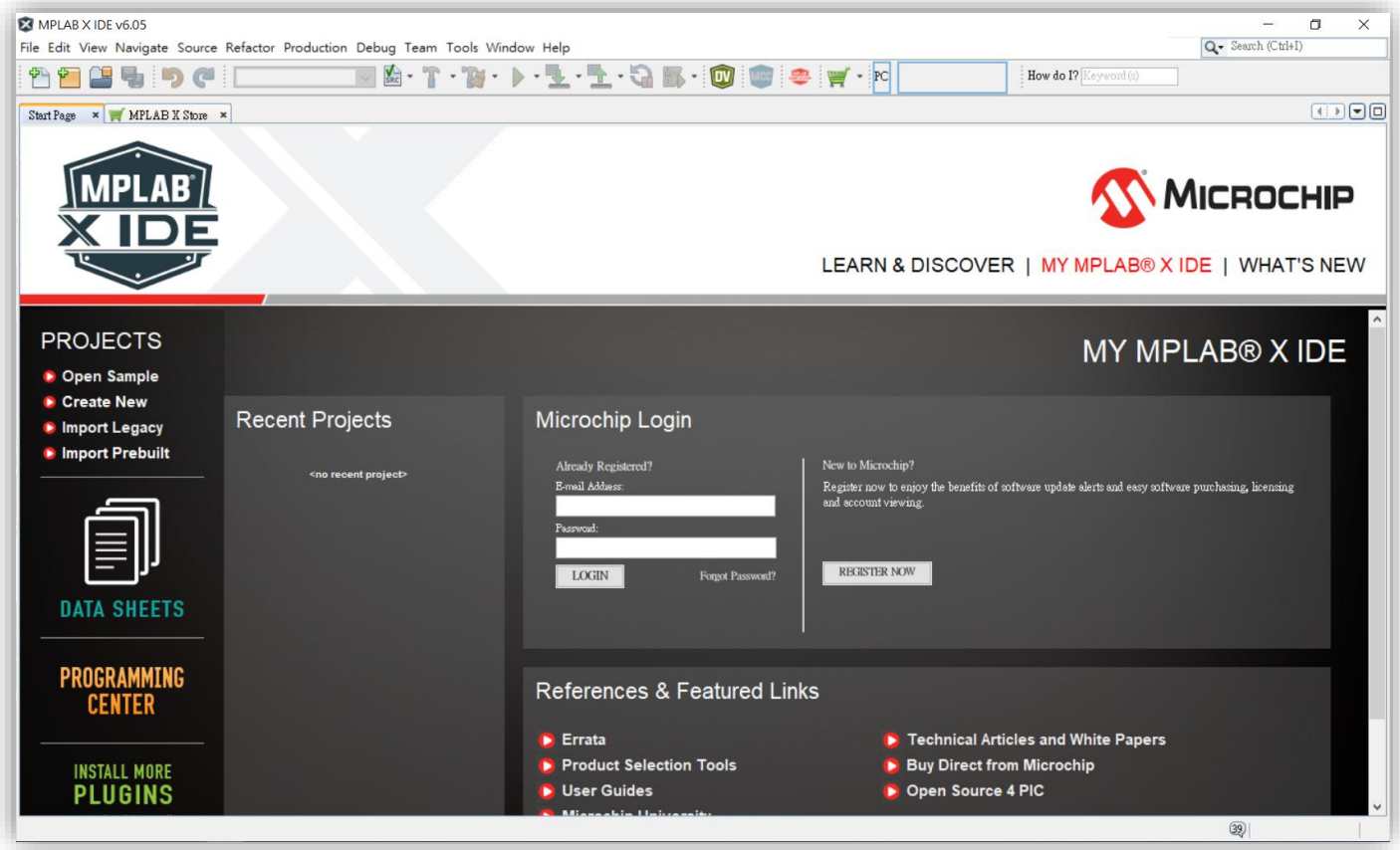
- How to Start ?

Lab0 Create Project

Step 1

- Open MPLAB X IDE v6.05 firstly.

MPLAB X IDE
v6.00



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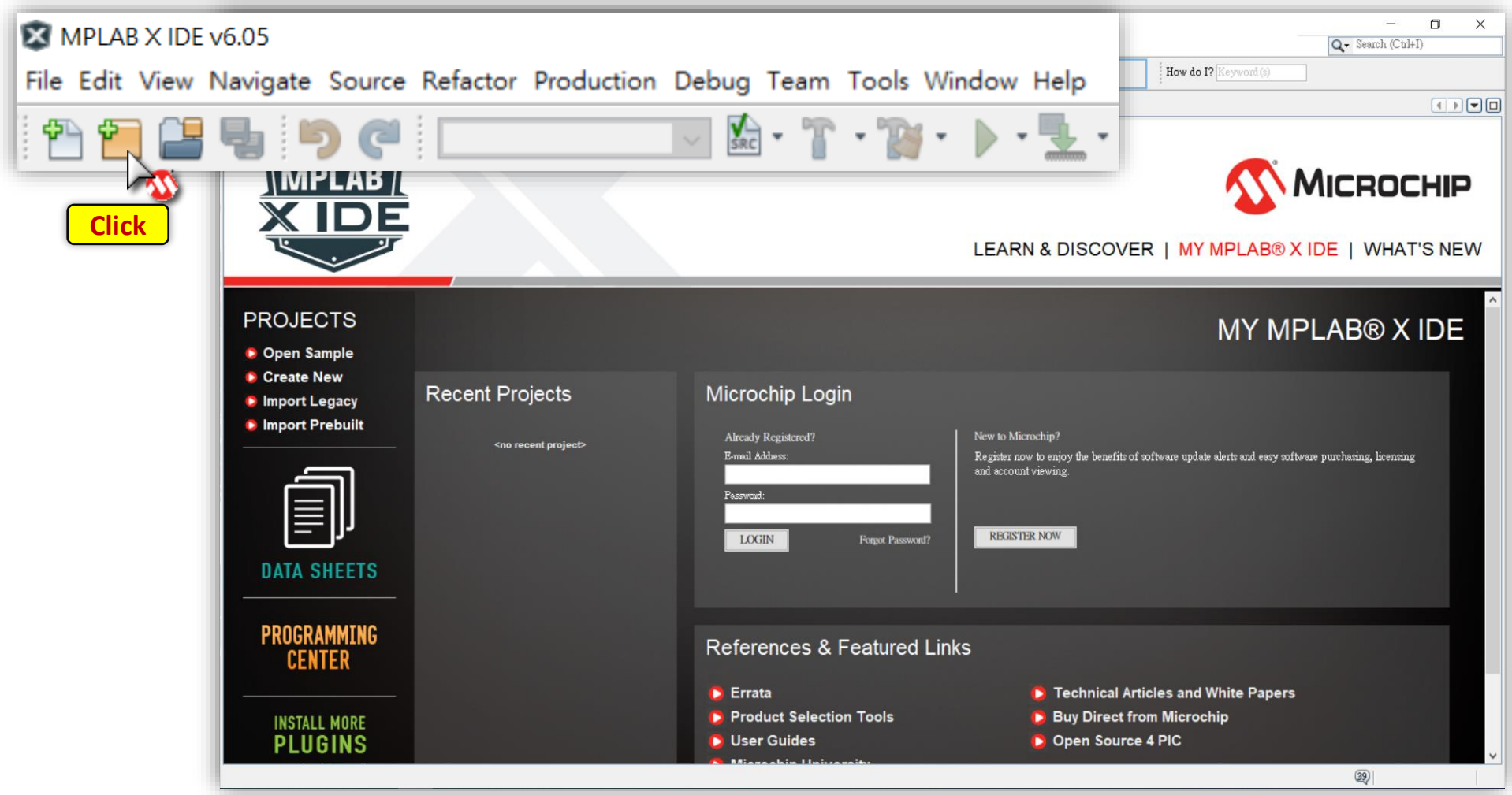
Lab0 Create Project

Step 2

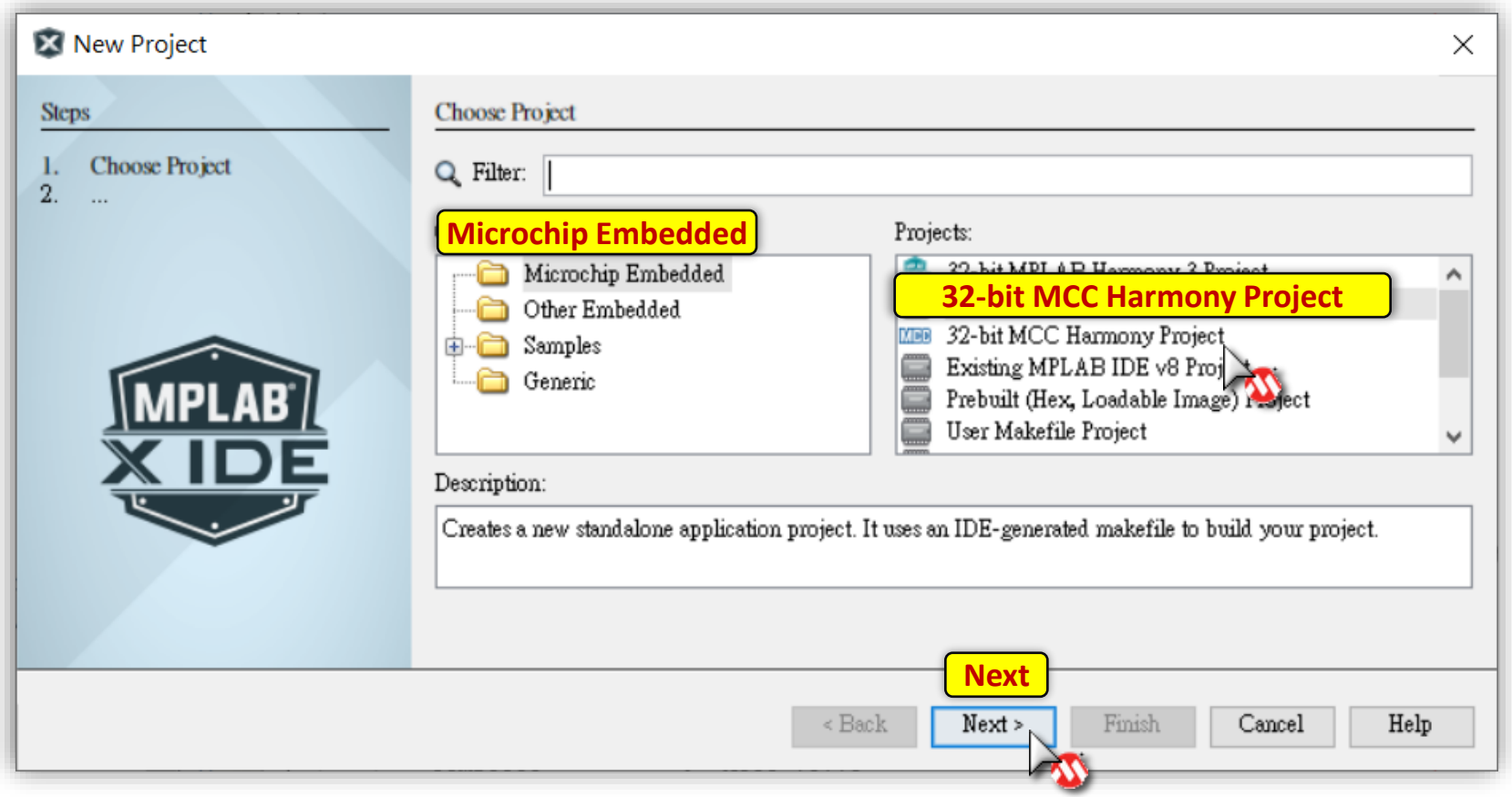
- Select to File > New > Project or Click icon 



Lab0 First Project

Step 3

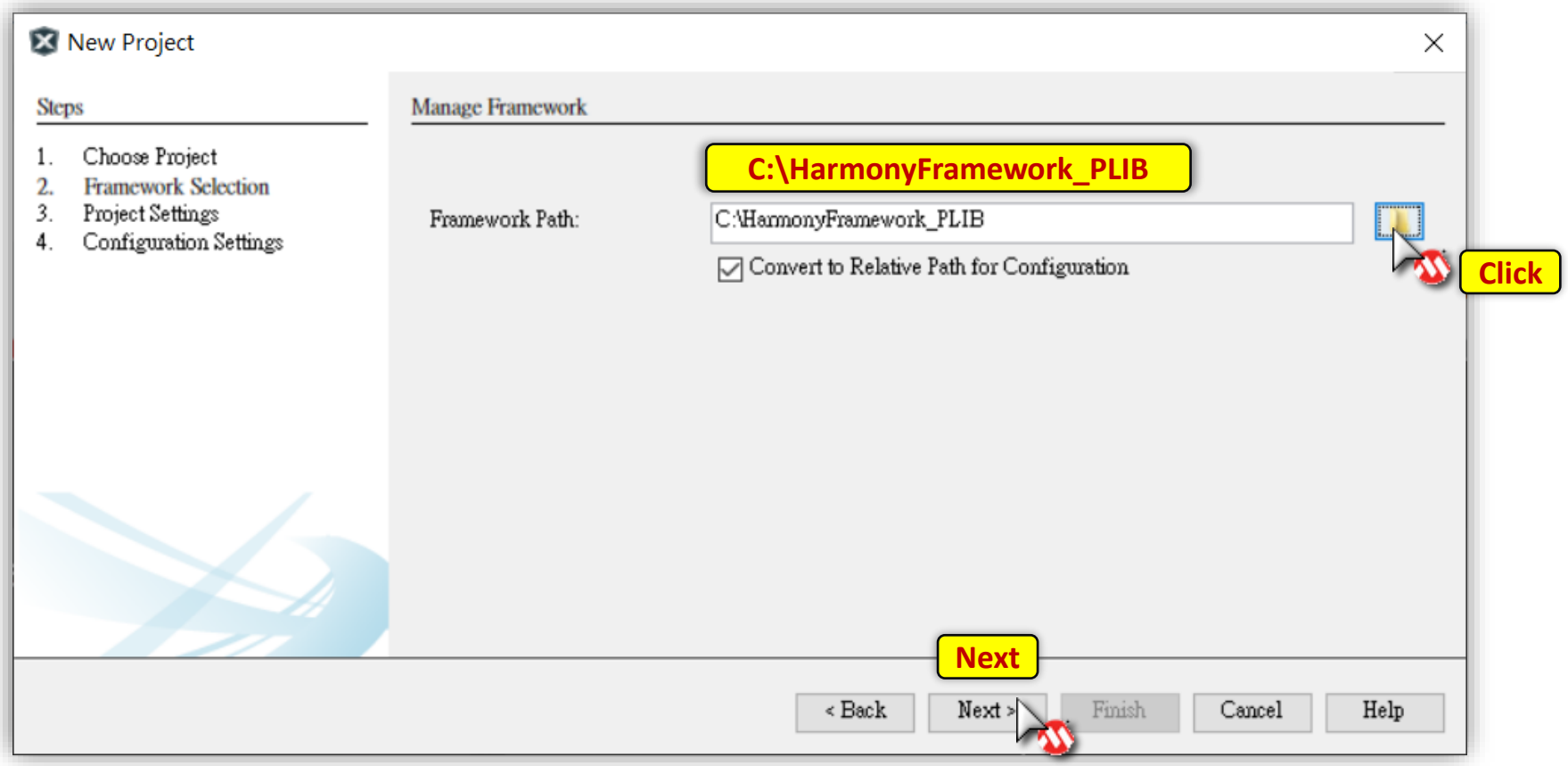
- Categories : Microchip Embedded
- Projects : 32-bit MCC Harmony Project



Lab0 First Project

Step 4

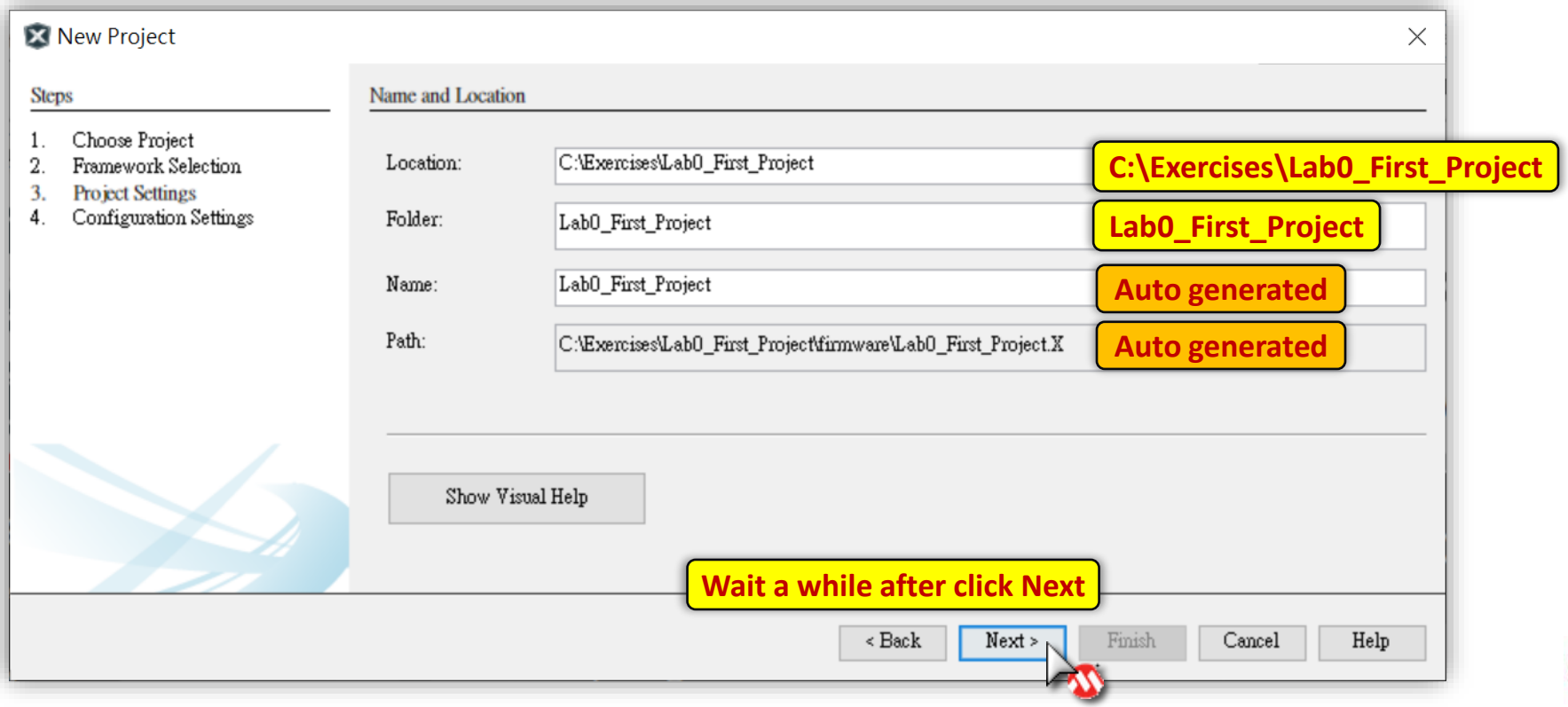
- **Assign MCC Harmony framework directory**
  - **Framework Path : C:\HarmonyFramework_PLIB**



Lab0 Create Project

Step 5

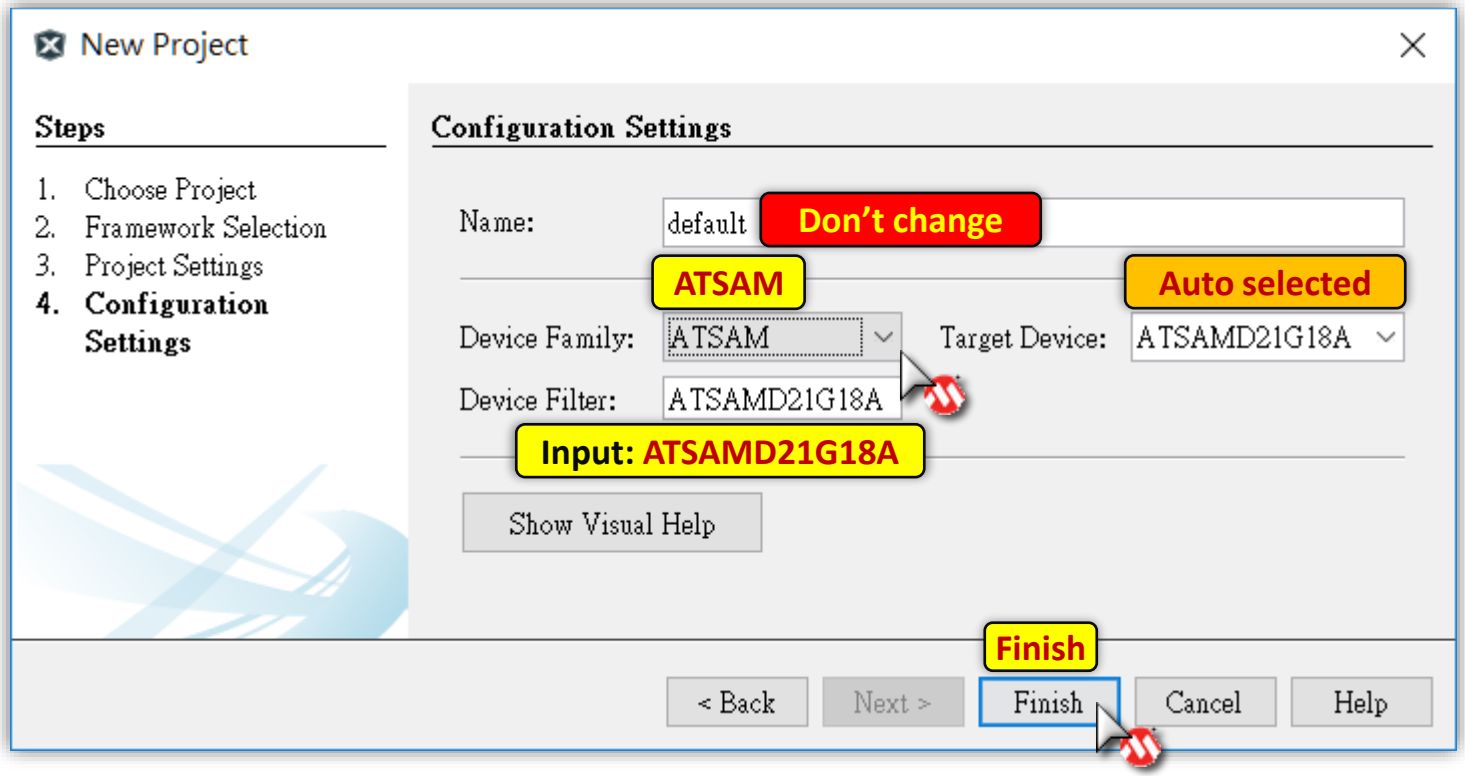
- Location : C:\Exercises\Lab0_First_Project **Don't forget C:**
- Folder : Lab0_First_Project **No white space of project folder**
- Name : Lab0_First_Project
- Path : C:\Exercises\Lab0_First_Project.X\firmware\Lab0_First_Project.X



Lab0 Create Project

Step 6

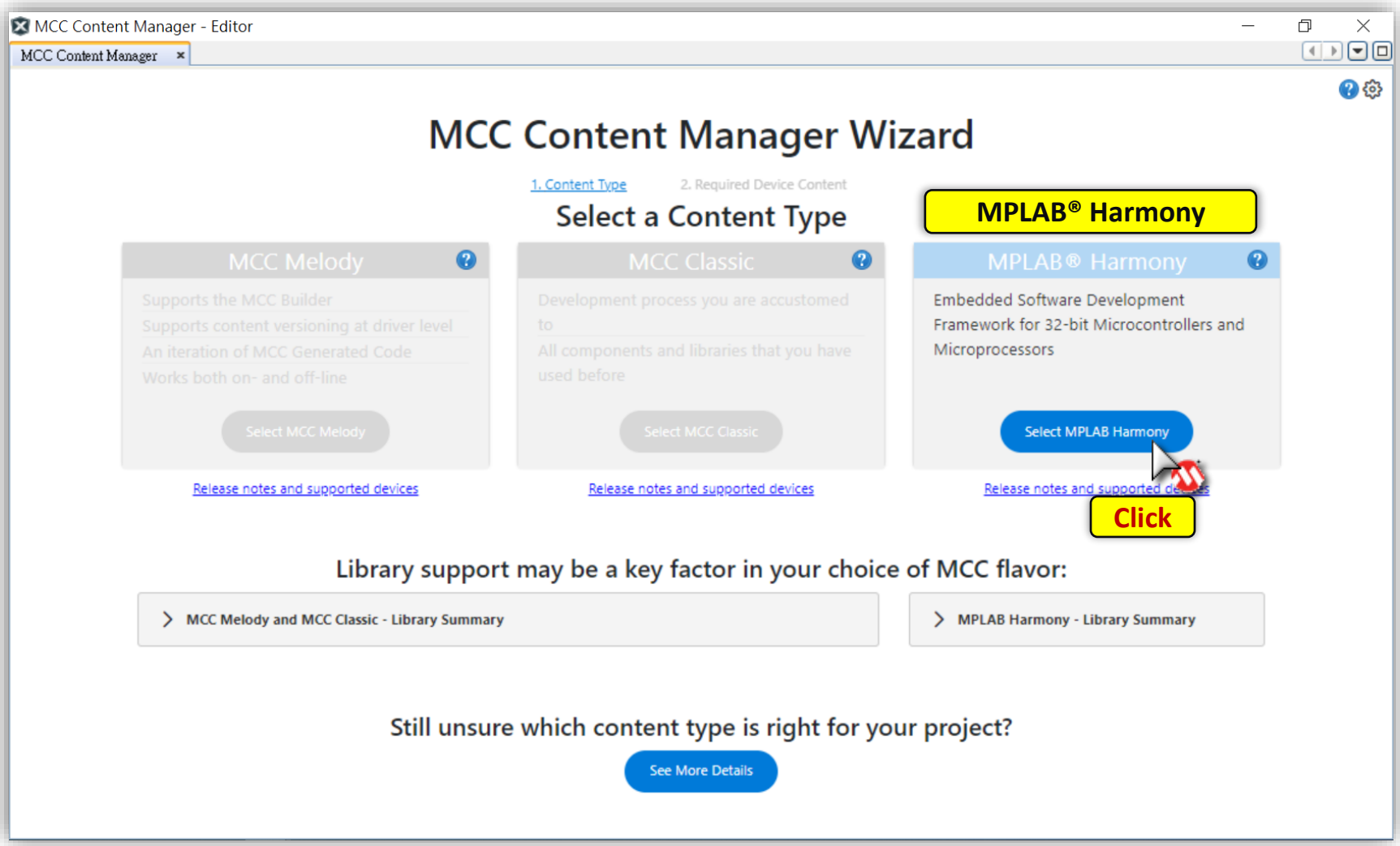
- Name : default
- Device Family : ATSAM Target Device : ATSAMD21G18A
- Device Filter : ATSAMD21G18A **Don’t miss any character**



Lab0 Create Project

Step 7

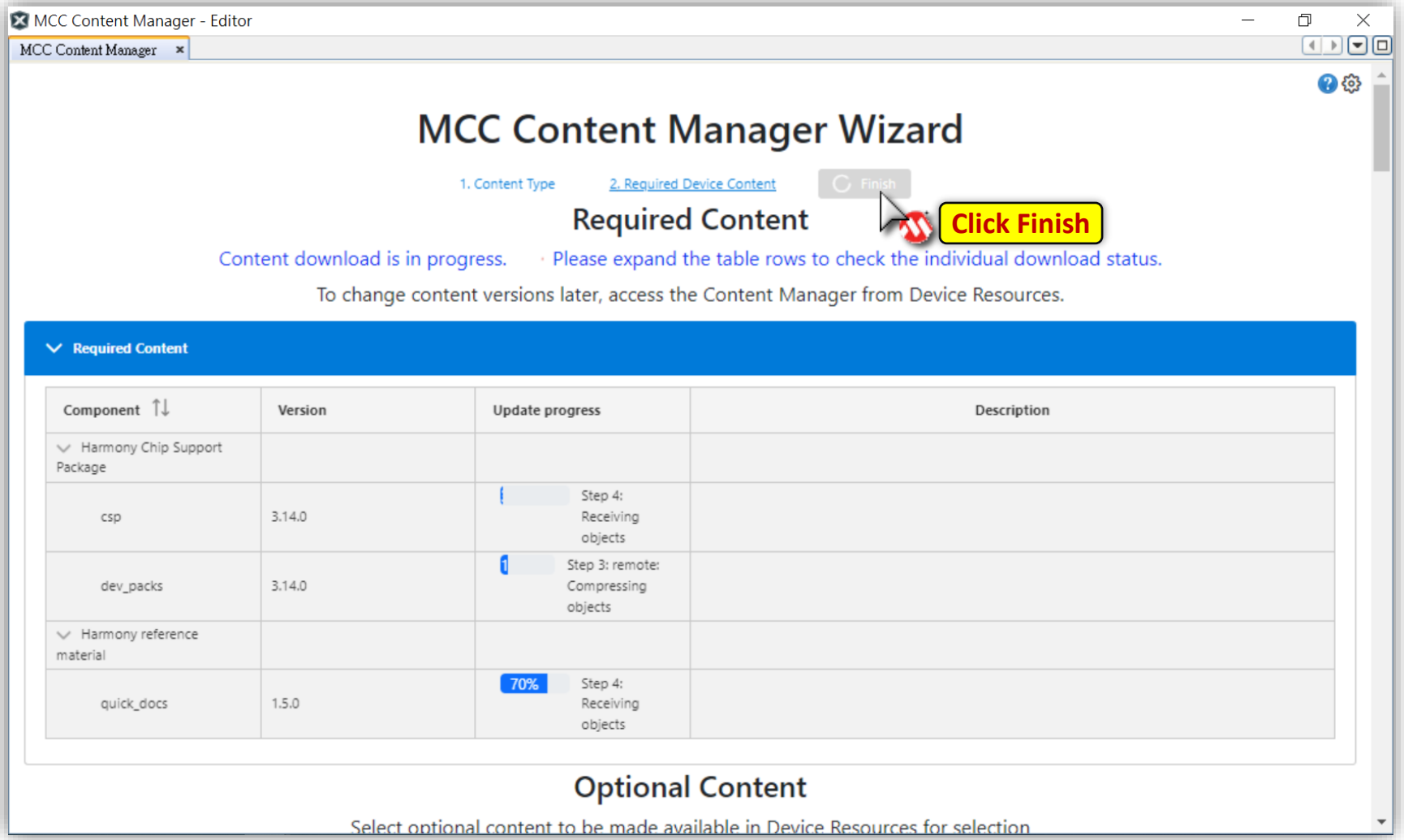
- **Select MPLAB Harmony.**



Lab0 Create Project

Step 8

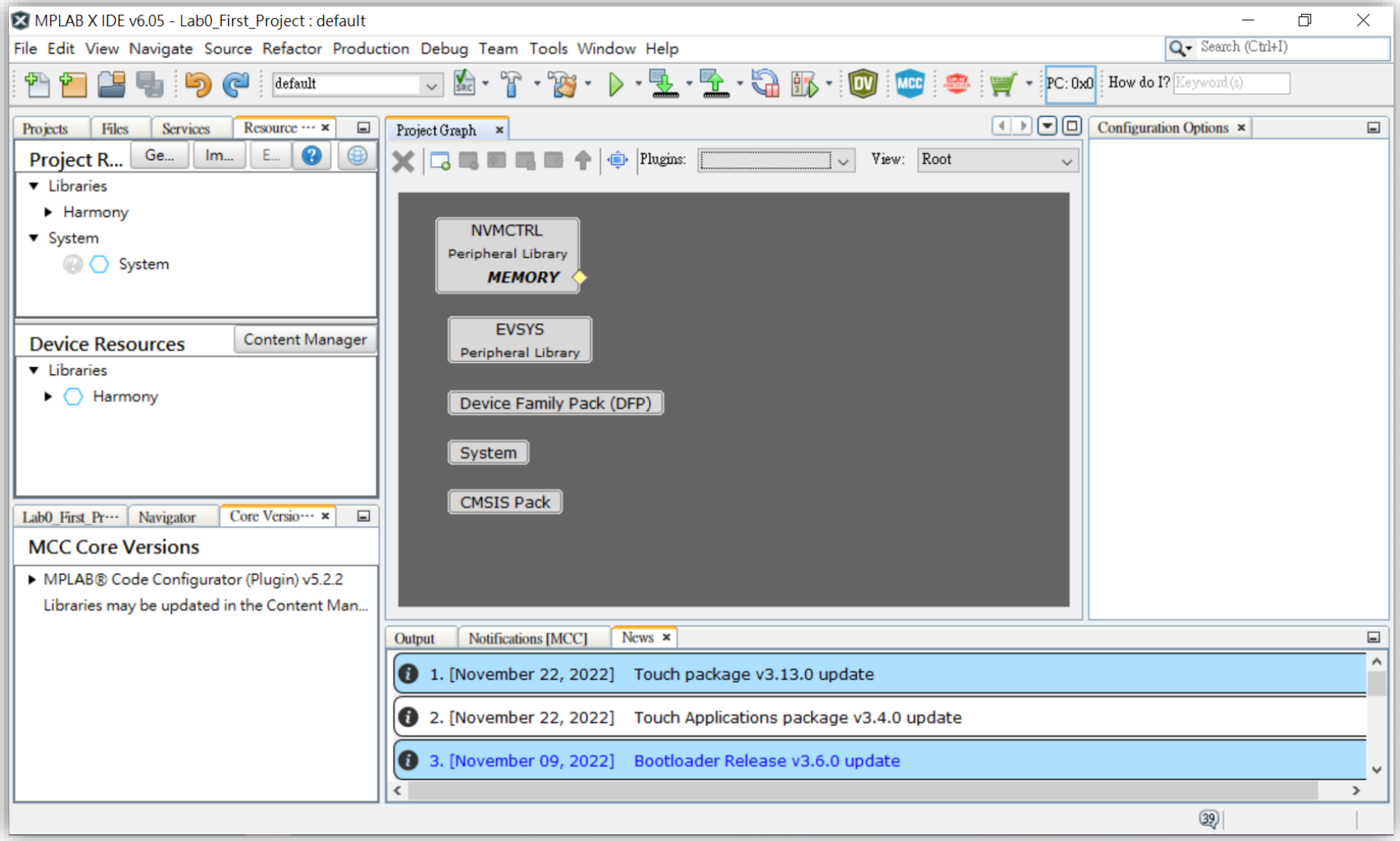
- Click Finish and Wait Download Framework.



Lab0 Create Project

Step 9

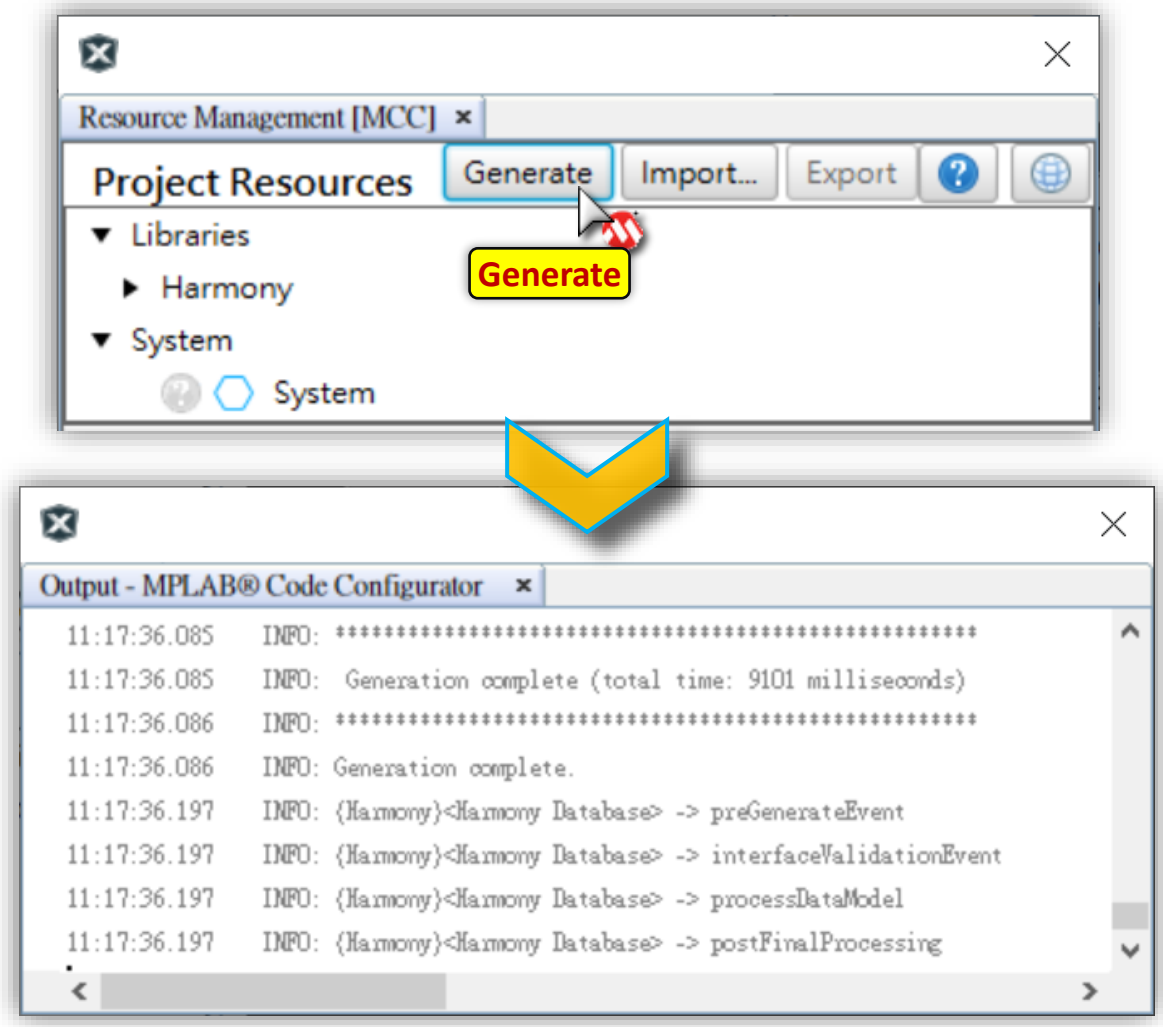
- **Harmony Configurator interface show up, let's come back later.**



Lab0 Generate Code

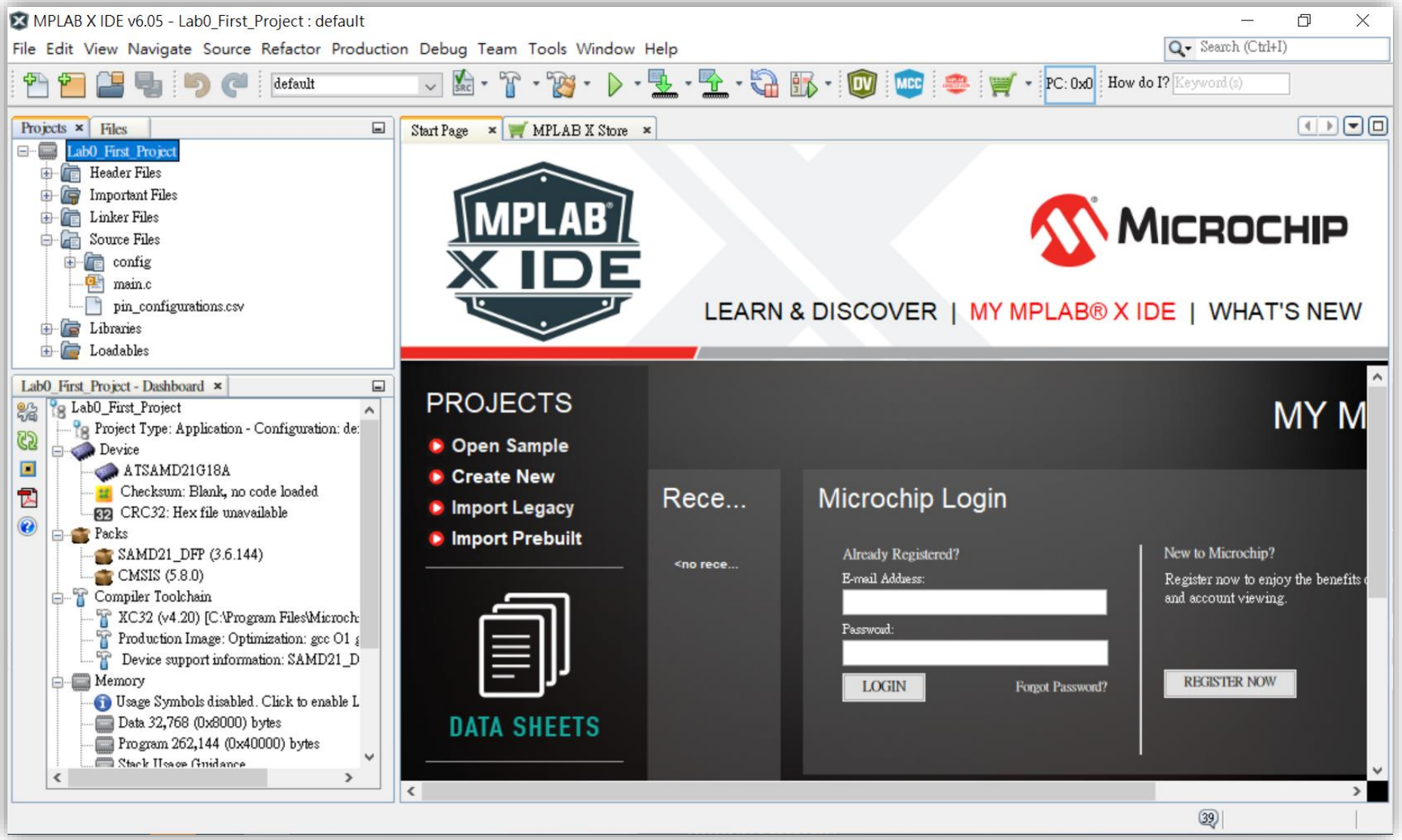
Step 10

- Click "Generate" Button to Generate your Code.



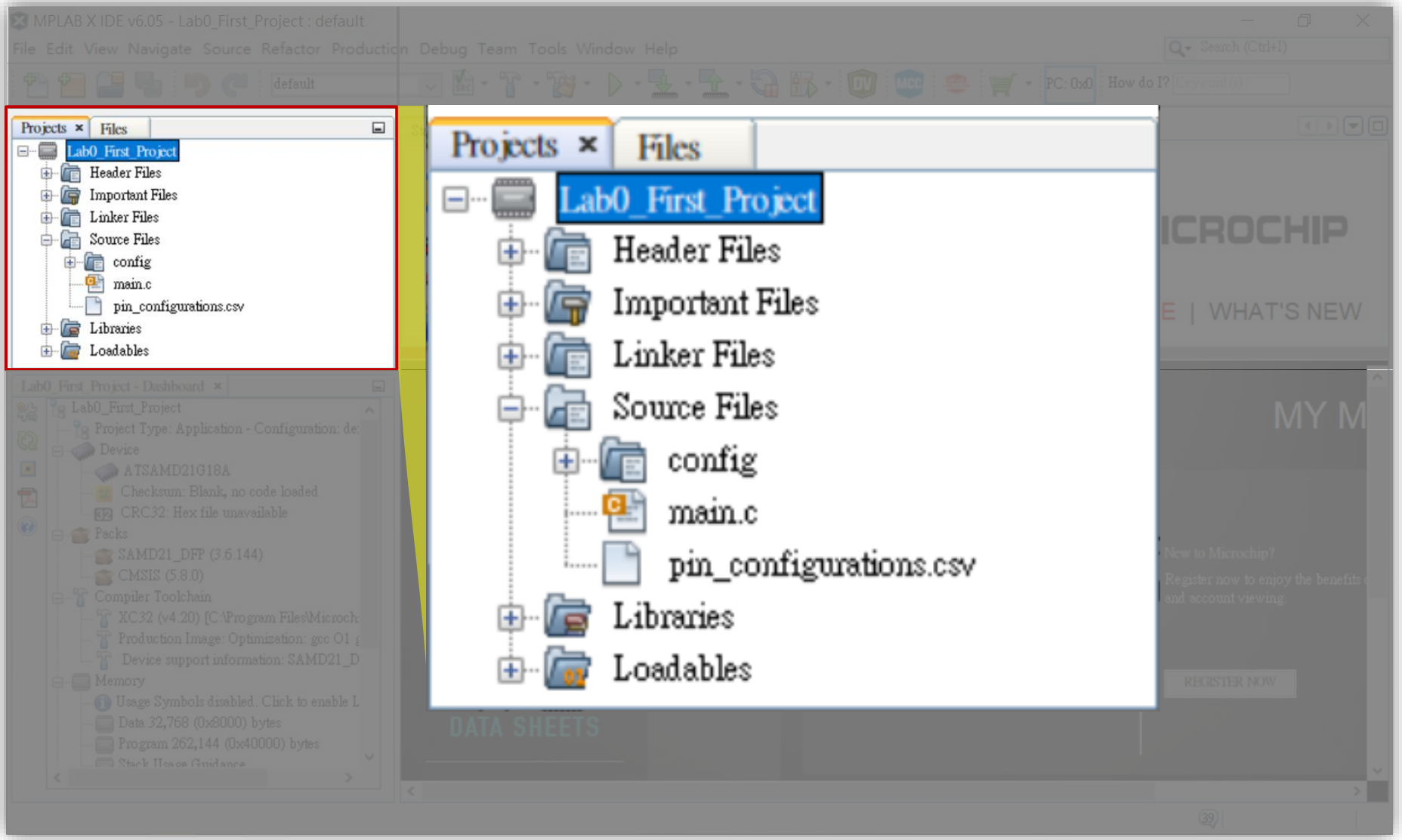
MPLAB X IDE Interface

- **Return to MPLAB X IDE, let's go through its interface.** (The version of modules might be different to yours.)



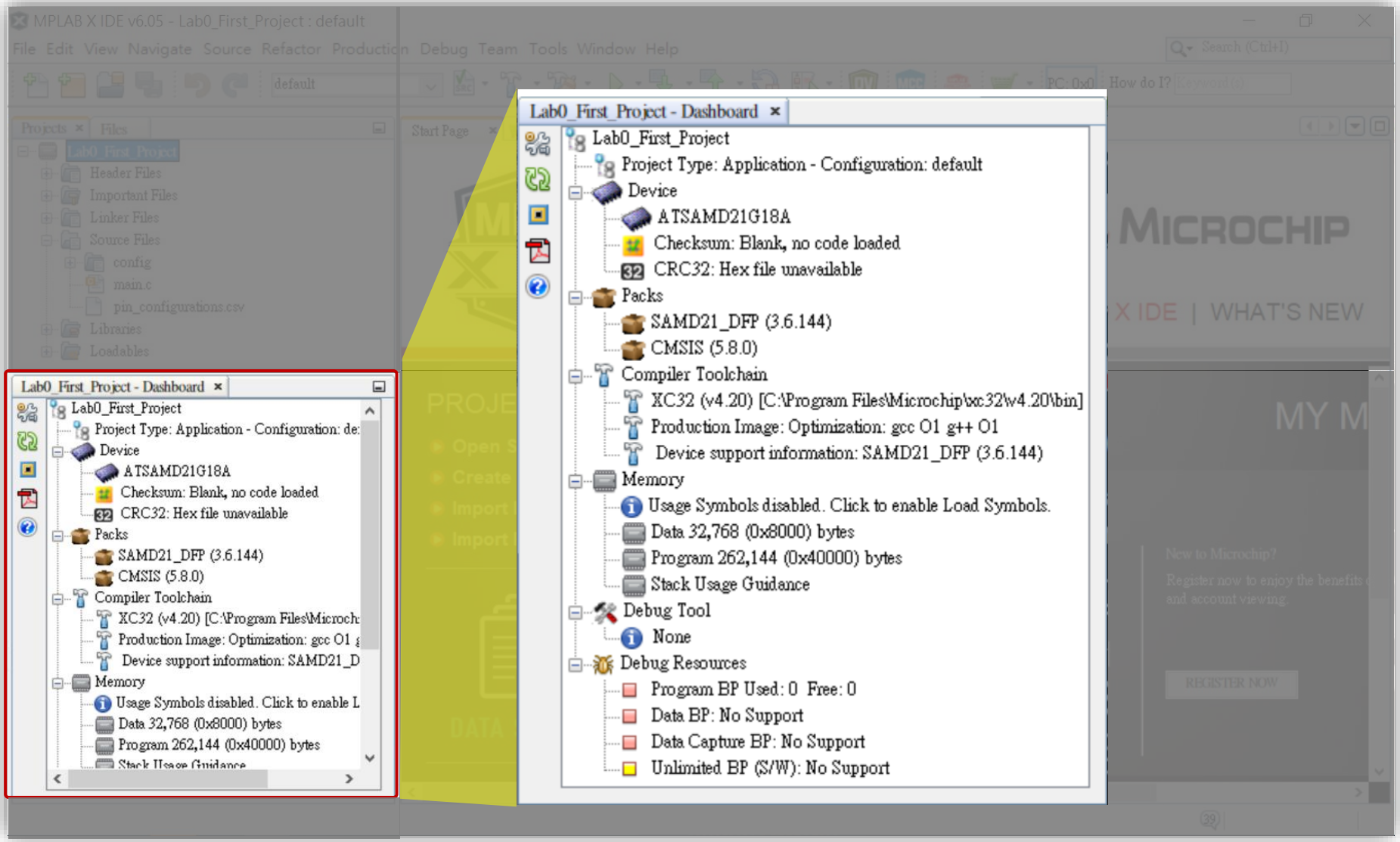
MPLAB X IDE Interface

- **Project window.**



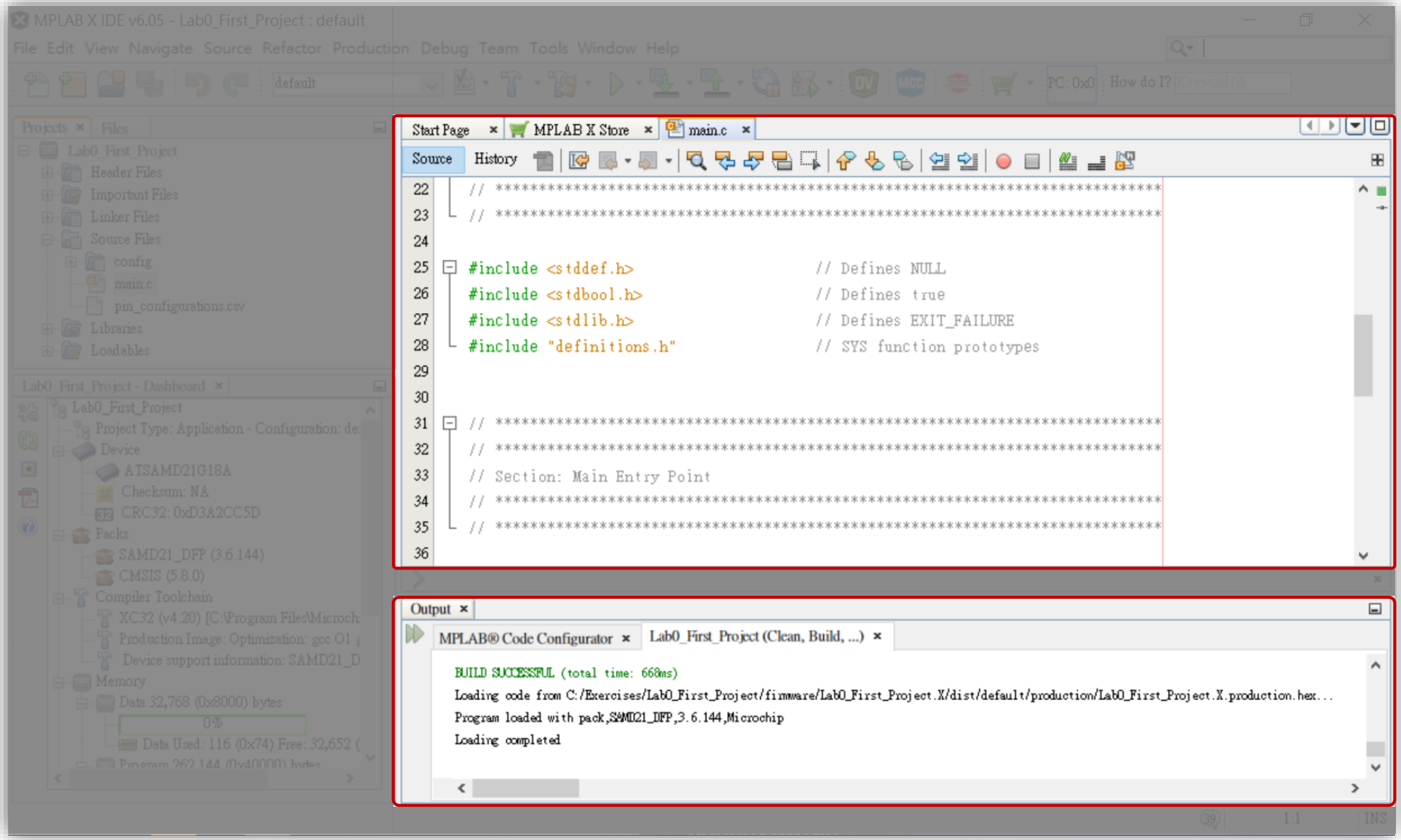
MPLAB X IDE Interface

- **Dashboard window.** **(The version of modules might be different to yours.)**



MPLAB X IDE Interface

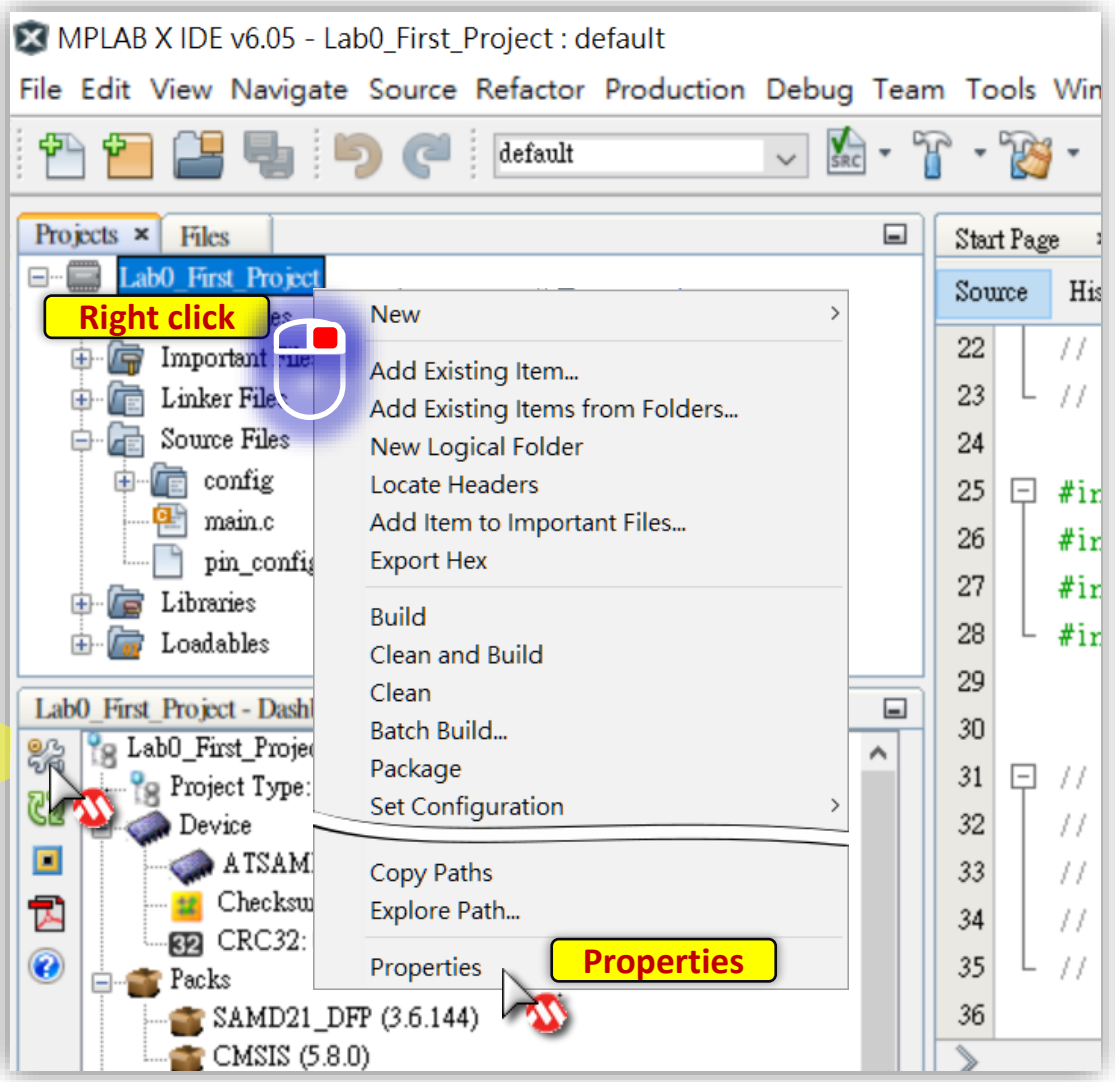
- **Source code and Output window.**



Lab0 Project Properties

Step 11

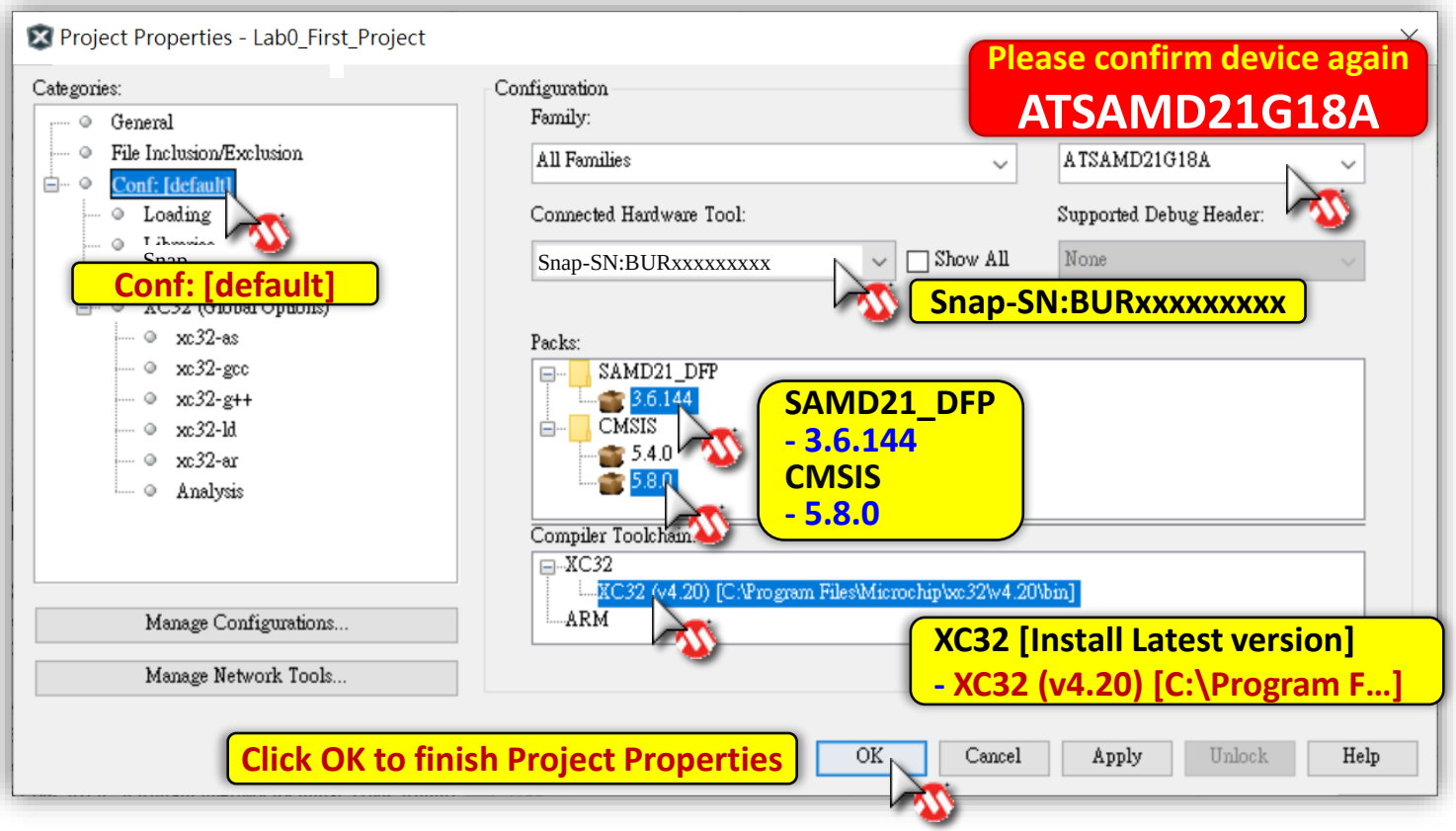
- Now we need do some settings in project properties :
- Click  on Dashboard or Right click on project and select to Properties.



Lab0 Project Properties

Step 12

- Select Connected Hardware Tool : Snap-SN: BURxxxxxxxxx
- SAMD21_DFP : 3.6.144
- CMSIS : 5.8.0
- Compiler Toolchain : XC32 (v4.20) [C:\Program Files\Microchip…]



Lab0 Add Code

Step 13

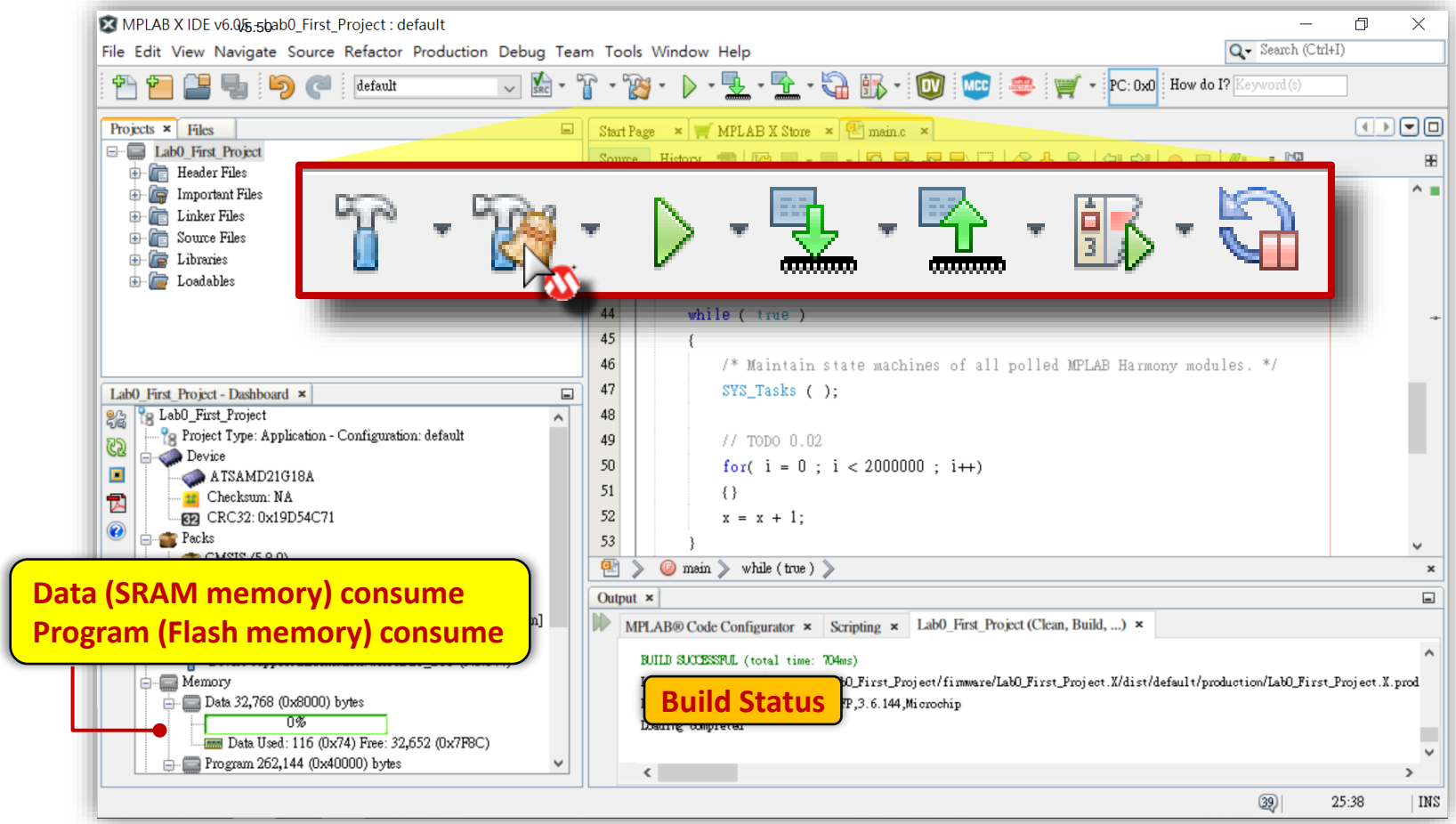
- Add below code segment to main.c

```
// TODO 0.01
uint32_t i = 0;
uint32_t x = 0;

int main( void )
{
    SYS_Iinitialize(NULL);

    while( true )
    {
        SYS_Tasks();

        // TODO 0.02
        for( i = 0 ; i < 2000000 ; i++);
        x = x + 1;
    }

    return ( EXIT_FAILURE);
}
```

Lab0 Build Project

Step 14

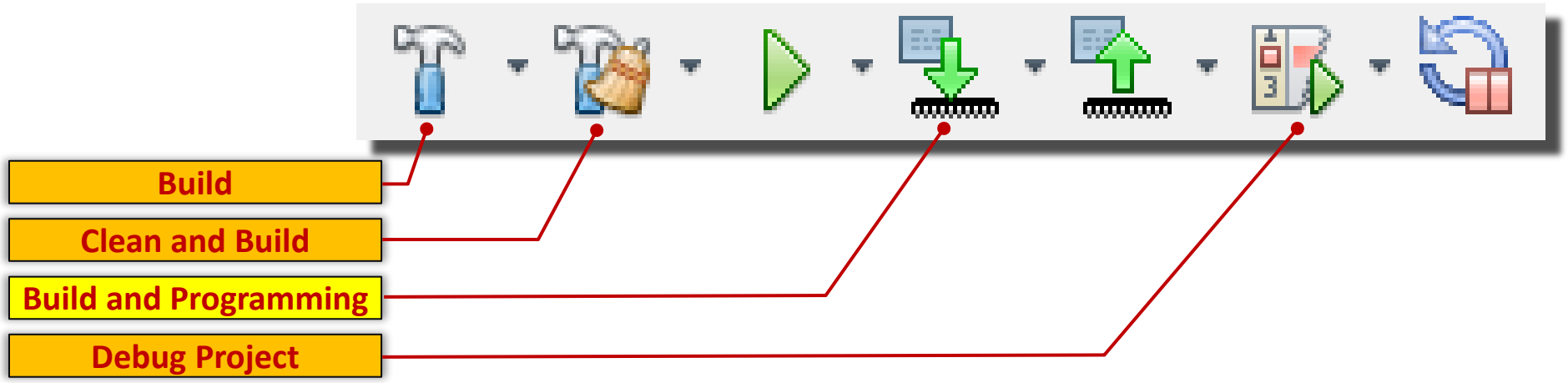
- Click Icon  or press **F11** to build your project.
- Compile result message will show to output windows.



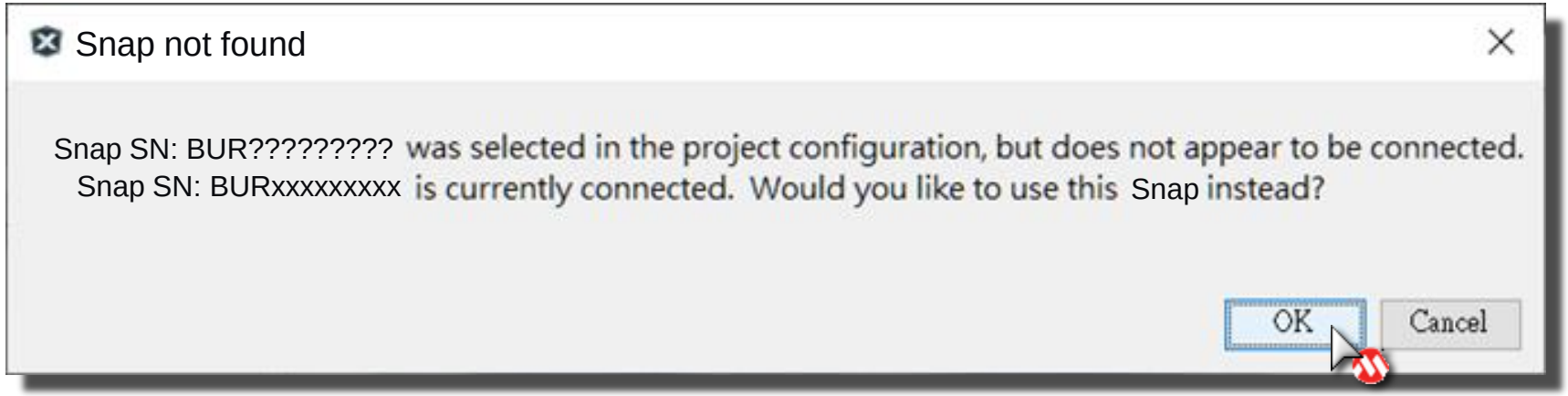
Lab0 Programming Project

Step 15

- Click Icon  to build and program firmware to EVB.



- Different Programmer SN of your project while programming.

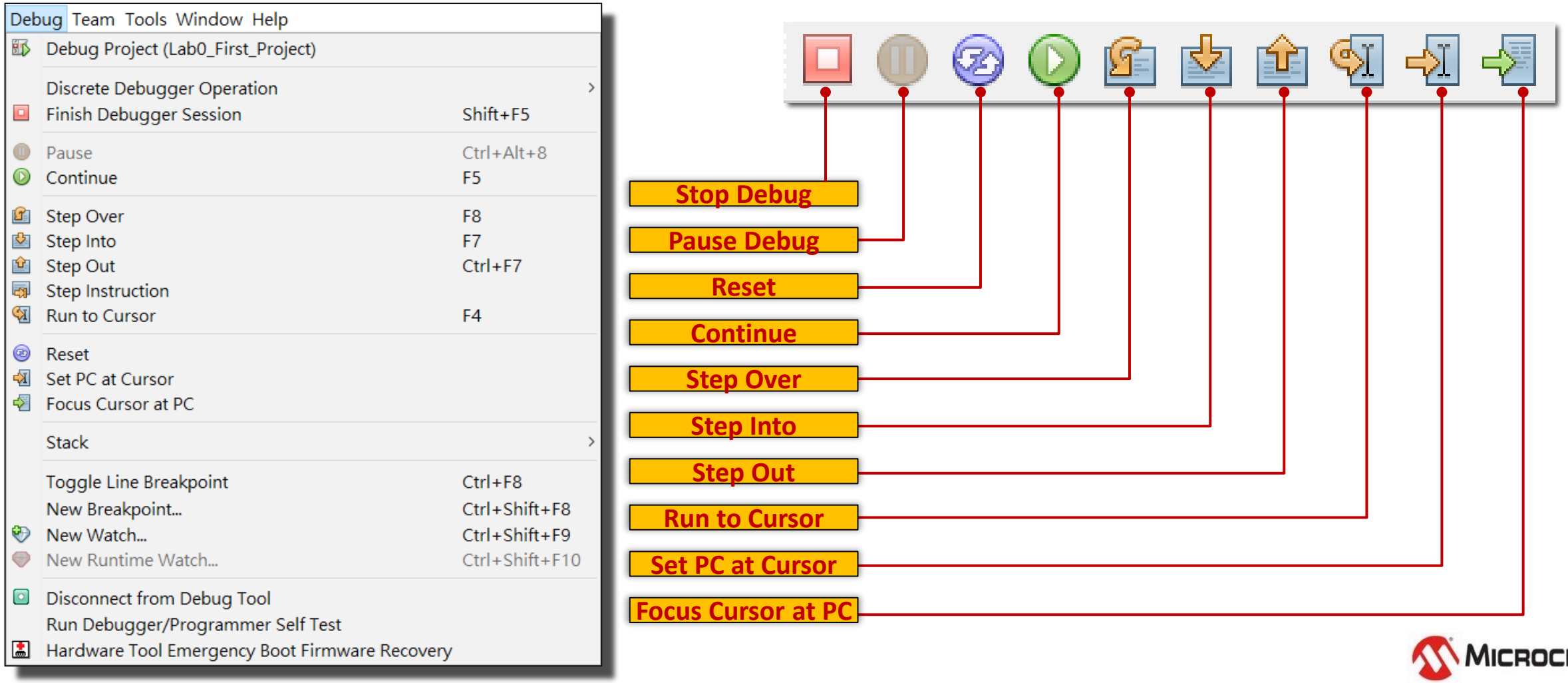


MICROCHIP

Lab0 Debug Project

Step 16

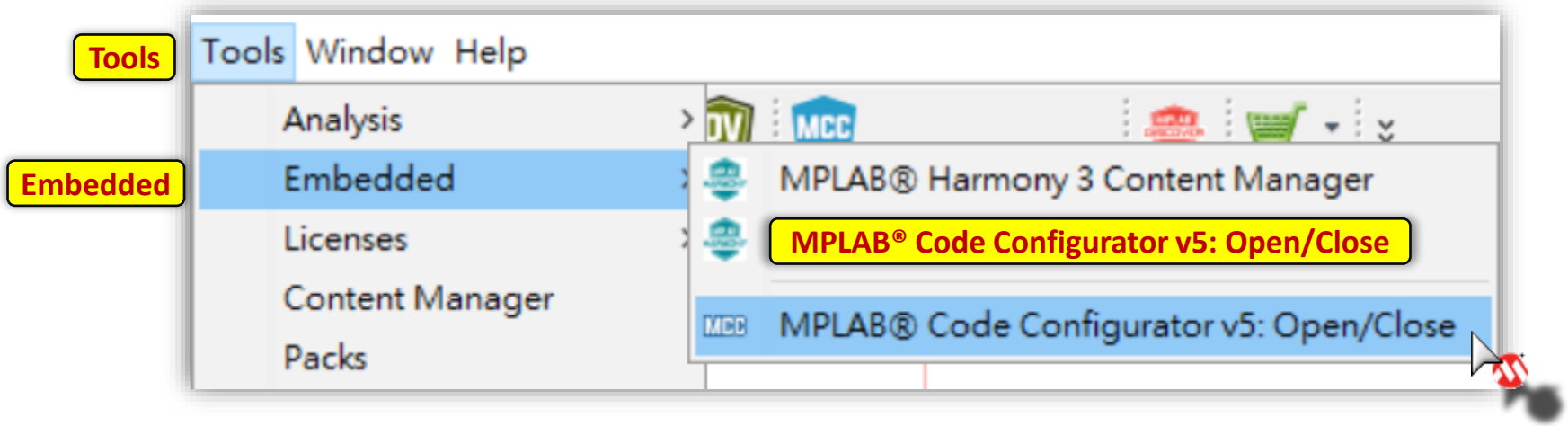
- **MPLAB X IDE provide a lot of debug window, select the Debug**



MPLAB® MCC Harmony Interface introduction

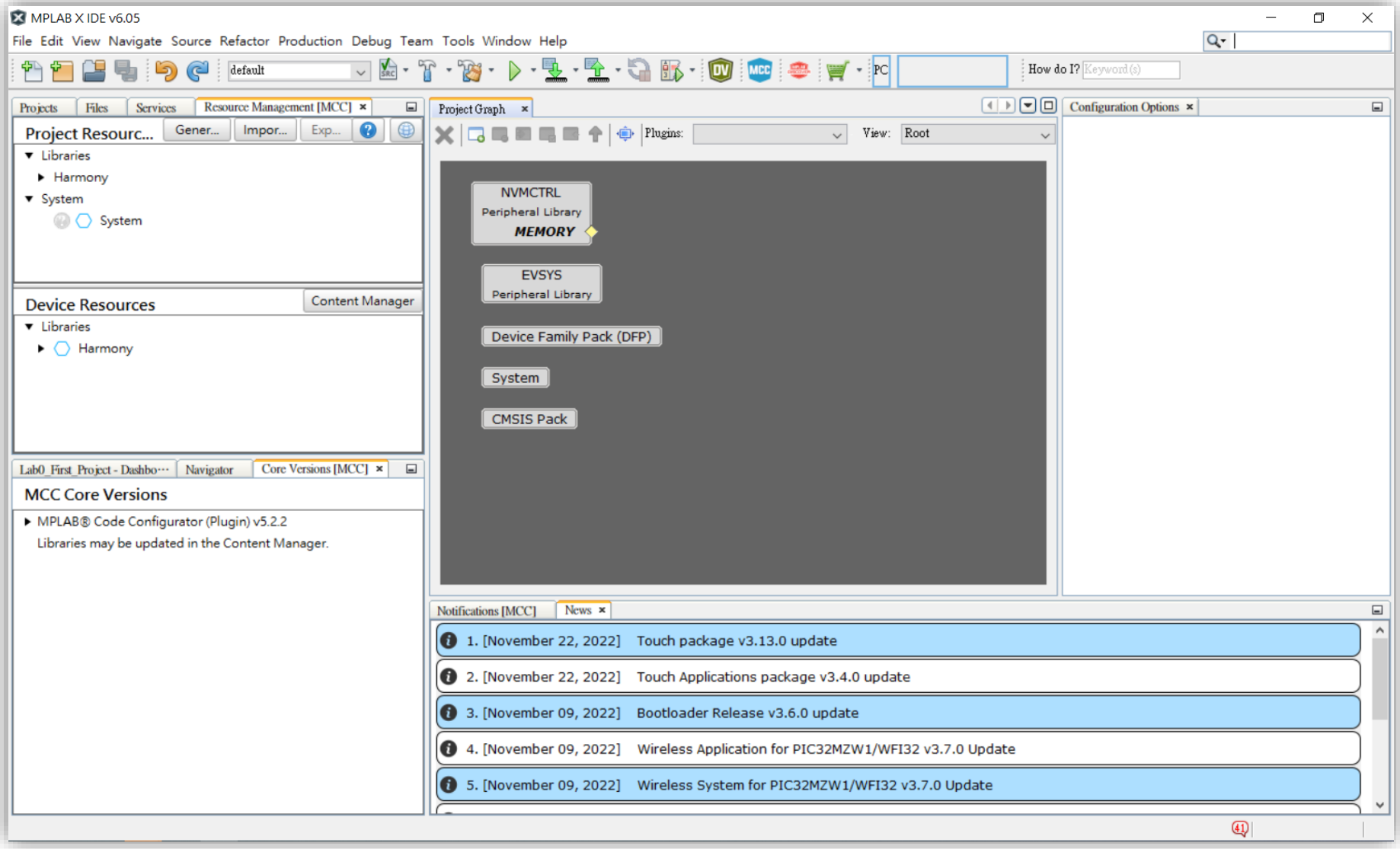
MCC Harmony Interface

- **Notice !** **If you already close MCC Harmony, please open it through below steps.**
- **Select to Tools > Embedded > MPLAB® Code Configurator v5: Open/Close**



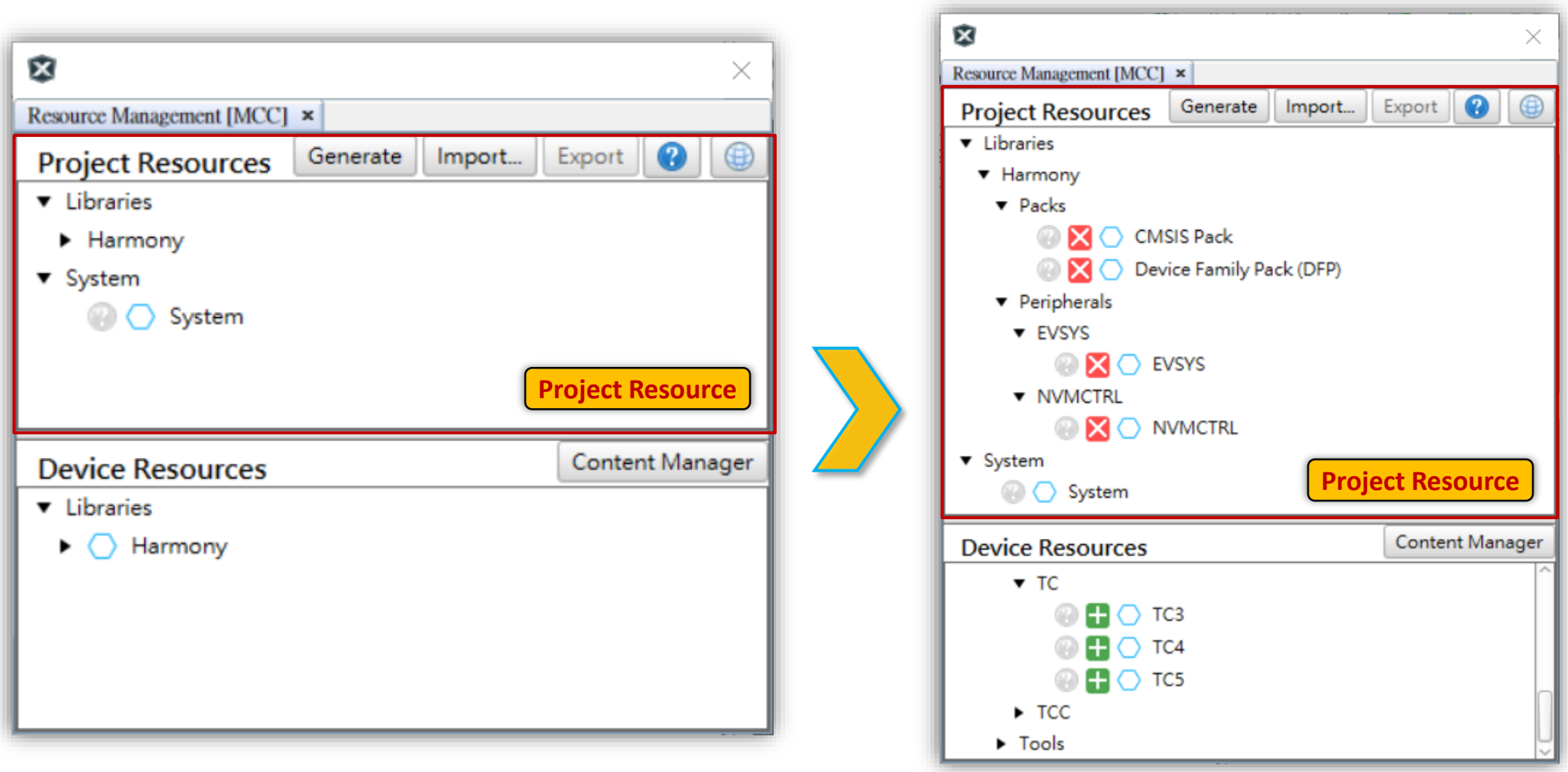
MCC Harmony Interface

- **Now let's walk through MCC Harmony.**



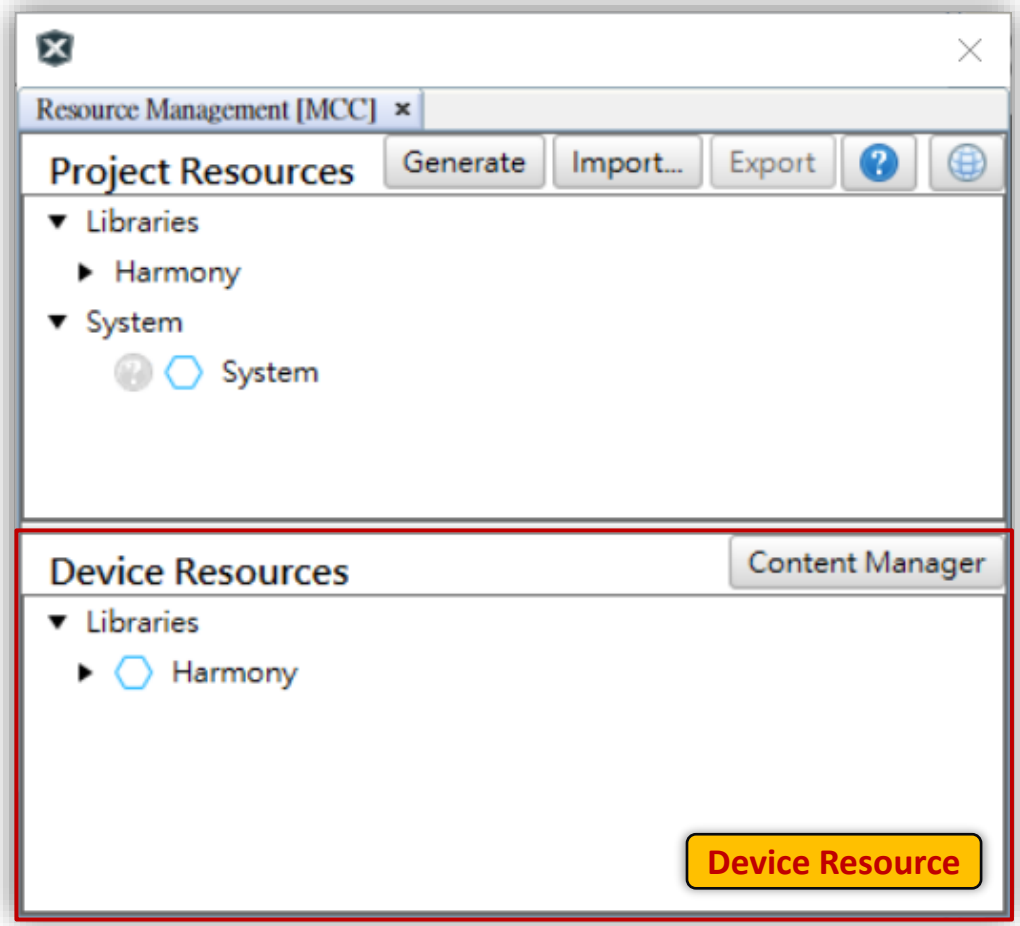
MCC Harmony Interface

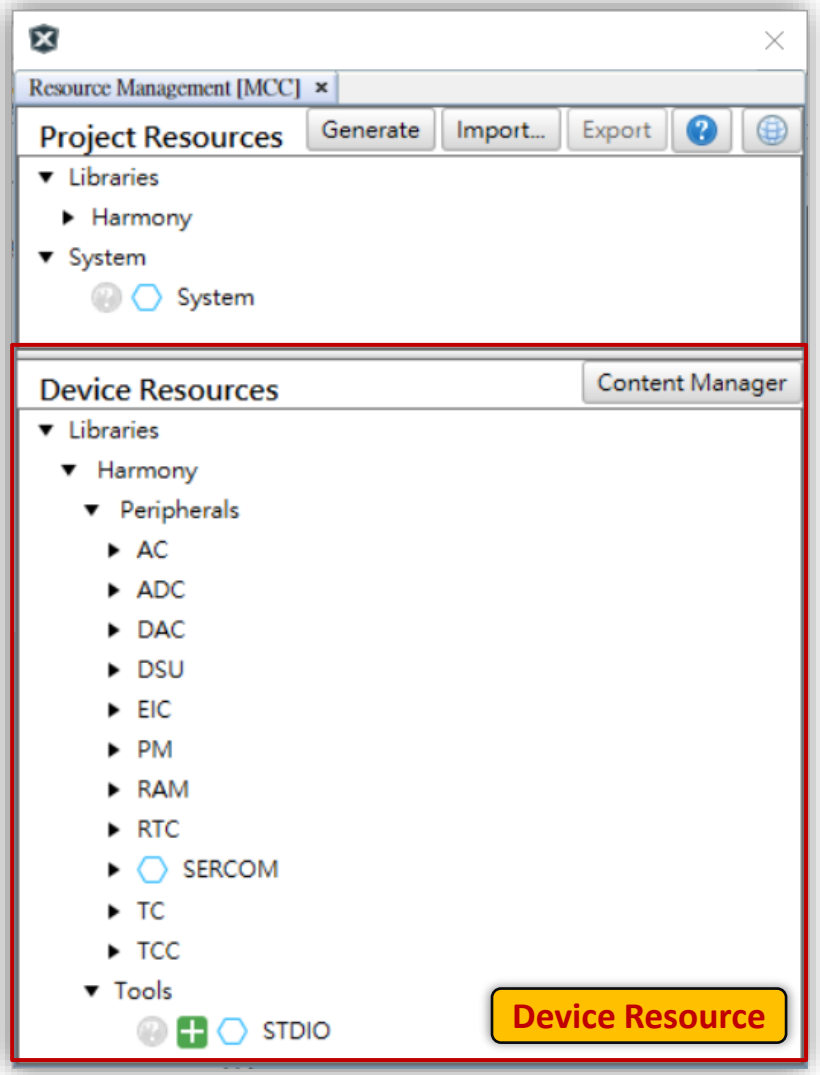
- **Project Resource. (Current modules in project)**



MCC Harmony Interface

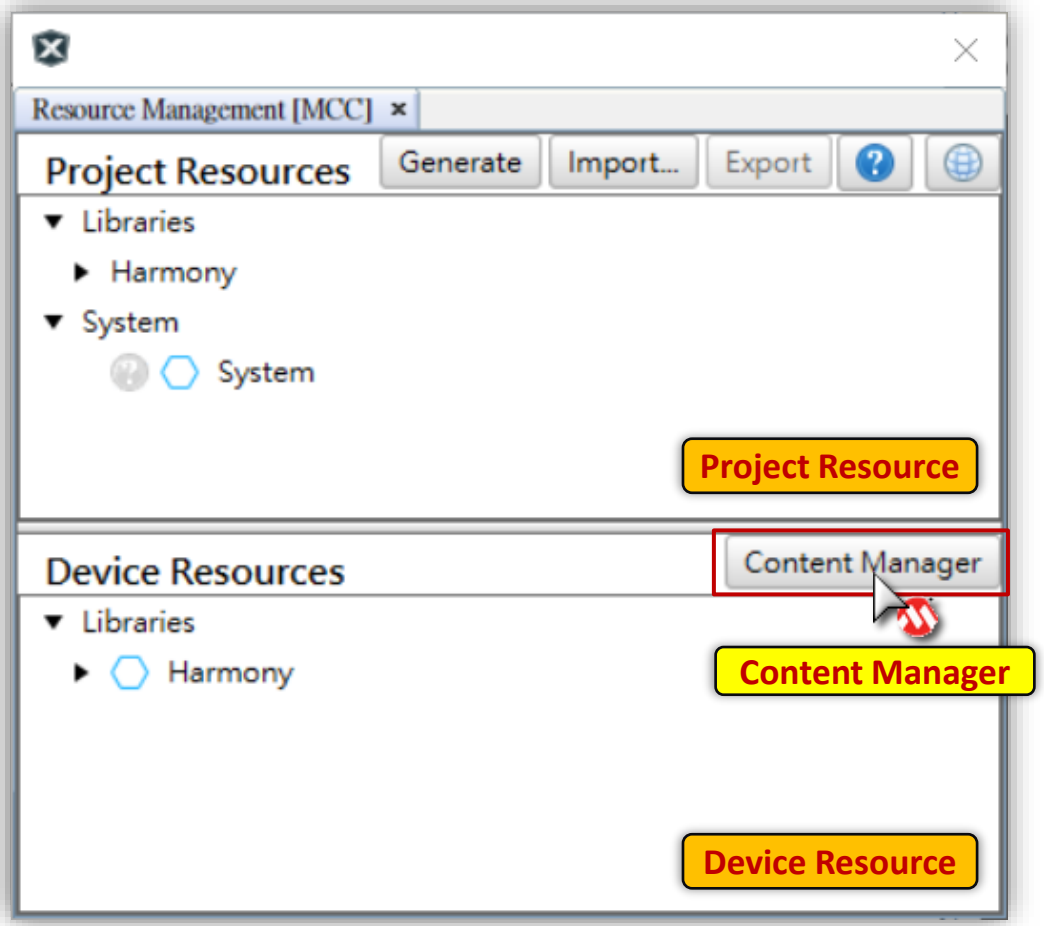
- **Device Resource. (Modules you could add-in project)**

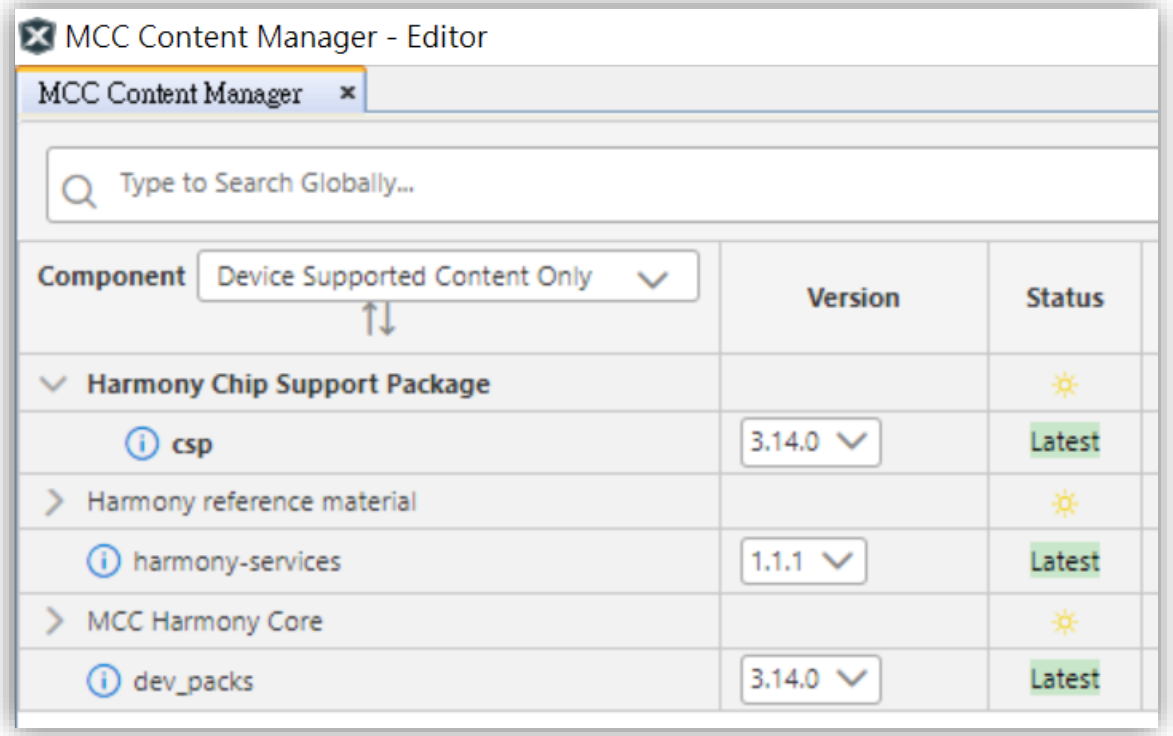




MCC Harmony Interface

- **Content Manager.(Existing Framework)**

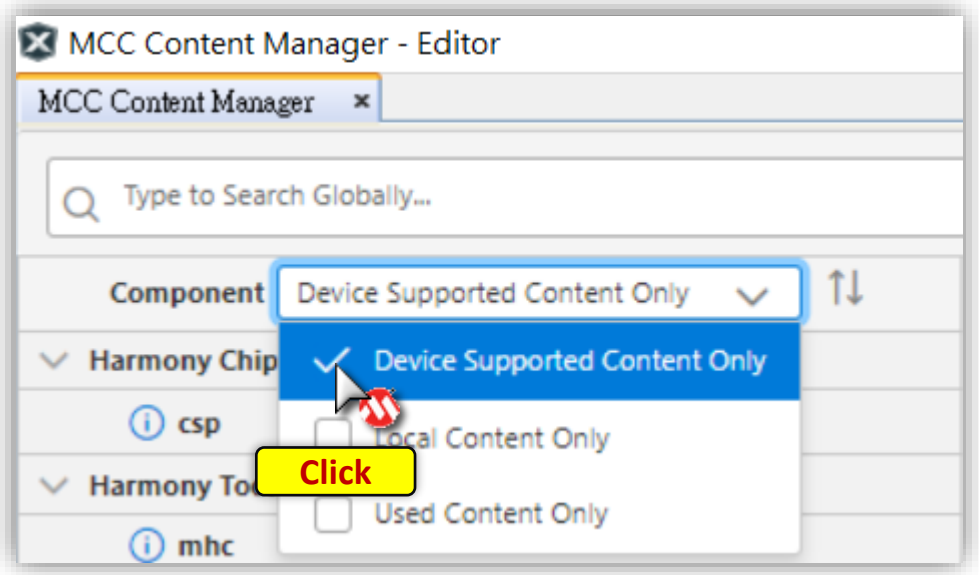


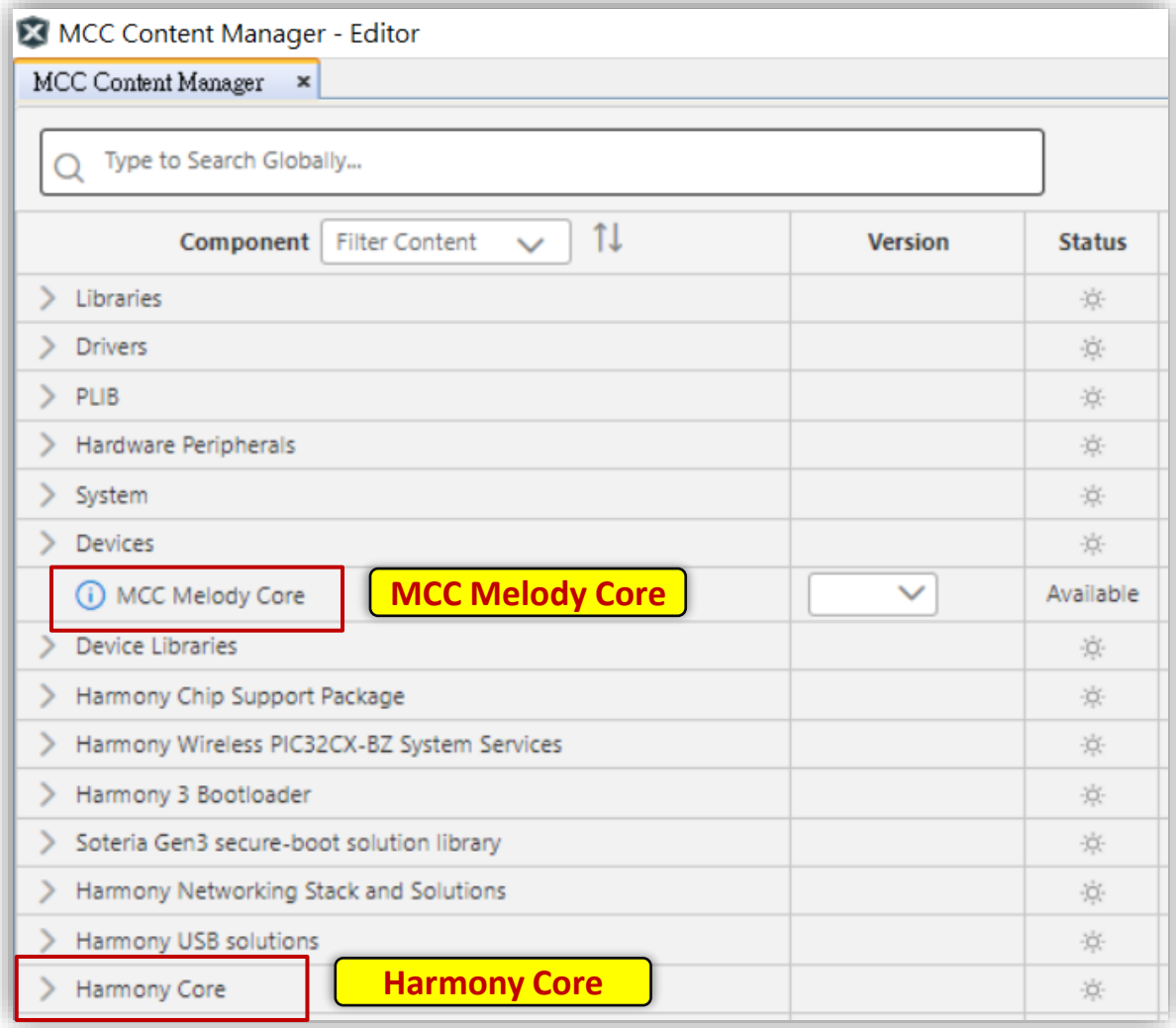


MICROCHIP

MCC Harmony Interface

- View All Framework.(Include MCC Harmony and MCC Melody)
  - Disable Device Supported Content Only.

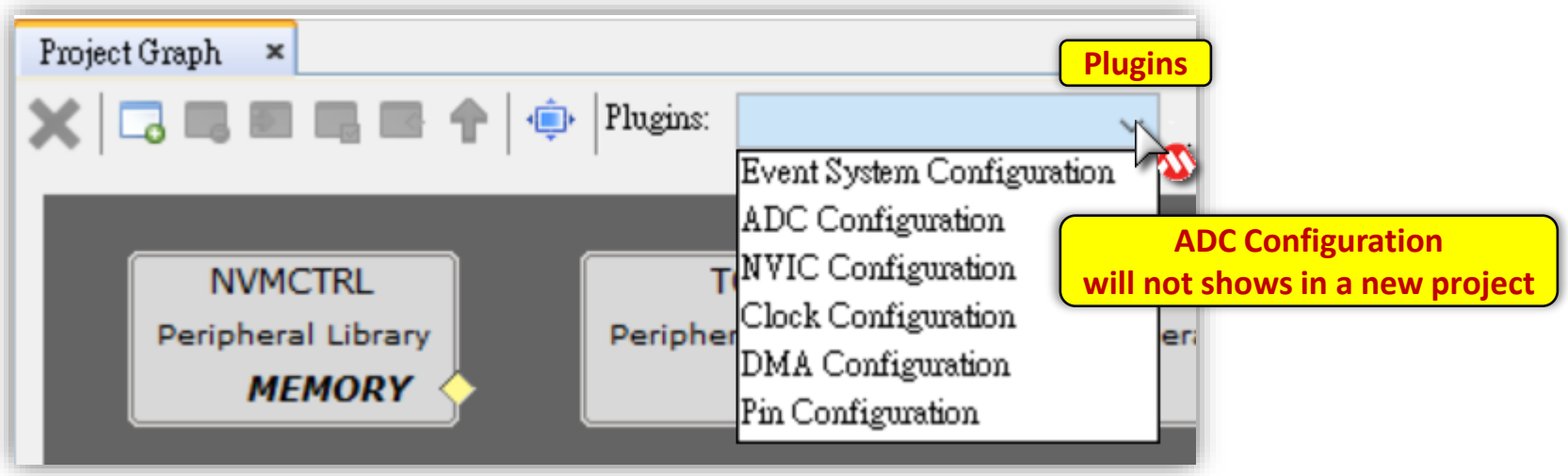




MCC Harmony Interface

Easy View Configuration

- **Plugins (Easy View Configuration)**

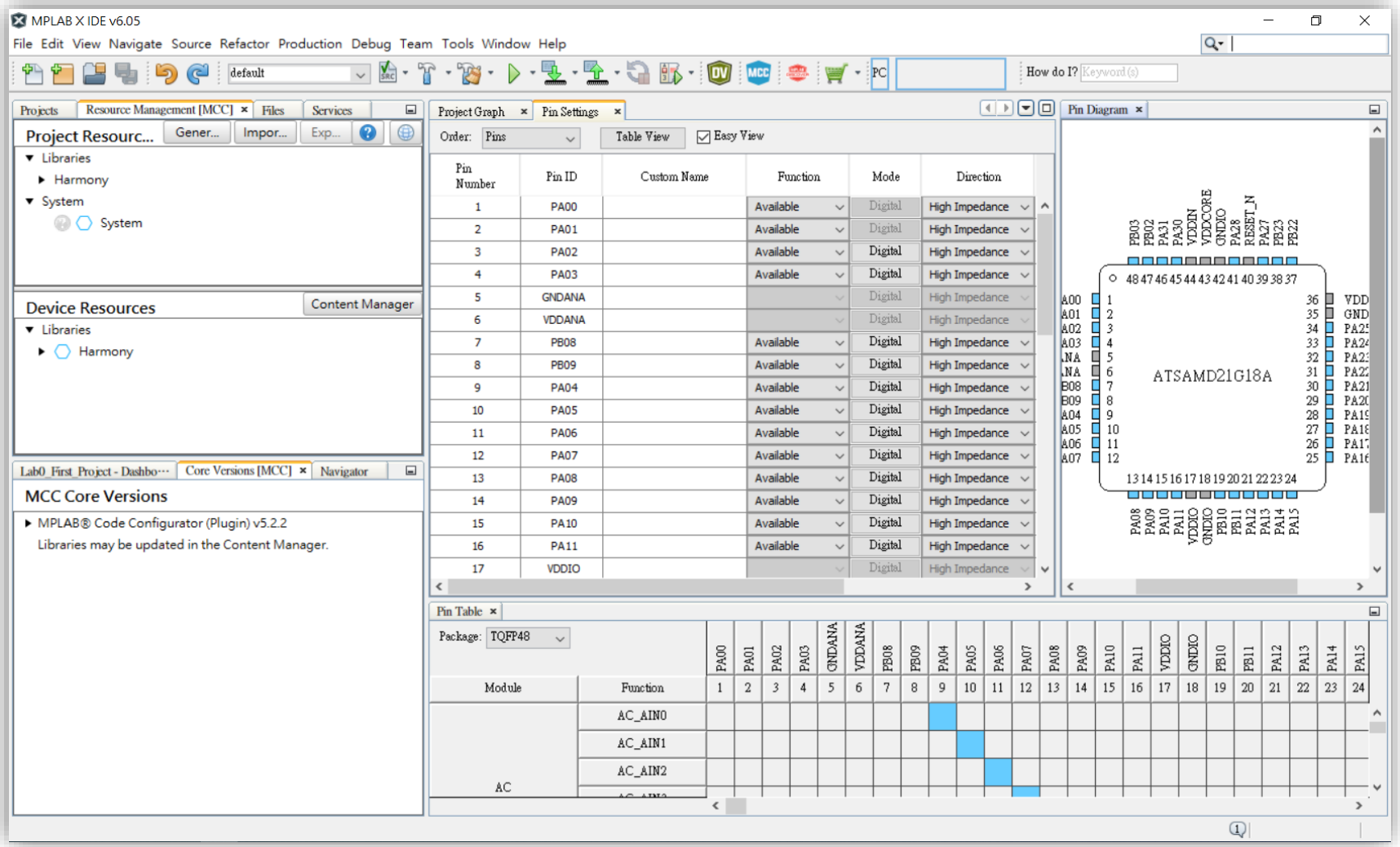


Easy View Configuration Tools will shows depend on what peripheral you already added-in.

MCC Harmony Interface

Easy View Configuration

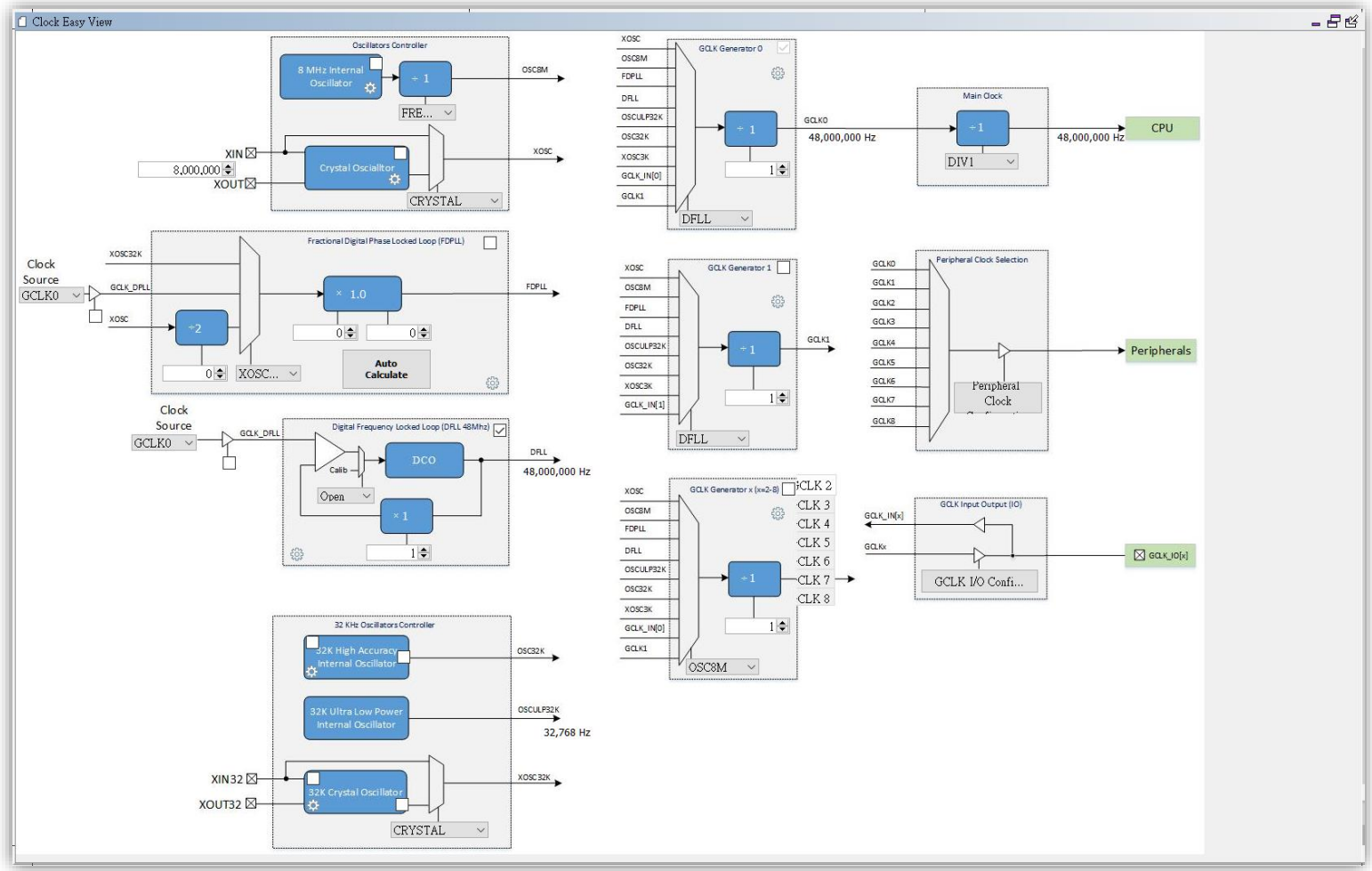
- **Plugins : Pin Configuration**



MCC Harmony Interface

Easy View Configuration

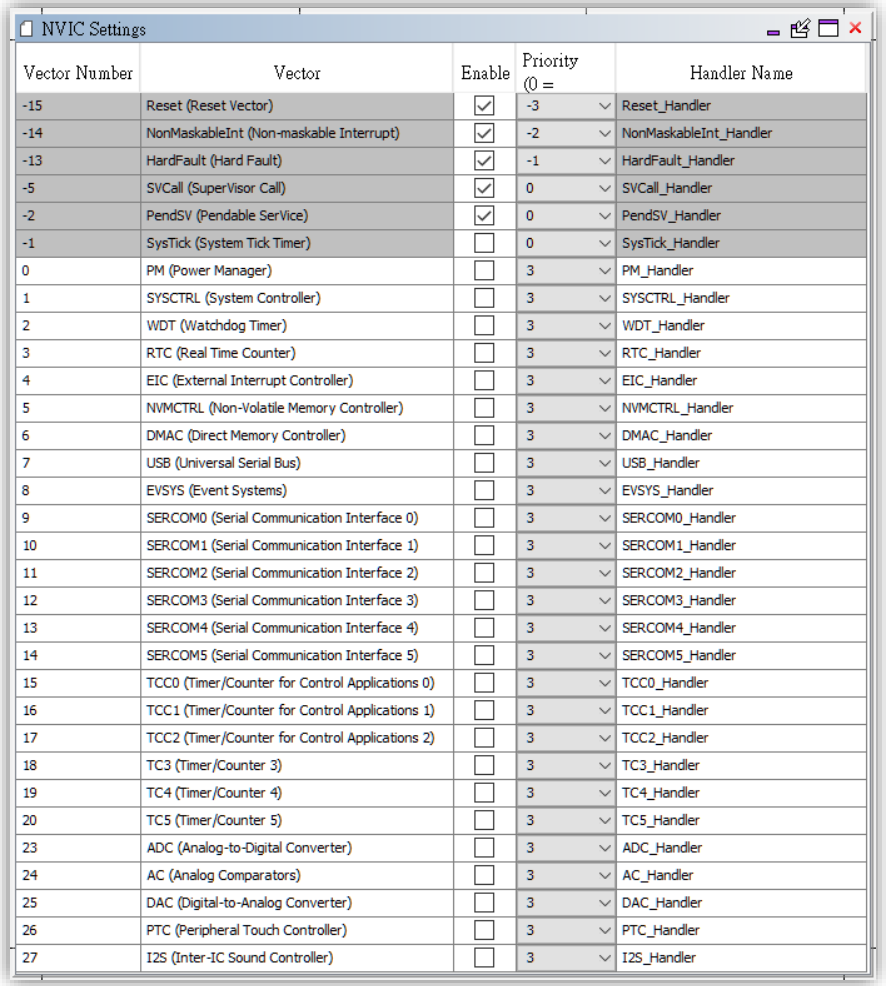
- **Plugins : Clock Configuration**



MCC Harmony Interface

Easy View Configuration

- **Plugins : NVIC Configuration**



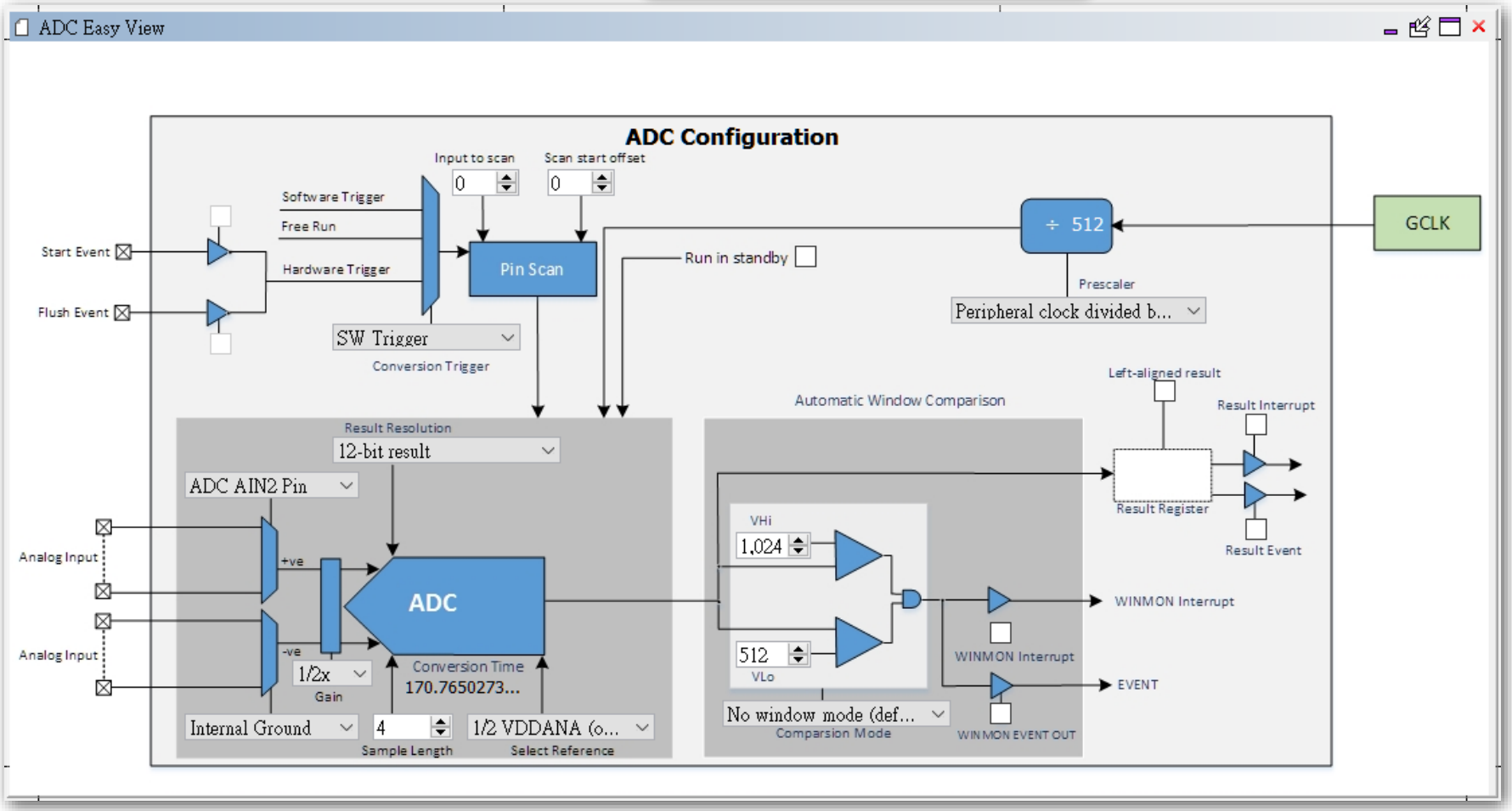
Vector Number	Vector	Enable	Priority (0 =	Handler Name
-15	Reset (Reset Vector)	☑	-3	Reset_Handler
-14	NonMaskableInt (Non-maskable Interrupt)	☑	-2	NonMaskableInt_Handler
-13	HardFault (Hard Fault)	☑	-1	HardFault_Handler
-5	SVCall (SuperVisor Call)	☑	0	SVCall_Handler
-2	PendSV (Pendable SerVice)	☑	0	PendSV_Handler
-1	SysTick (System Tick Timer)	☐	0	SysTick_Handler
0	PM (Power Manager)	☐	3	PM_Handler
1	SYSCTRL (System Controller)	☐	3	SYSCTRL_Handler
2	WDT (Watchdog Timer)	☐	3	WDT_Handler
3	RTC (Real Time Counter)	☐	3	RTC_Handler
4	EIC (External Interrupt Controller)	☐	3	EIC_Handler
5	NVMCTRL (Non-Volatile Memory Controller)	☐	3	NVMCTRL_Handler
6	DMAC (Direct Memory Controller)	☐	3	DMAC_Handler
7	USB (Universal Serial Bus)	☐	3	USB_Handler
8	EVSYS (Event Systems)	☐	3	EVSYS_Handler
9	SERCOM0 (Serial Communication Interface 0)	☐	3	SERCOM0_Handler
10	SERCOM1 (Serial Communication Interface 1)	☐	3	SERCOM1_Handler
11	SERCOM2 (Serial Communication Interface 2)	☐	3	SERCOM2_Handler
12	SERCOM3 (Serial Communication Interface 3)	☐	3	SERCOM3_Handler
13	SERCOM4 (Serial Communication Interface 4)	☐	3	SERCOM4_Handler
14	SERCOM5 (Serial Communication Interface 5)	☐	3	SERCOM5_Handler
15	TCC0 (Timer/Counter for Control Applications 0)	☐	3	TCC0_Handler
16	TCC1 (Timer/Counter for Control Applications 1)	☐	3	TCC1_Handler
17	TCC2 (Timer/Counter for Control Applications 2)	☐	3	TCC2_Handler
18	TC3 (Timer/Counter 3)	☐	3	TC3_Handler
19	TC4 (Timer/Counter 4)	☐	3	TC4_Handler
20	TC5 (Timer/Counter 5)	☐	3	TC5_Handler
23	ADC (Analog-to-Digital Converter)	☐	3	ADC_Handler
24	AC (Analog Comparators)	☐	3	AC_Handler
25	DAC (Digital-to-Analog Converter)	☐	3	DAC_Handler
26	PTC (Peripheral Touch Controller)	☐	3	PTC_Handler
27	I2S (Inter-IC Sound Controller)	☐	3	I2S_Handler

MCC Harmony Interface

Easy View Configuration

- **Plugins : ADC Configuration**

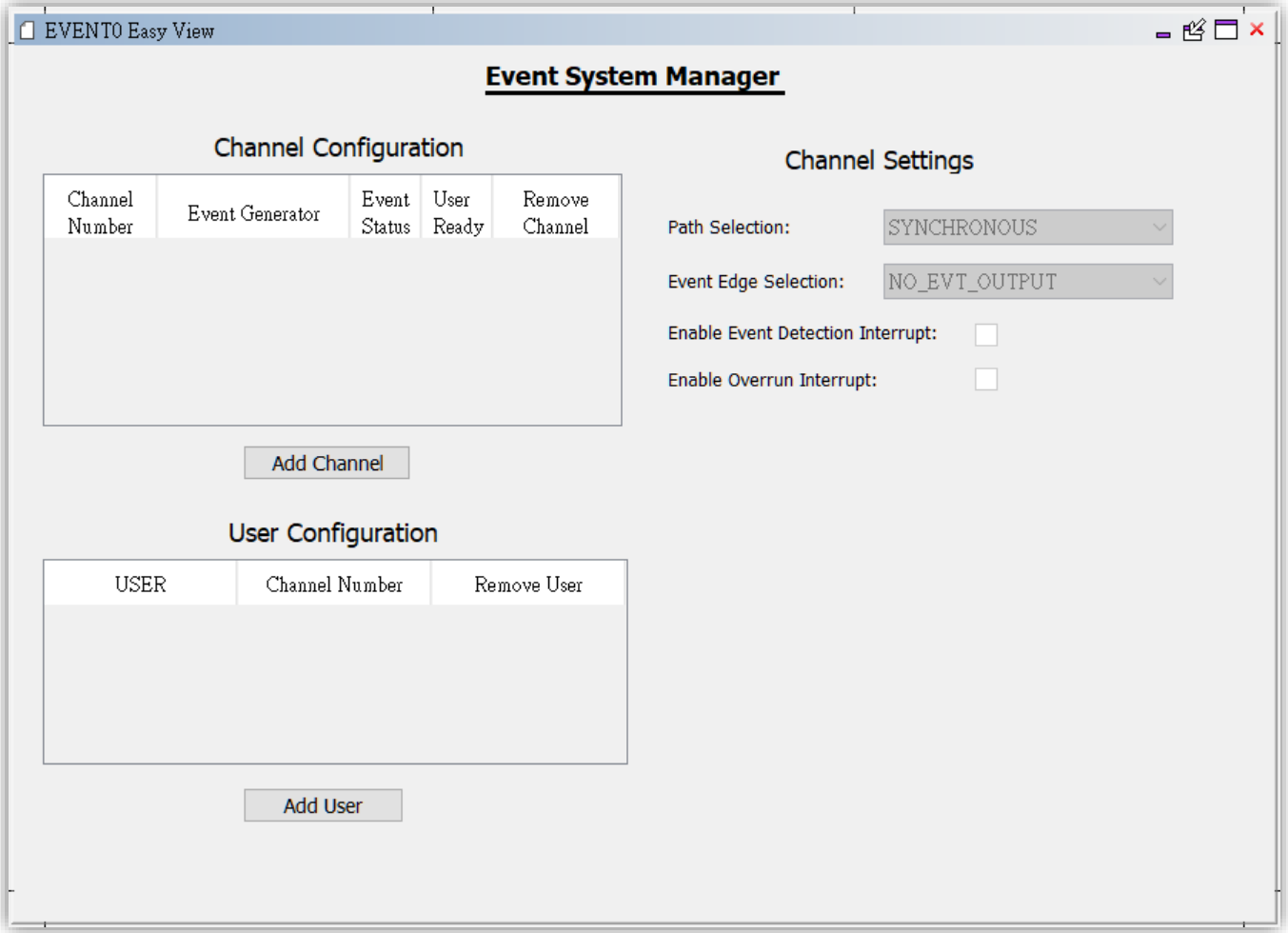
ADC Configuration will not shows in a new project



MCC Harmony Interface

Easy View Configuration

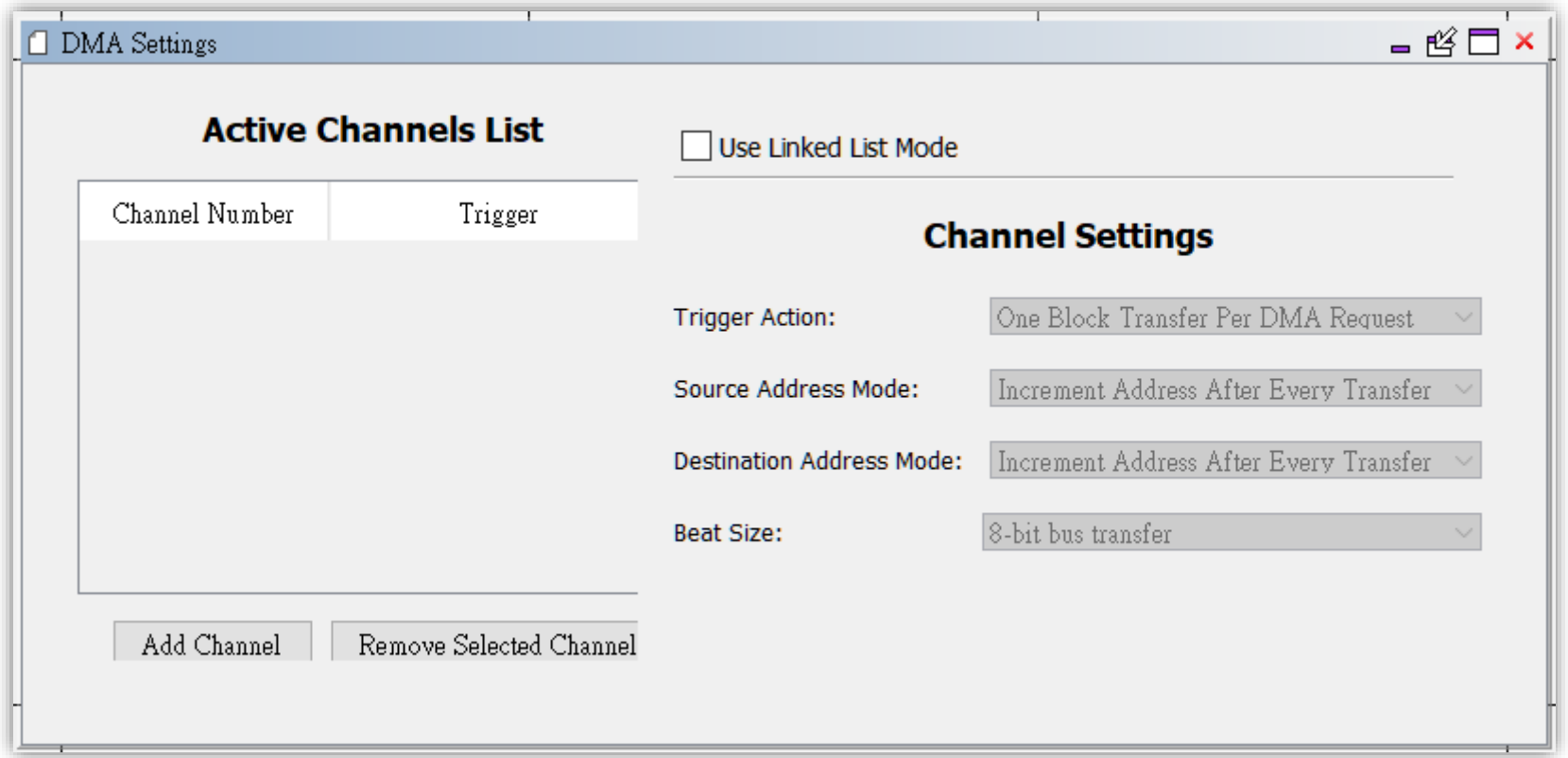
- **Plugins : Event System Configuration**



MCC Harmony Interface

Easy View Configuration

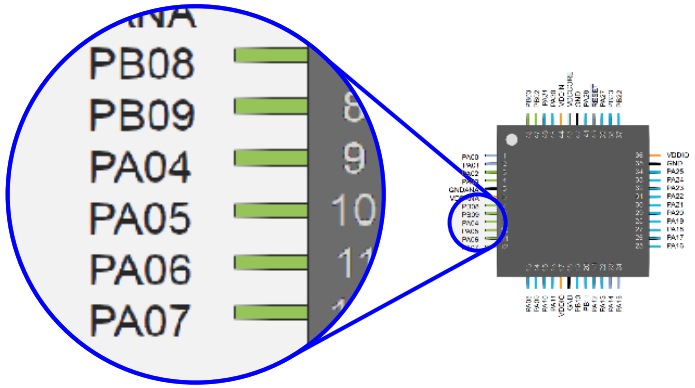
- **Plugins : DMA Configuration**

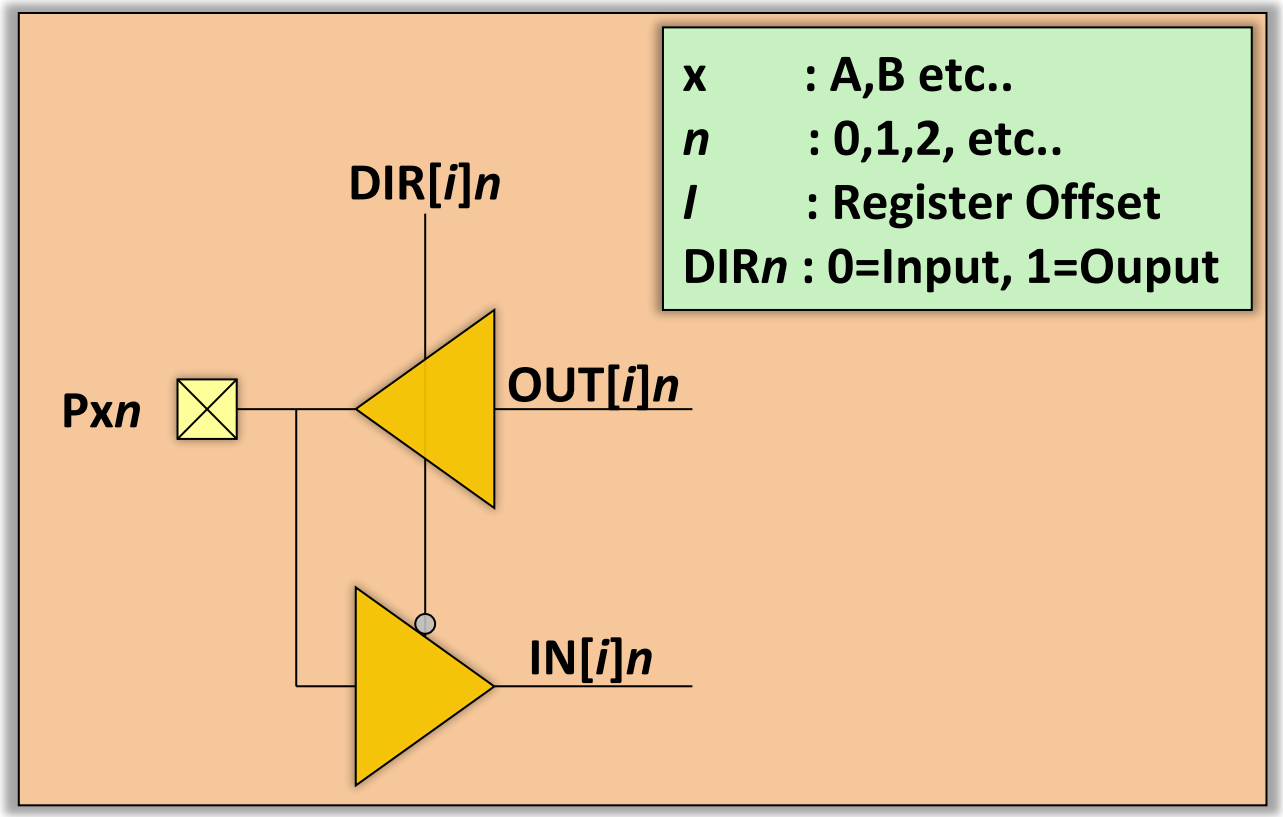


PORT I/O Architecture

PORT Block Diagram

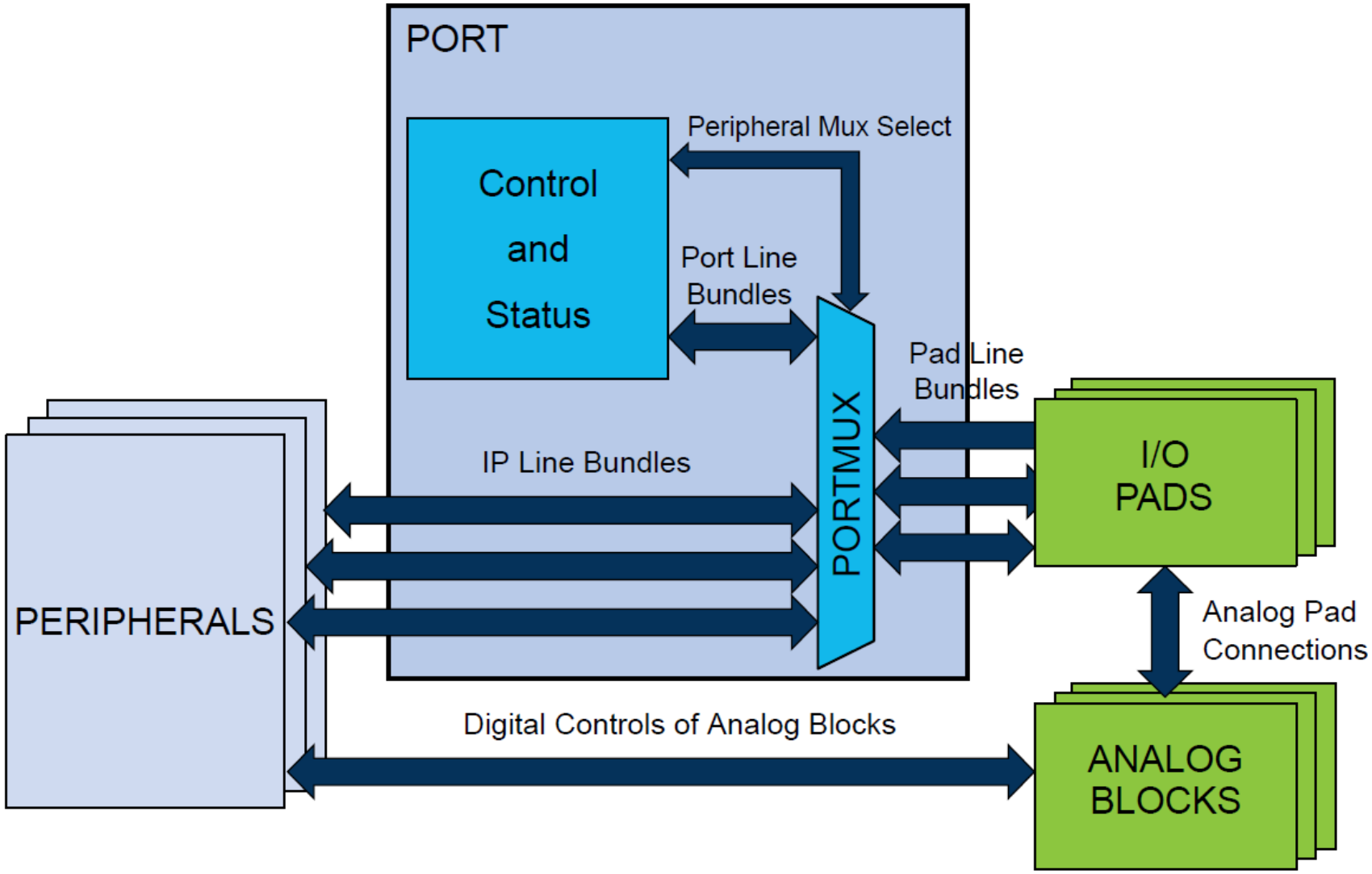
- Please refer to the block diagram, this is the concept for programming model. The real and detail block diagram please refer to the following slide.
- DIR: use to determine in or out. 0 for input, 1 for output.
- OUT: set output drive value for Output pins.
- IN: reaction logical level from Input pins.



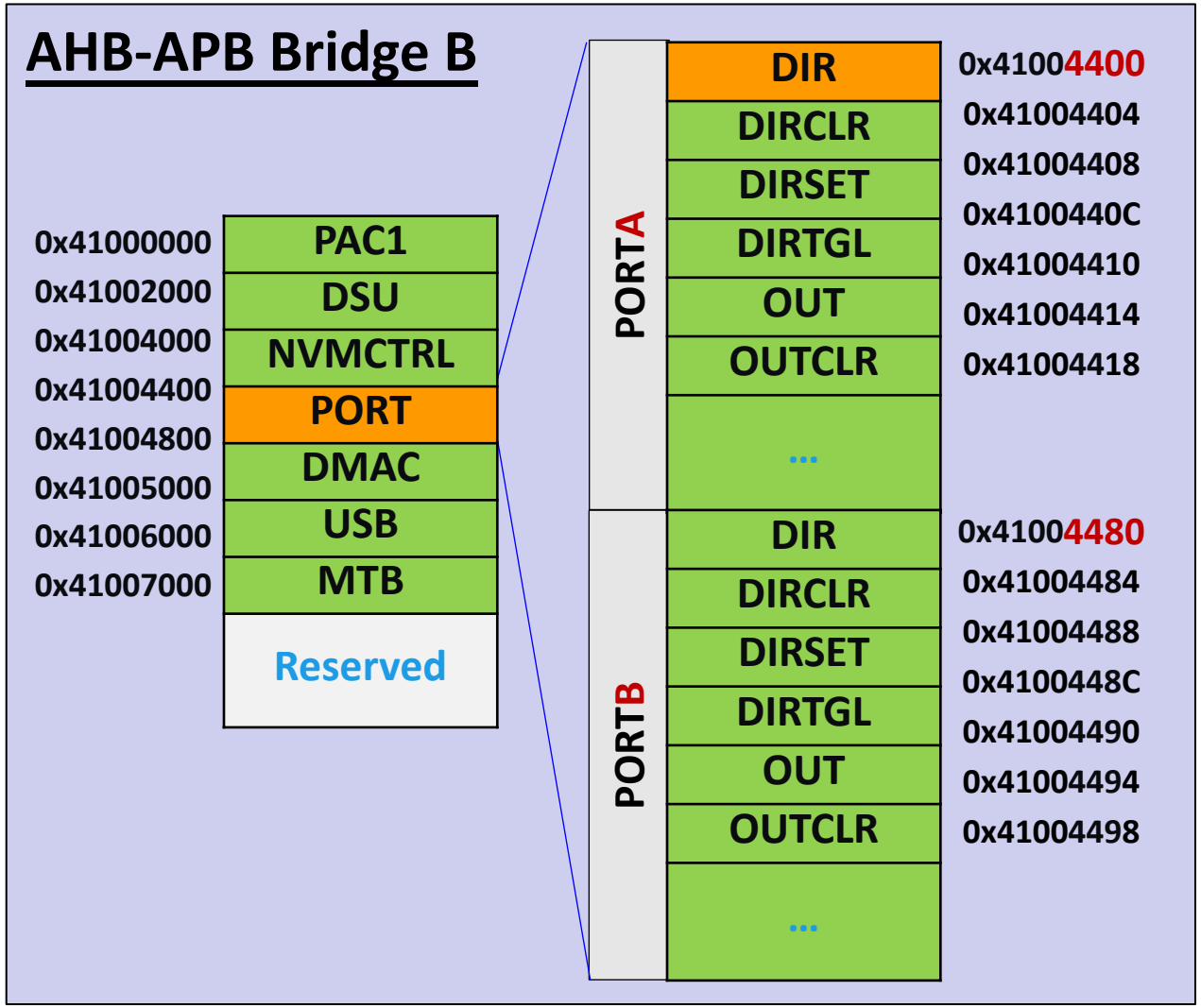


PORT Block Diagram

- **SAMD21G18A PORT Block Diagram**



Register Access



Register Summary from datasheet

Offset	Name	Bit Pos.
0x00	DIR	7:0
0x01		15:8
0x02		23:16
0x03		31:24
0x04	DIRCLR	7:0
0x05		15:8
0x06		23:16
0x07		31:24
0x08	DIRSET	7:0
0x09		15:8
0x0A		23:16
0x0B		31:24
0x0C	DIRTGL	7:0
0x0D		15:8
0x0E		23:16
0x0F		31:24
0x10	OUT	7:0
0x11		15:8
0x12		23:16
0x13		31:24
0x14	OUTCLR	7:0
0x15		15:8
0x16		23:16
0x17		31:24

Register Access

- There are two way to access Register:
  - Access by Register Pointer

```
*(__IO uint32_t *) (0x41004400U) = 0x55; /* 0x41004400U : PORTA DIR */
*(__IO uint32_t *) (0x41004480U) = 0x55; /* 0x41004480U : PORTB DIR */
```

  - Access by Pre-defined Struct

```
PORT_REGS->GROUP[0].PORT_DIR = 0x55; /* Group[0] : PORTA Register Set */
PORT_REGS->GROUP[1].PORT_DIR = 0x55; /* Group[1] : PORTB Register Set */
```

atsamd21g18a.h

```
#define PORT_REGS  ((port_registers_t*)0x41004400)
```

port.h

```
typedef struct
{  /* Port Module */
      port_group_registers_t    GROUP[GROUP_NUMBER];
} port_registers_t;
```

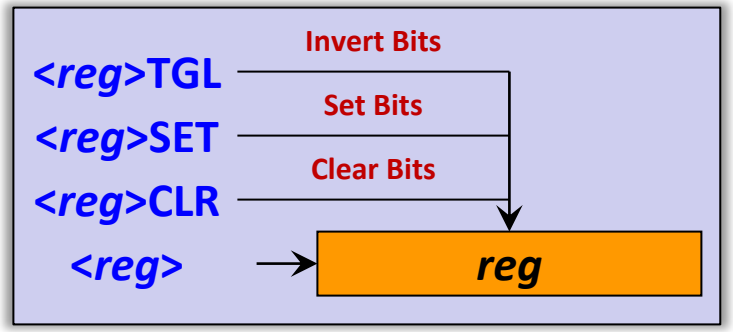
port.h

```
typedef struct
{
  __IO  uint32_t    PORT_DIR;
  __IO  uint32_t    PORT_DIRCLR;
  __IO  uint32_t    PORT_DIRSET;
  __IO  uint32_t    PORT_DIRTGL;
  …
} port_group_registers_t;
```

Atomic Bits Manipulation

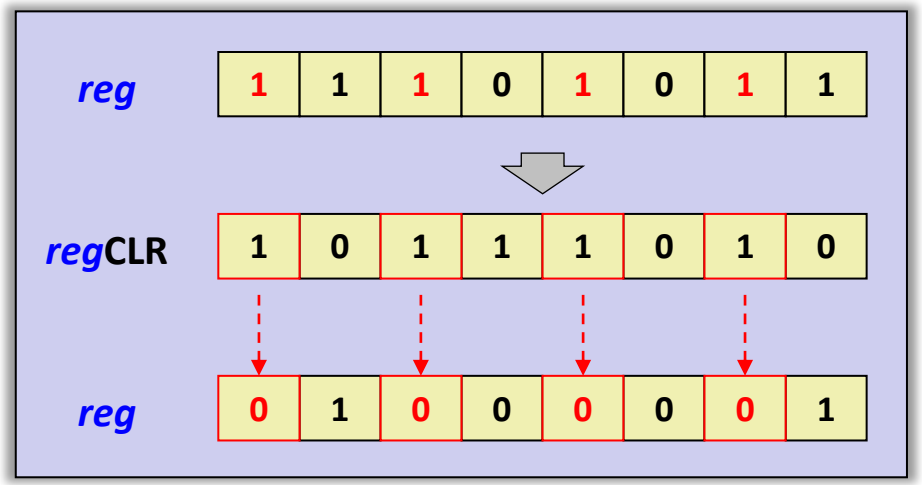
- **Some register provide <*reg*>CLR, <*reg*>SET , <*reg*>TGL register for atomic bits manipulation.**

- **This register manipulated without doing a read-modify-write operation by using below**
  - <*reg*> Toggle (<*reg*>TGL)
  - <*reg*> Clear (<*reg*>CLR)
  - <*reg*> Set (<*reg*>SET)

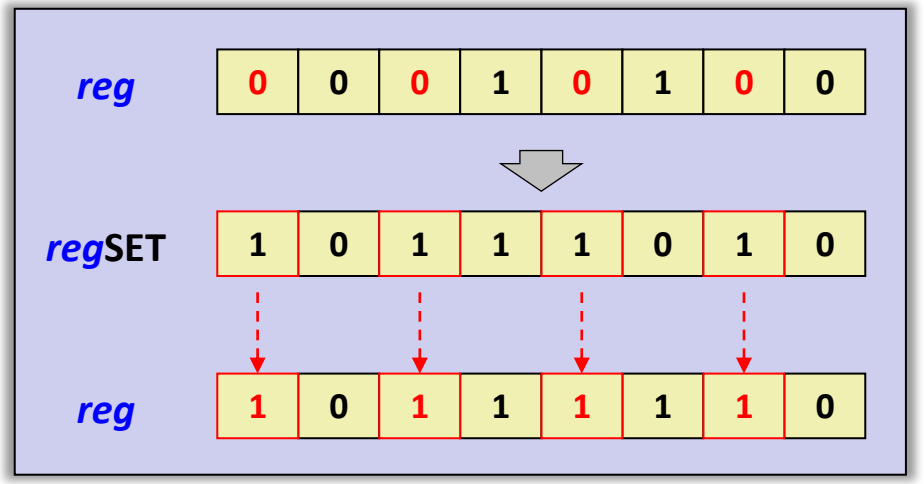


- **Setting the manipulation register bits corresponding to the base register will set the bits to 1, clear to 0 or toggle.**

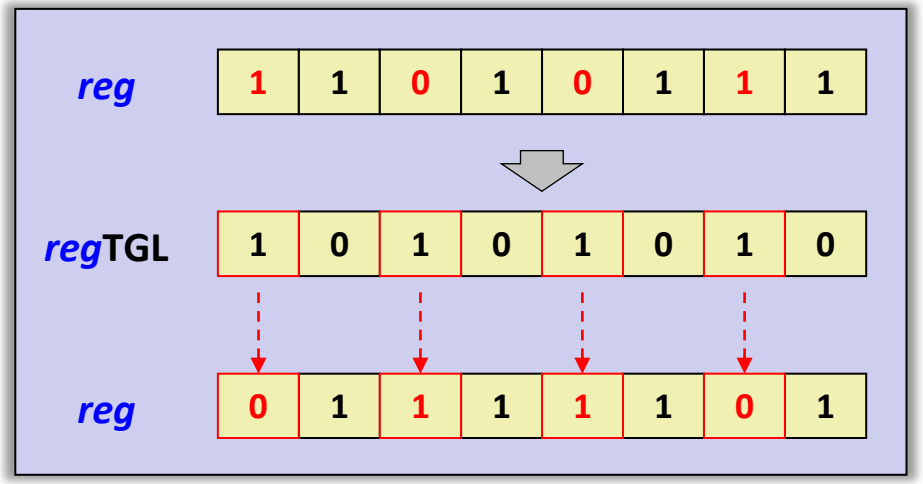
Atomic Bits Manipulation



*reg*CLR : corresponding bits clear to 0



*reg*SET : corresponding bits set to 1



*reg*TGL : corresponding bits toggled
(0 -> 1, 1 -> 0)

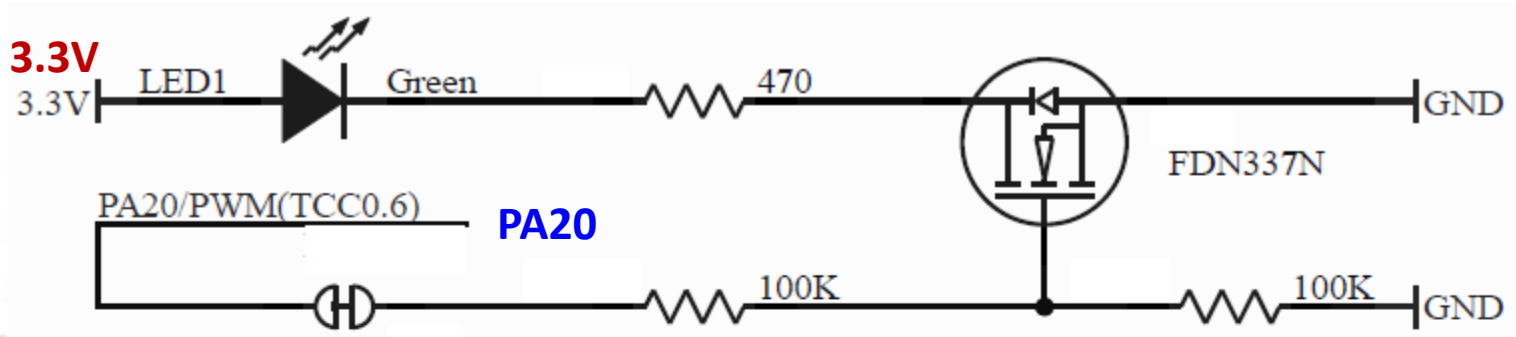
MICROCHIP

Lab1 PORT Output

- Try to control LED1(PA20) continues toggle.
  (period around 500ms ~ 1S).
- You can use register pointer or pre-defined struct to access PORT.

- How to start ?

Check Schematic



LED1	PA20
LED2	PA21
LED3	PA17
BT1	PA14
BT2	PA15

Lab1 PORT Output

Step 1

a **Add code segment to your main loop**

```
// TODO 1.01
uint32_t i = 0;

int main (void)
{
   SYS_Initialize ( NULL );

   // TODO 1.02
   *(__IO uint32_t *)(0x41004400U + 0x08U) = 0x00100000;

   while( true )
   {
      for ( i = 0 ; i < 2000000 ; i++ )
      {}
      // TODO 1.03
      *(__IO uint32_t *)(0x41004400U + 0x1CU) = 0x00100000;
   }
}
```

Access by Register Pointer

Period Control

b **Program firmware to target board then observe result.**

Lab1 PORT Output

Register Description

```
0x00100000                                   (Hex)
0000 0000 0001 0000 0000 0000 0000 0000 b    (Binary)
3322 2222 2222 1111 1111 11
1098 7654 3210 9876 5432 1098 7654 3210
```

LED1 Pin PA20

```
// TODO 1.01
uint32_t i = 0;

int main (void)
{
   SYS_Initialize ( NULL );

   // TODO 1.02
    *(__IO uint32_t *)(0x41004400U + 0x08U) = 0x00100000;

   while( true )
   {
      for ( i = 0 ; i < 2000000 ; i++ );

      // TODO 1.03
       *(__IO uint32_t *)(0x41004400U + 0x1CU) = 0x00100000;
   }
}
```

Offset	Name
0x00	DIR
0x01	
0x02	
0x03	
0x04	DIRCLR
0x05	
0x06	
0x07	
0x08	DIRSET
0x09	
0x0A	
0x0B	
0x1C	OUTTGL
0x1D	
0x1E	
0x1F	

MICROCHIP

Lab1 PORT Output

Step 2

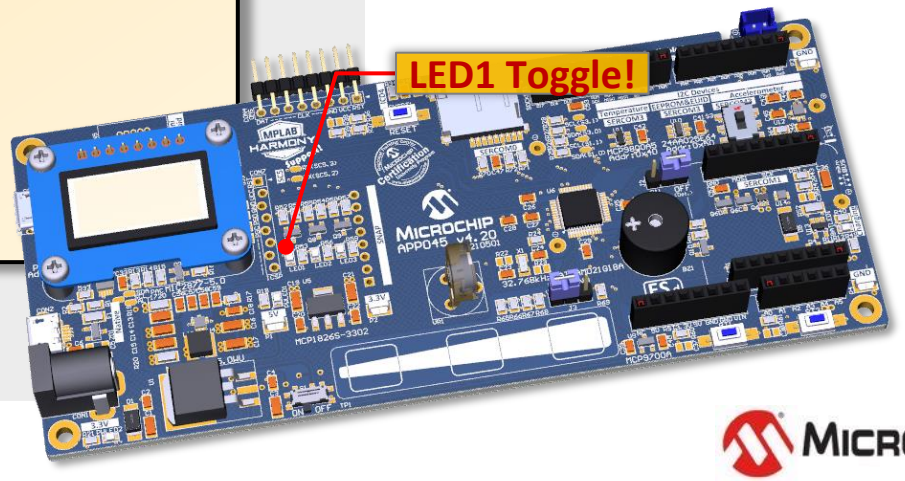
a **Modify code segment to your main loop**

```
// TODO 1.01
uint32_t i = 0;

int main (void)
{
   SYS_Initialize ( NULL );

   // TODO 1.02
    PORT_REGS->GROUP[0].PORT_DIRSET = 1<<20;

   while( true )
   {
      for ( i = 0 ; i < 2000000 ; i++ );

      // TODO 1.03
       PORT_REGS->GROUP[0].PORT_OUTTGL = 1<<20;
   }
}
```

Access by Pre-defined Struct

Period Control

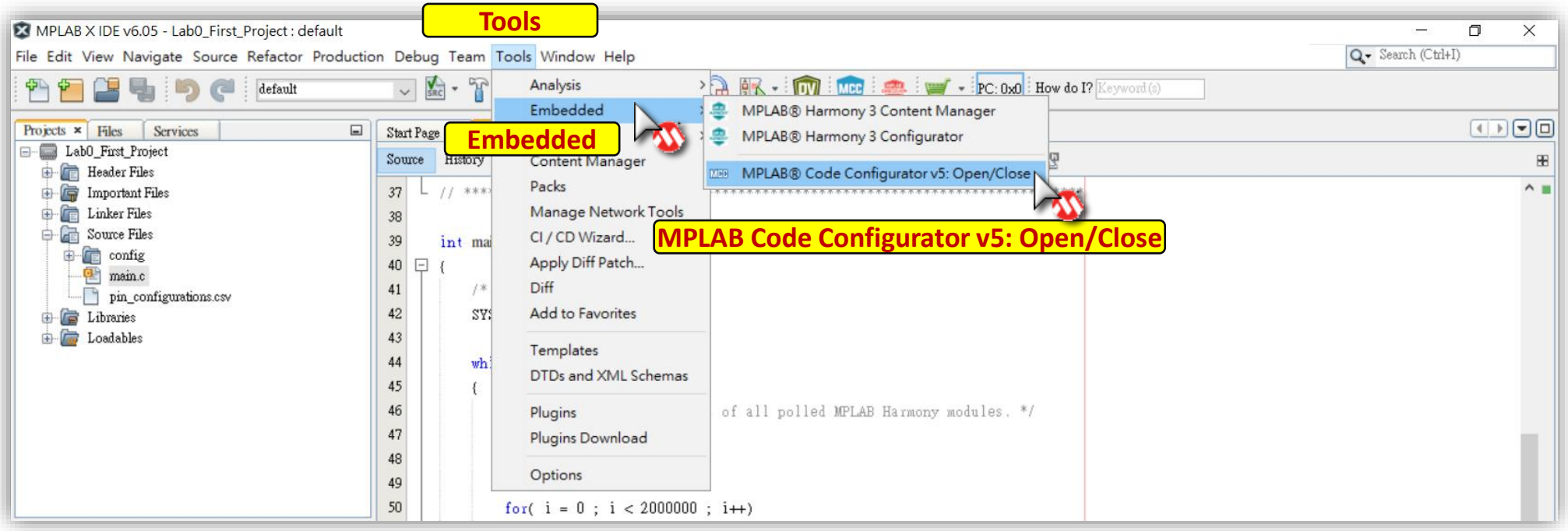
b **Program firmware to target board then observe result.**



MICROCHIP

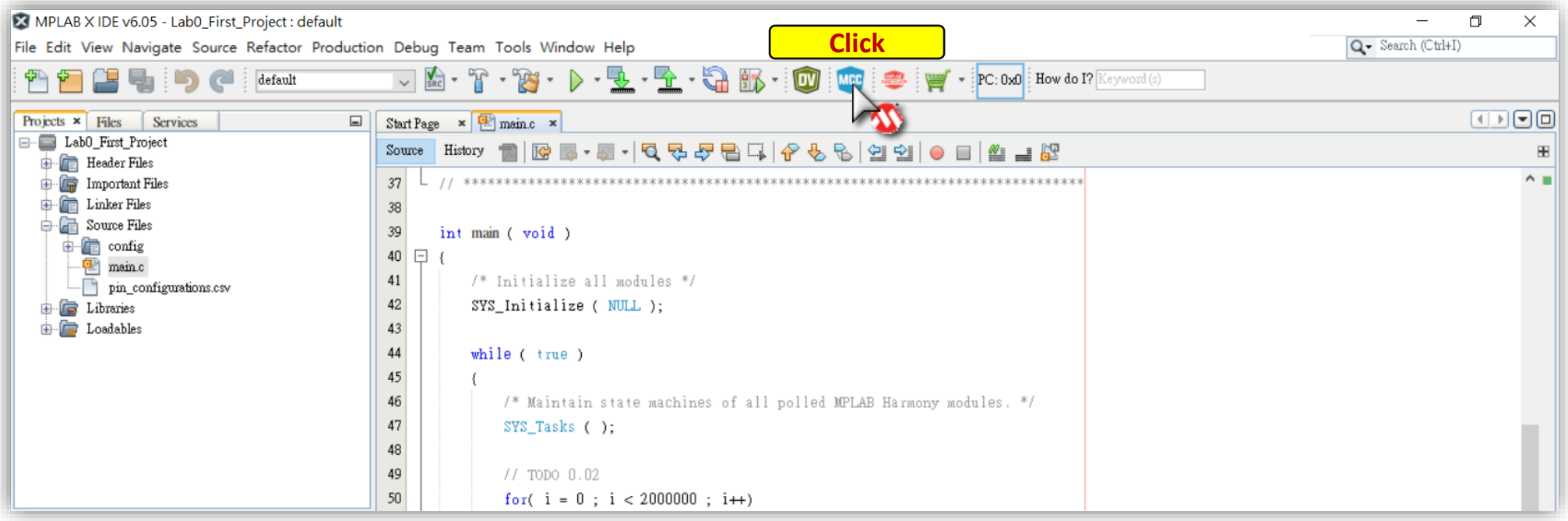
Pin Configuration using MCC Harmony

- If you already close MCC Harmony, please open it through below steps.
- Menu Tools > Embedded > MPLAB Code Configurator v5: Open/Close or Click



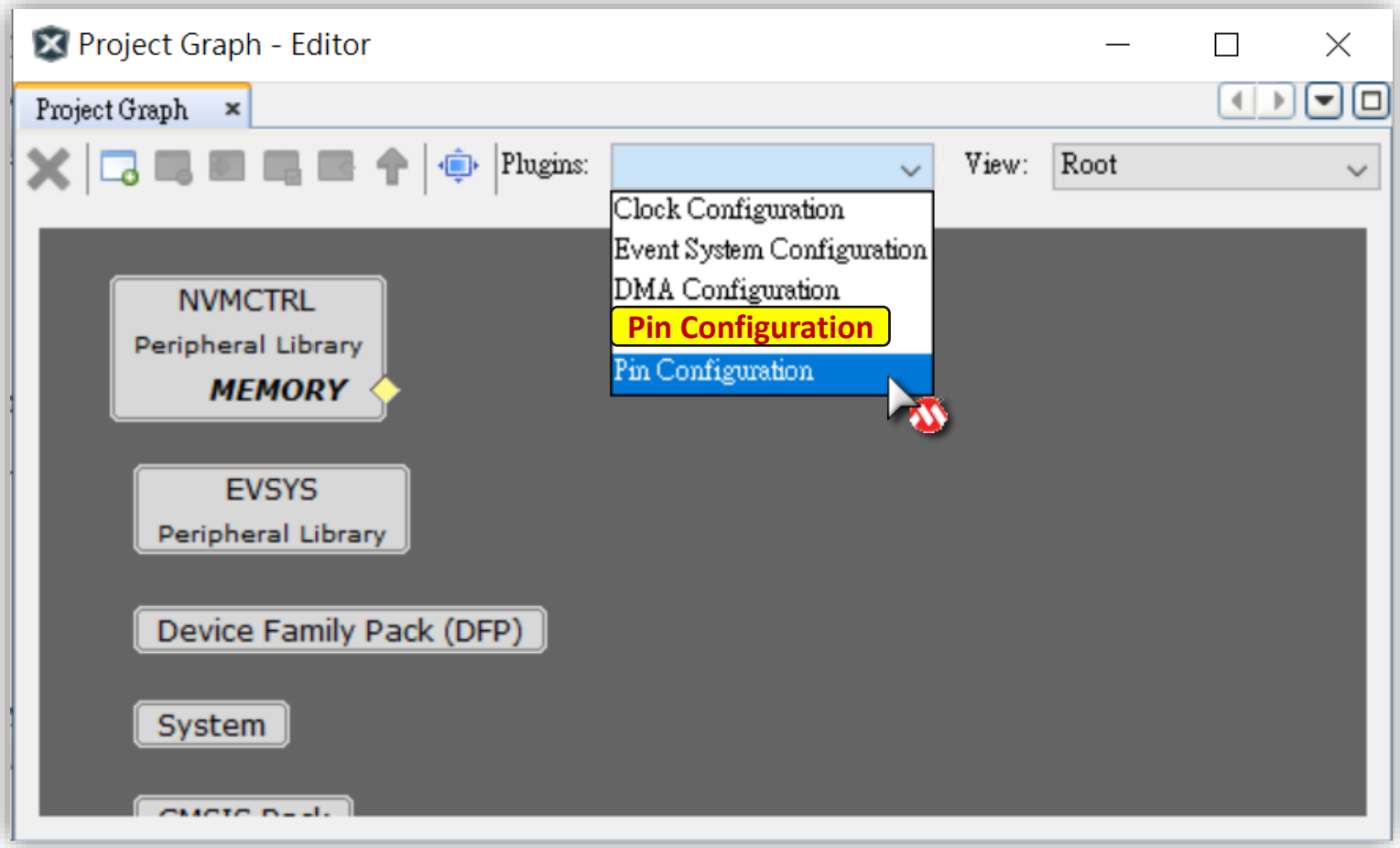
Pin Configuration using MCC Harmony

- Click MCC Icon.



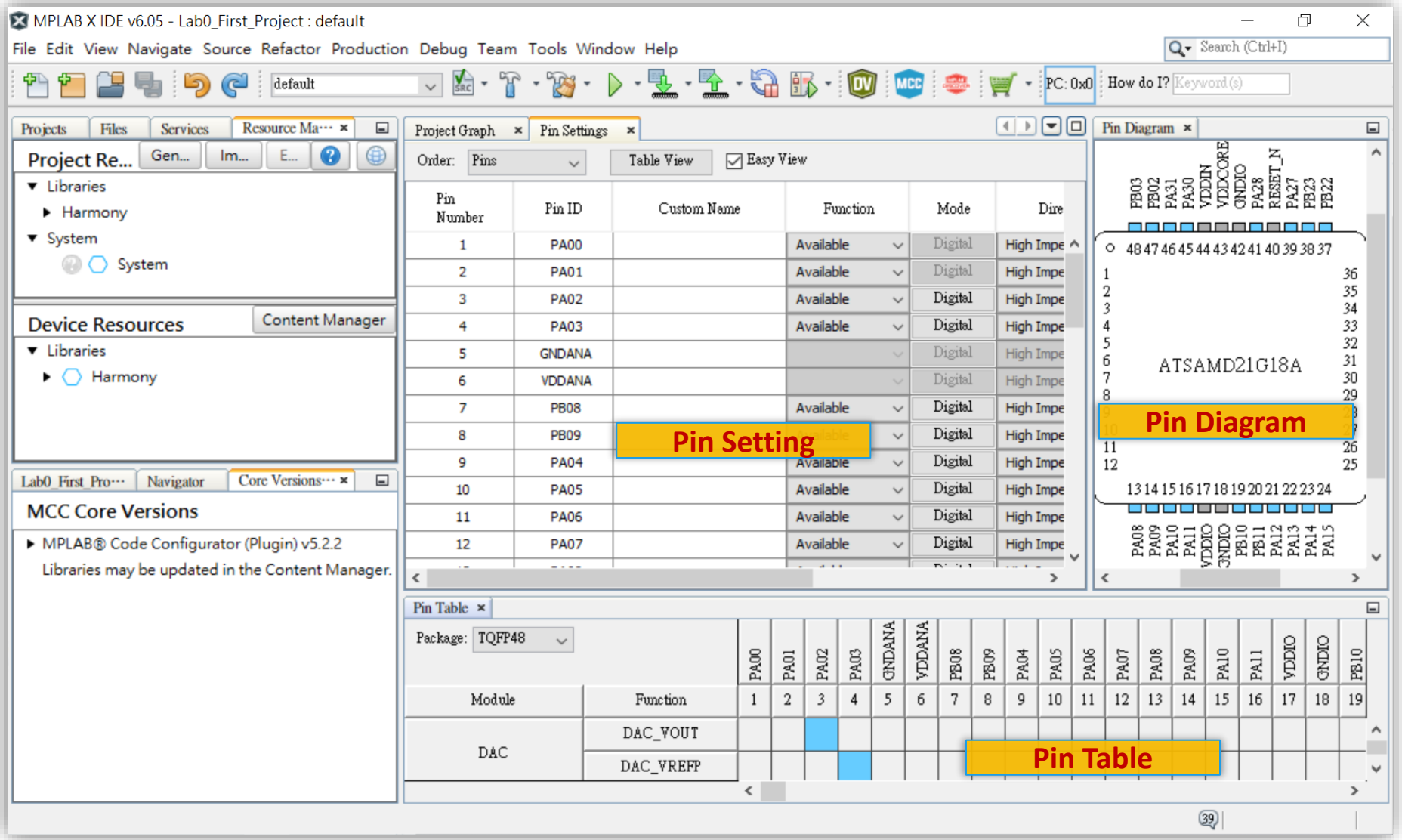
Pin Configuration using MCC Harmony

- Return to Harmony Configurator.
- Select **Project Graph > Plugins > Pin Configuration**



Pin Configuration using MCC Harmony

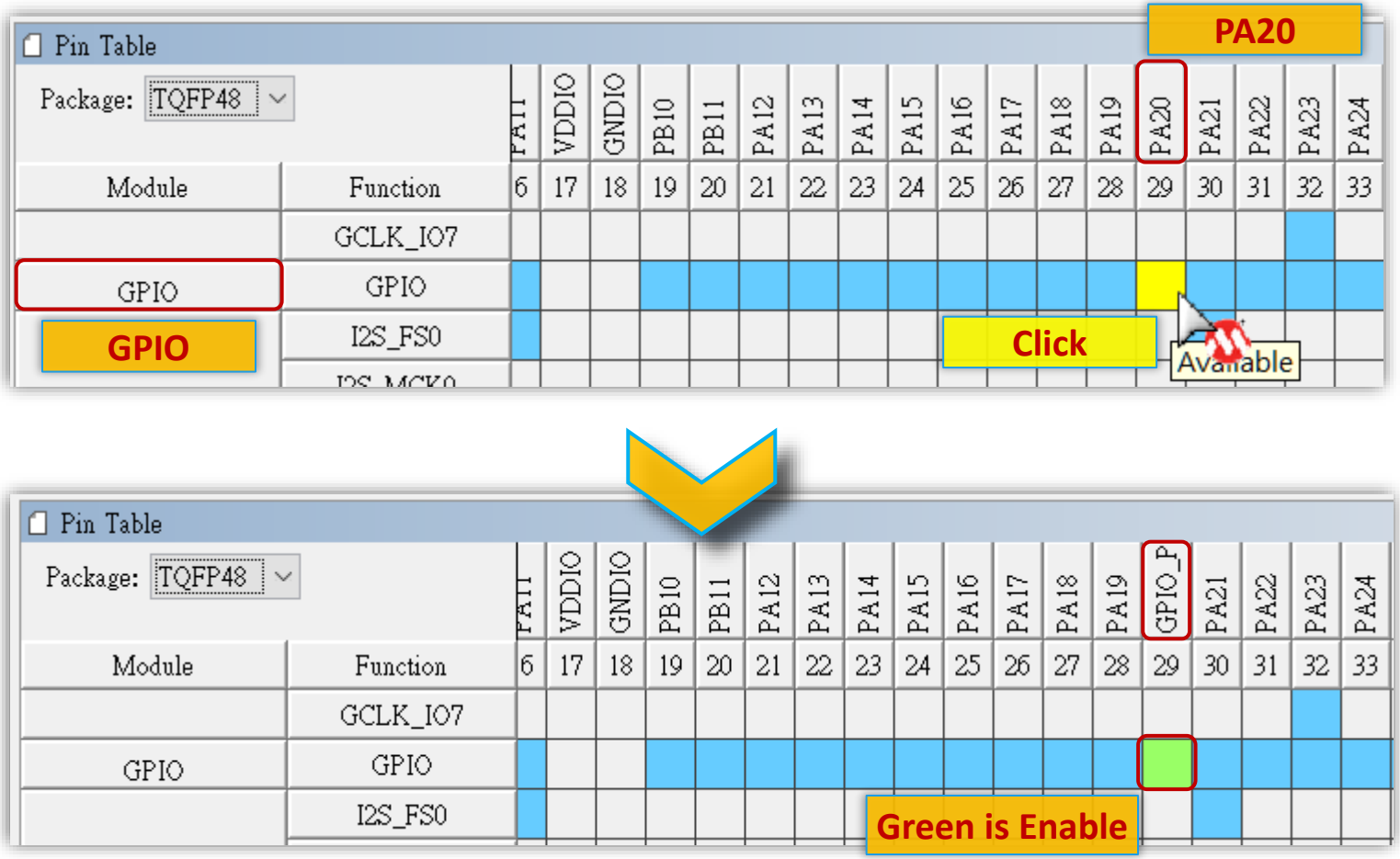
- **Docking three Pin Configuration windows as below.**



Lab1 PORT Output

Step 3

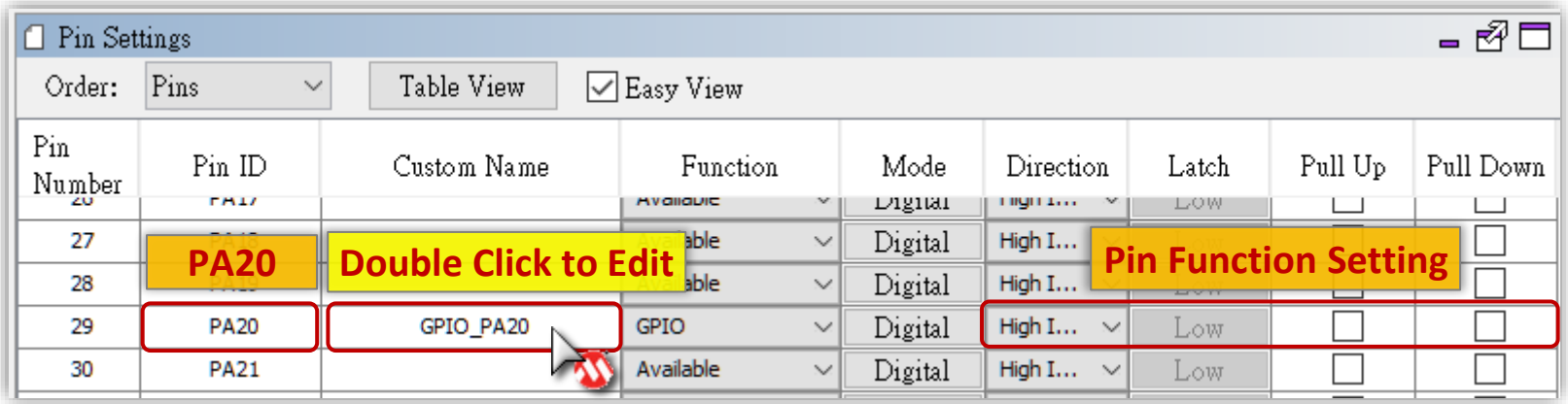
- **Pin Table configure. (Enable or Disable Pin)**

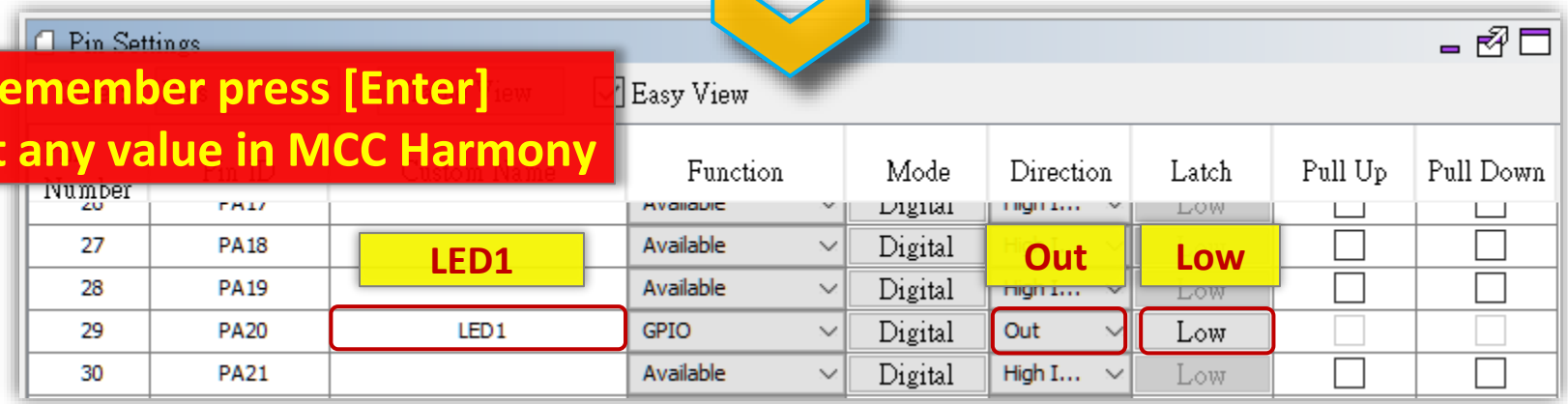


Lab1 PORT Output

Step 4

- **Pin Setting. (Pin Function Setting)**



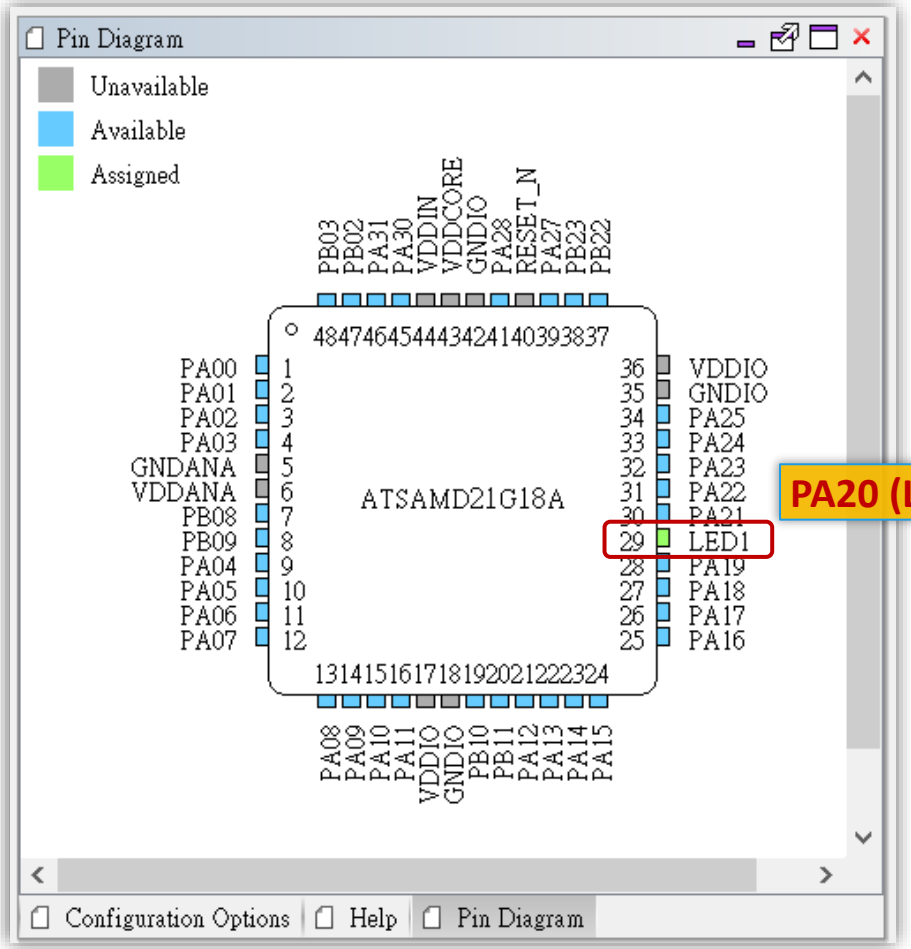


Always remember press [Enter] after to input any value in MCC Harmony

Lab1 PORT Output

Step 5

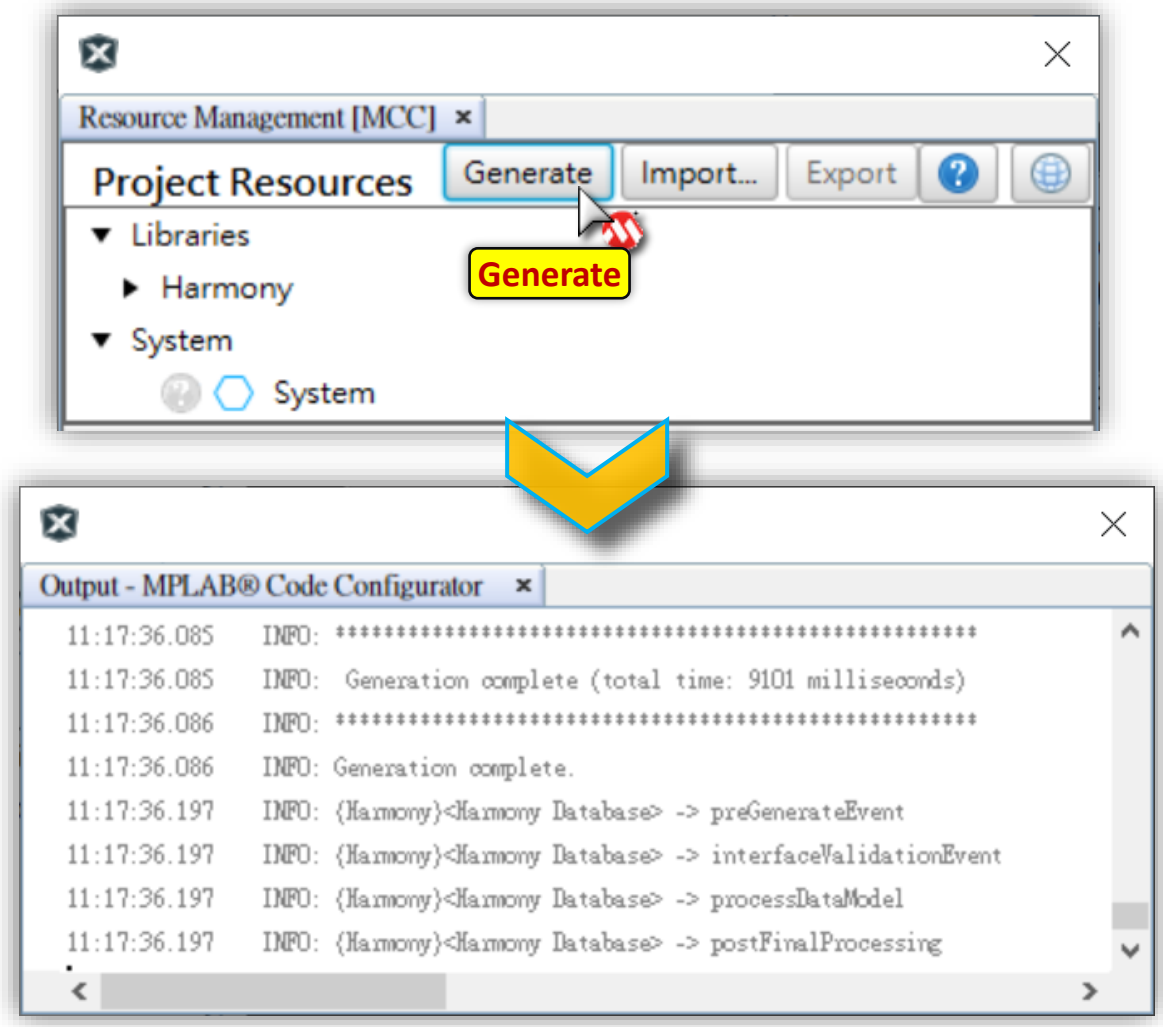
- **Pin Diagram. (Hardware design reference)**



Lab1 PORT Output

Step 6

- Click "Generate" Button to Generate your Code.



MCC Harmony GPIO Macros

Plib_port.h

```
/*** Macros for LED1 pin ***/
#define LED1_Set()              (PORT_REGS->GROUP[0].PORT_OUTSET = 1 << 20)
#define LED1_Clear()            (PORT_REGS->GROUP[0].PORT_OUTCLR = 1 << 20)
#define LED1_Toggle()           (PORT_REGS->GROUP[0].PORT_OUTTGL = 1 << 20)
#define LED1_Get()              (((PORT_REGS->GROUP[0].PORT_IN >> 20)) & 0x01)
#define LED1_OutputEnable()     (PORT_REGS->GROUP[0].PORT_DIRSET = 1 << 20)
#define LED1_InputEnable()      (PORT_REGS->GROUP[0].PORT_DIRCLR = 1 << 20)
#define LED1_PIN                PORT_PIN_PA20
```

Plib_port.c

```
void PORT_Initialize(void)
{
  /************************** GROUP 0 Initialization **************************/
  PORT_REGS->GROUP[0].PORT_DIR = 0x100000;
  PORT_REGS->GROUP[0].PORT_OUT = 0x100000;

  /************************** GROUP 1 Initialization **************************/
}
```

MICROCHIP

Lab1 PORT Output

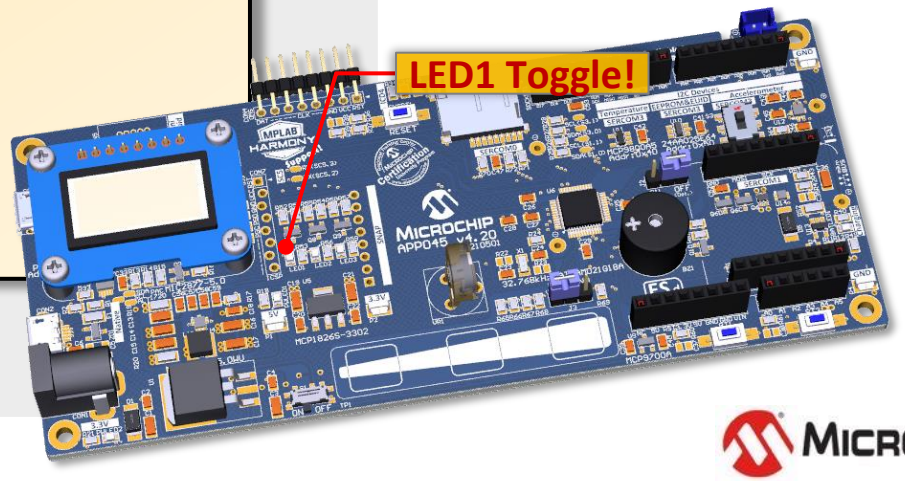
Step 7

a **Modify code segment to your main loop**

```
// TODO 1.01
uint32_t i = 0;

int main (void)
{
   SYS_Initialize ( NULL );

   // TODO 1.02
   //PORT_REGS->GROUP[0].PORT_DIRSET = 1<<20;

   while( true )
   {
      for ( i = 0 ; i < 2000000 ; i++ );

      // TODO 1.03
      LED1_Toggle();
   }
}
```

PORT initialization already done here

Comment out this line

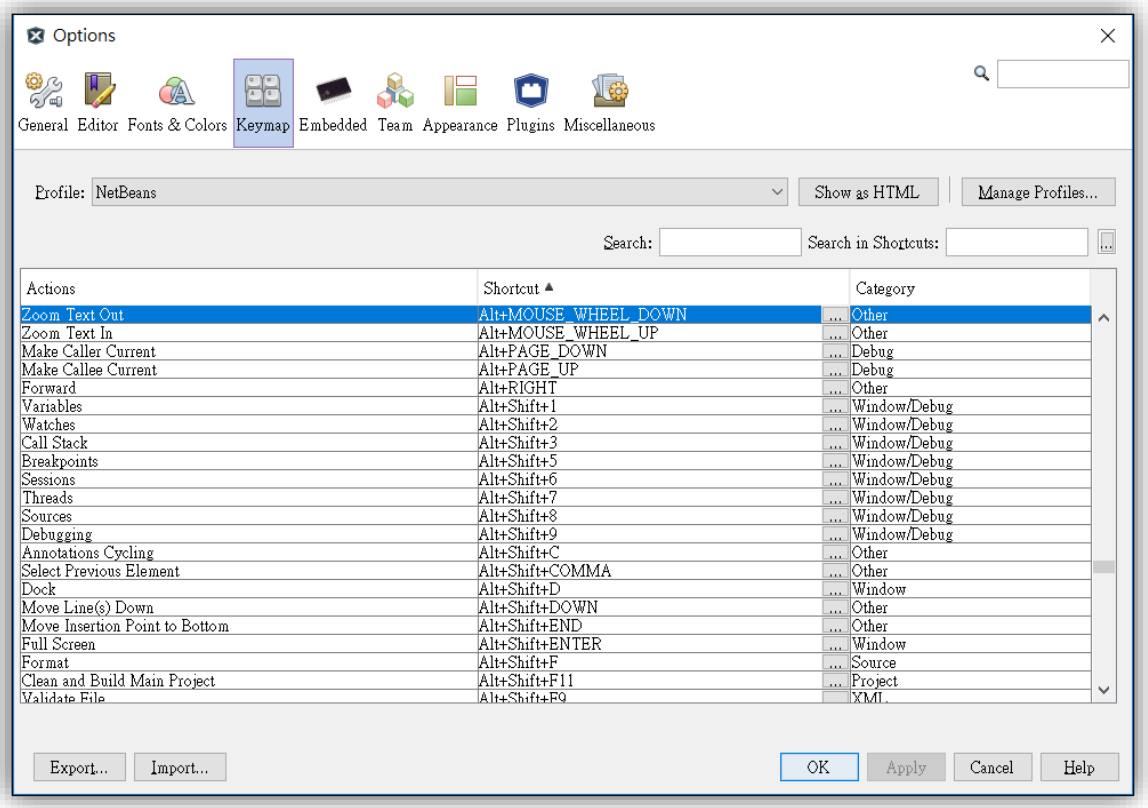


b **Program firmware to target board then observe result.**

MPLAB X IDE Shortcut key

- **MPLAB X IDE Provide a few shortcut key to enhance your performance.**
  - **Ctrl + Alt + ** : Show All Code Completion
    (Alternative shortcut : Ctrl **+ ** , Ctrl + Alt + Space**)**
  - **Ctrl + Mouse Left Click** : Open Macro (Code Trace)
  - **Alt + Left** : Backward (Code Trace)
  - **Alt + Shift + F** : Code Format
  - **Ctrl + Shift + C** :Toggle Comment

- **More ?**
  - Tools > Options > Keymap

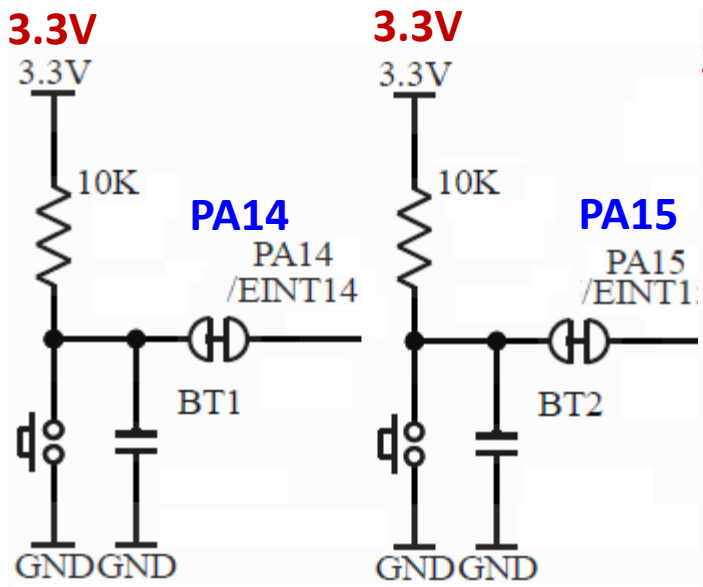


Lab2 PORT Input and Output

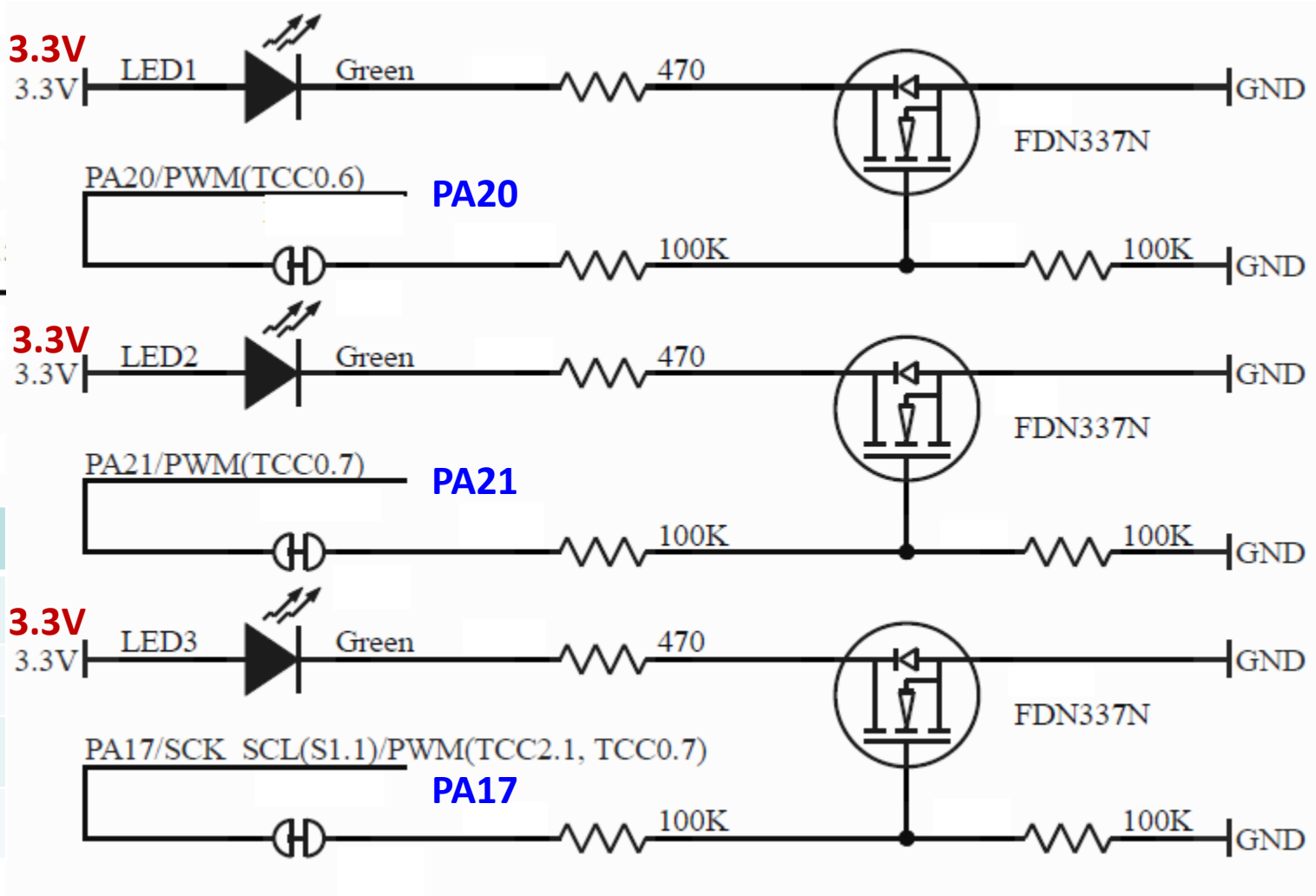
- **Based on Lab1, Try to add LED2(PA21) continues toggle (Period around 500ms ~ 1S).**
- **Get BT1(PA14) status then use to control LED3(PA17).**
  Pressed -> LED3 Light
  Released -> LED3 Dark

- **Let's go!**

Check Schematic



LED1	PA20
LED2	PA21
LED3	PA17
BT1	PA14
BT2	PA15

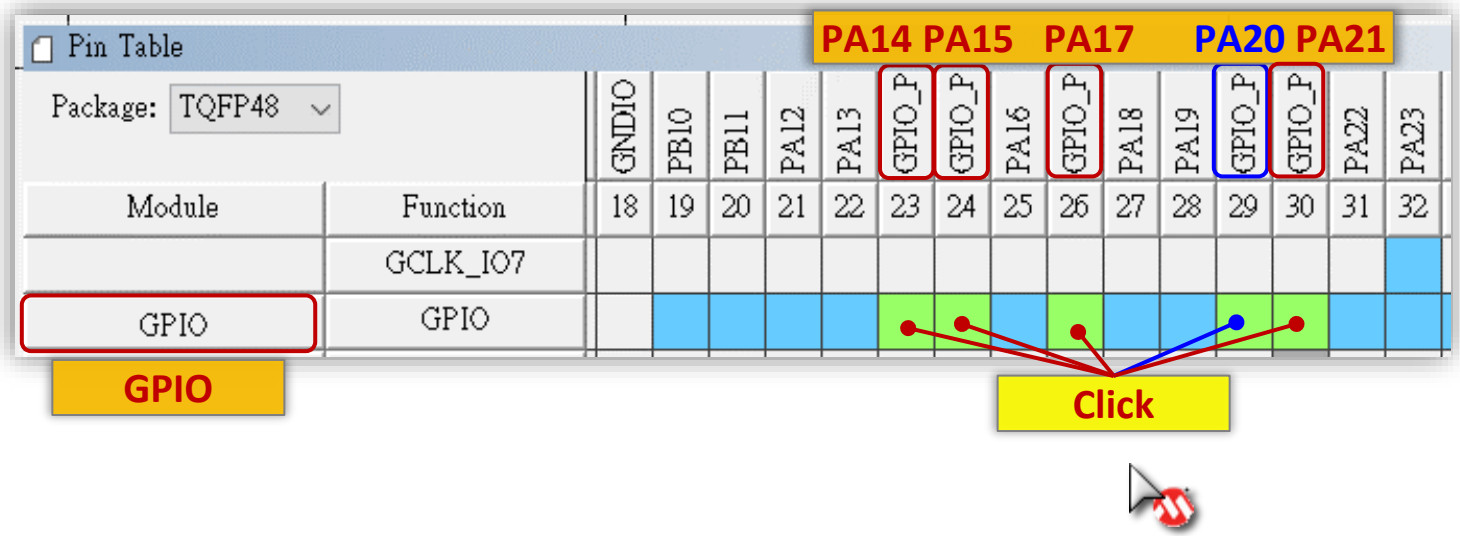


MICROCHIP

Lab2 PORT Input and Output

Step 1

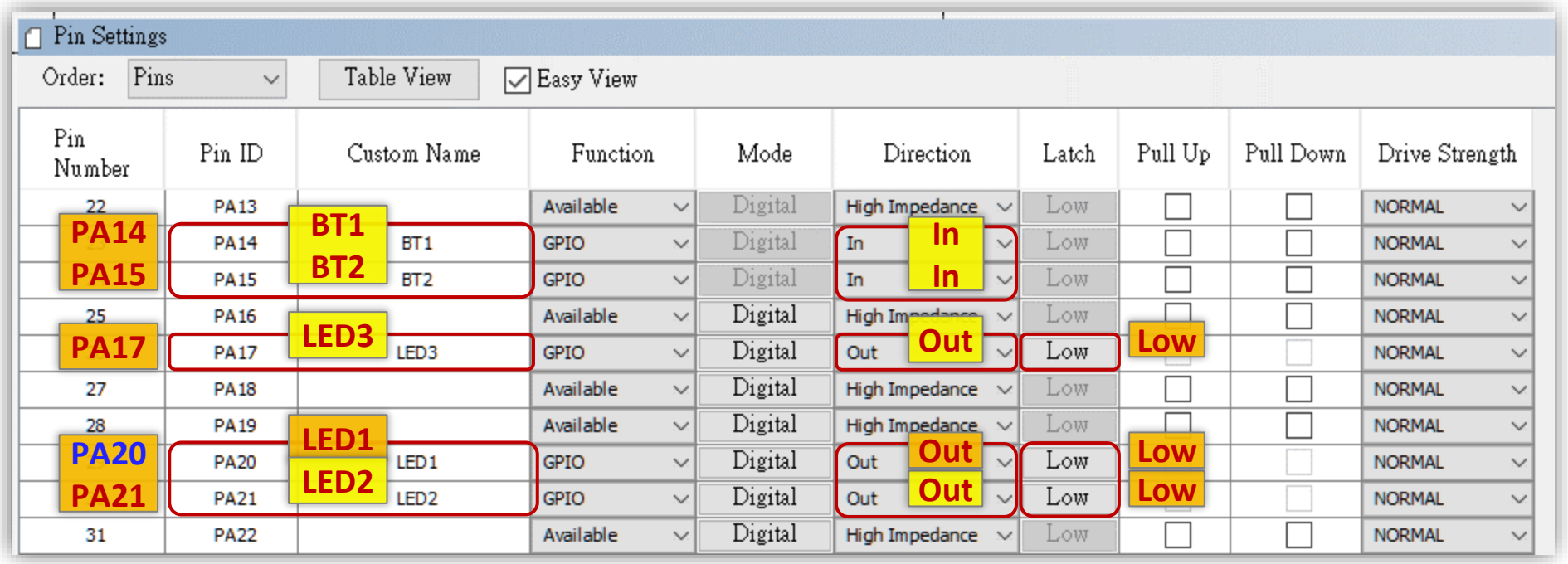
- **Pin Table configure. (Enable or Disable Pin)**



Lab2 PORT Input and Output

Step 2

- **Pin Setting. (Pin Function Setting)**

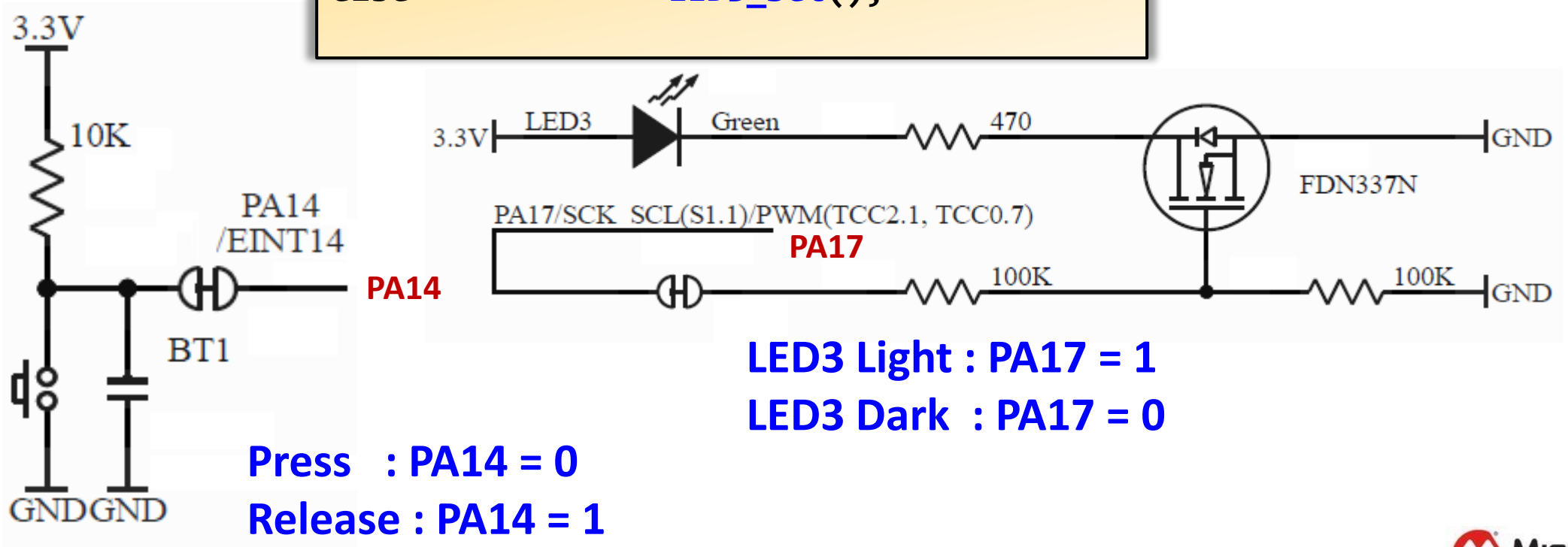


Lab2 PORT Input and Output

Schematic Describe

- Get BT1(PA14) status then use to control LED3(PA17).
  Pressed -> LED3 Light , Released -> LED3 Dark

```
if ( BT1_Get() ) LED3_Clear();
else             LED3_Set();
```



LED3 Light : PA17 = 1

LED3 Dark : PA17 = 0

Press : PA14 = 0

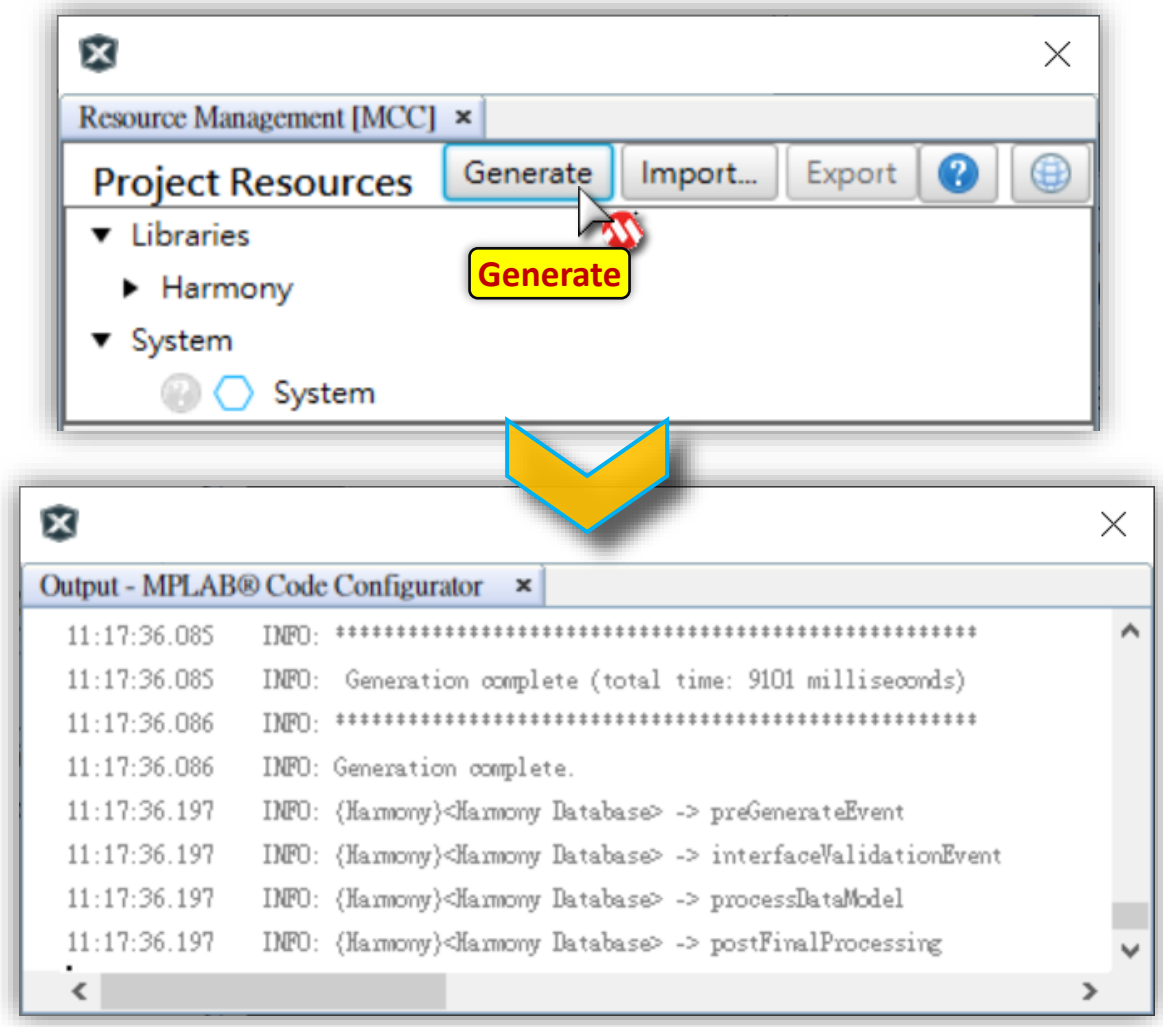
Release : PA14 = 1

MICROCHIP

Lab2 PORT Input and Output

Step 3

- Click "Generate" Button to Generate your Code.

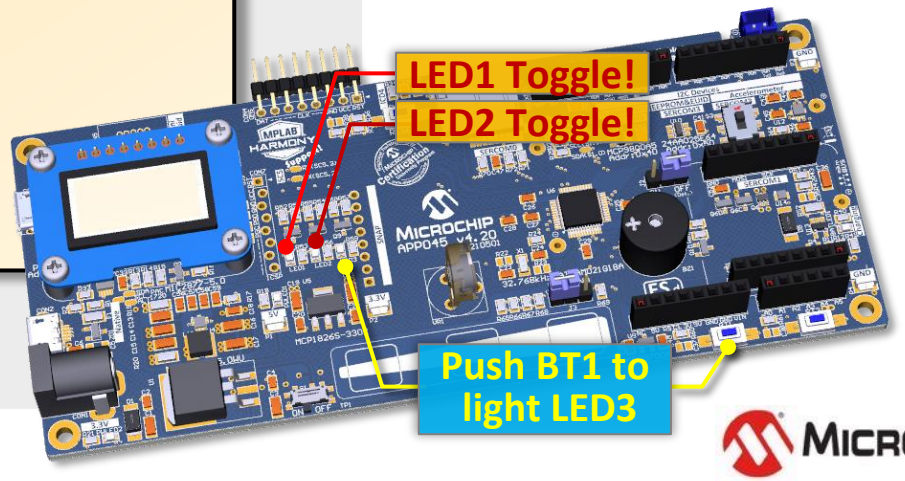


Lab2 PORT Input and Output

Step 4

a **Add code segment to your main loop**

```
uint32_t i = 0;
int main (void)
{
    SYS_Initialize ( NULL );

    while( true )
    {
        for ( i = 0 ; i < 2000000 ; i++ );

        // TODO 2.01
        LED1_Toggle();
        LED2_Toggle();

        // TODO 2.02
        if ( BT1_Get() ) LED3_Clear();
        else             LED3_Set();
    }
}
```



b **Program firmware to target board then observe result.**

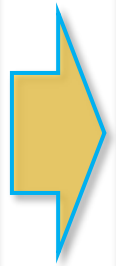
MICROCHIP

Lab2 PORT Input and Output

Button Response Discuss

- **Button Response Time Issue ?**
  The software delay will influence the polling interval.
  Try to change coding style to state machine mode.

```
while( true )
{
  for ( i = 0; i < 2000000 ; i++ )
  {}

  LEDs_Toggle();

  if ( Button_Detected() )
    LED_Light();
  else
    LED_Dark();
}
```



```
while( true )
{
  if ( i++ > 2000000 )
  {
    i = 0;

    LEDs_Toggle();
  }

  if ( Button_Detected() )
    LED_Light();
  else
    LED_Dark();
}
```

Lab2 PORT Input and Output

Step 5

a. change coding style to state machine mode

```
uint32_t i = 0;
int main (void)
{
   SYS_Initialize ( NULL );

   while( true )
   {
     if ( i++ > 2000000 )
     {
       i = 0;

       // TODO 2.01
       LED1_Toggle();
       LED2_Toggle();
     }

     // TODO 2.02
     if ( BT1_Get() ) LED3_Clear();
     else             LED3_Set();
   }
}
```

How about current LED toggle speed after change to state machine flow control ? Why ?

Timer/Counter, TC Architecture

SAMD21 Timer/Counter

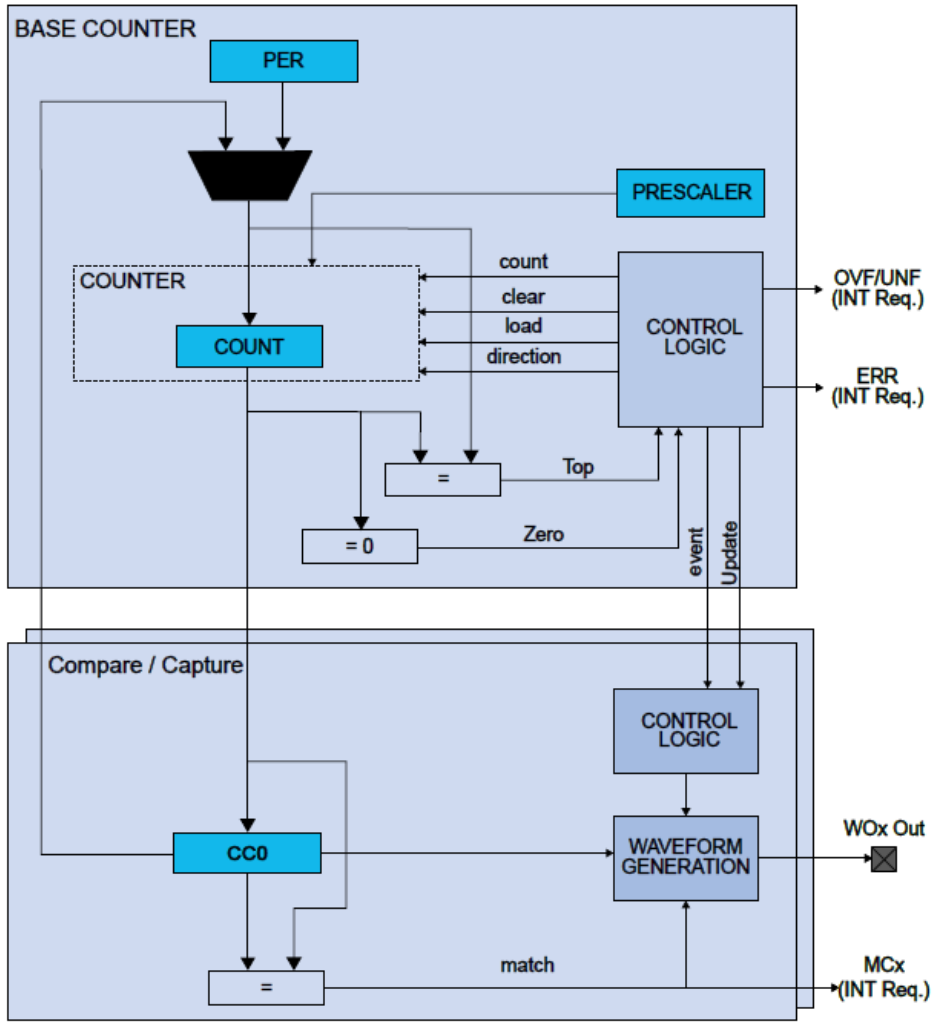
- The SAMD21 Timer/Counter, TC module consists 3 function Counter, Compare and Capture.

- The counter can be set to count events, or it can be configured to count clock pulses. The counter, together with the compare/capture channels, can be configured to timestamp input events, allowing capture of frequency and pulse width.

- It can also perform waveform generation, such as frequency generation and pulse-width modulation (PWM).

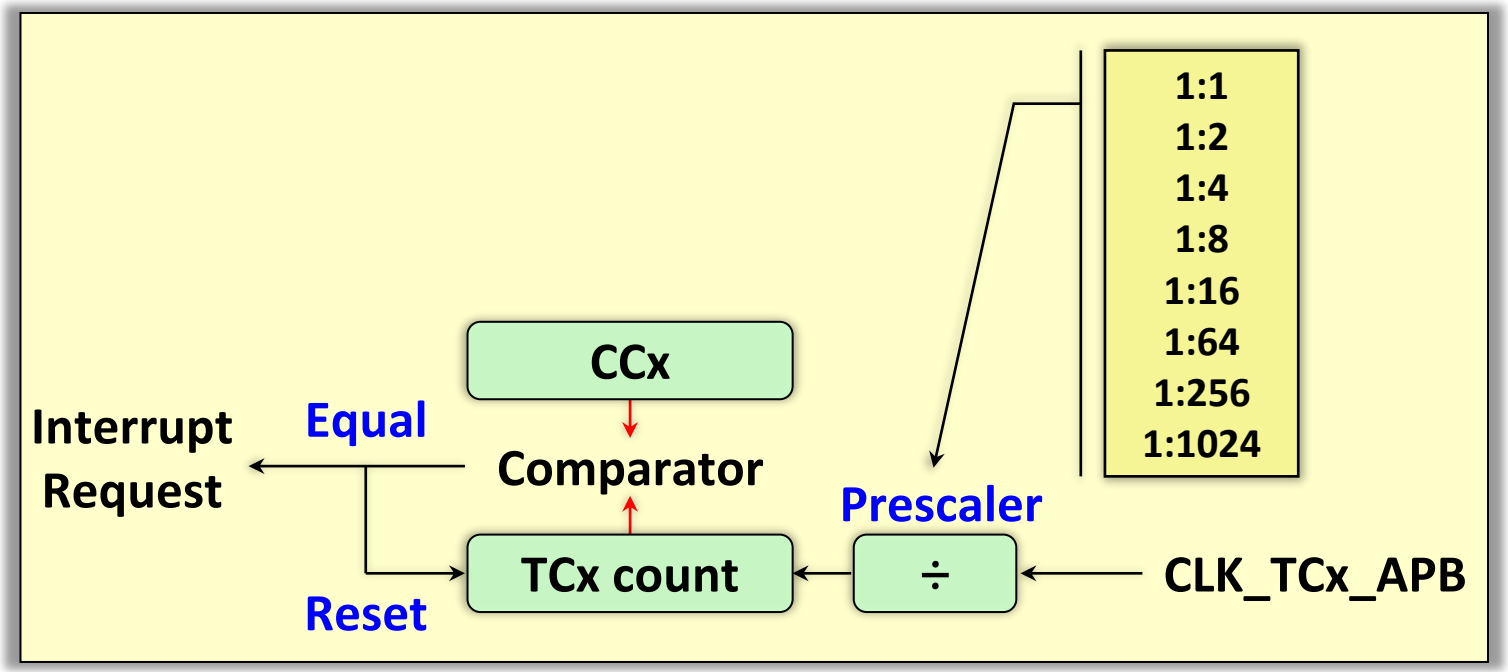
TC Block Diagram

- **SAMD21G18A TC Block Diagram**



SAMD21 Timer/Counter

- Please refer to the block diagram, Just a concept. The real and detail block diagram please refer to the following slide.
- Clock into TCx after prescaler. Comparator continuously compares the values of TCx and CCx.
  Asserts a into the interrupt request when equal, and resets TCx to zero.
- You can fill a value to CCx to determine period you want.



Match Pulse-Width Modulation (MPWM), 16Bit, Up count

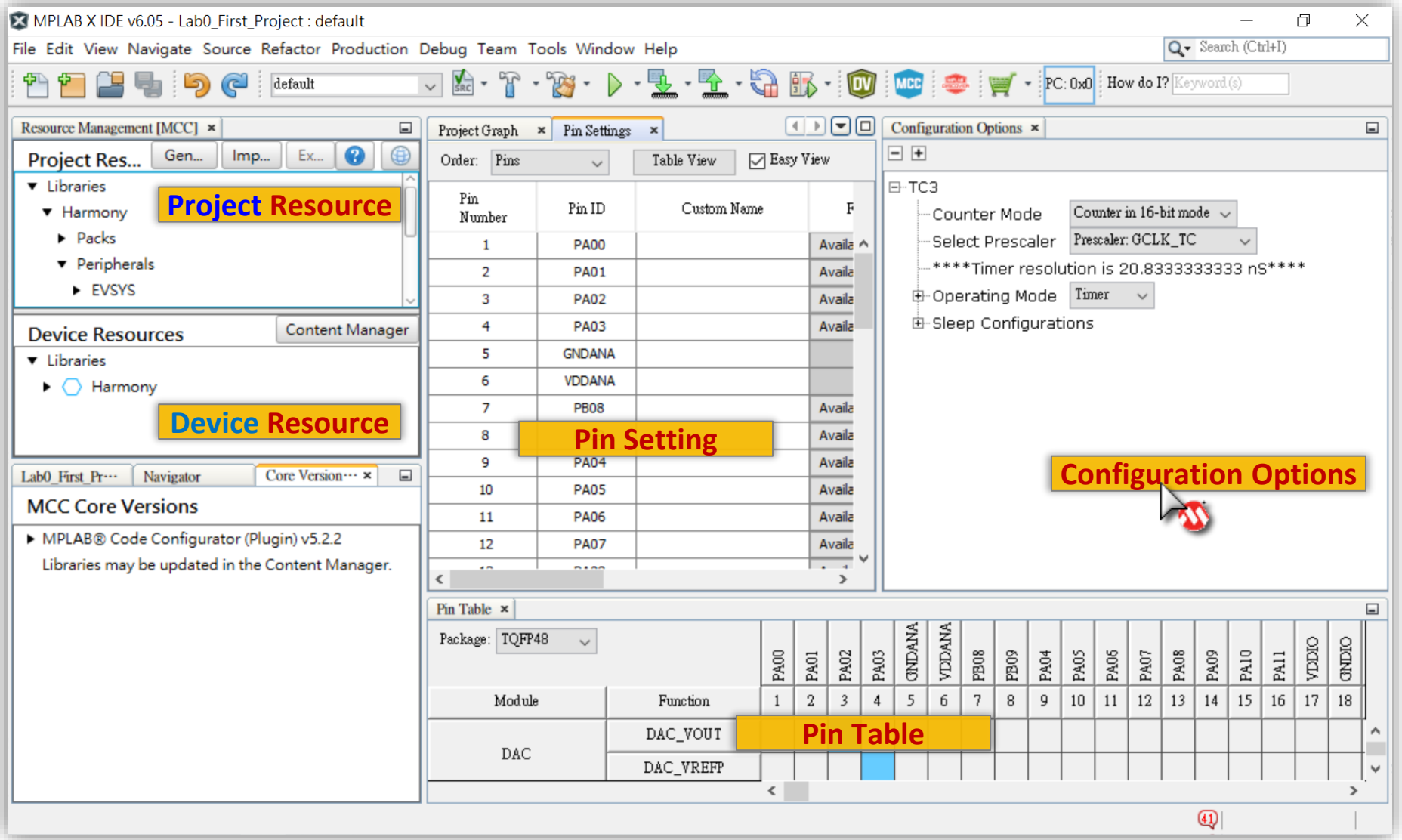
MICROCHIP

Timer/Counter

- **TC provide 4 difference operation mode for Timer, Counter and Compare.**
  This training only force on MFRQ mode. It's easy to use.
  if you want to know more, please refer appendix Timer/Counter Operation Mode.
  - **Normal Frequency Generation (NFRQ)**
    toggled on each compare match
  - **Match Frequency Generation (MFRQ)**
    toggles on each update condition
  - **Normal Pulse-Width Modulation Operation (NPWM)**
    toggles on each match & update condition
  - **Match Pulse-Width Modulation Operation (MPWM)**
    toggles on each match & update condition

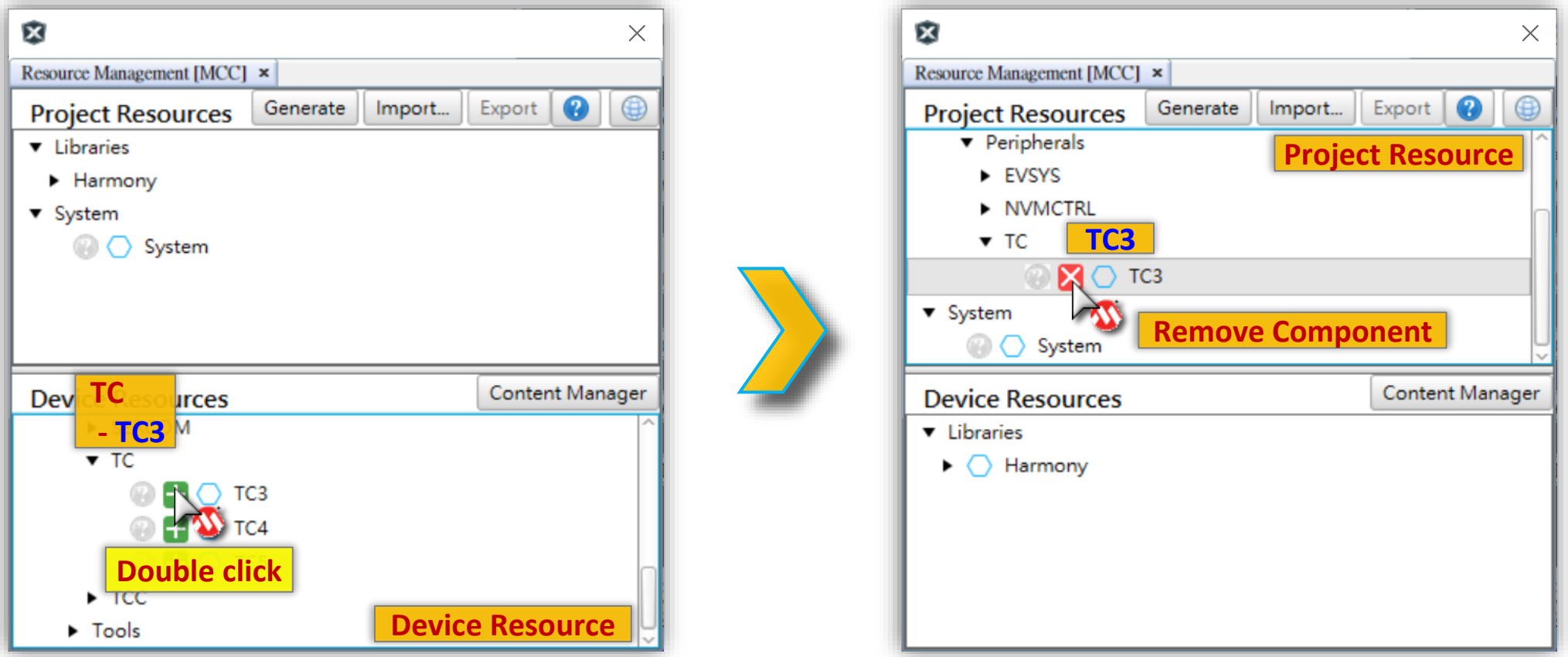
Docking MCC Harmony windows

- **Return to Harmony and docking windows as below.**



Add TC Function using MCC Harmony

- Find TC3 component in Device Resource window.
- Double click TC3 to add to Project Resource window.
- Click ✕ could remove component from Project Resource window.



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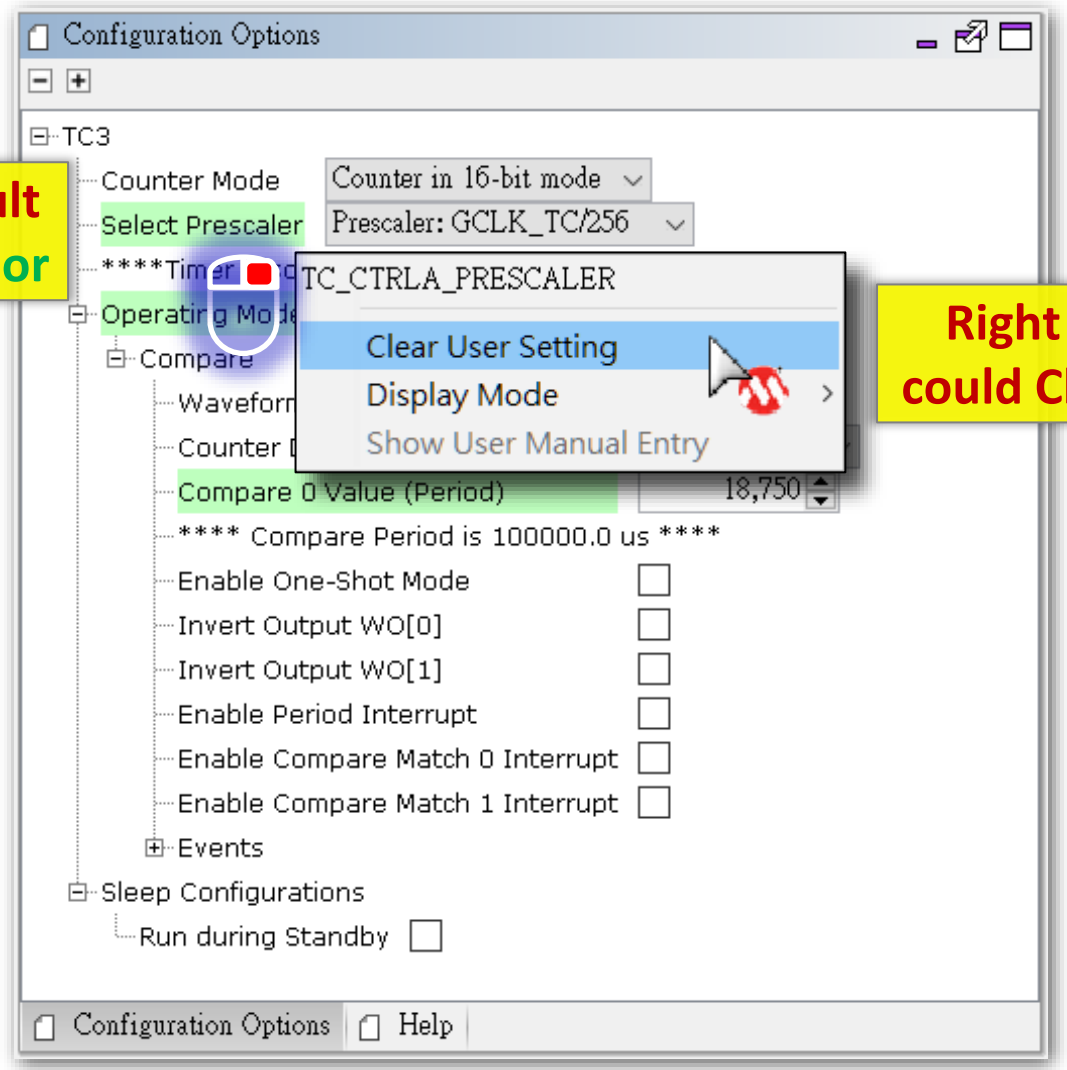
TC Configuration Options Example

Value different to default will change to green color



Right click the value could Clear User Setting

MICROCHIP

TC polling

Interface Routines

```
void TC3_TimerInitialize( void );
void TC3_TimerStart( void );
void TC3_TimerStop( void );
uint32_t TC3_TimerFrequencyGet( void );
void TC3_Timer16bitPeriodSet( uint16_t period );
uint16_t TC3_Timer16bitPeriodGet( void );
uint16_t TC3_Timer16bitCounterGet( void );
void TC3_Timer16bitCounterSet( uint16_t count );
bool TC3_TimerPeriodHasExpired ( void );
```

TC Interrupt Flag Event

- **The TC has the following interrupt sources:**
  - **Overflow/Underflow (OVF)**
    Counter overflow/underflow
  - **Match or Capture Channel x (MCx)**
    Compare match or capture
  - **Capture Overflow Error (ERR)**
    New capture interrupt occurs while interrupt flag is set.
  - **Synchronization Ready (SYNCRDY)**
    Read/Write synchronization ready.

- **How to polling TC overflow interrupt flag status ?**

TC Polling Code Example

TC Timer Method (MPWM Mode) Overflow Polling Example

```
...
TC3_TimerStart();

while( true )
{
   if (TC3_TimerPeriodHasExpired ())
   {
      LED1_Toggle();
   }
}
```

```
bool TC3_TimerPeriodHasExpired( void )
{
   bool timer_status;
   timer_status = (bool) ((TC3_REGS->COUNT16.TC_INTFLAG) & TC_INTFLAG_OVF_Msk);
   TC3_REGS->COUNT16.TC_INTFLAG = timer_status;
   return timer_status;
}
```

Lab3 TC Timer Method Polling

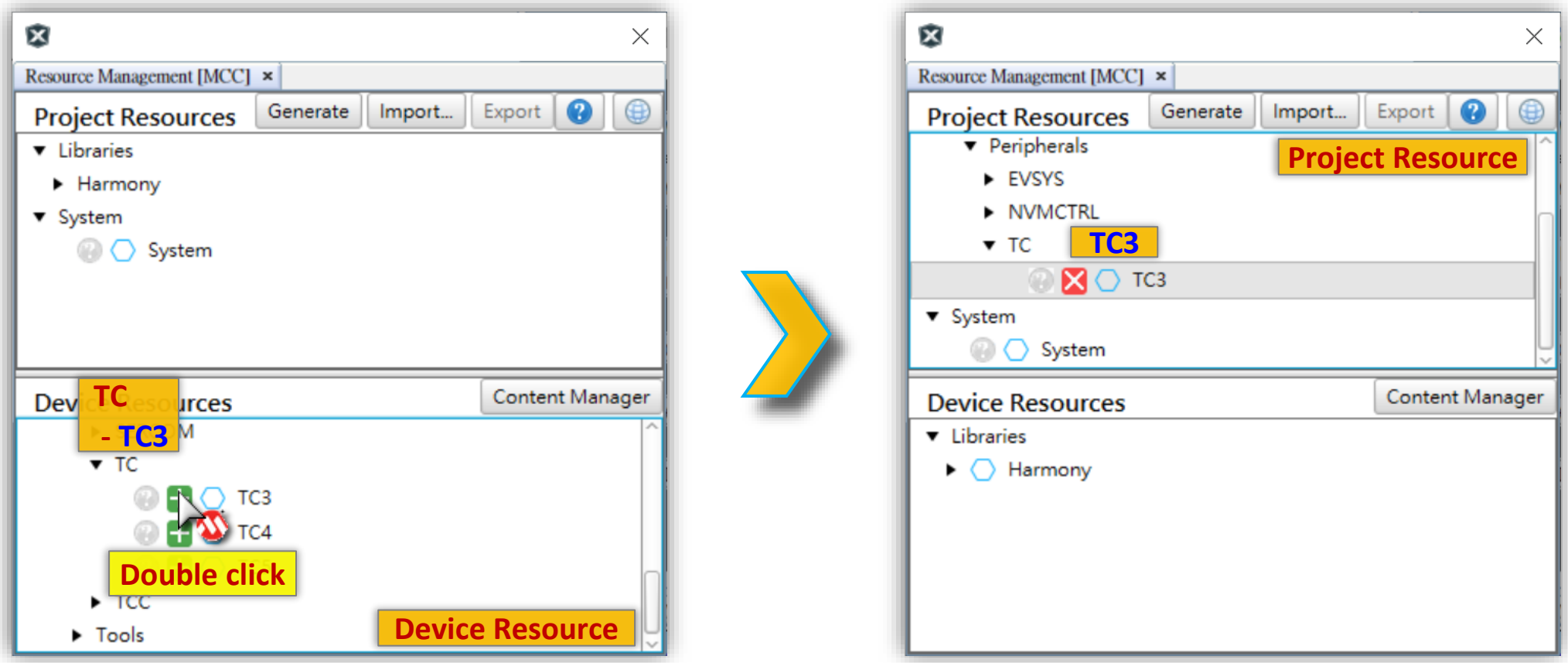
- Try add TC3 to replace software delay for control LED1(PA20) to continues toggle.
- The TC3 setup to Timer Mode (It's implemented by MPWM 16-bit mode), and setup the Timer period to 100ms.

- Let's go!

Lab3 TC Timer Method Polling

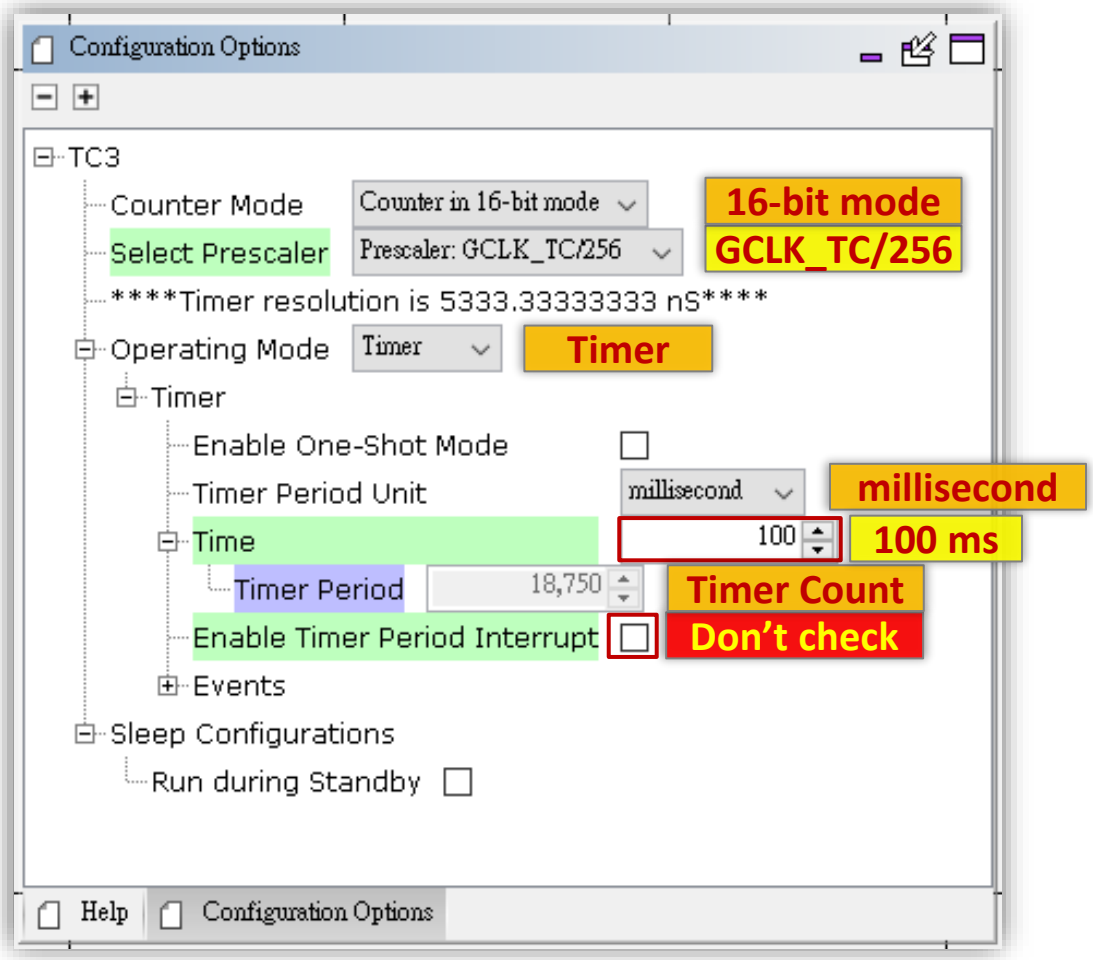
Step 1

- Find TC3 component in Device Resource window.
- Double click TC3 to add to Project Resource window.



Lab3 TC Timer Method Polling

Step 2



System Clock = 48MHz

One second counts of system clock :

48,000,000 counts

One second counts after Prescaler :

48000000 / 256 187,500 counts

100ms counts for LAB3 target :

187500 / 10 18,750 counts

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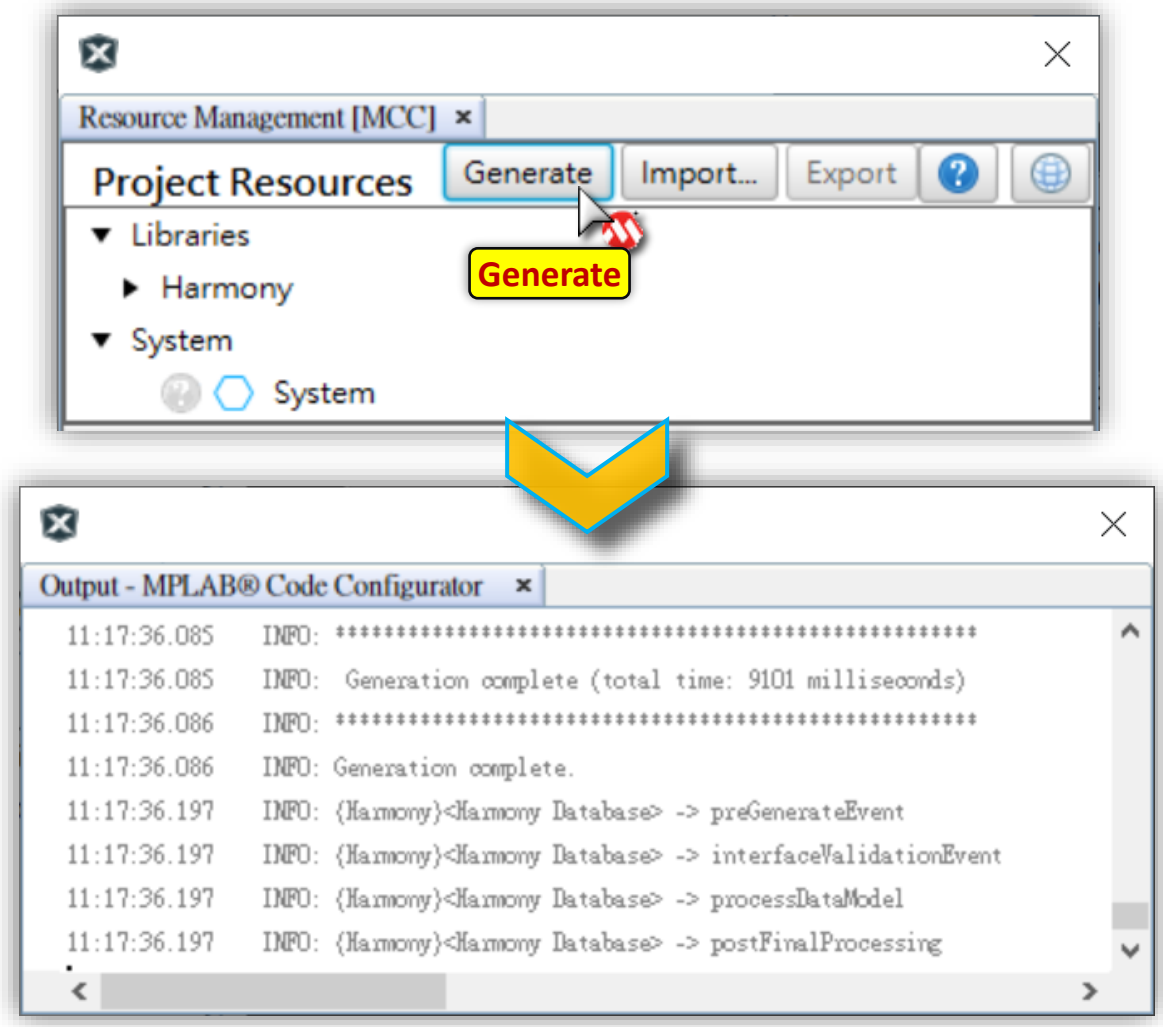
Lab3 TC Timer Method Polling

Step 3

- Click "Generate" Button to Generate your Code.



Lab3 TC Timer Method Polling

Step 4

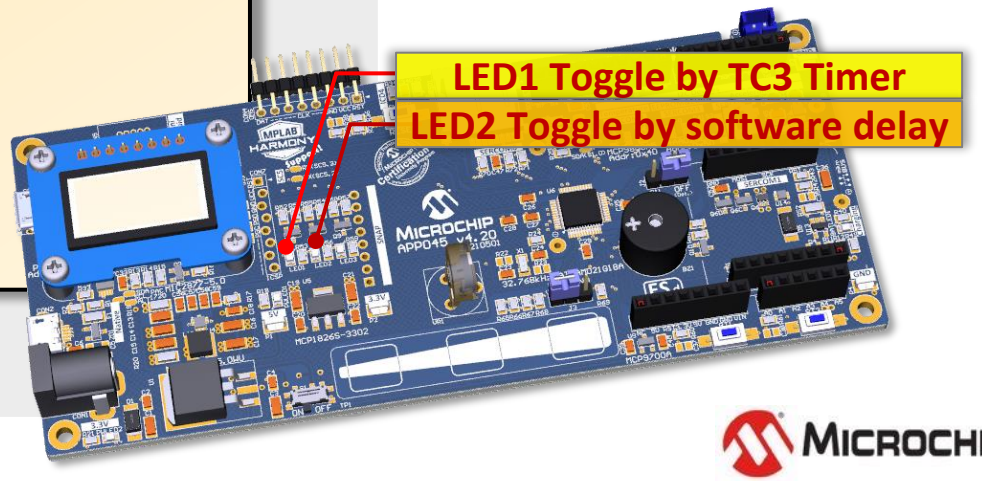
a **Add code segment to your main loop**

```
…
int main (void)
{
   SYS_Initialize ( NULL );

   // TODO 3.01
    TC3_TimerStart();

   while( true )
   {
      // TODO 3.02
       if ( TC3_TimerPeriodHasExpired() )
       {
            LED1_Toggle();
       }
      …
   }
}
```

Period Control



b **Program firmware to target board then observe result.**

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Lab4 TCs Timer Method Polling

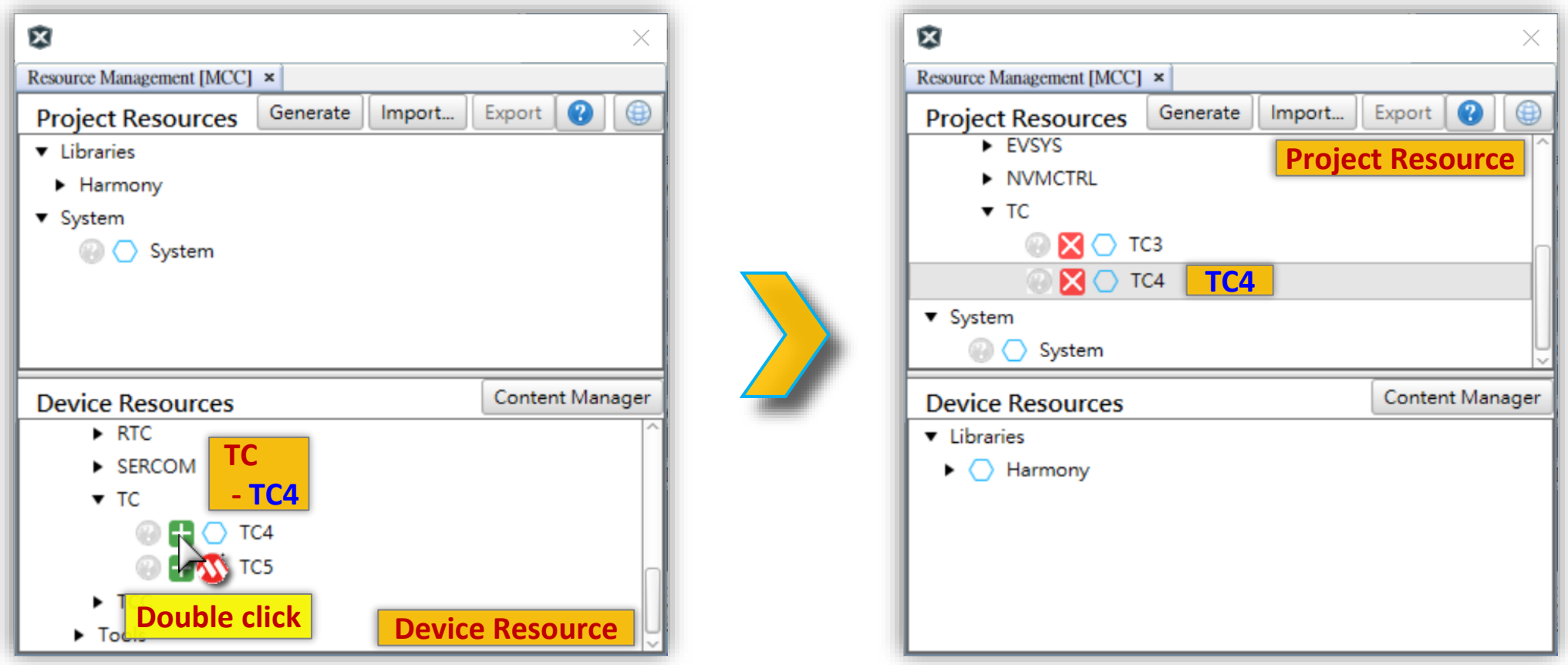
- Try add TC4 to replace software delay for control LED2(PA21) to continues toggle.
- The TC4 setup to Timer Mode (It's implemented by MPWM 16-bit mode), and setup the Timer period to 50ms.

- Let's go!

Lab4 TCs Timer Method Polling

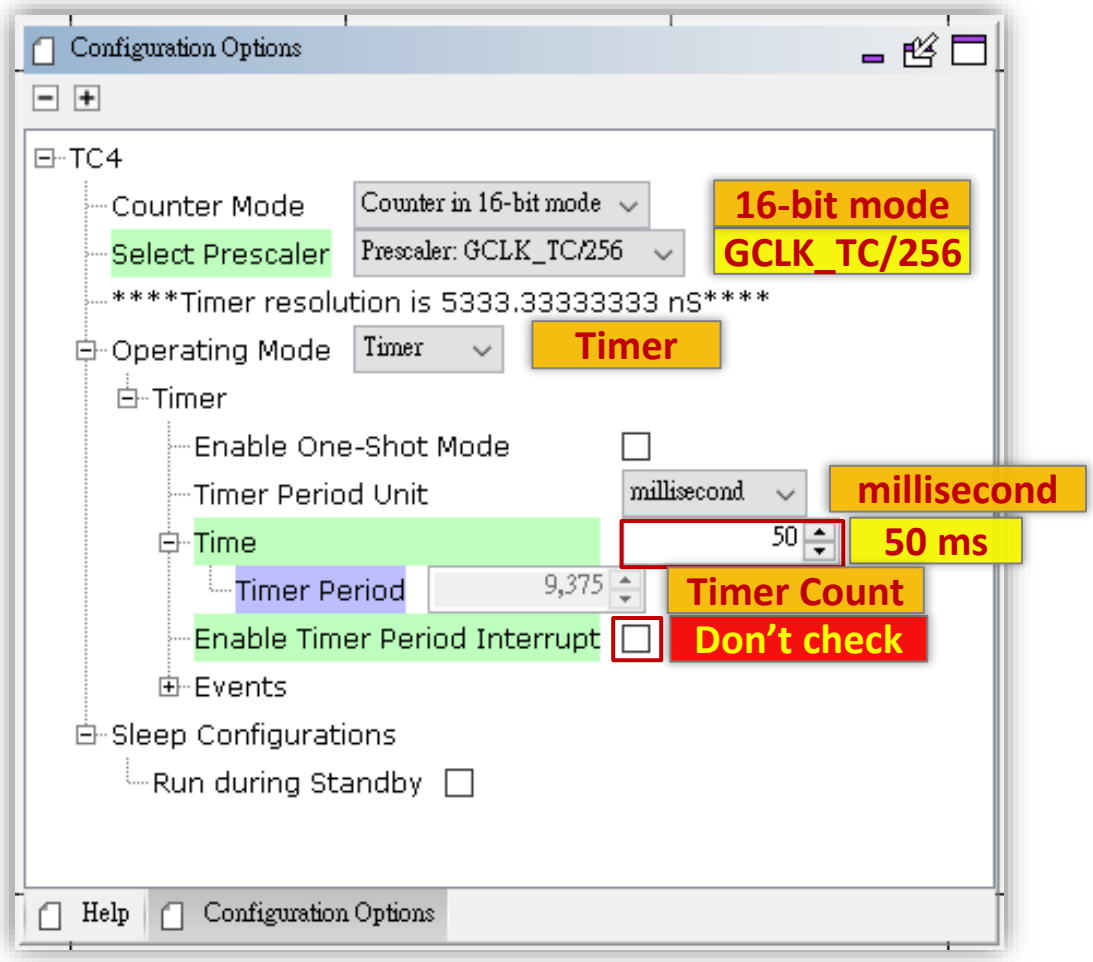
Step 1

- Find TC4 component in Device Resource window.
- Double click TC4 to add to Project Resource window.



Lab4 TCs Timer Method Polling

Step 2



System Clock = 48MHz

One second counts of system clock :

48,000,000 counts

One second counts after Prescaler :

48000000 / 256 187,500 counts

50ms counts for LAB4 target :

187500 / 20 9,375 counts

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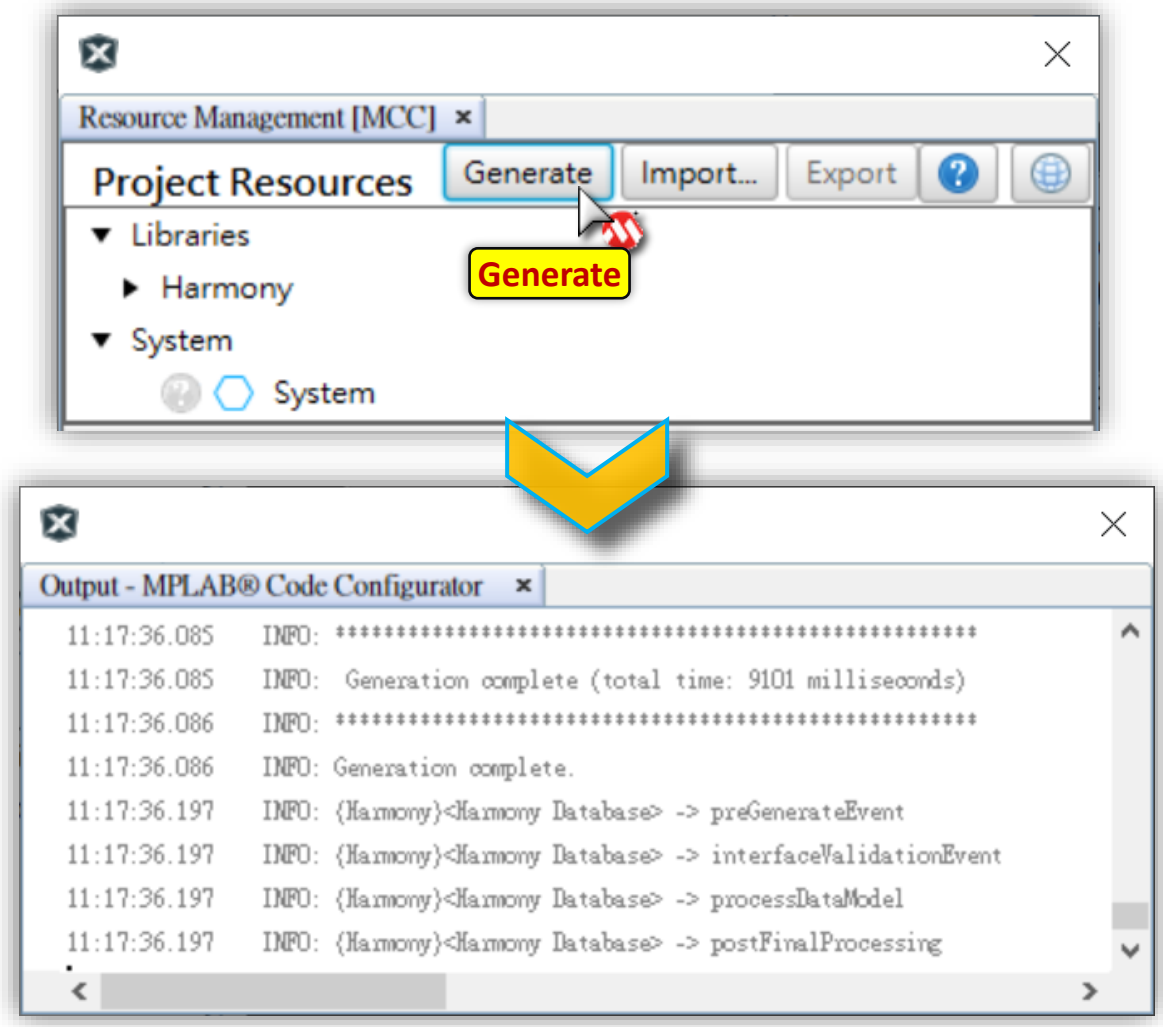
Lab4 TCs Timer Method Polling

Step 3

- Click "Generate" Button to Generate your Code.



Lab4 TCs Timer Method Polling

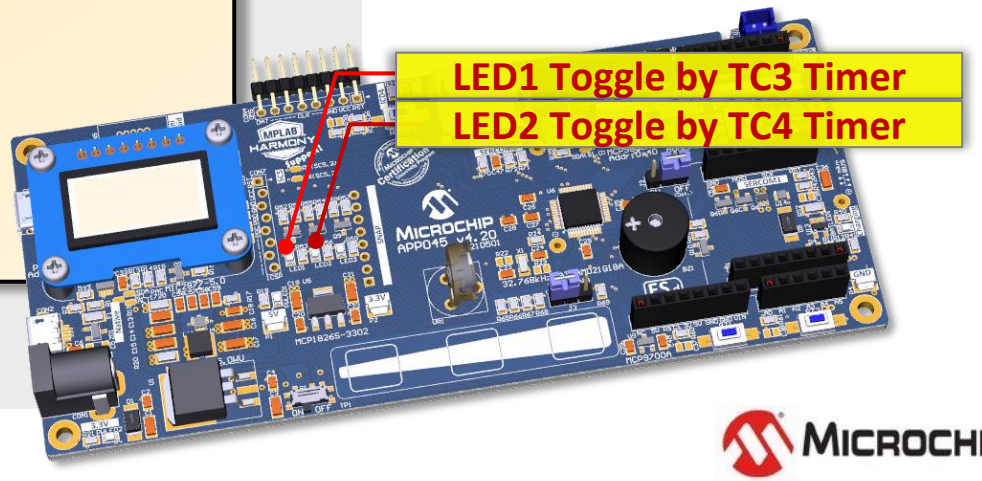
Step 4

a **Add code segment to your main loop**

```
int main (void)
{
   SYS_Initialize ( NULL );
   …
   TC3_TimerStart();
   // TODO 4.01
   TC4_TimerStart ();

   while( true )
   { …
     // TODO 4.02
      if ( TC4_TimerPeriodHasExpired() )
      {
           LED2_Toggle();
      }
     …
   }
}
```

Period Control

b **Program firmware to target board then observe result.**



MICROCHIP

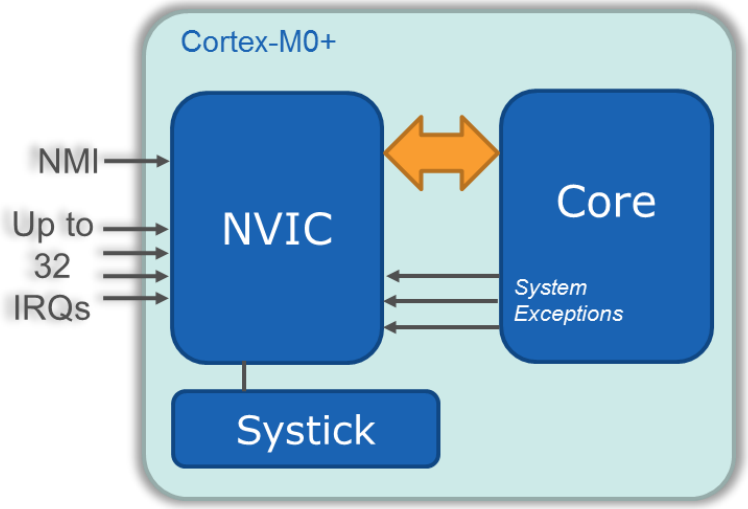
NVIC Architecture

Nested Vector Interrupt Controller Architecture

Nested Vector Interrupt Controller

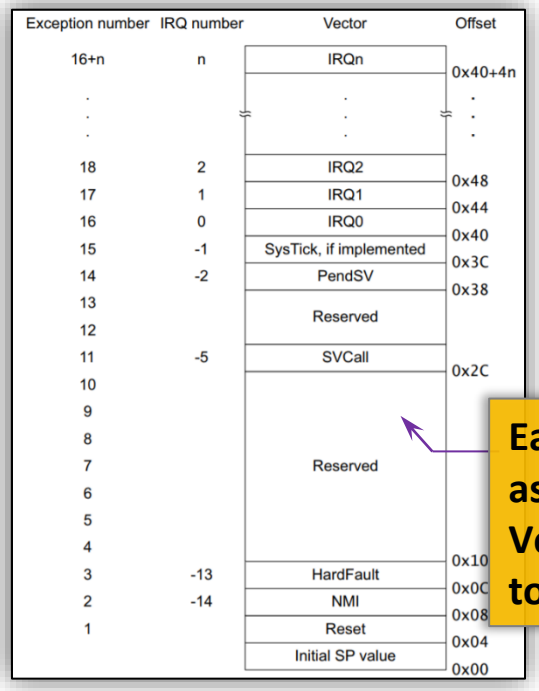
ARM® Cortex®M0+

- NVIC provides an interface between interrupt sources (peripherals and external pins) and the core.
- The priority (Level 0 ~ 3) for each interrupt source is programmable, Level 0 is highest priority.
- Each interrupt lines has connected to one peripheral instance and have one or more interrupt flags.
- An interrupt request is generated from the peripheral when the interrupt flag has been set and the corresponding interrupt is enabled.



Natural Priority

- **If two pending interrupts share the same priority, priority is given to the interrupt with the lowest exception number (lowest interrupt vector address).**



Each peripheral has been assigned to one of Vector table and based to address 0x00000000

TC3 (18)

TC4 (19)

Peripheral Source	NVIC Line
EIC NMI – External Interrupt Controller	NMI
PM – Power Manager	0
SYSCTRL – System Control	1
WDT – Watchdog Timer	2
RTC – Real Time Counter	3
EIC – External Interrupt Controller	4
NVMCTRL – Non-Volatile Memory Controller	5
DMAC - Direct Memory Access Controller	6
USB - Universal Serial Bus	7
EVSYS – Event System	8
SERCOM0 – Serial Communication Interface 0	9
SERCOM1 – Serial Communication Interface 1	10
SERCOM2 – Serial Communication Interface 2	11
SERCOM3 – Serial Communication Interface 3	12
SERCOM4 – Serial Communication Interface 4	13
SERCOM5 – Serial Communication Interface 5	14
TCC0 – Timer Counter for Control 0	15
TCC1 – Timer Counter for Control 1	16
TCC2 – Timer Counter for Control 2	17
TC3 – Timer Counter 3	18
TC4 – Timer Counter 4	19
TC5 – Timer Counter 5	20
TC6 – Timer Counter 6	21
TC7 – Timer Counter 7	22
ADC – Analog-to-Digital Converter	23
AC – Analog Comparator	24
DAC – Digital-to-Analog Converter	25
PTC – Peripheral Touch Controller	26
I2S - Inter IC Sound	27

SAMD21G18A IVT Define

Interrupt.c

```
__attribute__ ((section(".vectors")))
const DeviceVectors exception_table=
{
    /* Configure Initial Stack Pointer, using linker-generated symbols */
    .pvStack = (void*) (&_stack),

    .pfnReset_Handler           = ( void * ) Reset_Handler,
    .pfnNonMaskableInt_Handler  = ( void * ) NonMaskableInt_Handler,
    .pfnHardFault_Handler       = ( void * ) HardFault_Handler,
    .pfnSVCall_Handler          = ( void * ) SVCall_Handler,
    .pfnPendSV_Handler          = ( void * ) PendSV_Handler,
    .pfnSysTick_Handler         = ( void * ) SysTick_Handler,
    .pfnNVMCTRL_Handler         = ( void * ) NVMCTRL_Handler,
     …
    .pfnSERCOM5_Handler         = ( void * ) SERCOM0_Handler,
     …
    .pfnTCC2_Handler            = ( void * ) TCC2_Handler,
    .pfnTC3_Handler             = ( void * ) TC3_TimerInterruptHandler,
    .pfnTC4_Handler             = ( void * ) TC4_TimerInterruptHandler,
    …
    .pfnADC_Handler             = ( void * ) ADC_Handler,
    …
};
```

MICROCHIP

ISR Function Example

- So, You need Implement ISR (Interrupt Service Routine) by yourself like below ?

plib_tc3.c

```
#include "plib_tc3.h"
…

void TC3_TimerInterruptHandler( void )
{
    TC_TIMER_STATUS status;
    status = (TC_TIMER_STATUS) (TC3_REGS->COUNT16.TC_INTFLAG);
    /* Clear interrupt flags */
    TC3_REGS->COUNT16.TC_INTFLAG = TC_INTFLAG_Msk;

    // Getting starter add your code here now. !?


}
```

Now ? Hands-on Lab ?

No!

Callback Function

- MH3 module provide the interrupt mode driver.

- All flag and event handling by MH3 interrupt interface routine automatically, user just focus on application. It’s more powerful and easy to understand than operating a NVIC ISR function directly.

- The interrupt mode provide "callback" function to hook up your customer function to specific interrupt source and event.

- For Example,
  You can hook the LED toggle callback function in TC overflow event. Callback function will be executed automatically while TC overflow event has occurred.

TC Callback Hook Example

```
void TCn_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
   if( status & TC_INTFLAG_OVF_Msk )
      LED_Toggle();
}

TCn_TimerCallbackRegister (TCn_TimerExpired , (uintptr_t )NULL );
TCn_TimerStart ();
```

Hook (Register)

Callback

Application

System

```
/* Register callback function */
void TCn_TimerCallbackRegister( TC_TIMER_CALLBACK callback, uintptr_t context )
{
   TCn_CallbackObject.callback = callback;

   TCn_CallbackObject.context = context;
}
```

Function Pointer

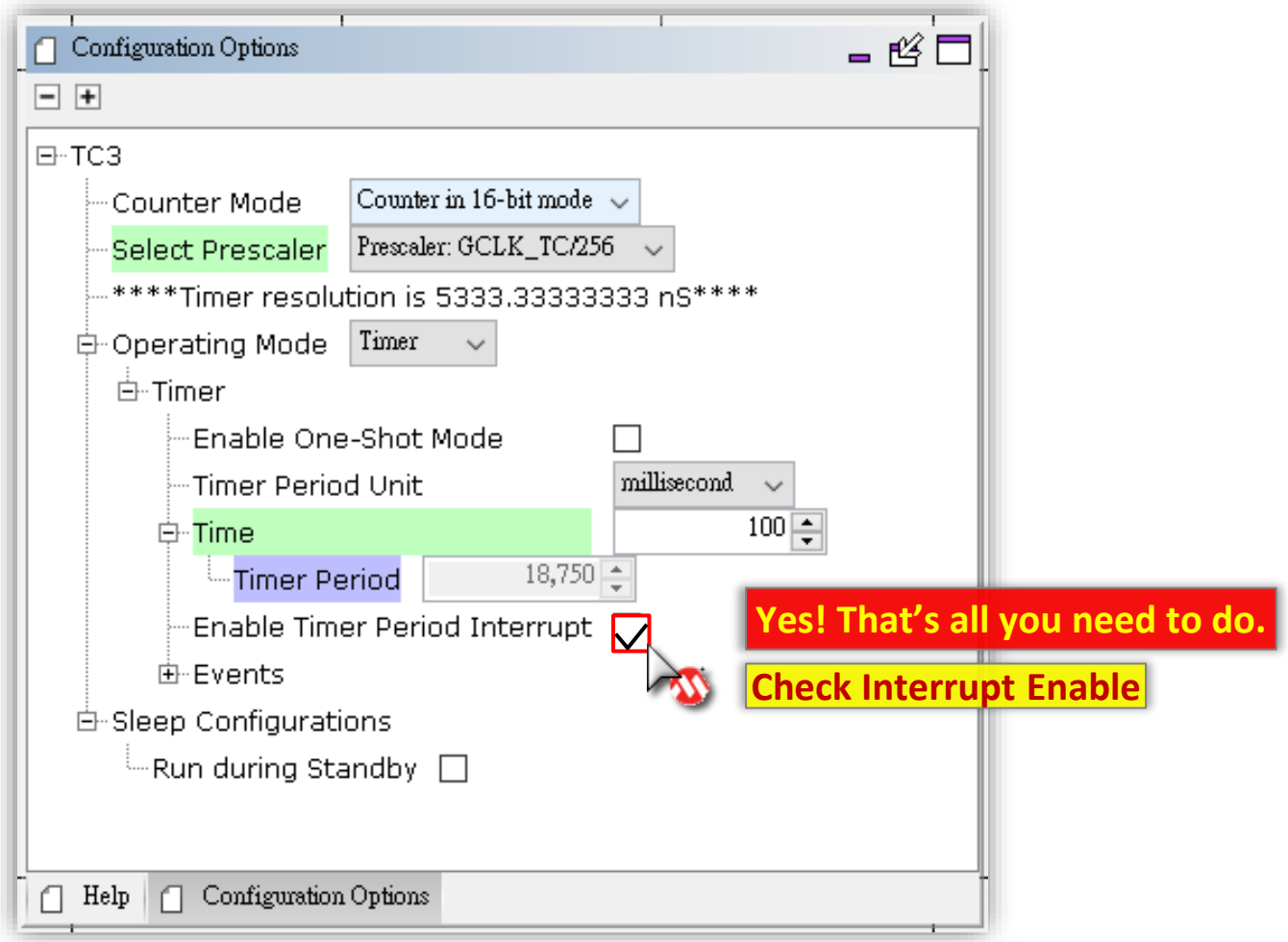
```
/* Timer Interrupt handler */
void TCn_TimerInterruptHandler ( void )
{
   TC_TIMER_STATU Sstatus;
   status = (TC_TIMER_STATUS) TCn_REGS->COUNT16.TC_INTFLAG;
   /* Clear interrupt flags */
   TCn_REGS->COUNT16.TC_INTFLAG = TC_INTFLAG_Msk;
   if( TCn_CallbackObject.callback != NULL )
   {
      TCn_CallbackObject.callback( status, TCn_CallbackObject.context );
   }
}
```

Interrupt

MICROCHIP

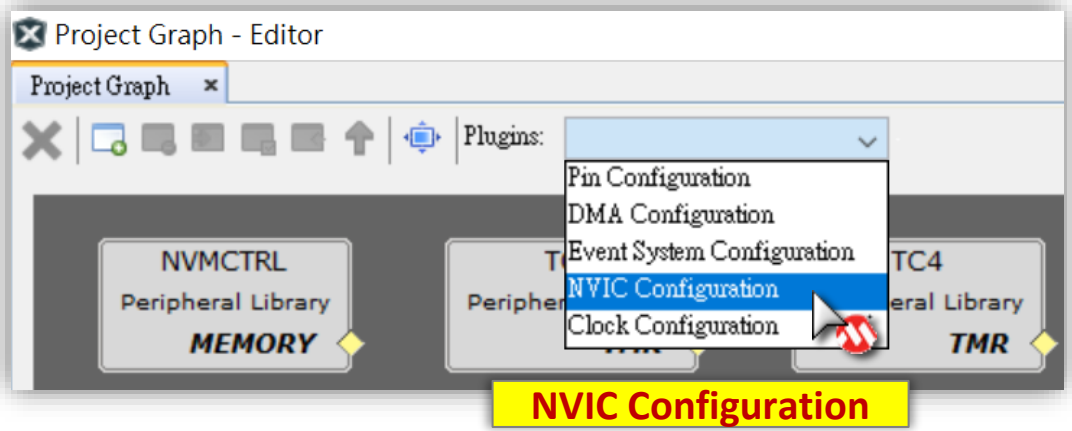
MCC Harmony Interrupt Example

- **Enable Interrupt in TC configuration windows.**
  - **Only one click !**



NVIC Priority Settings in MCC Harmony

- **Open NVIC Settings windows in Project Graph > Plugins > NVIC Configuration.**



NVIC Settings

Vector Number	Vector	Enable	Priority (0 =	Handler Name
-15	Reset (Reset Vector)	☑	-3	Reset_Handler
-14	NonMaskableInt (Non-maskable Interrupt)	☑	-2	NonMaskableInt_Handler
-13	HardFault (Hard Fault)	☑	-1	HardFault_Handler
-5	SVCall (SuperVisor Call)	☑	0	SVCall_Handler
-2	PendSV (Pendable SerVice)	☑	0	PendSV_Handler
-1	SysTick (System Tick Timer)	☐	0	SysTick_Handler
0	PM (Power Manager)	☐	3	PM_Handler
1	SYSCTRL (System Controller)	☐	3	SYSCTRL_Handler
2	WDT (Watchdog Timer)	☐	3	WDT_Handler
3	RTC (Real Time Counter)	☐	3	RTC_Handler
4	EIC (External Interrupt Controller)	☐	3	EIC_Handler
5	NVMCTRL (Non-Volatile Memory Controller)	☐	3	NVMCTRL_Handler
6	DMAC (Direct Memory Controller)	☐	3	DMAC_Handler
7	USB (Universal Serial Bus)	☐	3	USB_Handler
8	EVSYS (Event Systems)	☐	3	EVSYS_Handler
9	SERCOM0 (Serial Communication Interface 0)	☐	3	SERCOM0_Handler
15	TCC0 (Timer/Counter for Control Applications 0)	☐	3	TCC0_Handler
16	TCC1 (Timer/Counter for Control Applications 1)	☐	3	TCC1_Handler
17	TCC2 (Timer/Counter for Control Applications 2)	☐	3	TCC2_Handler
18	TC3 (Timer/Counter 3)	☑	3	TC3_TimerInterruptHandler
19	TC4 (Timer/Counter 4)	☑	3	TC4_TimerInterruptHandler
20	TC5 (Timer/Counter 5)	☐	3	TC5_Handler
23	ADC (Analog-to-Digital Converter)	☐	3	ADC_Handler
24	AC (Analog Comparators)	☐	3	AC_Handler
25	DAC (Digital-to-Analog Converter)	☐	3	DAC_Handler
26	PTC (Peripheral Touch Controller)	☐	3	PTC_Handler
27	I2S (Inter-IC Sound Controller)	☐	3	I2S_Handler

18	TC3 (Timer/Counter 3)	☑	3	TC3_TimerInterruptHandler
19	TC4 (Timer/Counter 4)	☑	3	TC4_TimerInterruptHandler

TC Interrupt

Interface Routines

```
void TC3_TimerInitialize( void );
void TC3_TimerStart( void );
void TC3_TimerStop( void );
uint32_t TC3_TimerFrequencyGet( void );
void TC3_Timer16bitPeriodSet( uint16_t period );
uint16_t TC3_Timer16bitPeriodGet( void );
uint16_t TC3_Timer16bitCounterGet( void );
void TC3_Timer16bitCounterSet( uint16_t count );
void TC3_TimerCallbackRegister( TC_Timer_CALLBACK callback, uintptr_t context );
```

One new function than polling mode.

Lab5 TC Timer Method Interrupt Callback

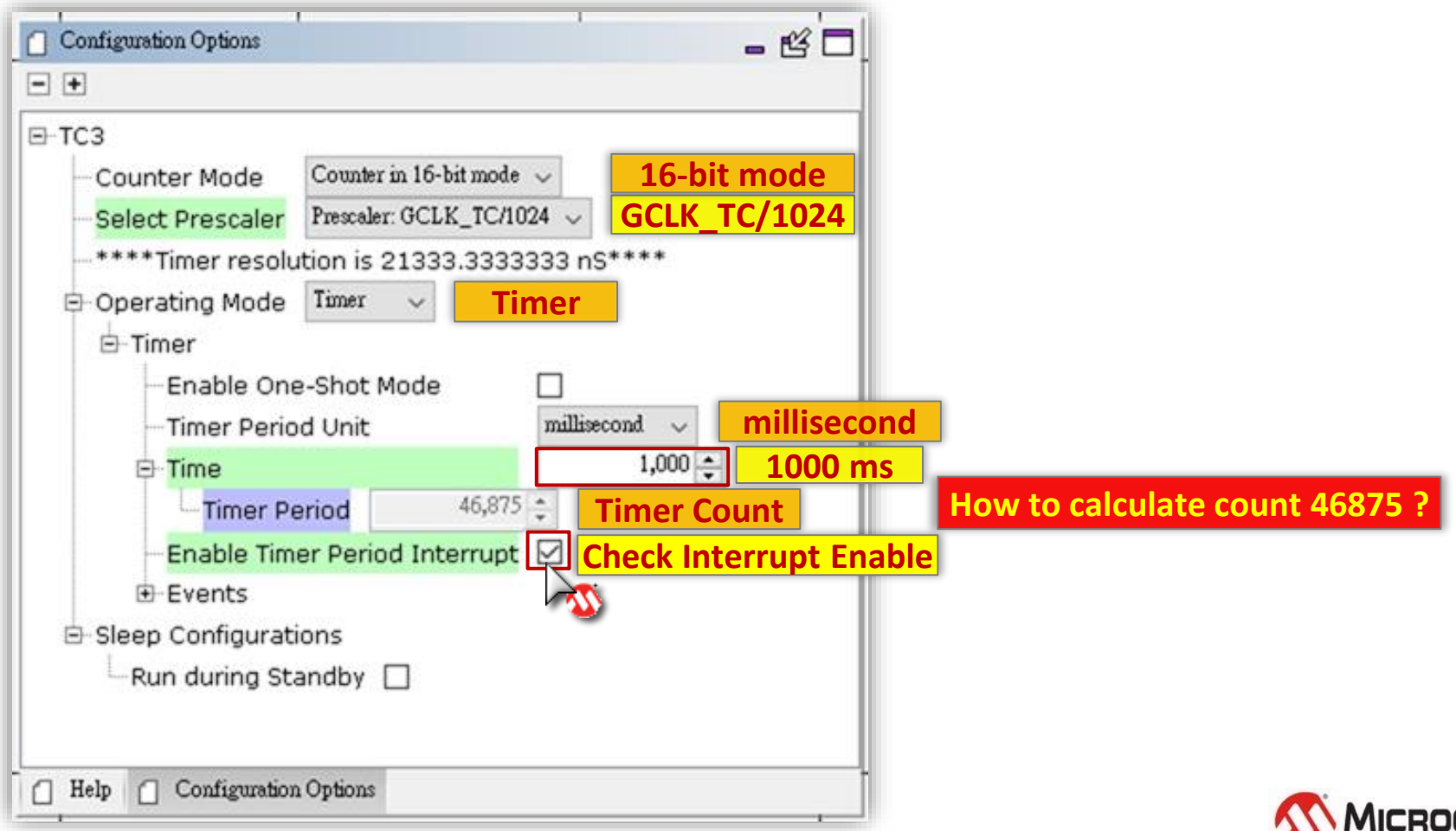
- **Try to configure TC3 to use interrupt callback method.**
  LED1 will toggle in Timer Callback while Timer Period Expired interrupt.
- **Modify TC3 Timer Period to 1 second in MH3 for easy observe the toggle.**
- **Modify code segment in main() and follow below sequence.**
  - Firstly, remove Timer polling LED1 toggle from main loop.
  - Secondary, Create a TC3 Timer Callback function for LED1 toggle
  - Finally, hook(register) up TC3 Timer Callback function to TC3 Timer Interrupt event.

- **Let's go!**

Lab5 TC Timer Method Interrupt Callback

Step 1

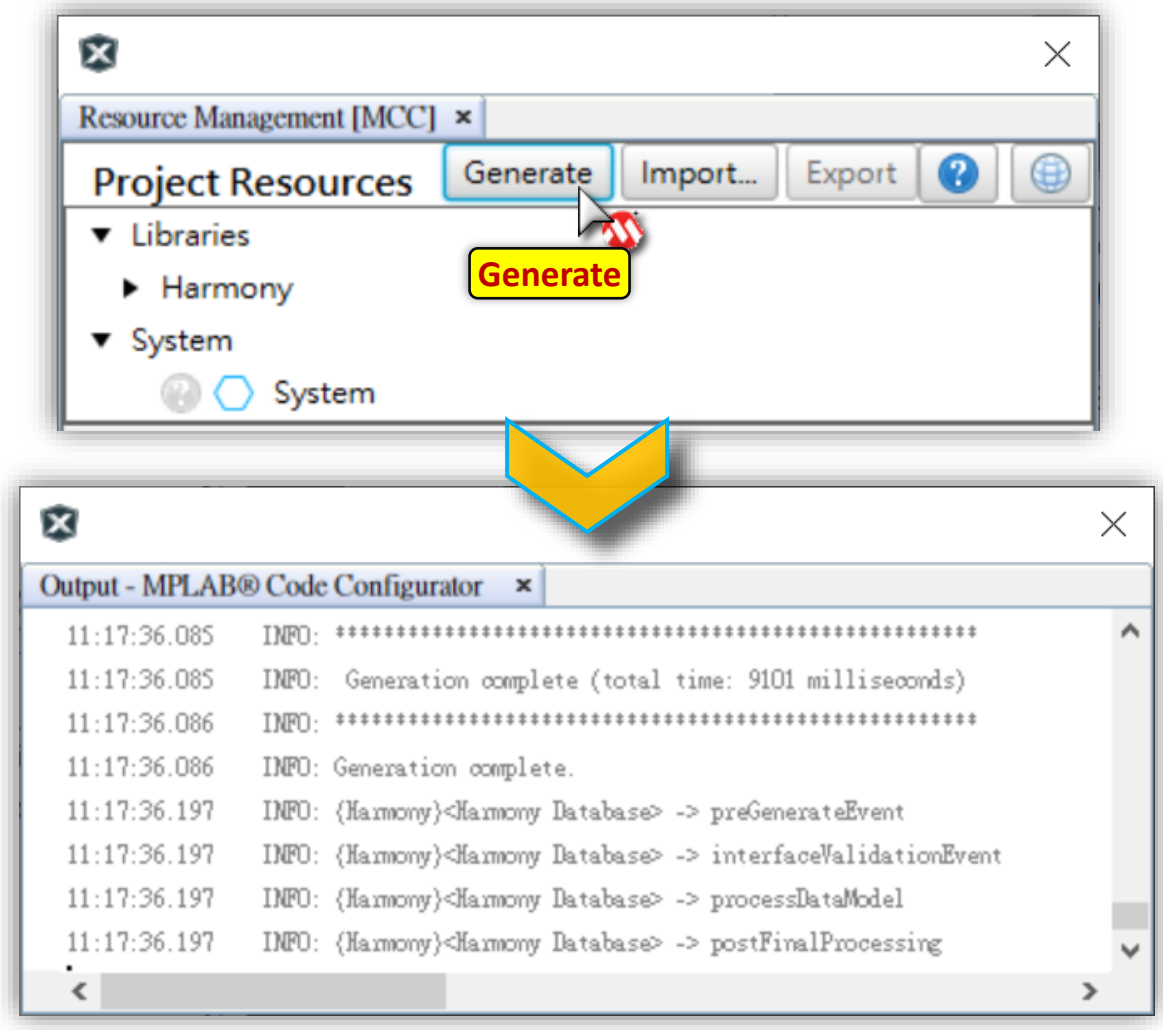
- **Configure TC3 Period to 1 second and Enable Period Interrupt in configuration.**



Lab5 TC Timer Method Interrupt Callback

Step 2

- Click "Generate" Button to Generate your Code.



Lab5 TC Timer Method Interrupt Callback

Step 3

a. **Add code segment to your main loop**

```
// TODO 5.01
void TC3_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
  if( status & TC_INTFLAG_OVF_Msk )
    LED1_Toggle();
}

int main (void)
{
   SYS_Initialize ( NULL );
   ...
   // TODO 5.02
   TC3_TimerCallbackRegister( TC3_TimerExpired, (uintptr_t )NULL );
   TC3_TimerStart();

   while( true )
   { ...
   }
}
```

b. **Program firmware to target board then observe result.**

Lab6 TCs Timer Method Interrupt Callback

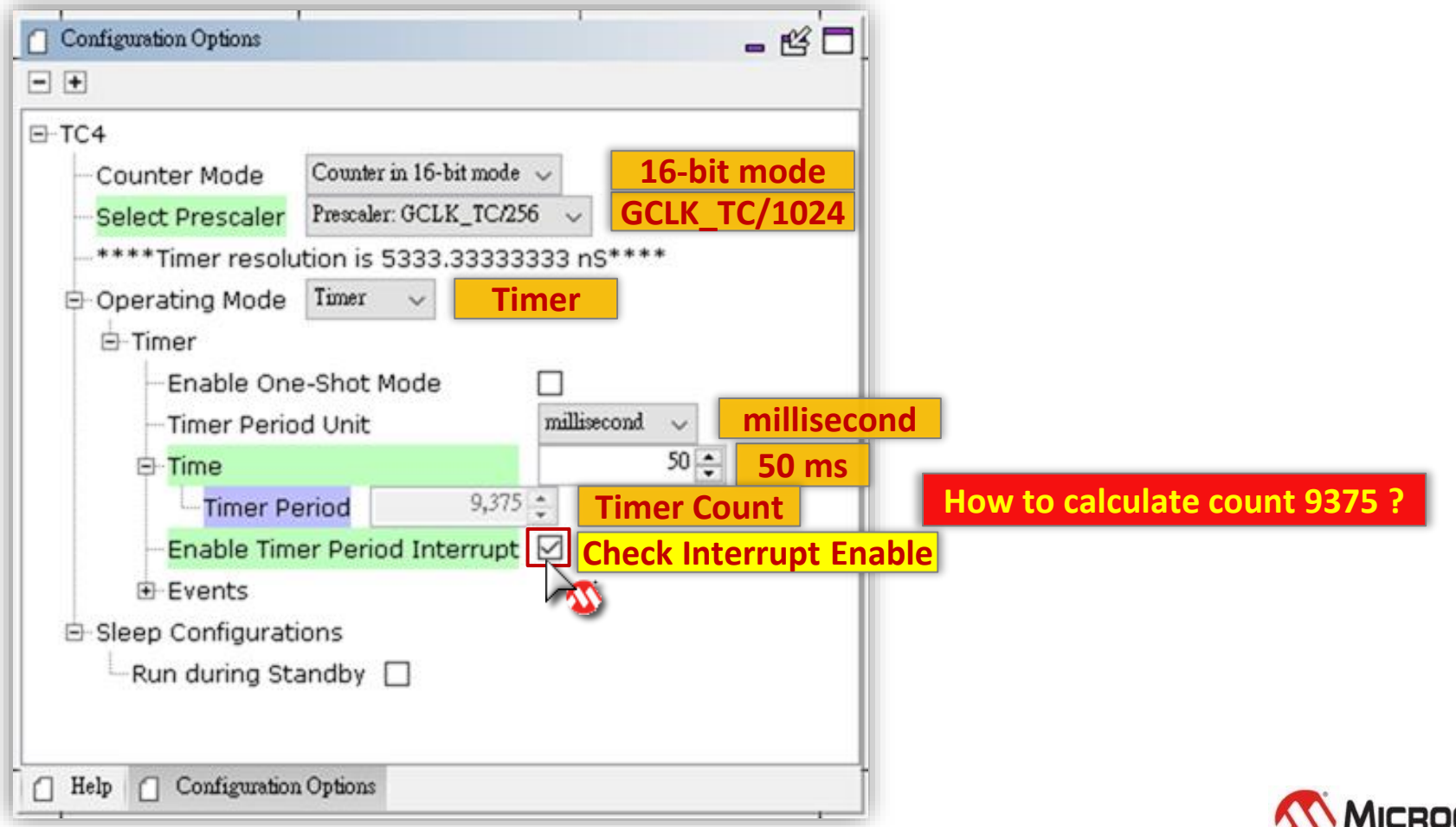
- **Try to configure TC4 to use interrupt callback method.**
  LED2 will toggle in Timer Callback while Timer Period Expired interrupt.
- **Keep TC4 Timer Period as 50ms in MH3 that we did in previous Lab.**
- **Modify code segment in main() and follow below sequence.**
  - Firstly, remove Timer polling LED2 toggle from main loop.
  - Secondary, Create a TC4 Timer Callback function for LED2 toggle
  - Finally, hook(register) up TC4 Timer Callback function to TC4 Timer Interrupt event.

- **Let's go!**

Lab6 TCs Timer Method Interrupt Callback

Step 1

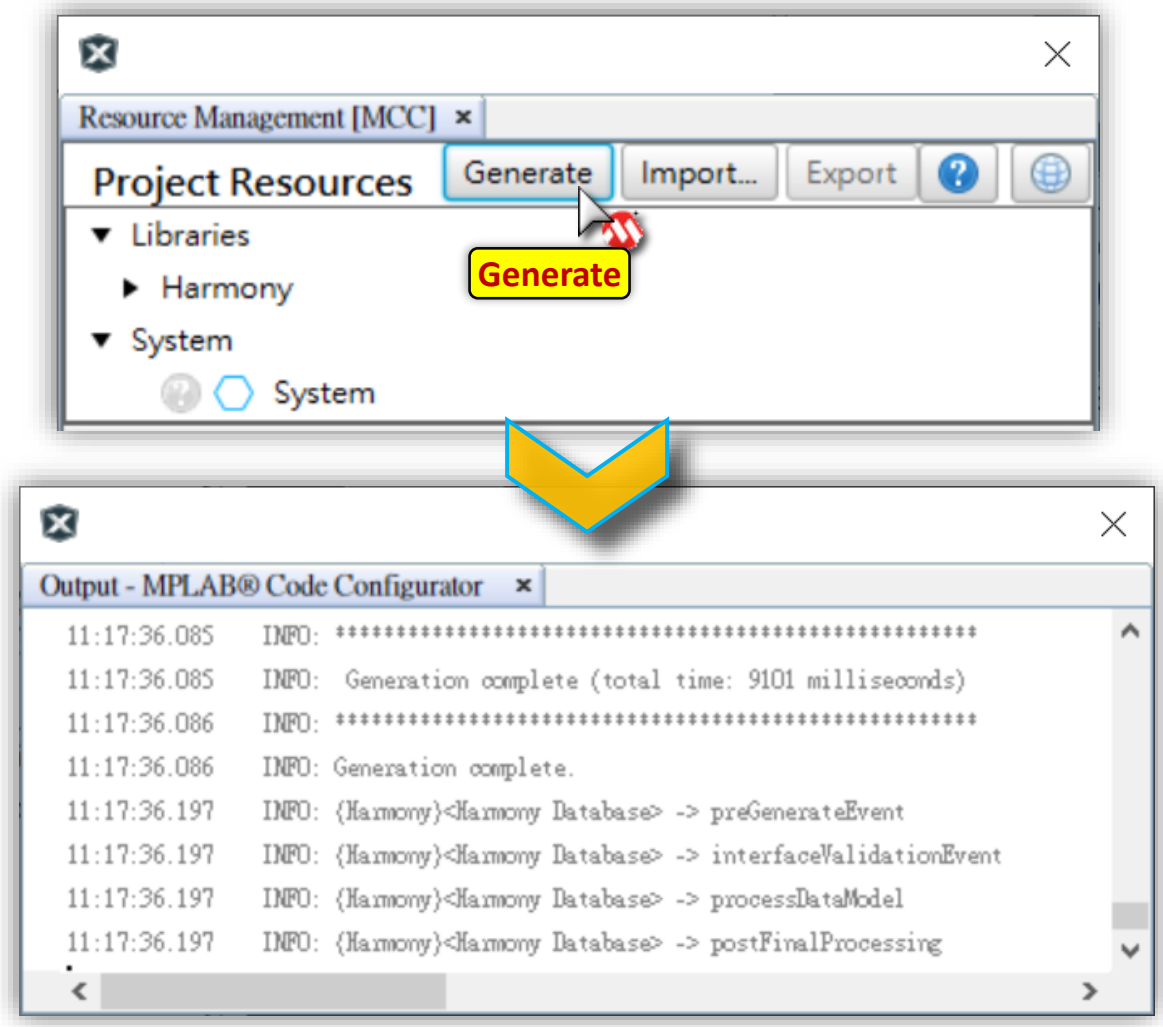
- **Enable Period Interrupt** of TC4 in configuration windows.



Lab6 TCs Timer Method Interrupt Callback

Step 2

- Click "Generate" Button to Generate your Code.



Lab6 TCs Timer Method Interrupt Callback

Step 3

a. **Add code segment to your main loop**

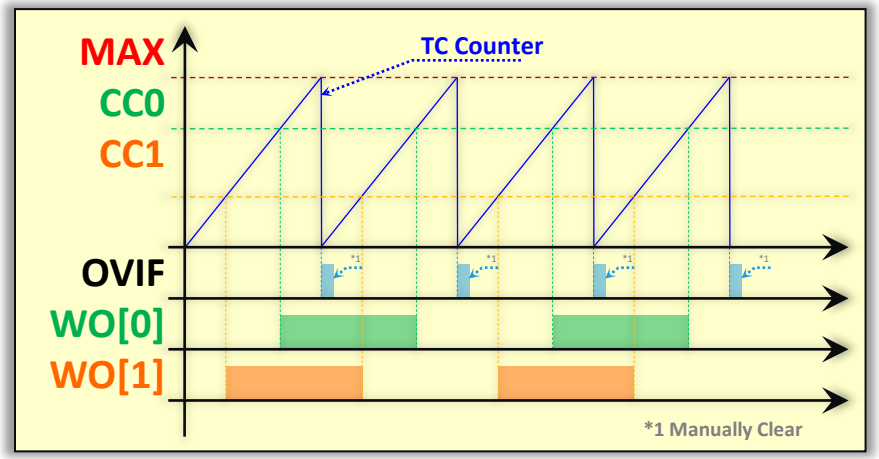
```
// TODO 6.01
void TC4_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
  if( status & TC_INTFLAG_OVF_Msk )
    LED2_Toggle();
}

int main (void)
{
  SYS_Initialize ( NULL );
  ...
  // TODO 6.02
  TC4_TimerCallbackRegister( TC4_TimerExpired, (uintptr_t )NULL );
  TC4_TimerStart();

  while( true )
  { ...
  }
}
```

b. **Program firmware to target board then observe result.**

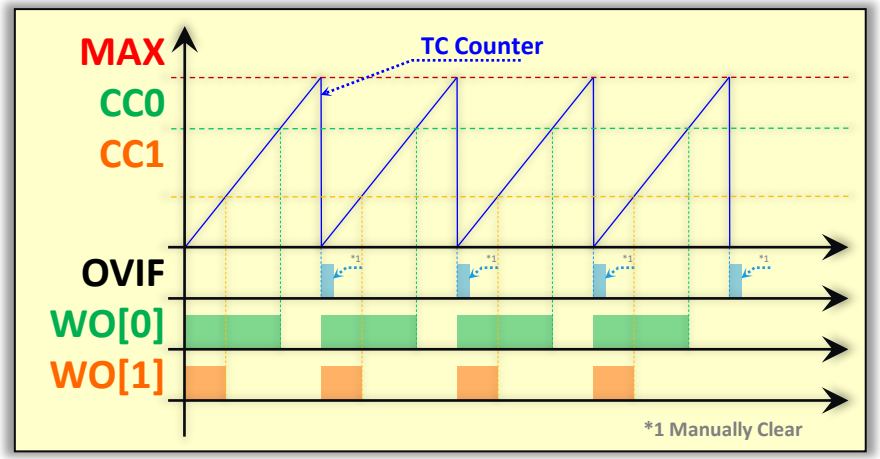
Study Advanced Features

The main course of this section will stop here, If you want to know more about TC/TCC Timer, you can refer to the SAM2001ADV course..

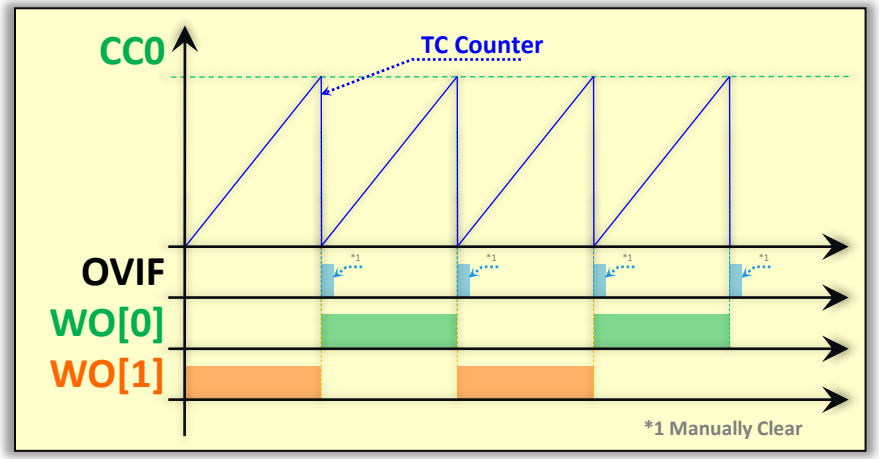
NFRQ, 16Bit, Up Count



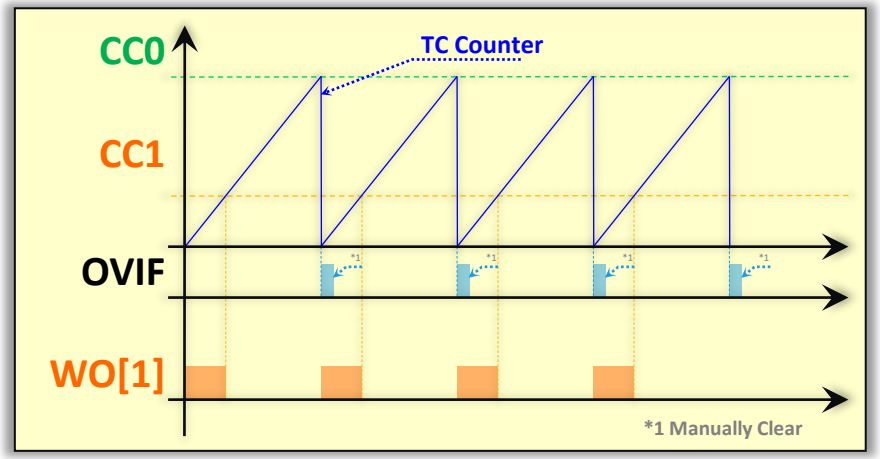
NPWM, 16Bit, Up Count



MFRQ, 16Bit, Up Count



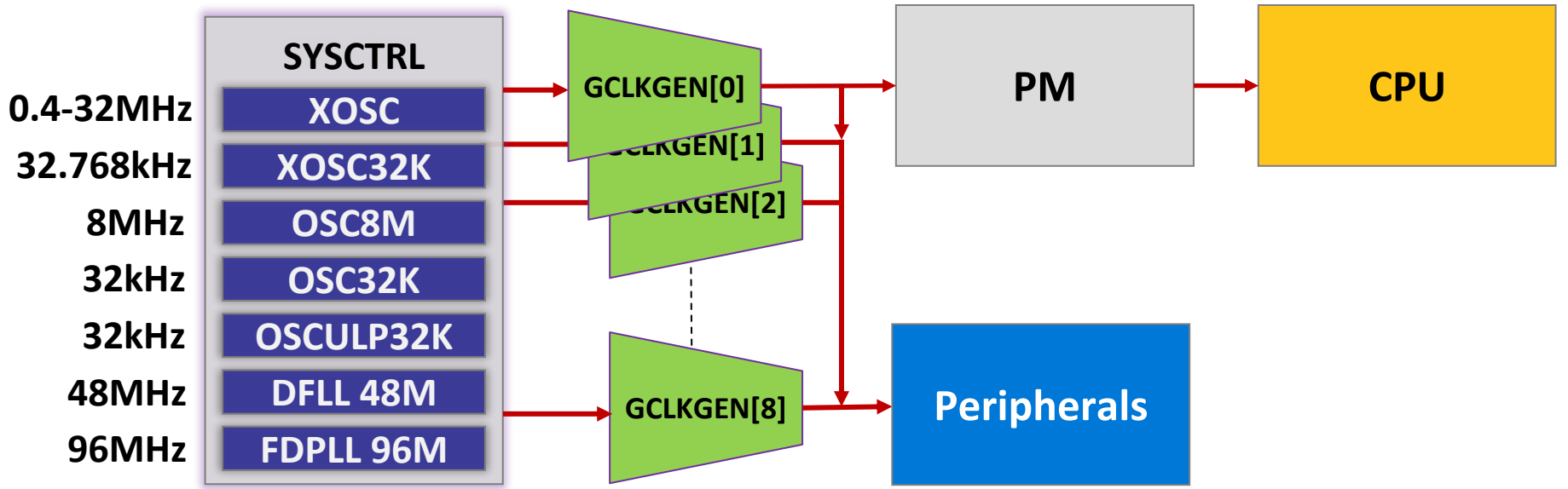
MPWM, 16Bit, Up Count



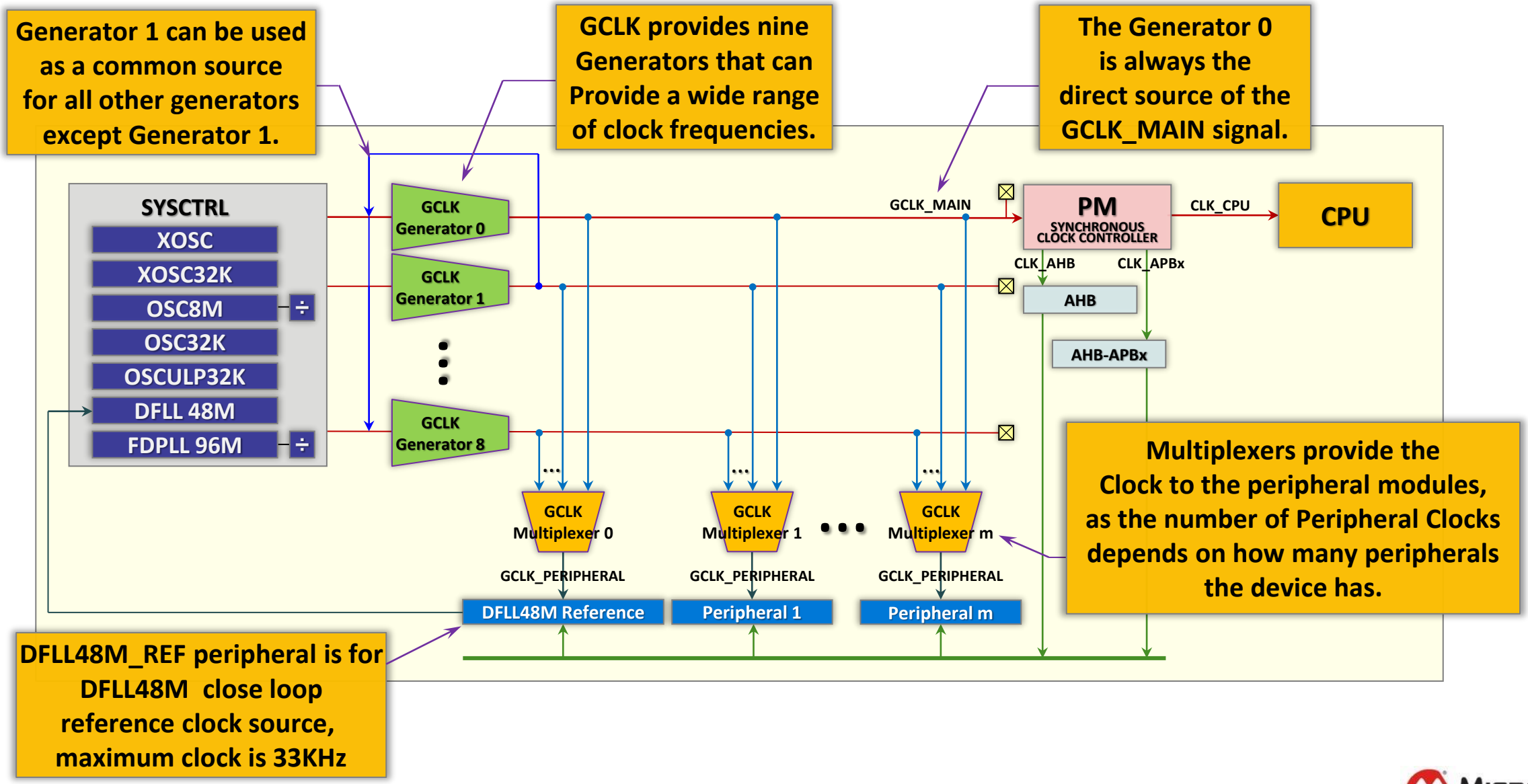
Clock System Architecture

Clock System

- Review previously section, SAMD21's clock system provides clock sources to the Generic Clock Controller。The available clock sources are XOSC, XOSC32K, OSC32K, OSCULP32K, OSC8M,DFLL48M and FDPLL96M。
- The bus clock can be enabled and disabled in the Power Manager(PM) include CPU Clock(GCLK_MAIN)。

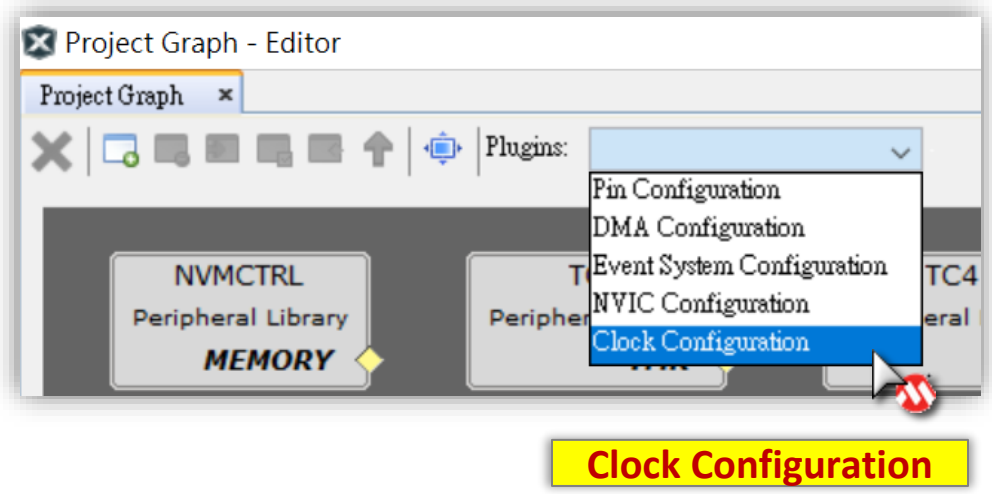


Clock System Block Diagram

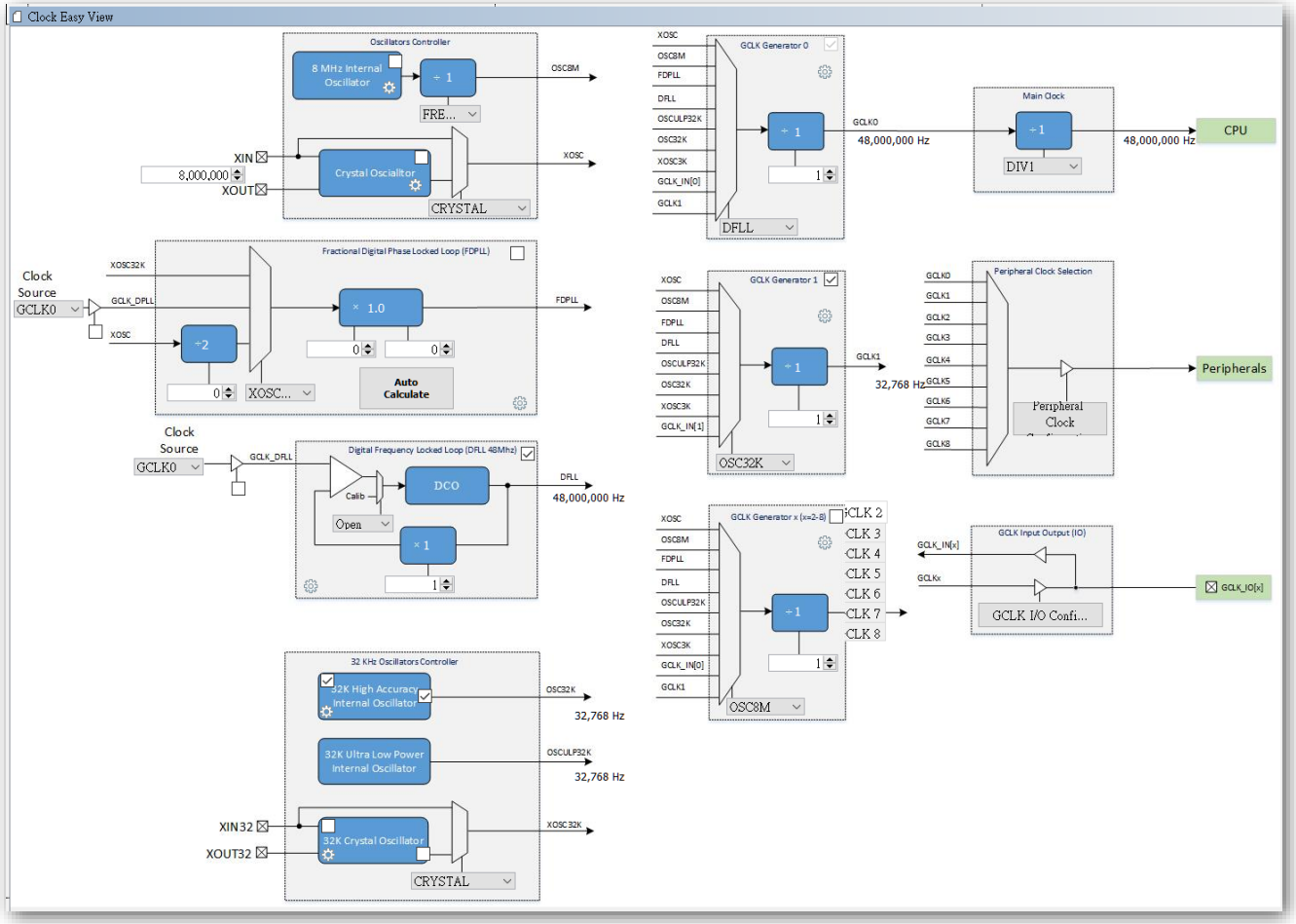


Clock Setting Use MCC Harmony

- **Open Clock Easy View windows in Project Graph > Plugins > Clock Configuration.**

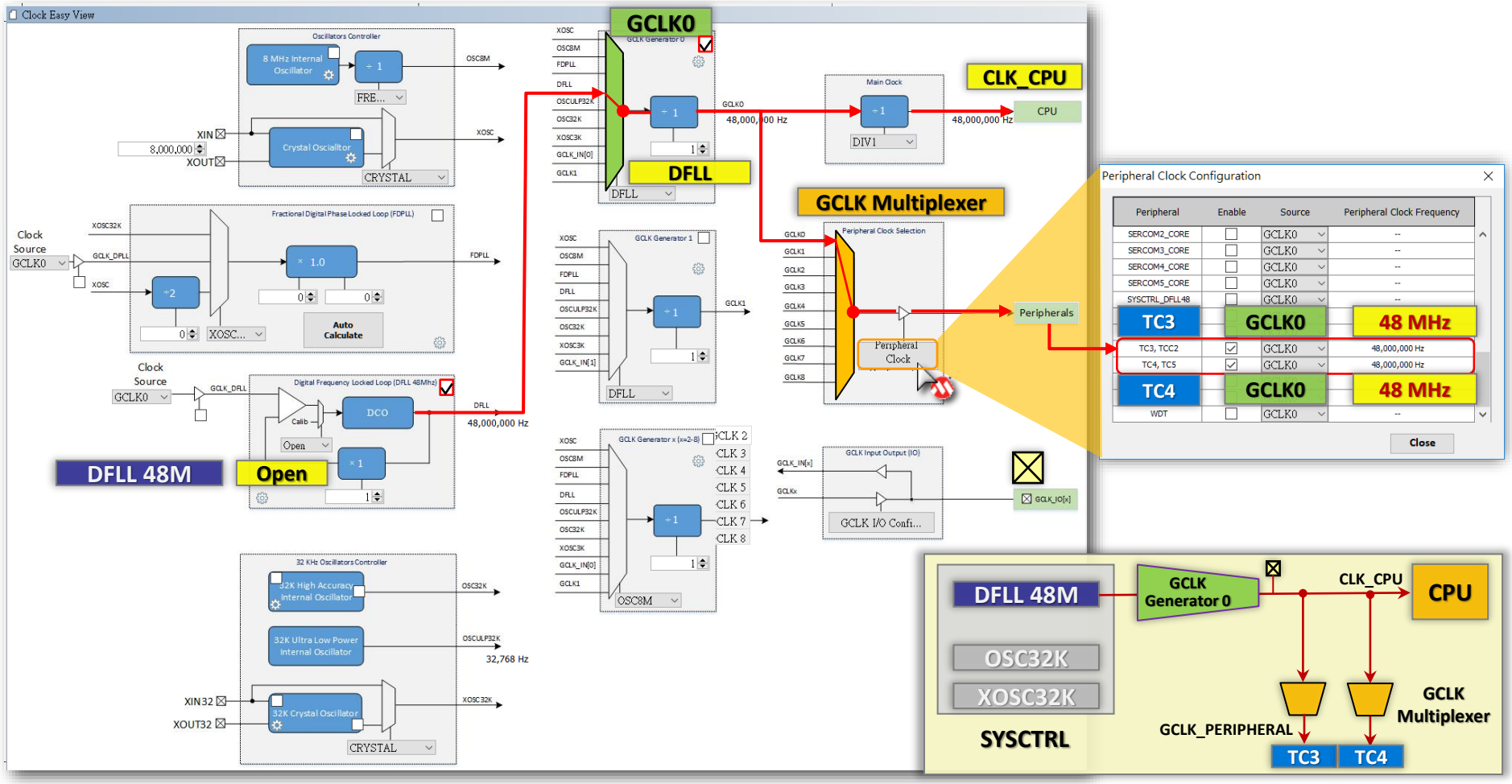


Clock Configuration



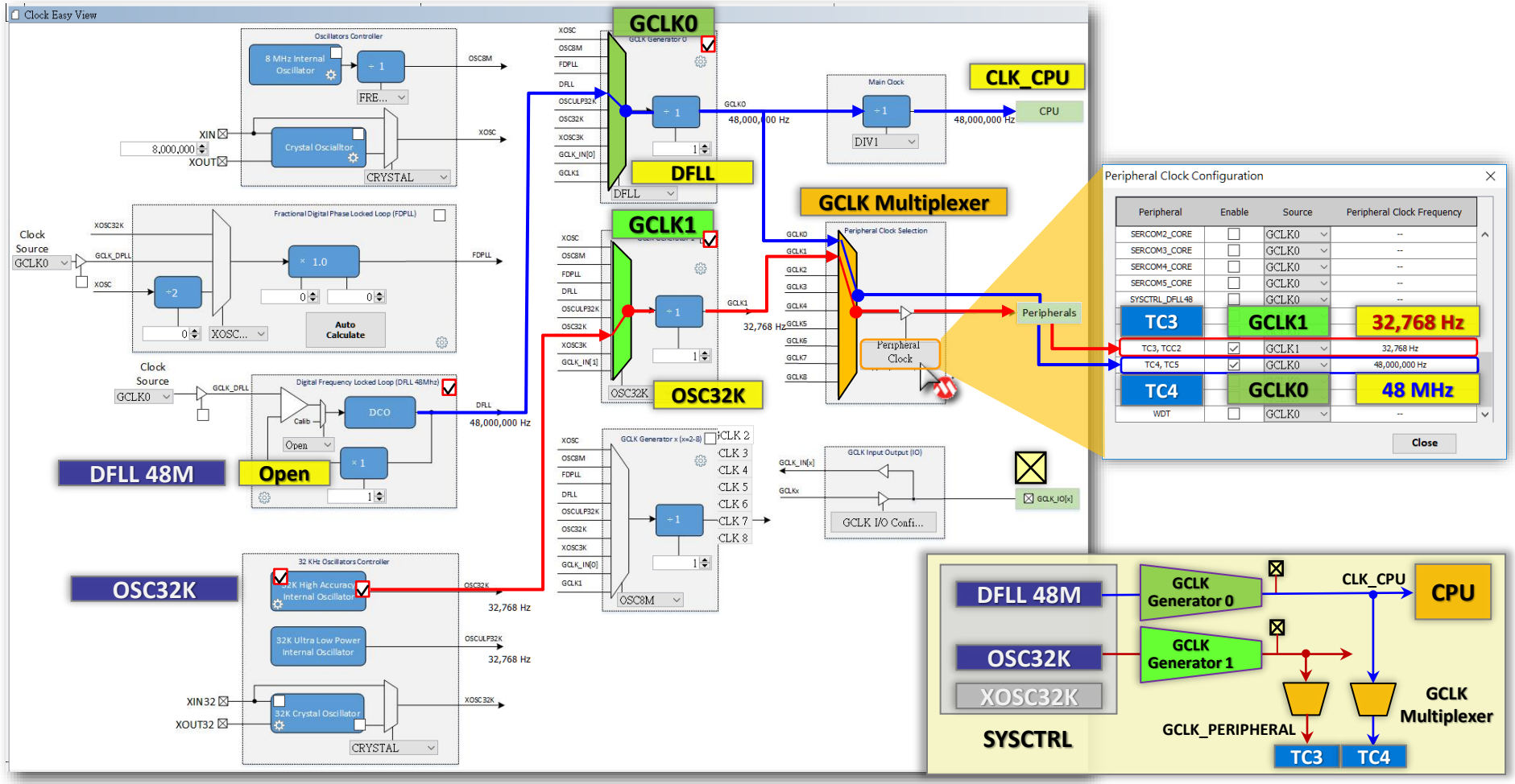
Clock Setting Use MCC Harmony

- **Default clock setting of new project (DFLL48M open loop).**



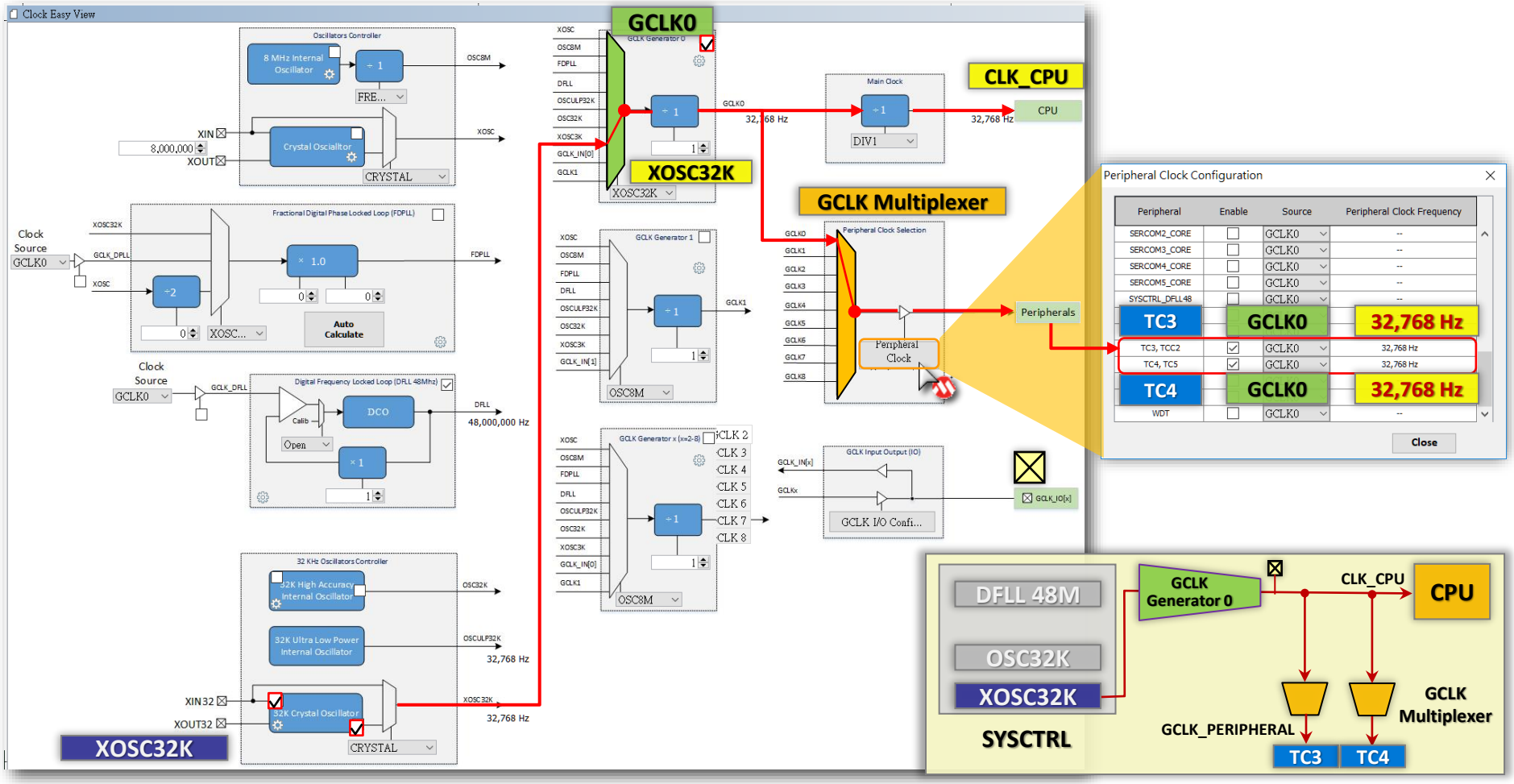
Clock Setting Use MCC Harmony

- **For Example : Internal 32k RC -> GCLK Generator 1 -> TC3**



Clock Setting Use MCC Harmony

- **For Example : External 32.768K -> Generator 0 -> CPU & TC3**



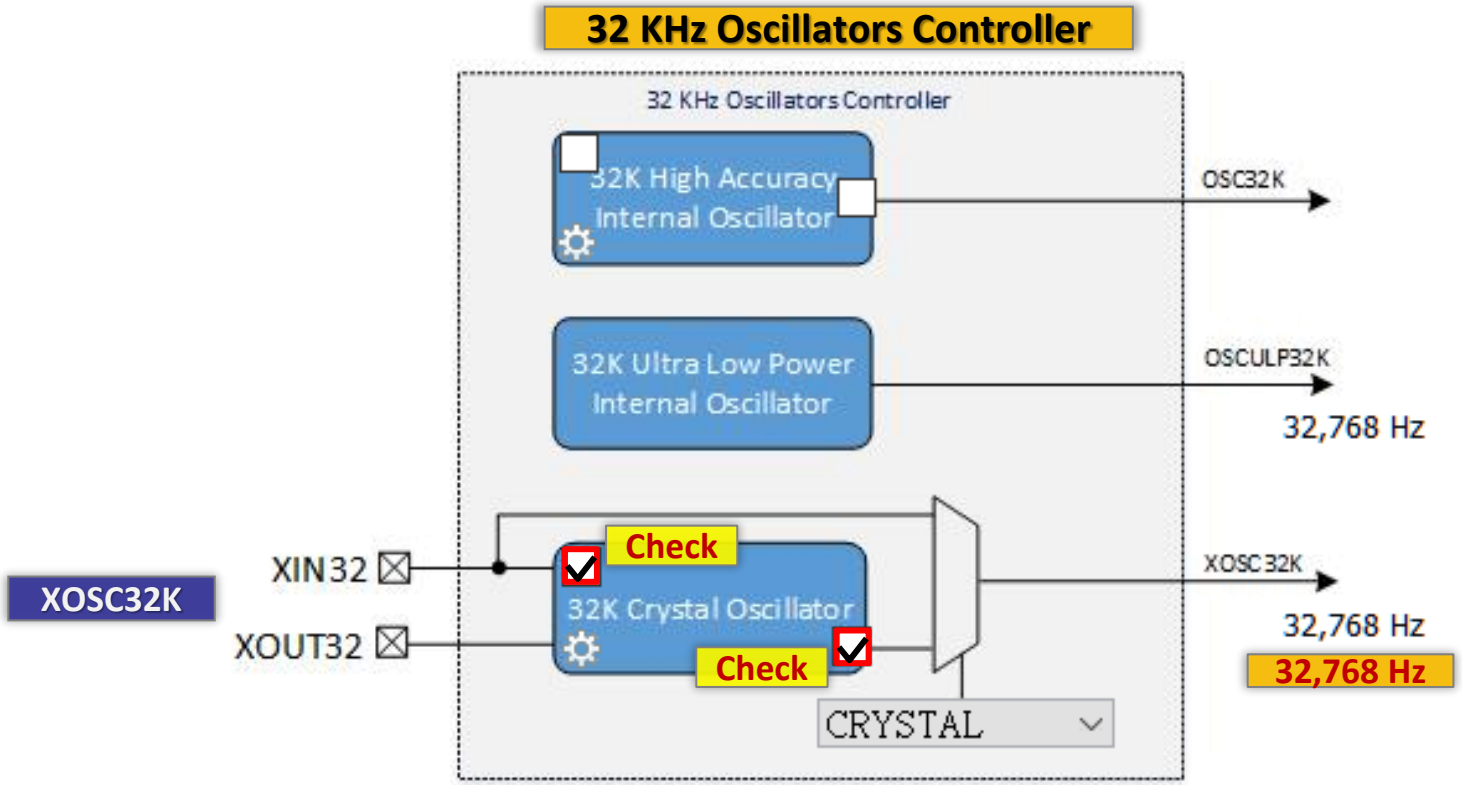
Lab7 System Clock XOSC32K

- Try to change main clock from default source to external 32.768K.
- Setting XOSC32K then enable it, first.
- Connect XOSC32K to Generator 0.
- Connect TC3, TC4 to Generator 0.

- Let’s go!

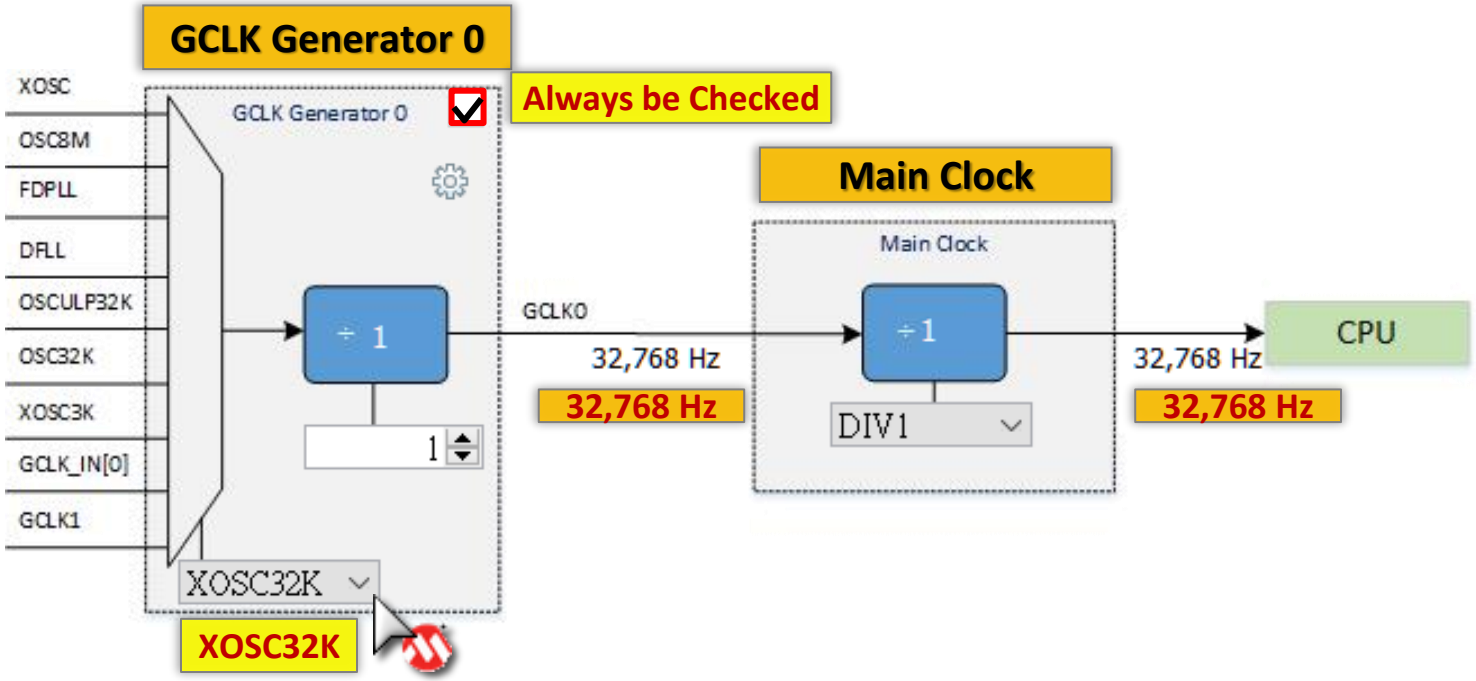
Lab7 System Clock XOSC32K

Step 1



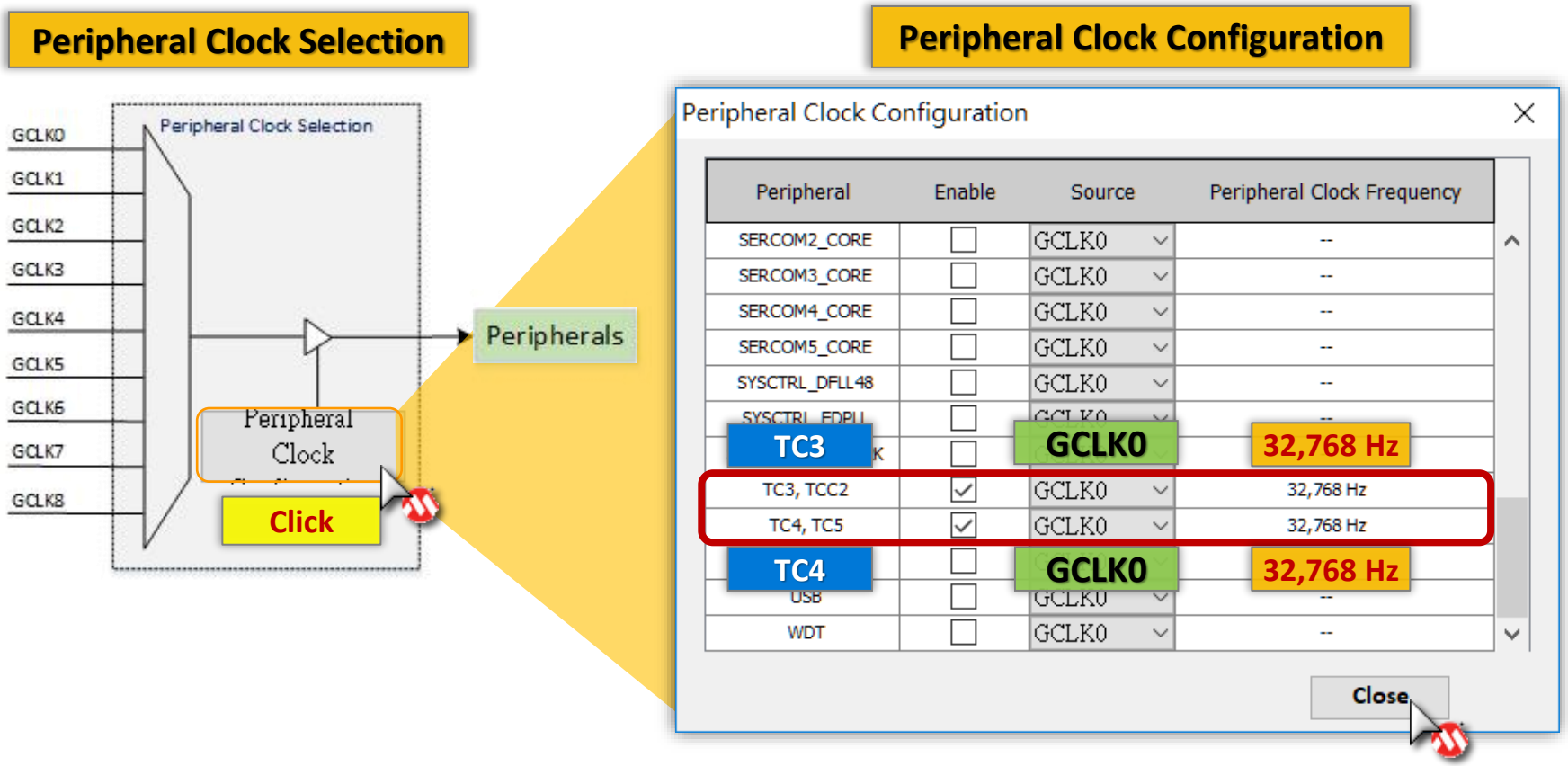
Lab7 System Clock XOSC32K

Step 2



Lab7 System Clock XOSC32K

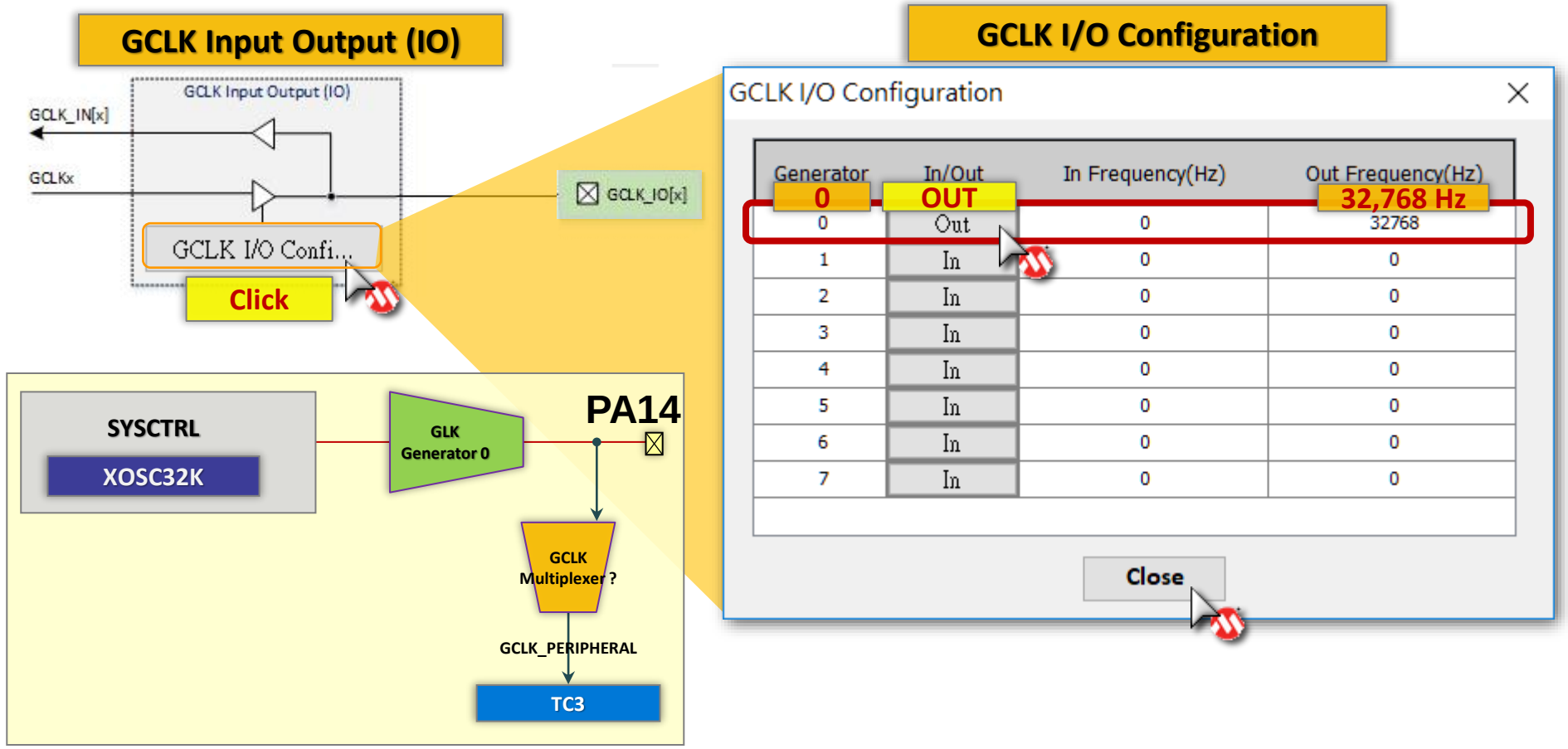
Step 3



Lab7 System Clock XOSC32K

Step 4

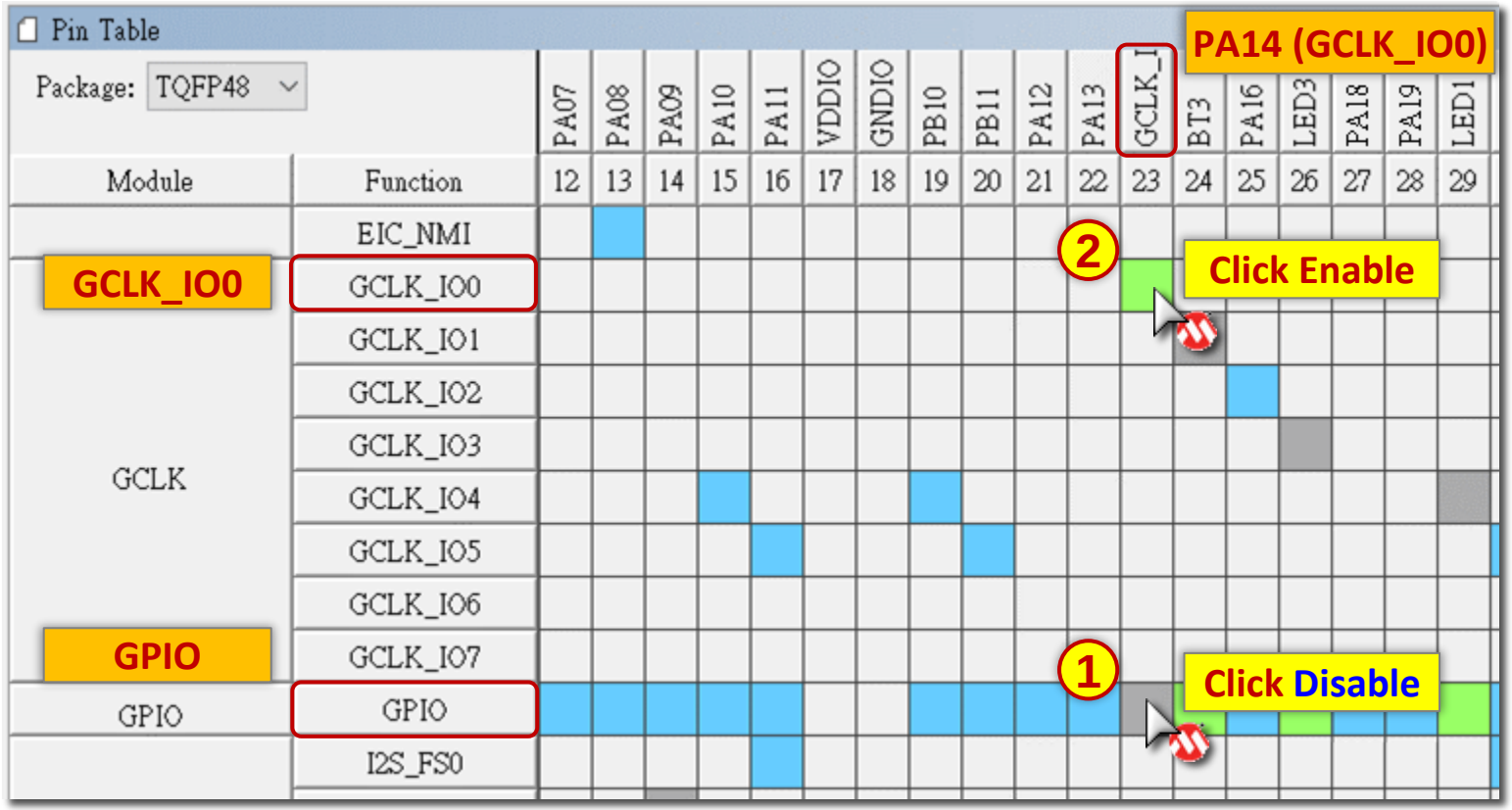
- **Configure GCLK Generator 0 to output clock.**



Lab7 System Clock XOSC32K

Step 5

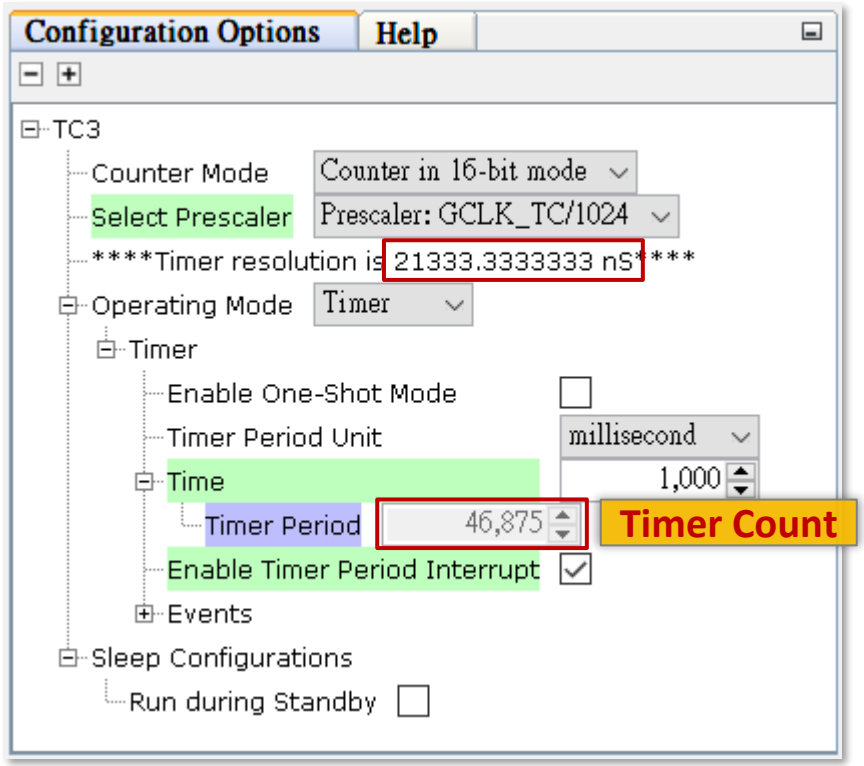
- Please **disable BT1(PA14) GPIO** pin function firstly and then reassign **PA14** as **GCLK_IO0** output pin.



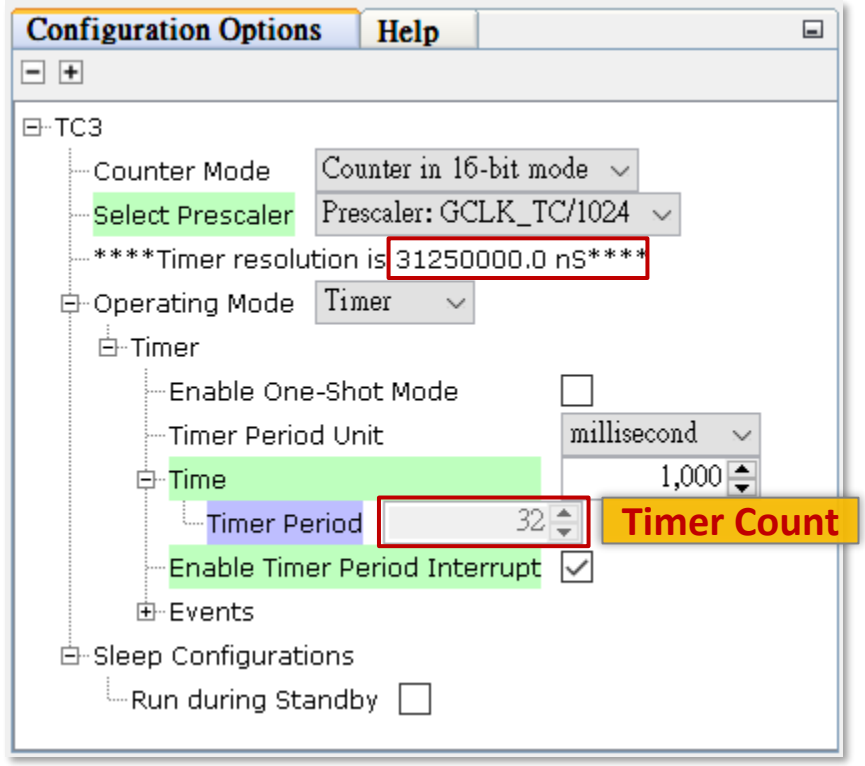
Lab7 System Clock XOSC32K

What's changed if to change main clock from 48MHz to 32.768KHz ?

- **Let's check TC3 configuration to see the difference after change the clock source.**



Clock Source : DFLL48M



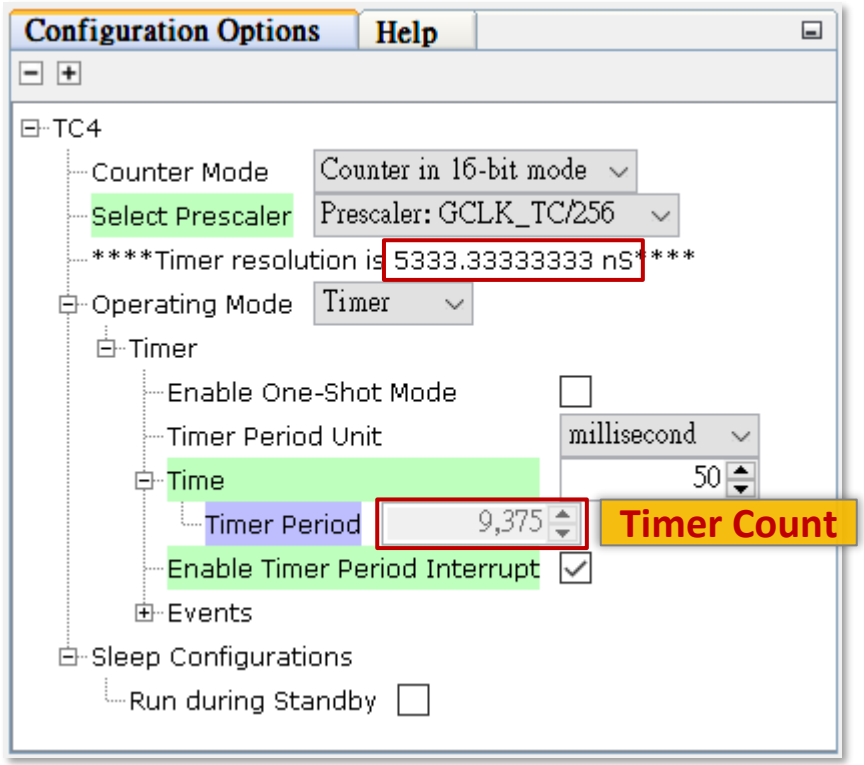
Clock Source : XOSC32K

MICROCHIP

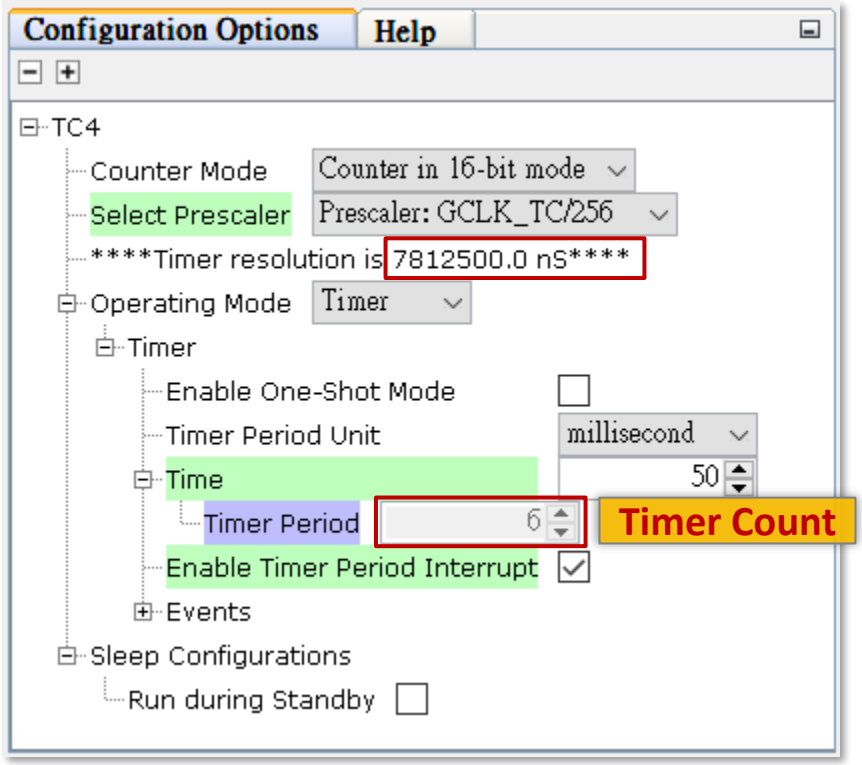
Lab7 System Clock XOSC32K

What's changed if to change main clock from 48MHz to 32.768KHz ?

- **Let's check TC4 configuration to see the difference after change the clock source.**



Clock Source : DFLL48M



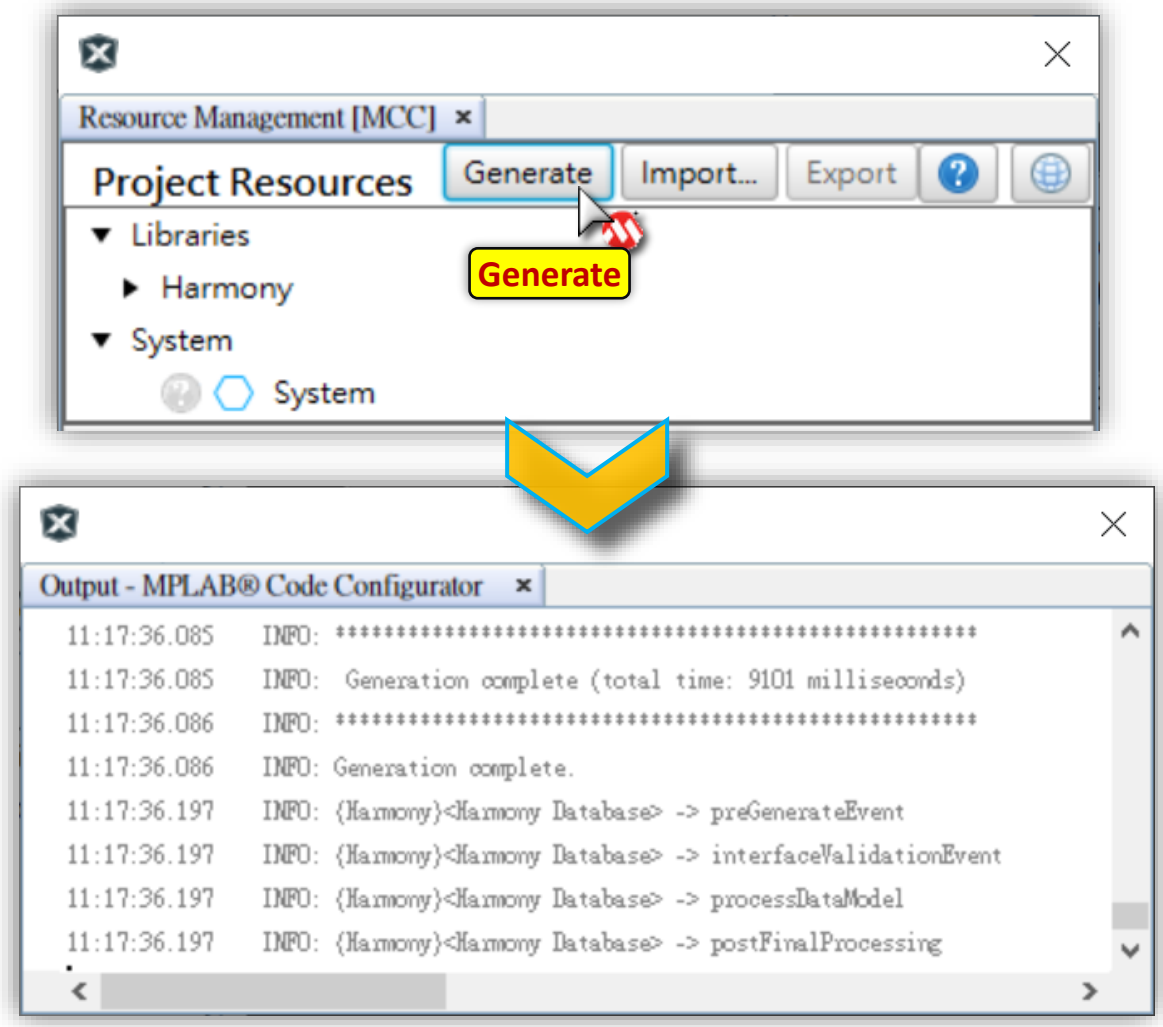
Clock Source : XOSC32K

MICROCHIP

Lab7 System Clock XOSC32K

Step 6

- Click "Generate" Button to Generate your Code.



Lab7 System Clock XOSC32K

Step 7

a **Comment out BT2(PA14) related GPIO code segment.**

```
…

int main (void)
{
   SYS_Initialize ( NULL );

   while( true )
   {
      …

      // TODO 7.01
      // if ( BT1_Get() ) LED3_Clear();
      // else             LED3_Set();
   }
}
```

Flash Access Time and Wait State

- The SAMD21 main flash Random Read time around 40nS. That means you must adjust Wait State to proper value if main clock over than 24MHz. The actual value shows in below, it will depend on system supply voltage.

V_{DD} range	NVM Wait States	Maximum Operating Frequency	Units
1.62V to 2.7V	0	14	MHz
	1	28	
	2	42	
	3	48	
2.7V to 3.63V	0	24	
	1	48	

CPU_CLK = 32.768KHz

VDD = 3.3V

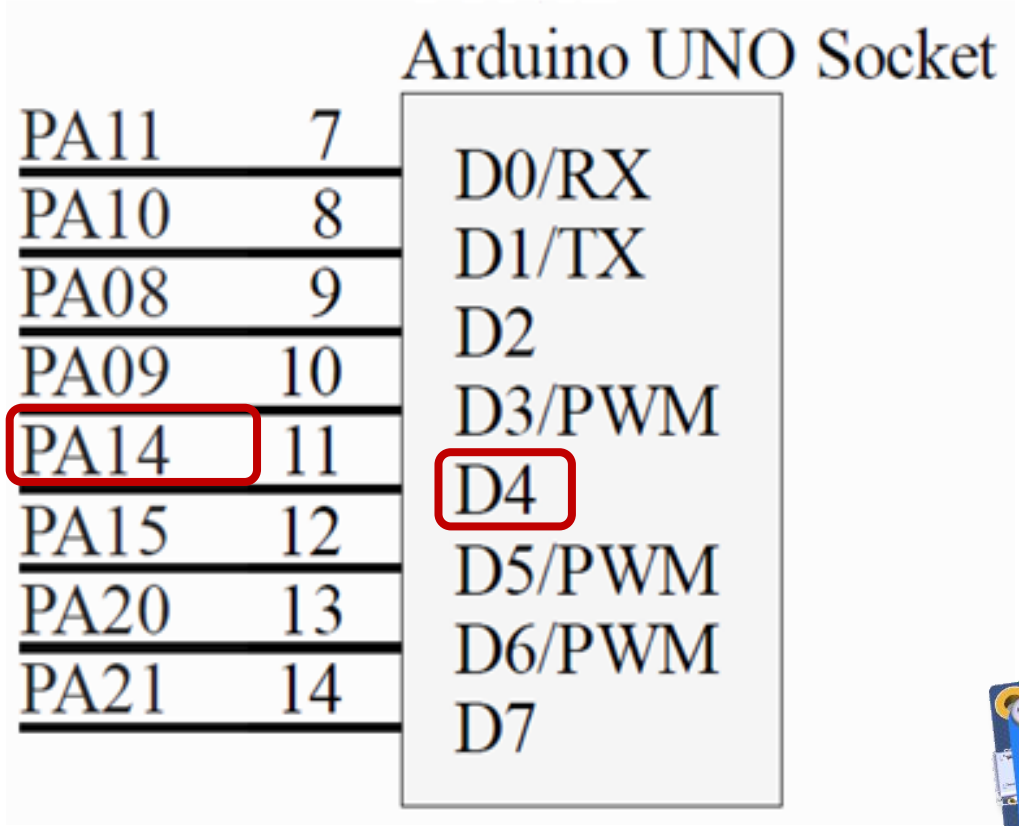
MCC Harmony will auto adjust proper NVM Wait State.
(In case of 3.3V voltage supply only).

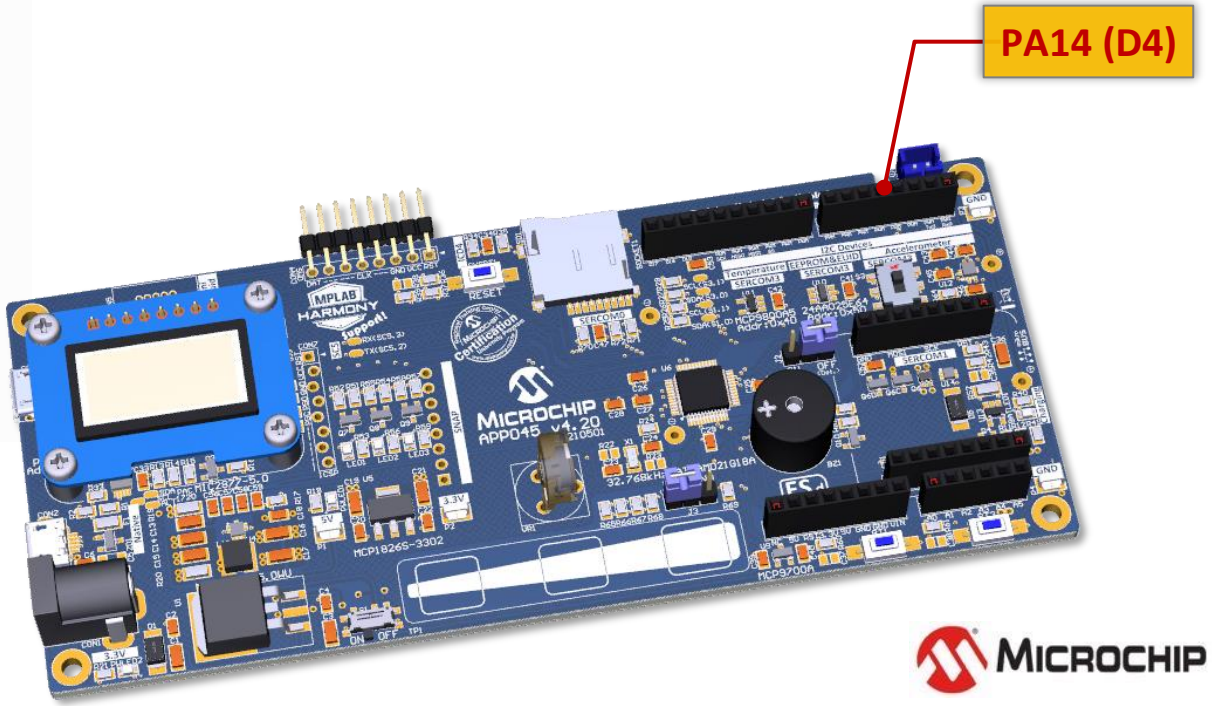
plib_nvmctrl.c

```
void NVMCTRL_Initialize(void)
{
    NVMCTRL_REGS->NVMCTRL_CTRLB =
        NVMCTRL_CTRLB_READMODE_NO_MISS_PENALTY |
        NVMCTRL_CTRLB_SLEEPPRM_WAKEONACCESS |
        NVMCTRL_CTRLB_RWS(0) |
        NVMCTRL_CTRLB_MANW_Msk;
}
```

Lab7 System Clock XOSC32K

Clock Output

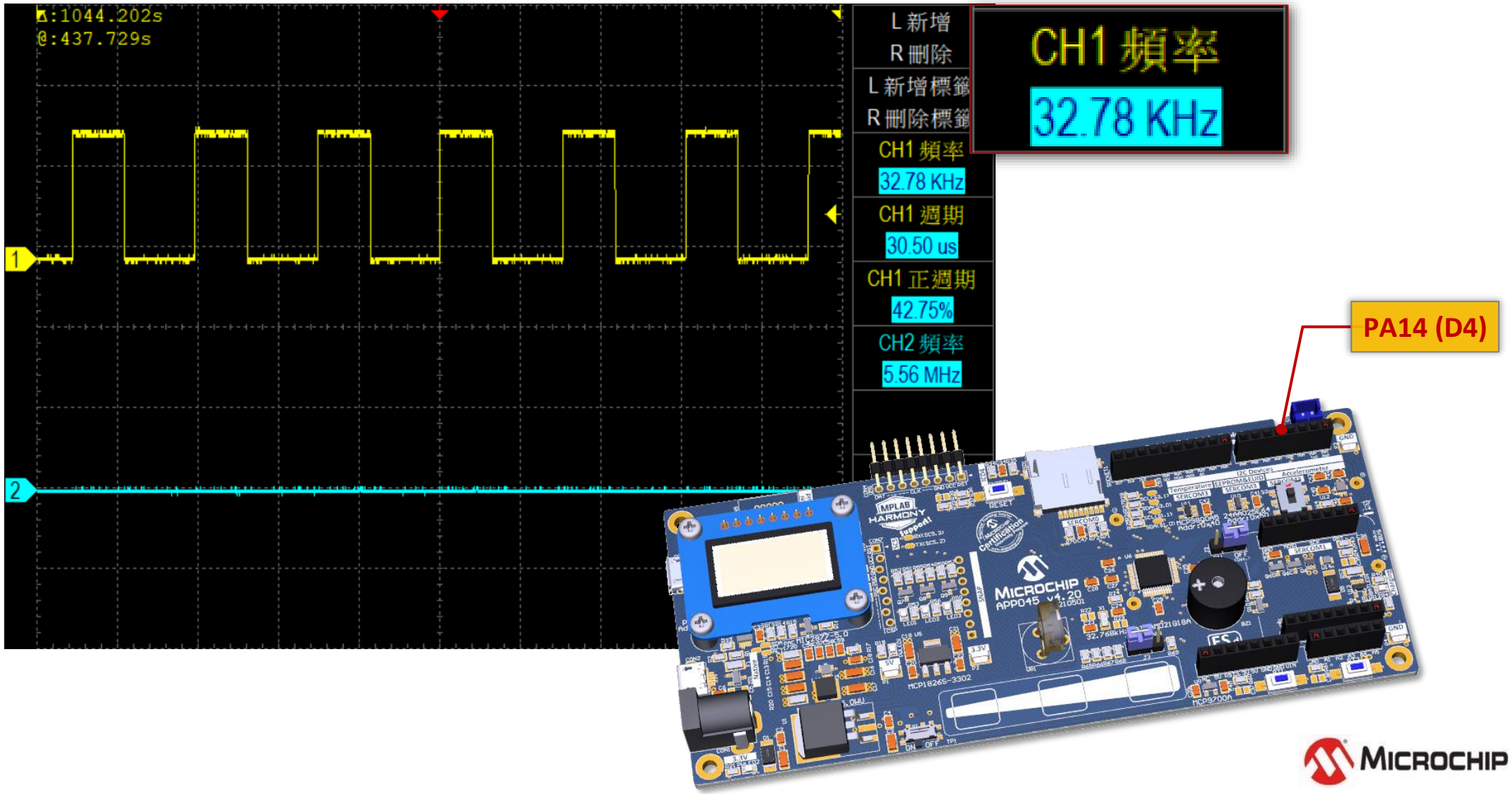




MICROCHIP

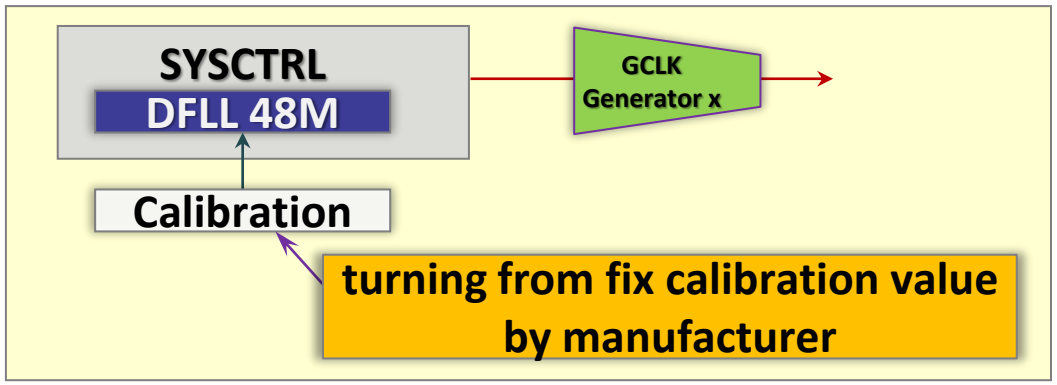
Lab7 System Clock XOSC32K

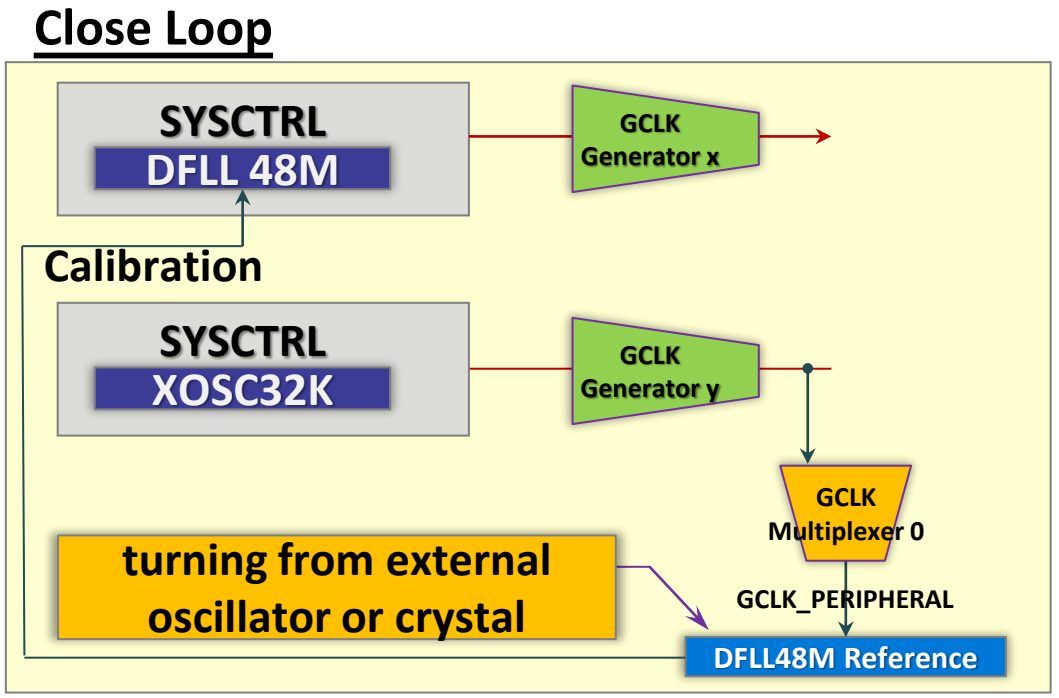
Clock Output



Clock source from DFLL48M

- There are 2 different mode for DFLL48M clock source
  - Open Loop : Project Default Use
    Clock turning from fix calibration value by manufacturer.
  - Close Loop :
    Clock turning from external oscillator or crystal.





MICROCHIP

Lab8 System Clock DFLL48M

Close Loop

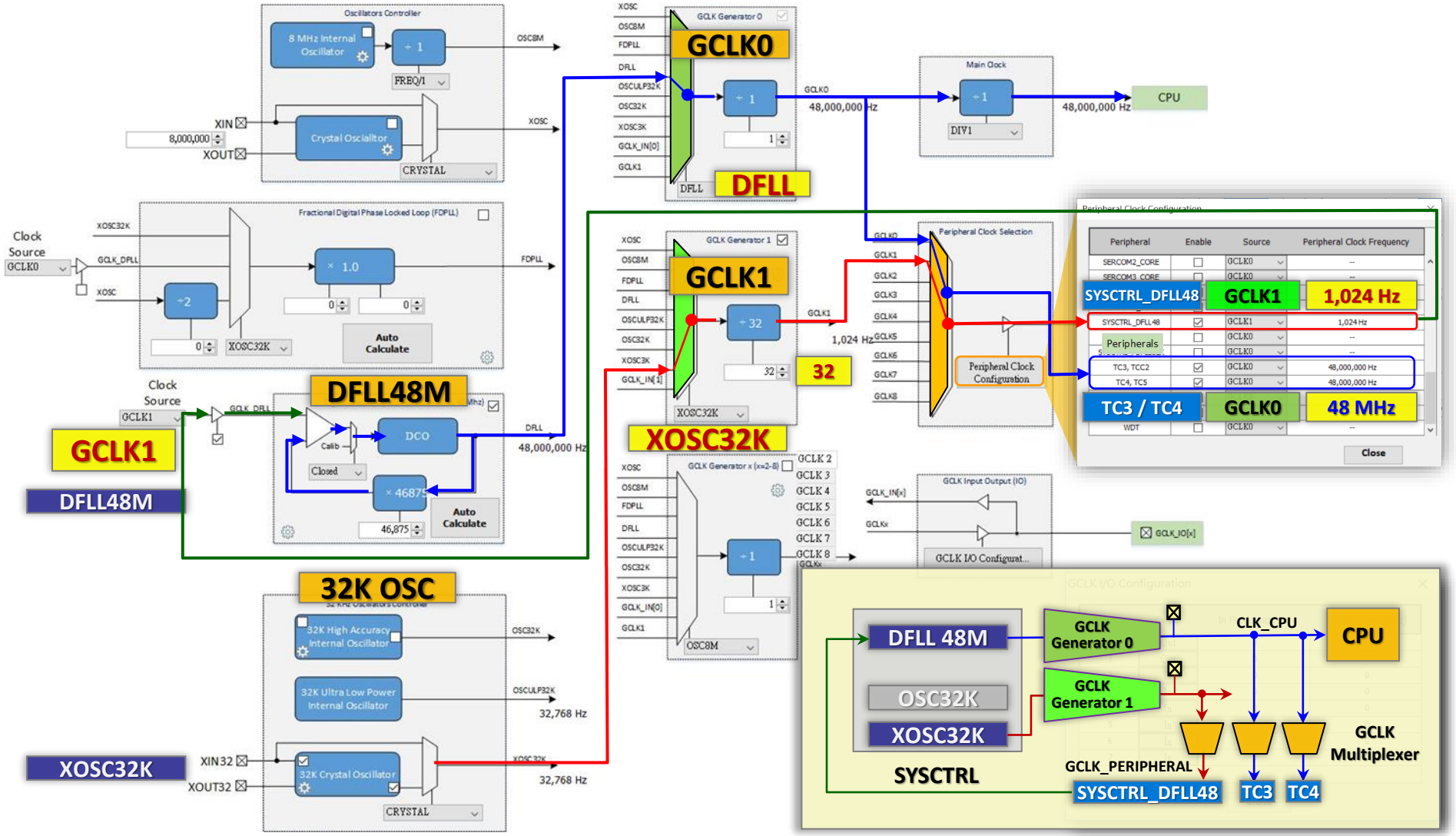
Configure DFLL48M(Close loop) as source of main clock(GCLK0).

- **Enable XOSC32K clock source.**
- **Enable GCLK Generator 1 and assign XOSC32K as source of it.**
- **Enable DFLL48M and assign GCLK1 as source or it.**
- **Select Close Loop calibration of DFLL48M.**
- **Click Auto Calculate to generate multiplier factor of DFLL48M.**
- **Assign DFLL48M as clock source of GCLK Generator 0.**
- **CPU wait state will auto judge by MCC Harmony.**

- **Let's go!**

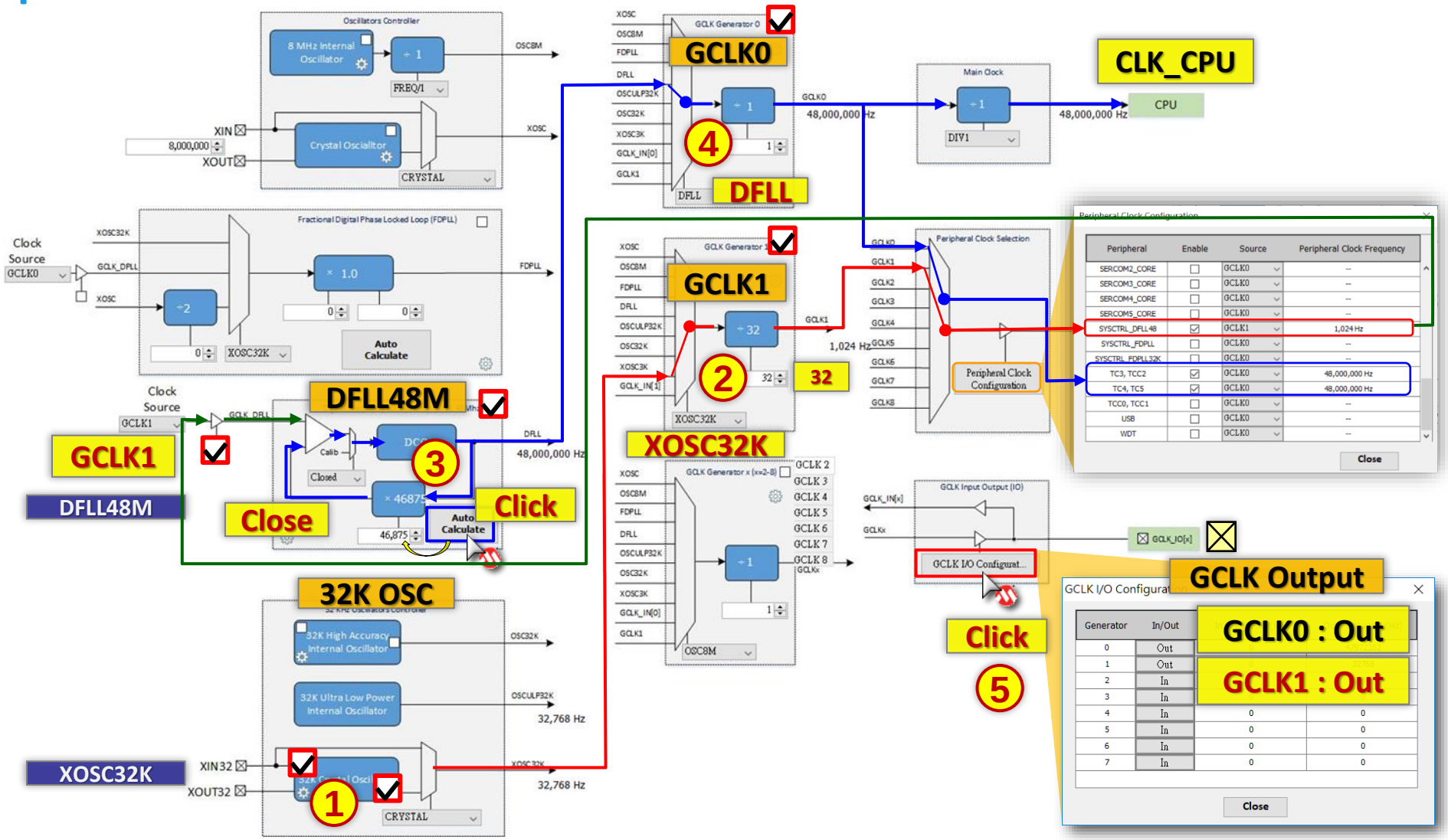
Lab8 System Clock DFLL48M

Overview



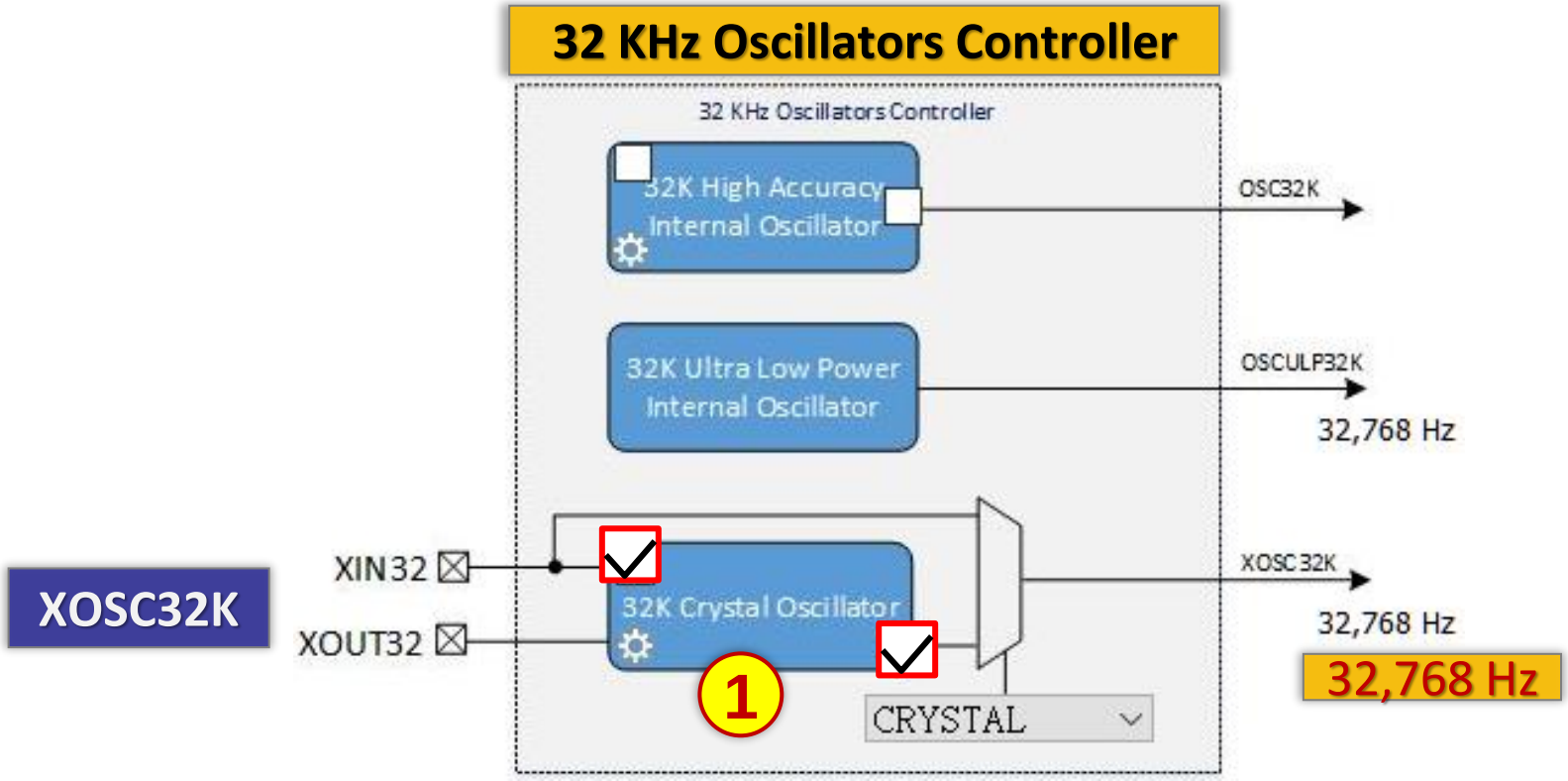
Lab8 System Clock DFL48M

Setup Steps Overview



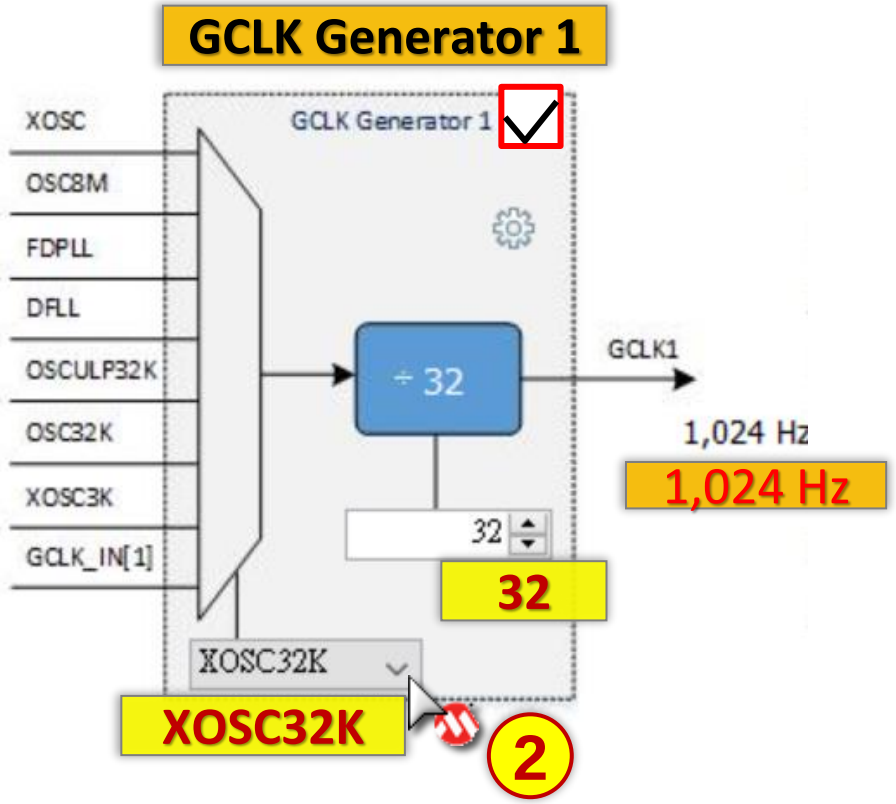
Lab8 System Clock DFLL48M

Step 1



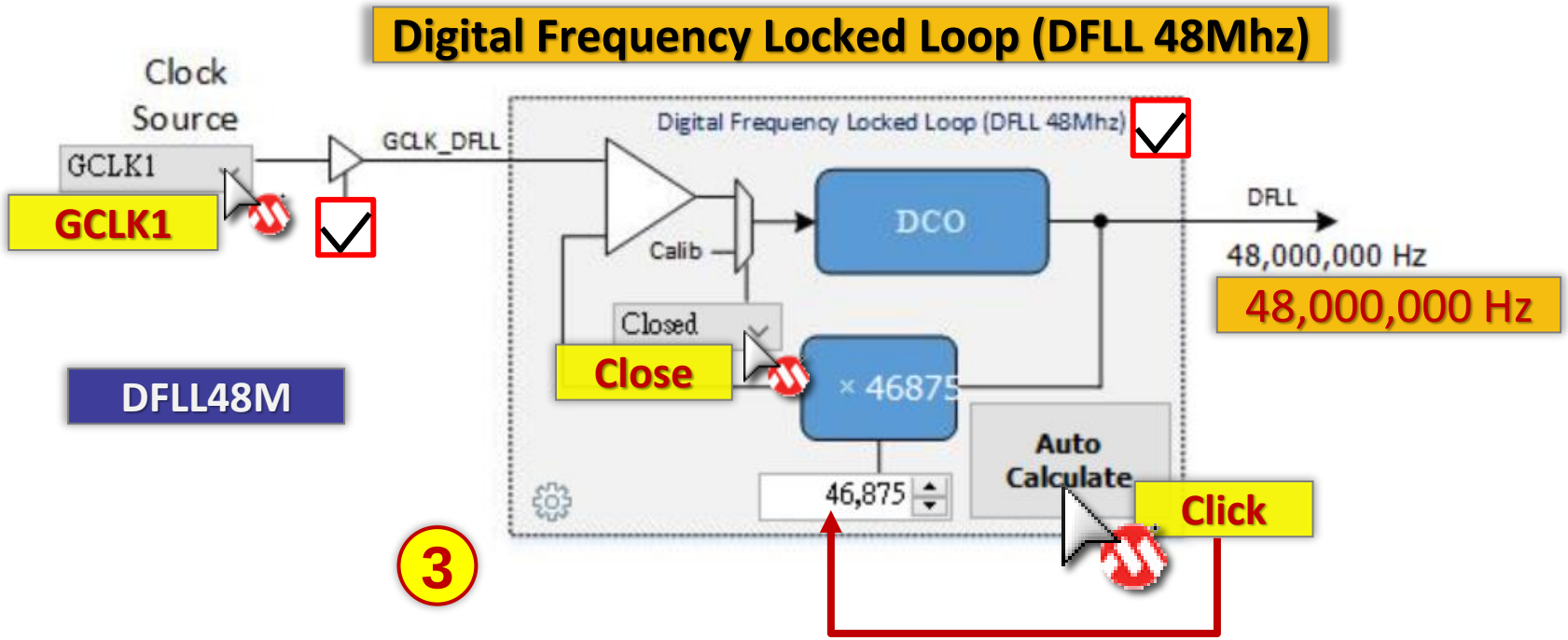
Lab8 System Clock DFL48M

Step 2



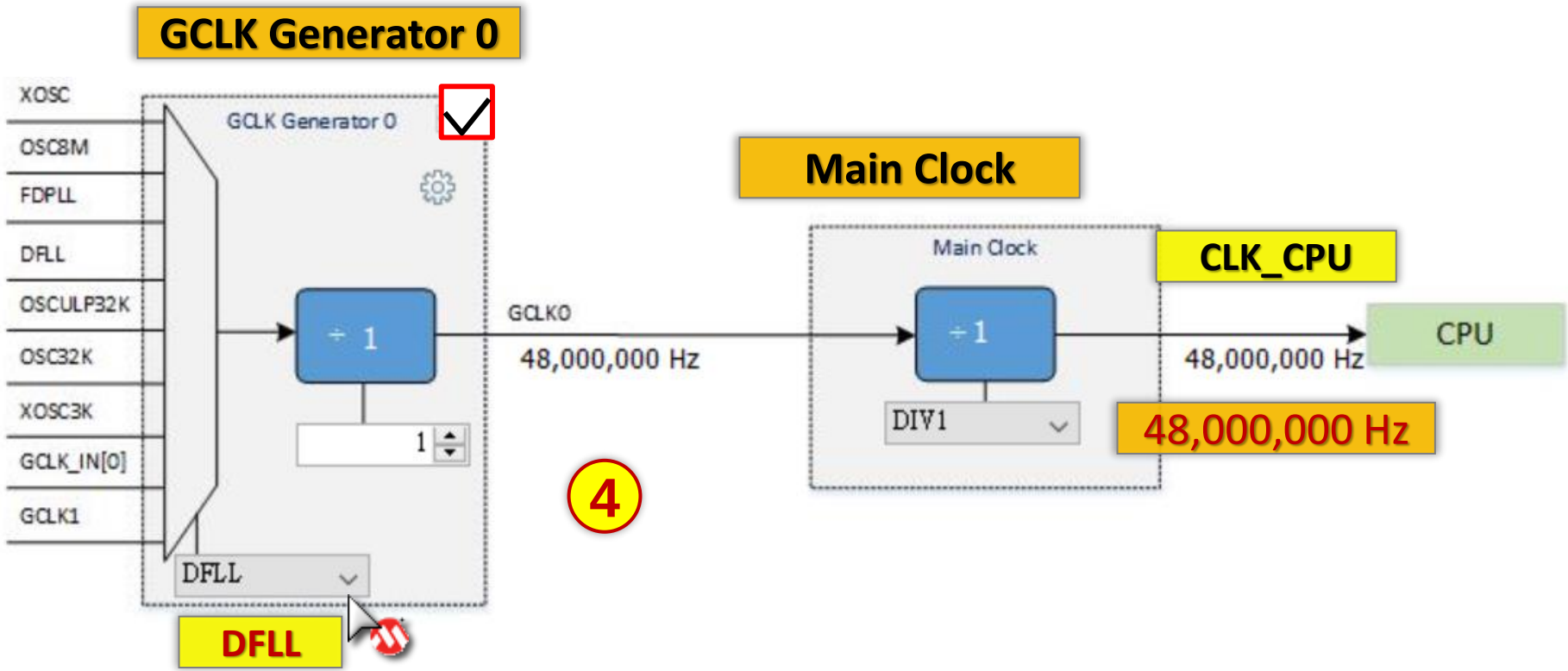
Lab8 System Clock DFLL48M

Step 3



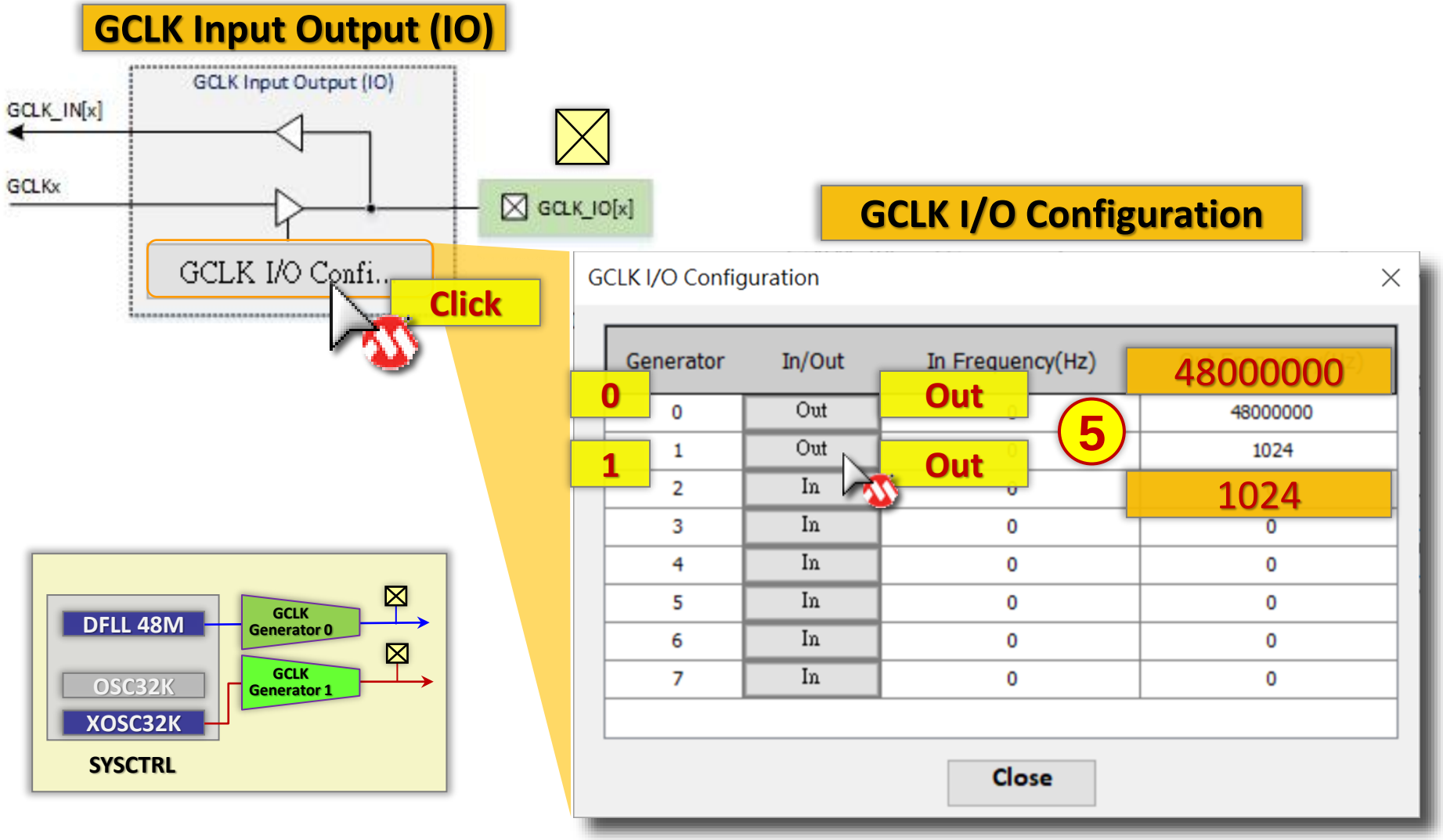
Lab8 System Clock DFL48M

Step 4



Lab8 System Clock DFLL48M

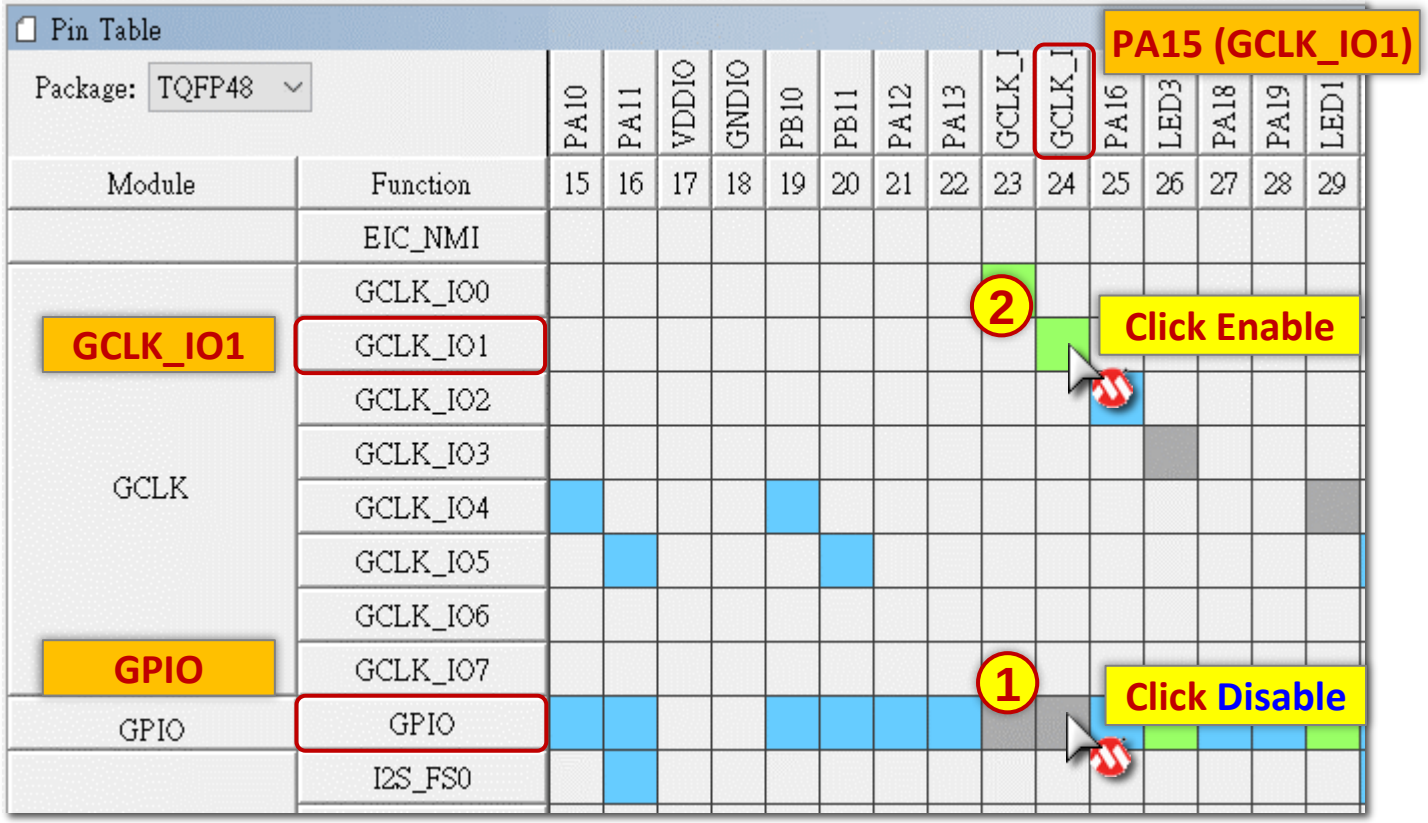
Step 5



Lab8 System Clock DFL48M

Step 6

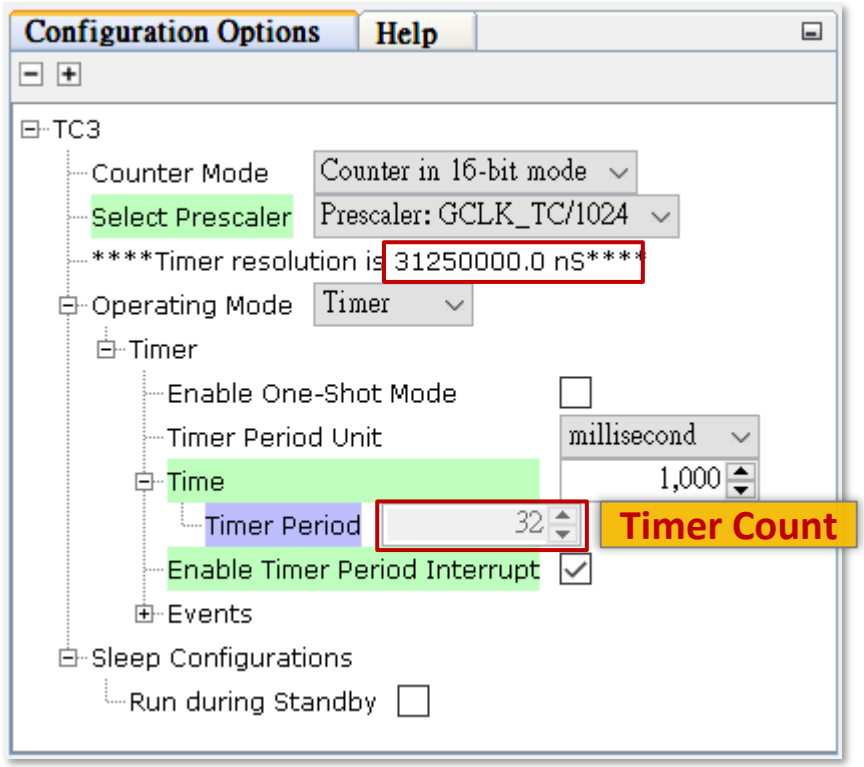
- Please disable GPIO PA15 pin function firstly and then reassign PA15 as GCLK_IO1 output pin.



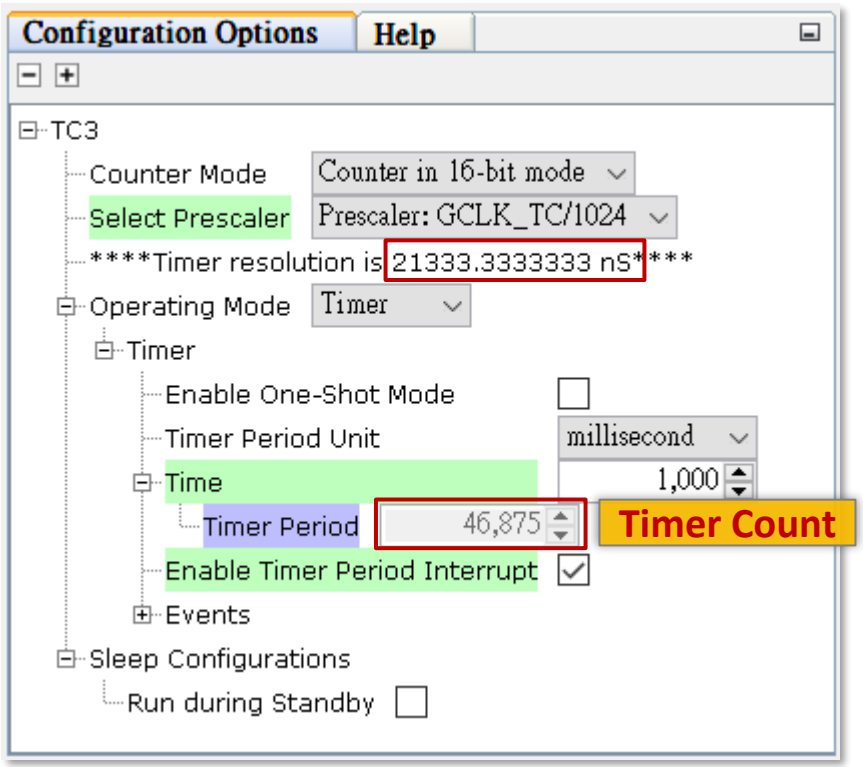
Lab8 System Clock DFLL48M

What's changed if to change main clock from 32.768KHz to DFLL Close Loop ?

- **Let's check TC3 configuration to see the difference after change the clock source.**



Clock Source : XOSC32K



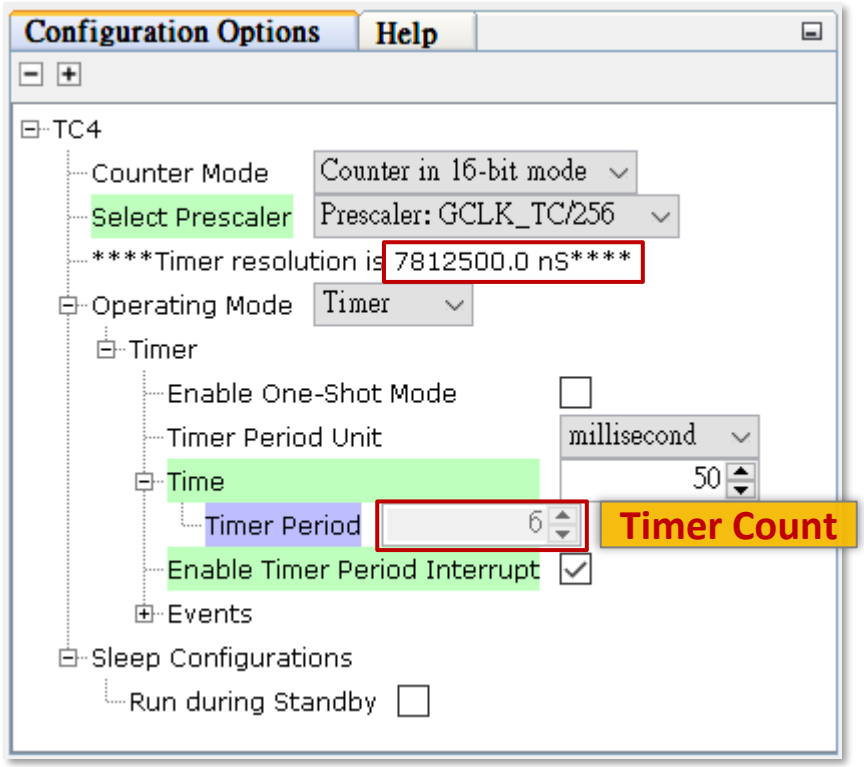
Clock Source : DFLL48M

MICROCHIP

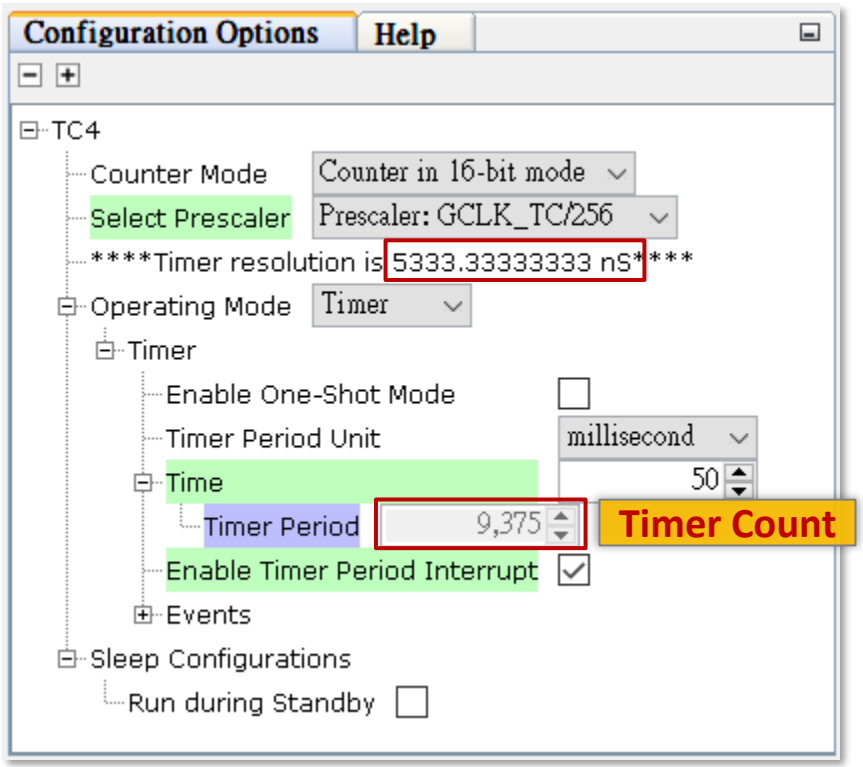
Lab8 System Clock DFLL48M

What's changed if to change main clock from 32.768KHz to DFLL Close Loop ?

- **Let's check TC4 configuration to see the difference after change the clock source.**



Clock Source : XOSC32K



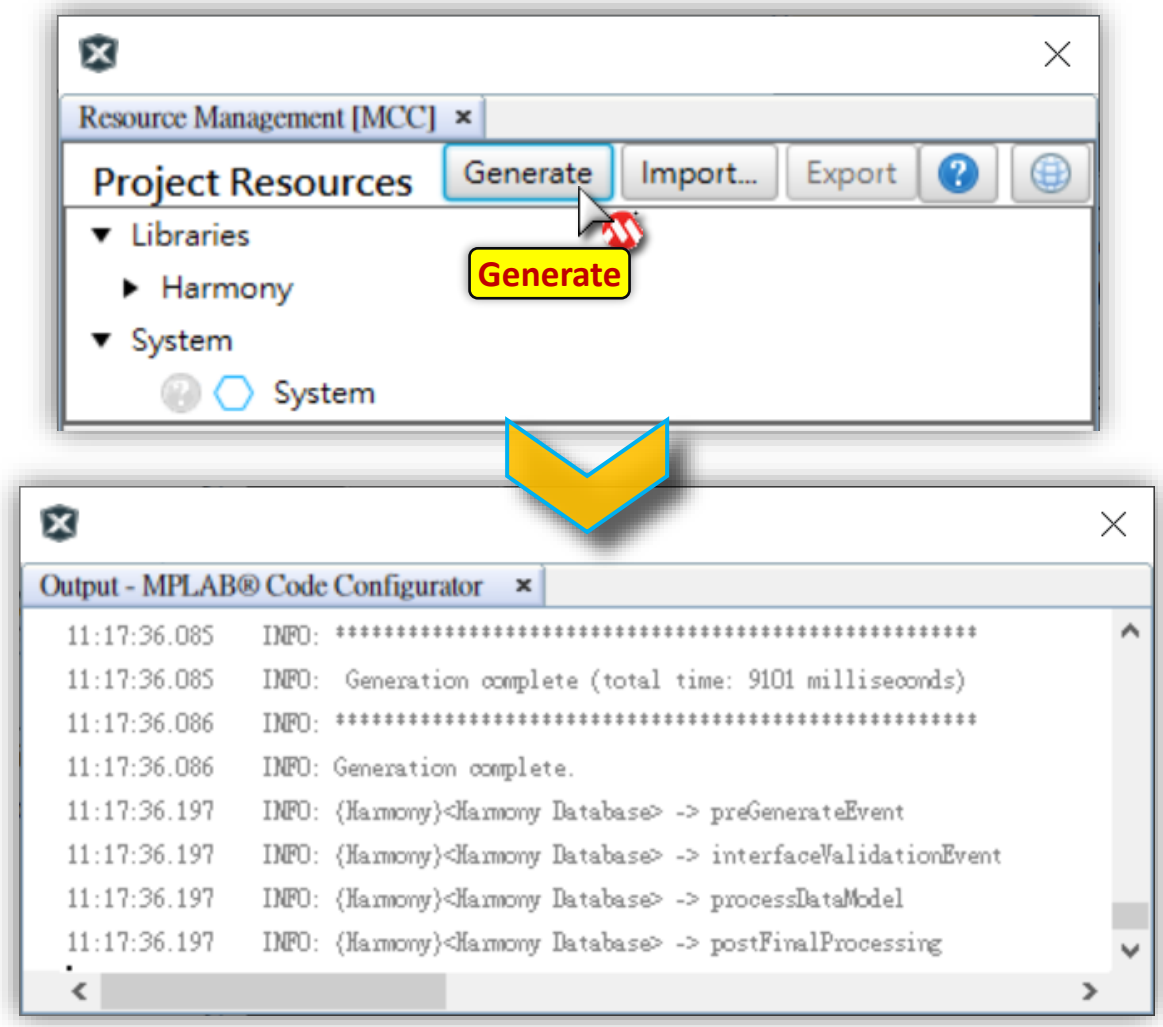
Clock Source : DFLL48M

MICROCHIP

Lab8 System Clock DFLL48M

Step 7

- Click "Generate" Button to Generate your Code.



Lab8 System Clock DFLL48M

Step 8

a **Compiler and programming to your EVB to check the result.**

```
...

int main (void)
{
    SYS_Initialize ( NULL );

    wh
    {
        ...

        // TODO 7.01
        // if ( BT2_Get() ) LED3_Clear();
        // else             LED3_Set();
    }
}
```

No code need to change or modify.

Flash Access Time and Wait State

- MCC Harmony will auto adjust proper NVM Wait State, also.

plib_nvmctrl.c

```
void NVMCTRL_Initialize(void)
{
   NVMCTRL_REGS->NVMCTRL_CTRLB =
         NVMCTRL_CTRLB_READMODE_NO_MISS_PENALTY |
         NVMCTRL_CTRLB_SLEEPPRM_WAKEONACCESS |
         NVMCTRL_CTRLB_RWS(1) |
         NVMCTRL_CTRLB_MANW_Msk;
}
```

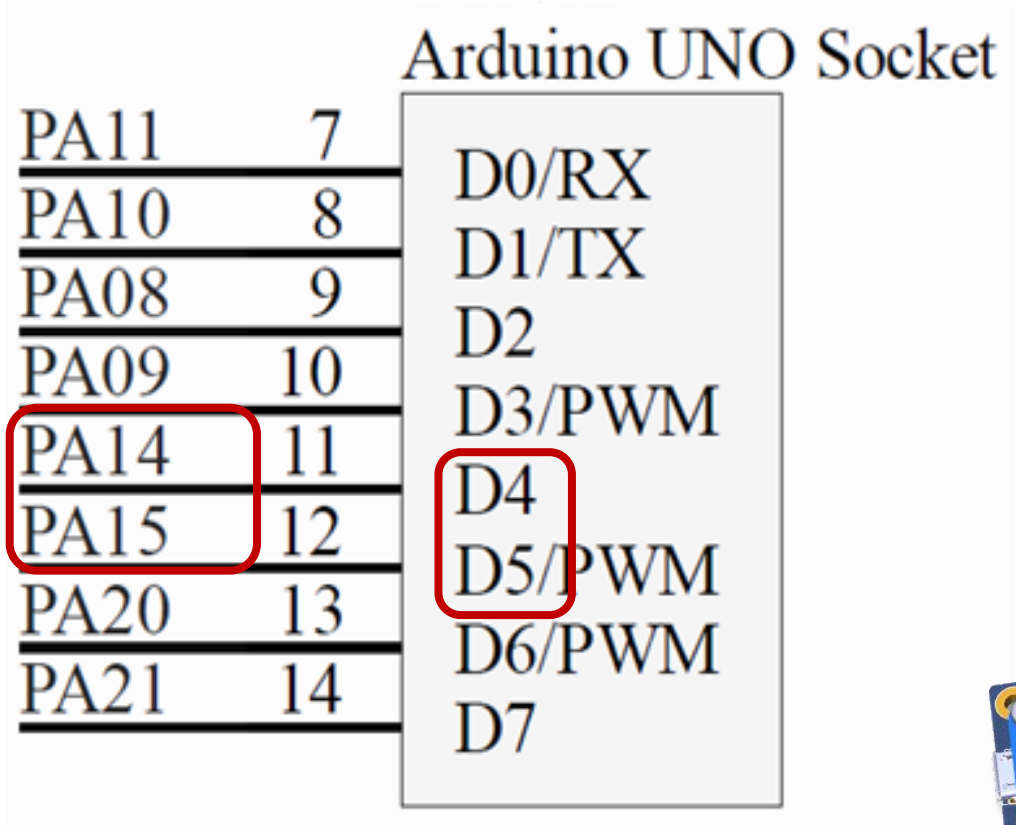
V_{DD} range	NVM Wait States	Maximum Operating Frequency	Units
1.62V to 2.7V	0	14	MHz
	1	28	
	2	42	
	3	48	
2.7V to 3.63V	0	24	
	1	48	

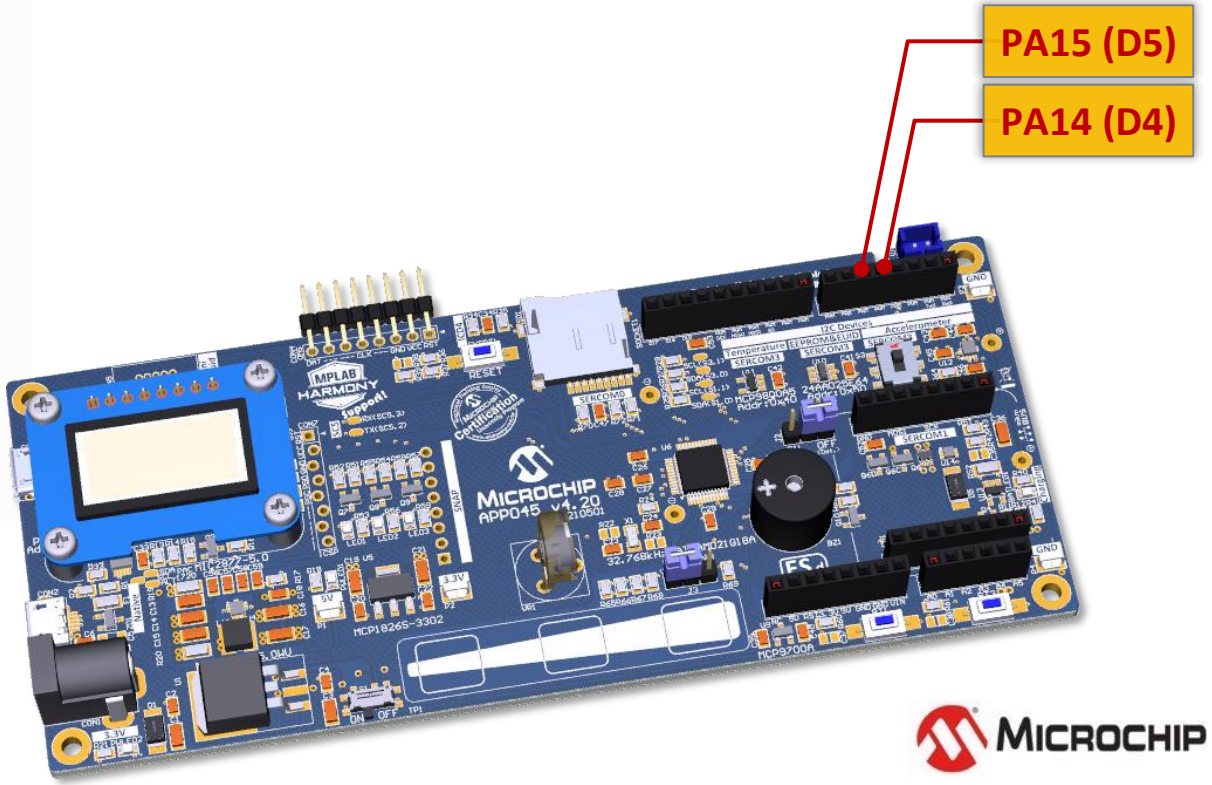
VDD = 3.3V

CPU_CLK = 48MHz

Lab8 System Clock DFL48M

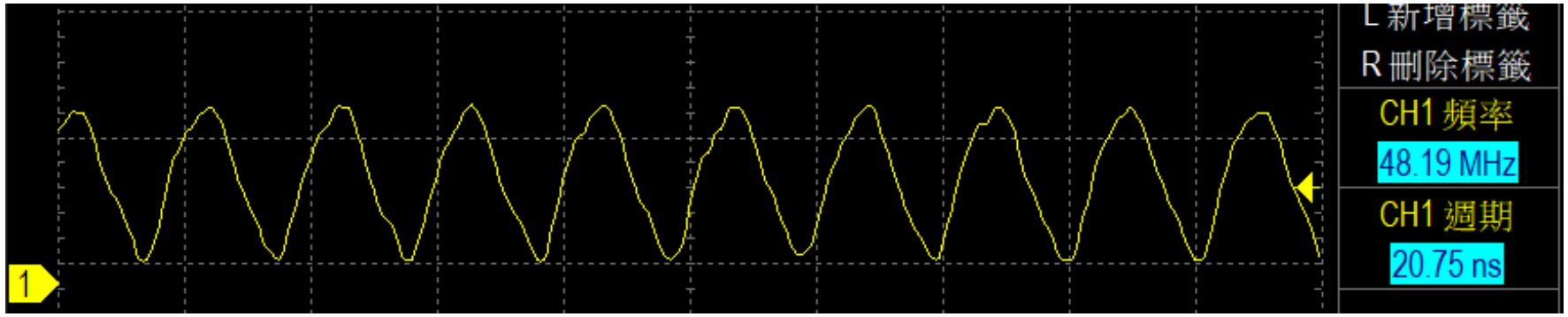
Clock Output

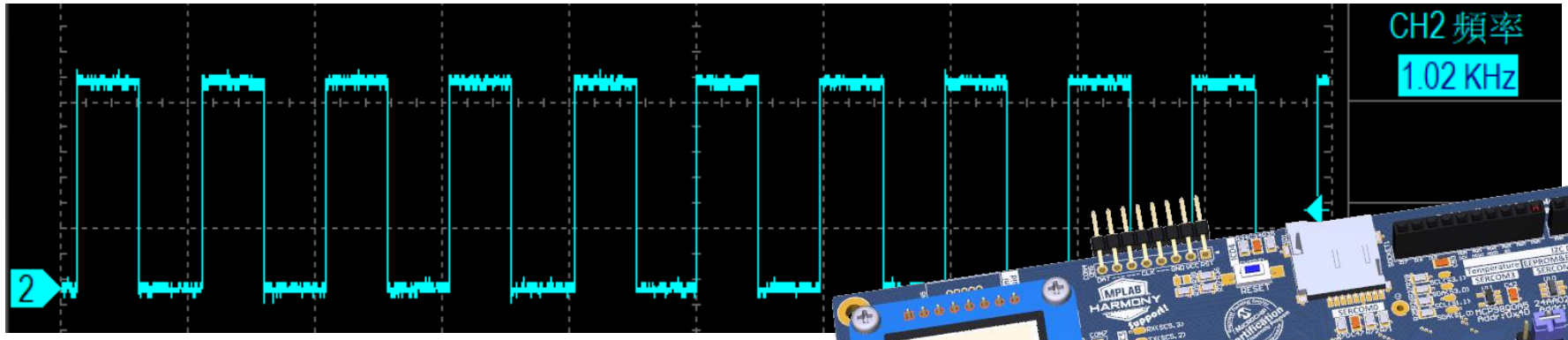


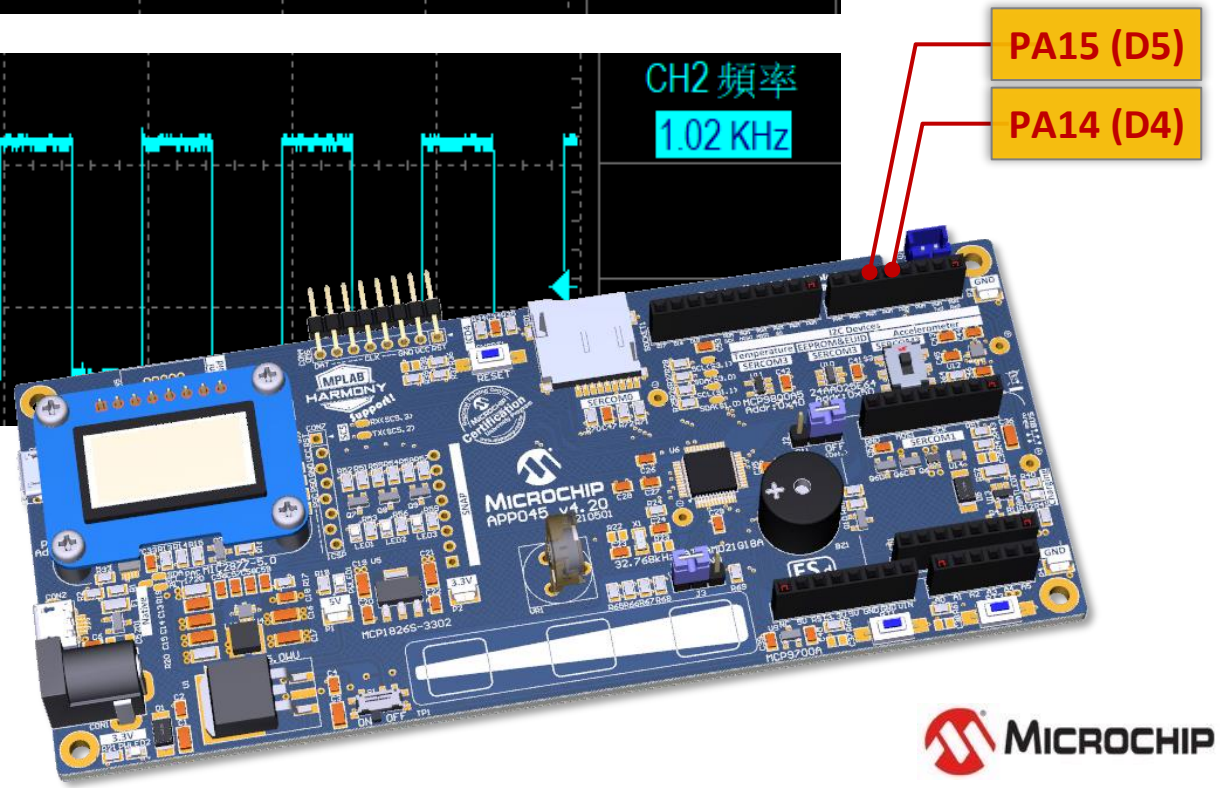


Lab8 System Clock DFLL48M

Clock Output



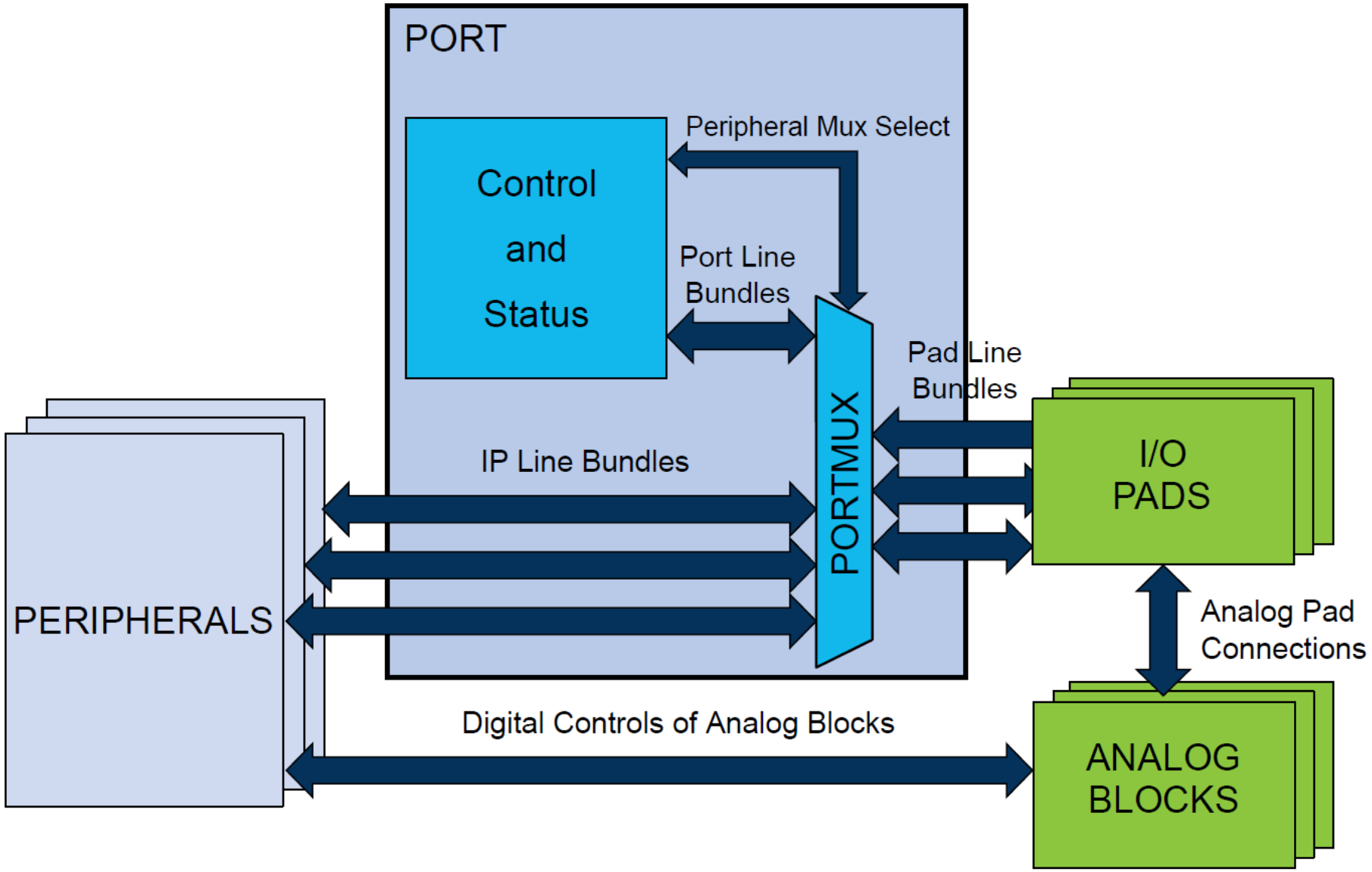




MICROCHIP

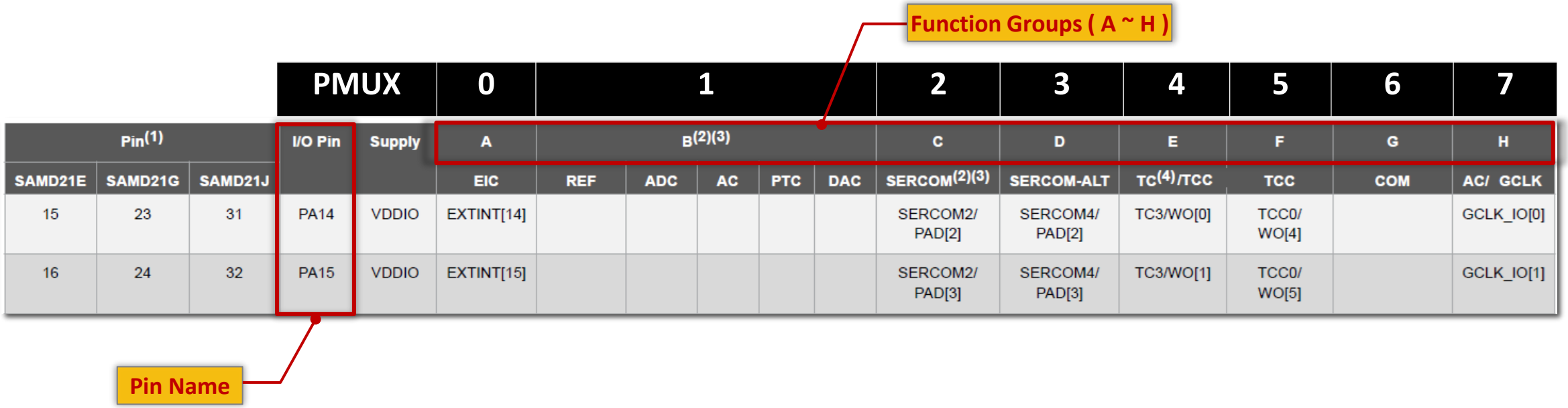
Pin Multiplexer (PINMUX)

What's PINMUX ?



What's PINMUX ?

- **Each pin is by default controlled by the PORT as a general purpose I/O and alternatively. It can be assigned to one of the peripheral functions group.**



Pin(1)			I/O Pin	Supply	PMUX 0	1					2	3	4	5	6	7
					A	B(2)(3)					C	D	E	F	G	H
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC	SERCOM(2)(3)	SERCOM-ALT	TC(4)/TCC	TCC	COM	AC/ GCLK
15	23	31	PA14	VDDIO	EXTINT[14]						SERCOM2/ PAD[2]	SERCOM4/ PAD[2]	TC3/WO[0]	TCC0/ WO[4]		GCLK_IO[0]
16	24	32	PA15	VDDIO	EXTINT[15]						SERCOM2/ PAD[3]	SERCOM4/ PAD[3]	TC3/WO[1]	TCC0/ WO[5]		GCLK_IO[1]

MICROCHIP

PINMUX PLIB Analysis

main() @ main.c

```
SYS_Initialize ( NULL );
```

SYS_Initialize() @ initialization.c

```
PORT_Initialize();
```

Offset	Name	7	6	5	4	3	2	1	0
0x30	PMUX0	PMUXO[3:0]				PMUXE[3:0]			
0x3F	PMUX15	PMUXO[3:0]				PMUXE[3:0]			
0x40	PINCFG0		DRVSTR				PULLEN	INEN	PMUXEN
0x5F	PINCFG31		DRVSTR				PULLEN	INEN	PMUXEN

PMUX

PMUXO (ODD)

PMUXE (EVEN)

PINCFG

INEN

PMUXEN

PORT_Initialize() @ plib_port.c

```
PORT_REGS->GROUP[0].PORT_DIR = 0x120200;
PORT_REGS->GROUP[0].PORT_OUT = 0x200;
PORT_REGS->GROUP[0].PORT_PINCFG[14] = 0x3;
PORT_REGS->GROUP[0].PORT_PINCFG[15] = 0x3;

PORT_REGS->GROUP[0].PORT_PMUX[7] = 0x77;
```

PA14 (GCLK_IO0) — INEN = 1 (Button)

PA15 (GCLK_IO1) — INEN = 1 (Button)

PMUX[7] : PA15 , PA14

MICROCHIP

PINMUX PLIB Analysis

	PMUX	0	1					2	3	4	5	6	7
Pin(1)			I/O Pin	Supply	A	B(2)(3)					C	D	E	F	G	H
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC	SERCOM(2)(3)	SERCOM-ALT	TC(4)/TCC	TCC	COM	AC/ GCLK
15	PA14 (7)		PA14	VDDIO	EXTINT[14]						SERCOM2/ PAD[2]	SERCOM4/ PAD[2]	TC3/WO[0]	TCC WO[4]	GCLK_IO[0]	GCLK_IO[0]
16	PA15 (7)		PA15	VDDIO	EXTINT[15]						SERCOM2/ PAD[3]	SERCOM4/ PAD[3]	TC3/WO[1]	TCC WO[5]	GCLK_IO[1]	GCLK_IO[1]

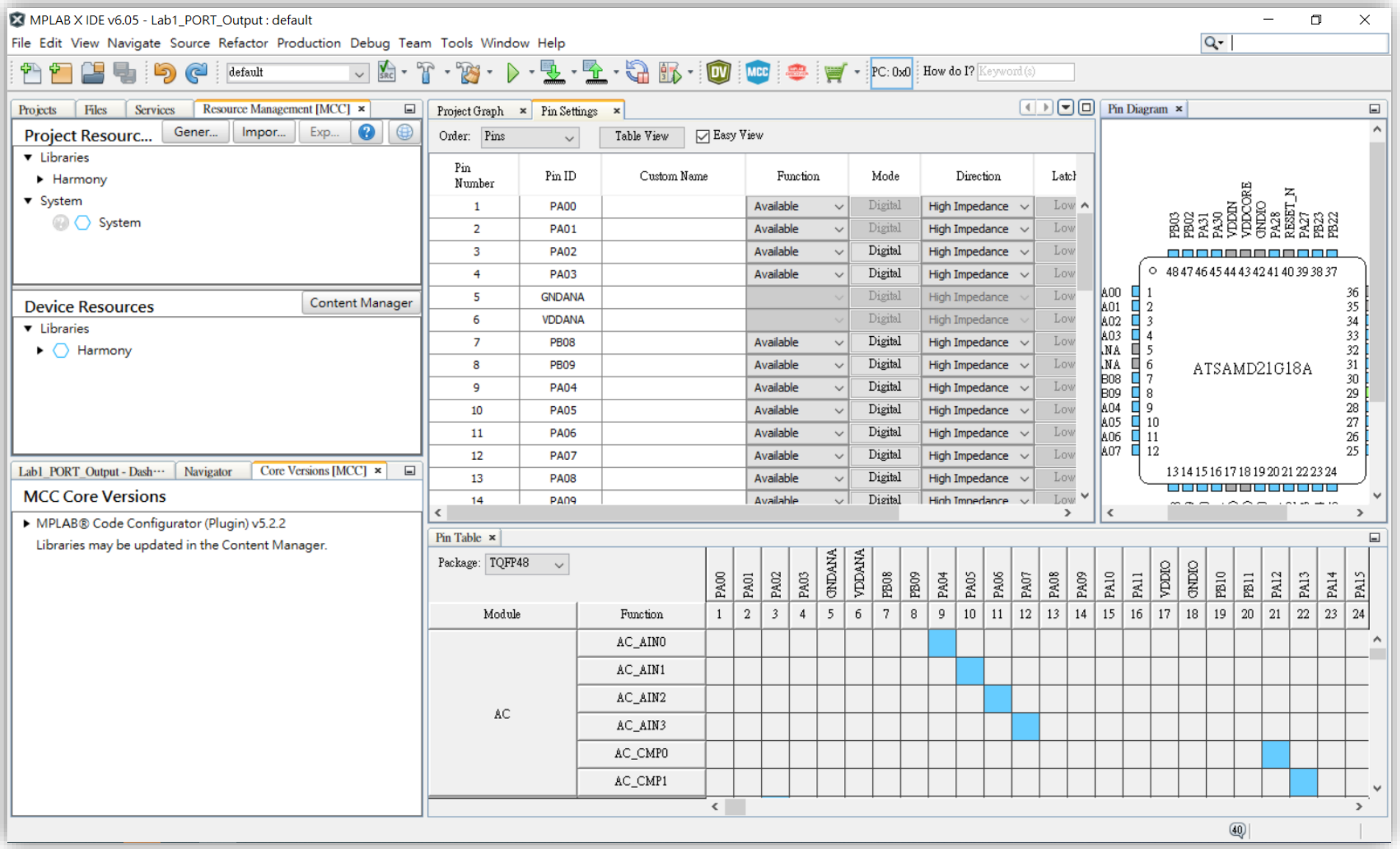
PORT_Initialize() @ plib_port.c

```
PORT_REGS->GROUP[0].PORT_DIR = 0x120200;
PORT_REGS->GROUP[0].PORT_OUT = 0x200;
PORT_REGS->GROUP[0].PORT_PINCFG[14] = 0x3;
PORT_REGS->GROUP[0].PORT_PINCFG[15] = 0x3;

PORT_REGS->GROUP[0].PORT_PMUX[7] = 0x77;
```

PMUX[7] : PA15 , PA14

MICROCHIP

PINMUX Configuration Example

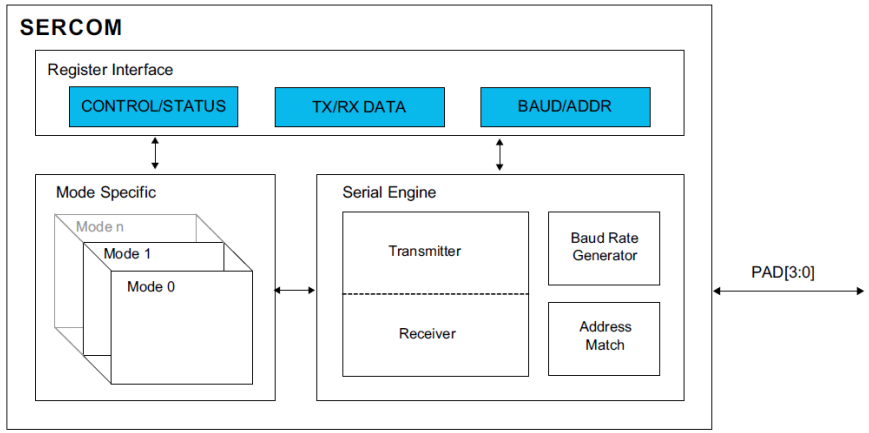


MICROCHIP

SERCOM – UART Architecture

SERCOM Introduction

- Serial Communication Interface, SERCOM be configured to support a number of modes :
  - I2C
  - SPI
  - USART : RS232, RS485, IrDA
- There are up to six instances of the serial communication interface SERCOM peripheral.

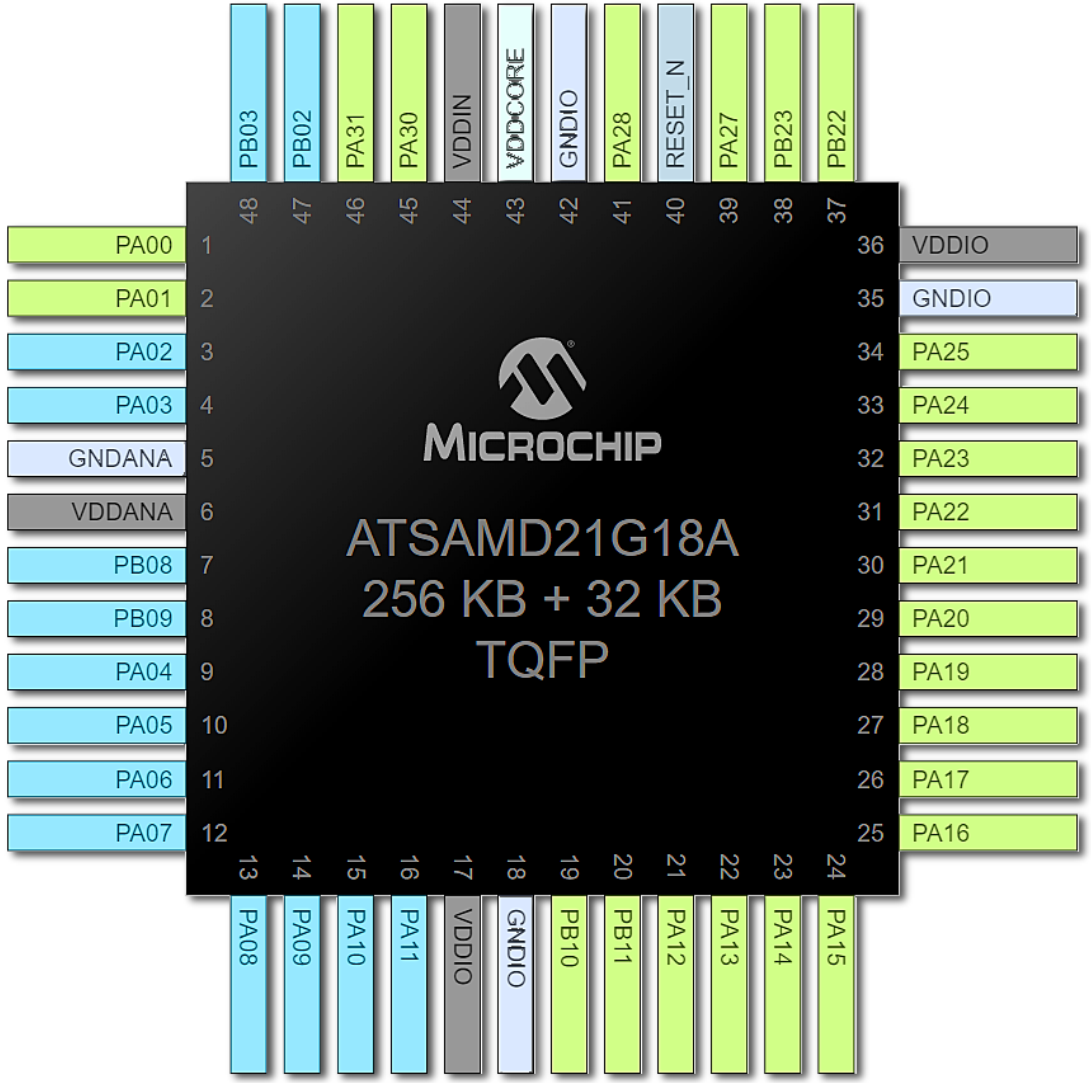


- The SERCOM serial engine consists of a transmitter and receiver, baud-rate generator and address matching functionality. It can use the internal generic clock or an external clock to operate in all sleep.

SERCOM Introduction

- **Pin Multiplex**

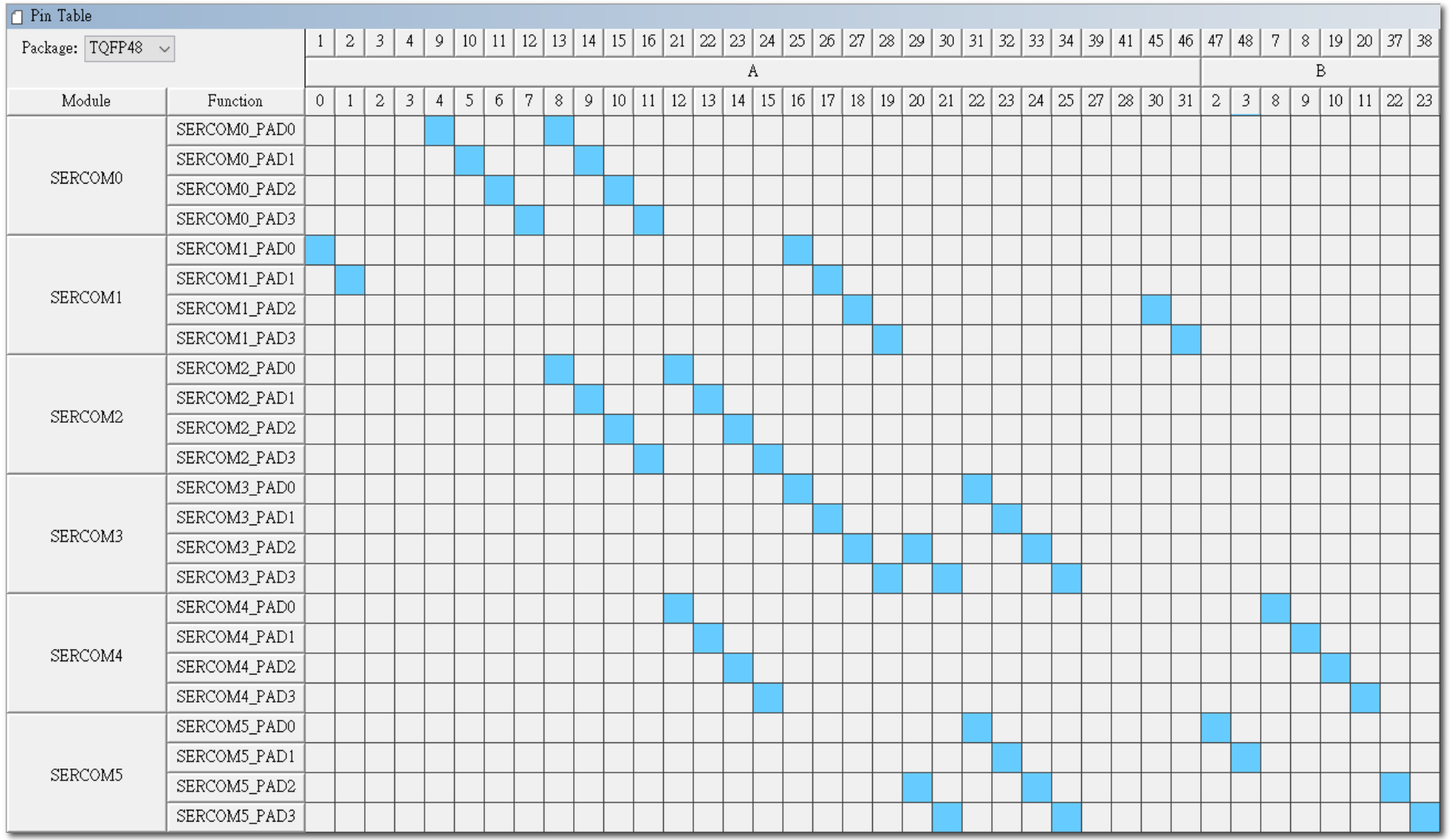
	PAD[0]	PAD[1]	PAD[2]	PAD[3]	PMUX
SERCOM0	PA04	PA05	PA06	PA07	D
	PA08	PA09	PA10	PA11	C
SERCOM1	PA00	PA01	PA30	PA31	D
	PA16	PA17	PA18	PA19	C
SERCOM2	PA08	PA09	PA10	PA11	D
	PA12	PA13	PA14	PA15	C
SERCOM3	PA16	PA17	PA18	PA19	D
			PA20	PA21	D
	PA22	PA23	PA24	PA25	C
SERCOM4	PA12	PA13	PA14	PA15	D
	PB08	PB09	PB10	PB11	D
SERCOM5			PA20	PA21	C
	PA22	PA23	PA24	PA25	D
	PB02	PB03	PB22	PB23	D



MICROCHIP

SERCOM Introduction

- **Pin Multiplex in Harmony (Clear)**

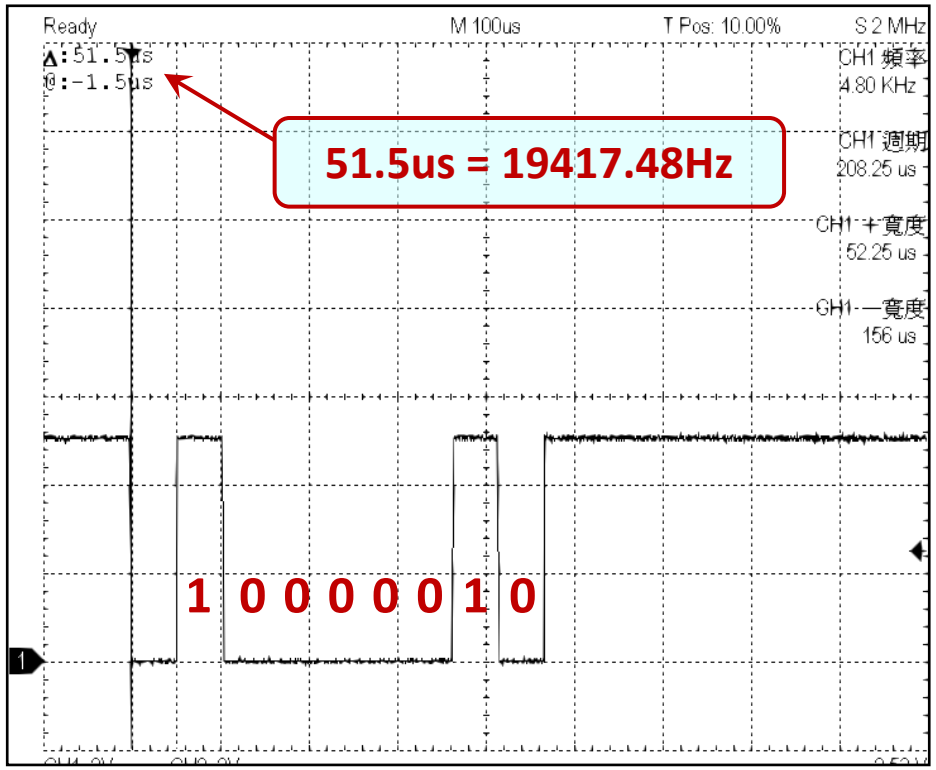


SERCOM Introduction

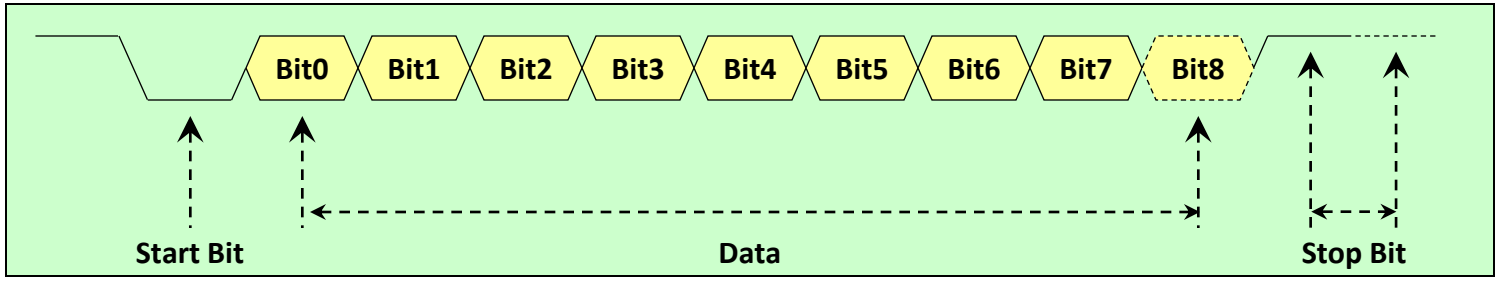
- **For I2C**
  - Fast Mode (400kHz)
  - Master or slave operation
  - SMBUS compatible
  - Wake on address match
- **For SPI**
  - Up to 24Mb/s
  - Supports all four SPI modes
  - Full-duplex operation
  - Single data direction mode frees unused MISO or MOSI pin
- **For USART**
  - Up to 24Mb/s
  - Half-/Full-duplex operation
  - Sync and Async operation

What's UART ?

- UART : Universal Asynchronous Receiver Transmitter.
- The module data exchange through serial communication.
- The data formatting include
  1 start bit,
  5 to 9 data bits and
  1 or 2 stop bits.



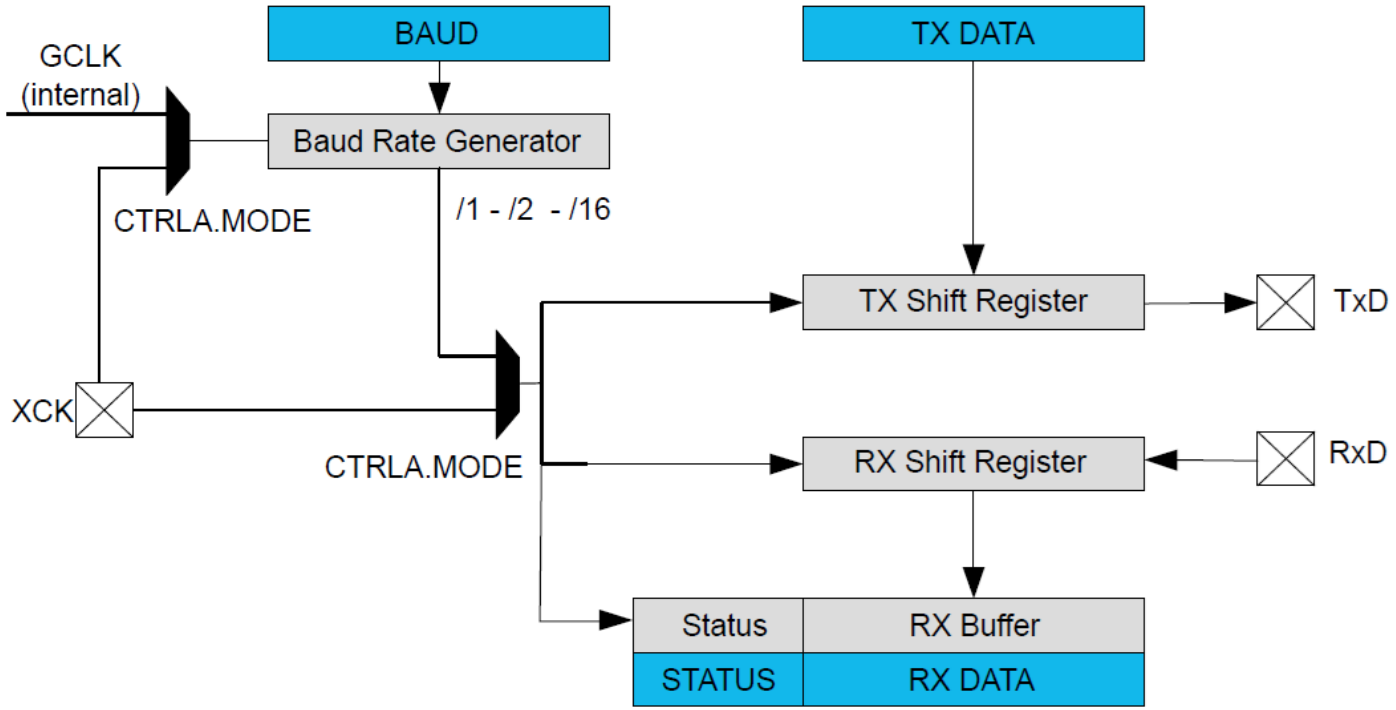
UART Transmit Example :
'A'(0x41), 19200 bps



MICROCHIP

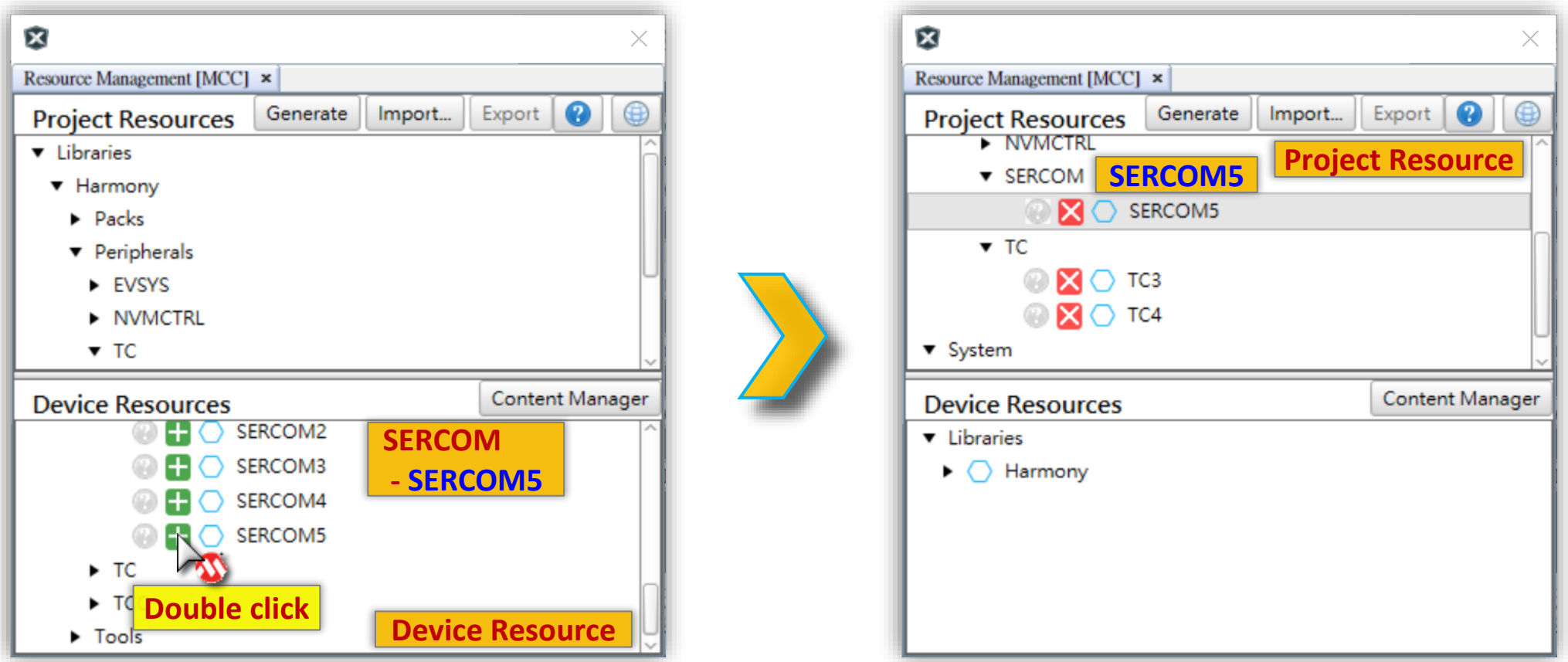
SERCOM - USART

- Supports serial frames with 5, 6, 7, 8 or 9 data bits and 1 or 2 stop bits, Parity Check, RTS and CTS flow control.
- Full-duplex operation, RS-232, RS-485 and IrDA Supported.
- Buffer overflow and frame error detection.
- Internal or external clock source for asynchronous and synchronous operation.



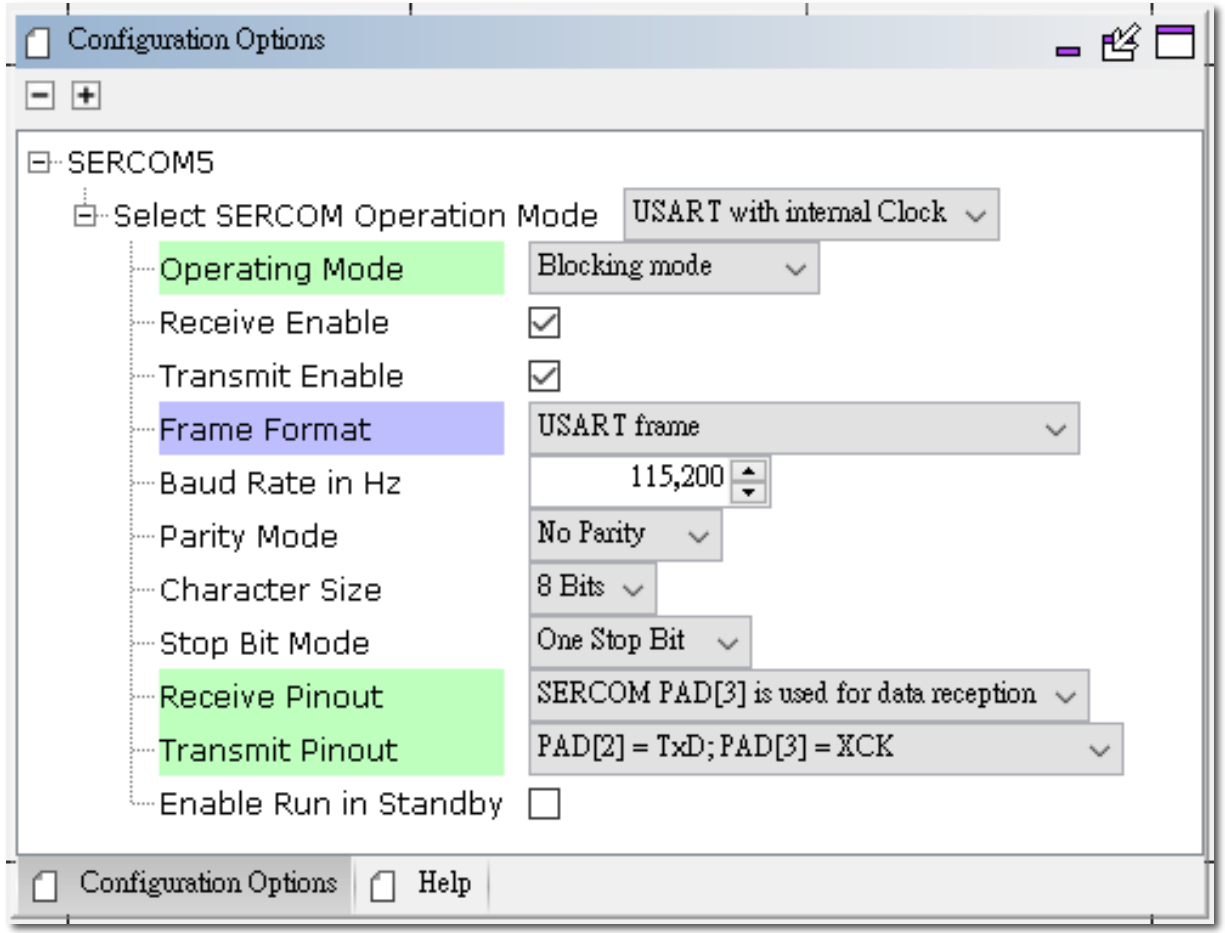
Add SERCOM Function using MCC Harmony

- Find SERCOM5 component in Device Resource window.
- Double click SERCOM5 to add to Project Resource window.

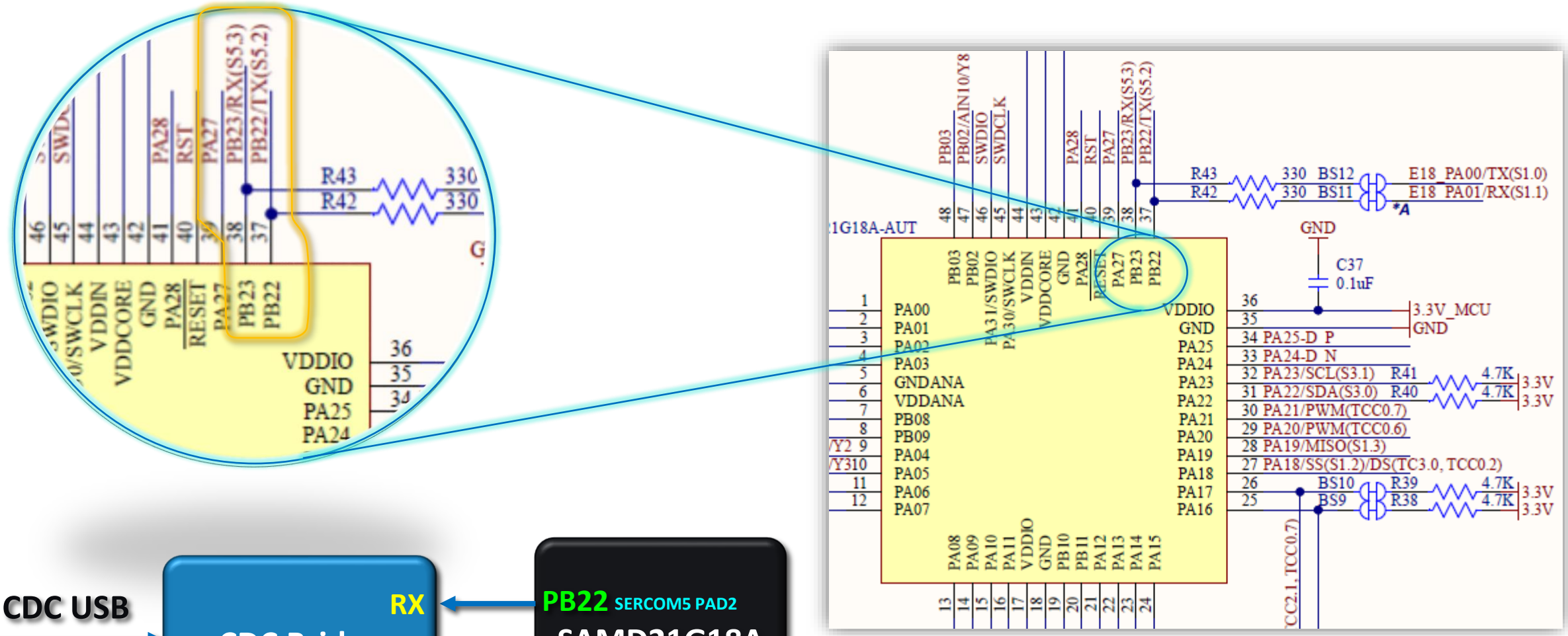


SERCOM USART Polling

Configuration Options Example



APP045 SERCOM USART Schematic



SERCOM USART

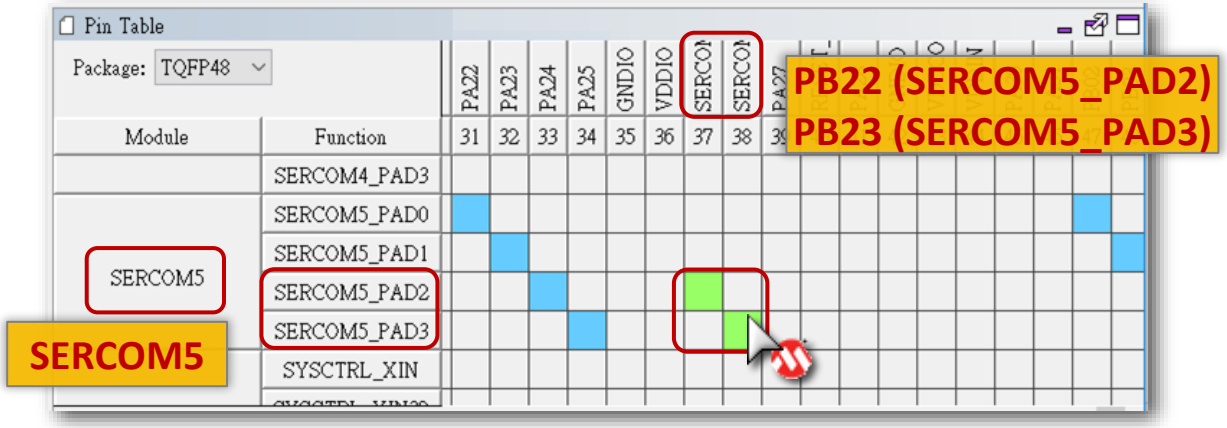
PINMUX Configuration Example

- SERCOM allow limited alternate pad index assignment.
- For example : PB22 as SERCOM5_PAD2
  PB23 as SERCOM5_PAD3

Pin(1)			I/O Pin	Supply	A	B(2)(3)					C	D	E	F	G	H
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC	SERCOM(2)(3)	SERCOM-ALT	TC(4)/TCC	TCC	COM	AC/ GCLK
	37	49	PB22	VDDIO	EXTINT[6]							SERCOM5/ PAD[2]				GCLK_IO[0]
	38		PB23	VDDIO	EXTINT[7]							SERCOM5/ PAD[3]		WO[1]		GCLK_IO[1]

PB22
PB23

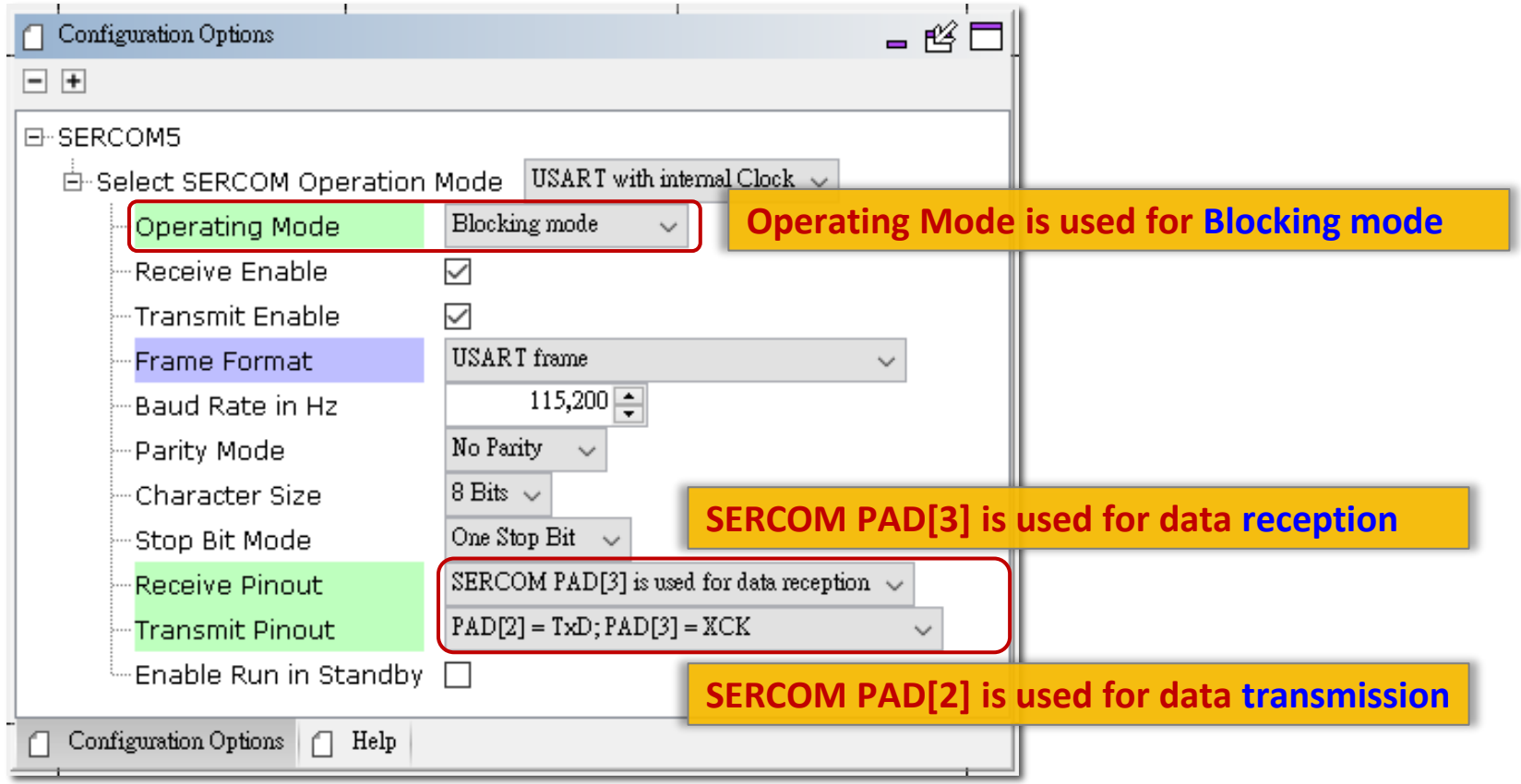
SERCOM5/PAD[2]
SERCOM5/PAD[3]



SERCOM USART

PINMUX Configuration Example

- **Remember arrange pads function in SERCOM module.**
- **For example : SERCOM5 PAD[2] as USART TXD (PB22)**
  SERCOM5 PAD[3] as USART RXD (PB23)



MICROCHIP

SERCOM USART Polling

Interface Routines

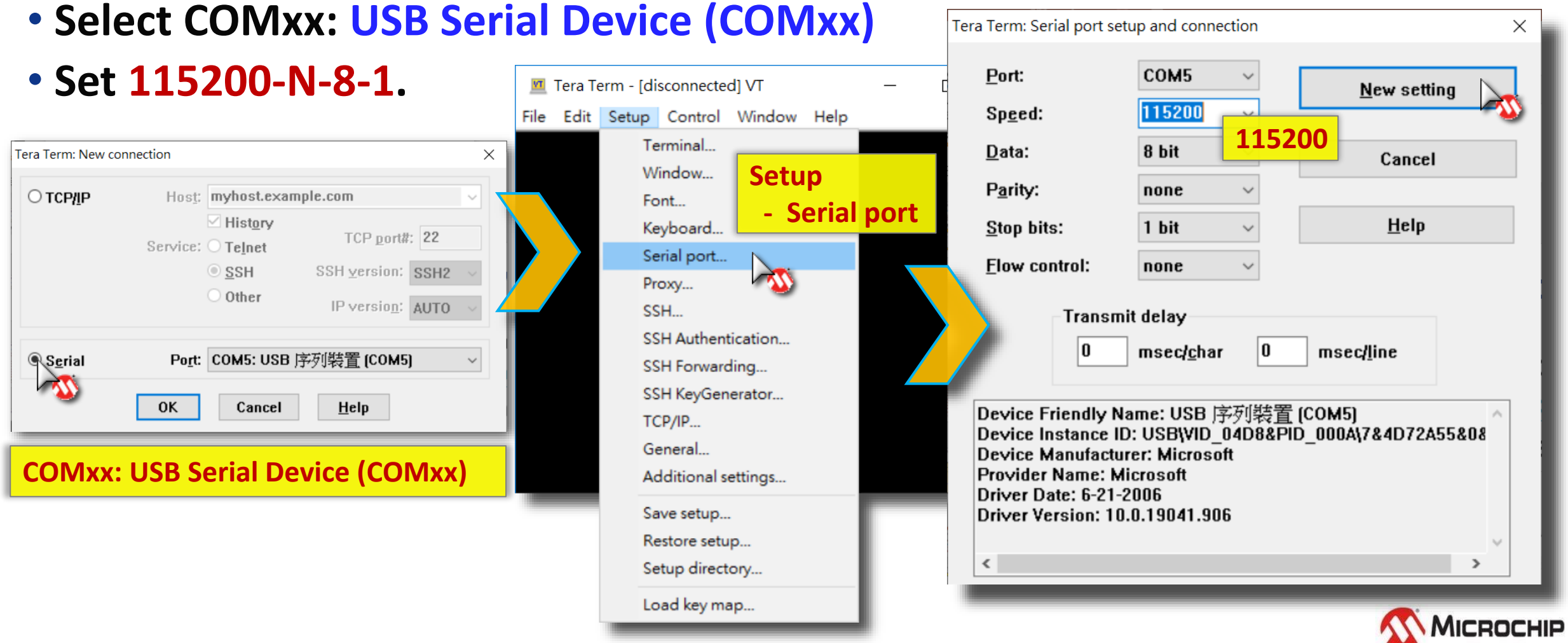
```
void SERCOM5_USART_Initialize( void );
bool SERCOM5_USART_SerialSetup( USART_SERIAL_SETUP * serialSetup,
                                uint32_t clkFrequency );
bool SERCOM5_USART_Write( void *buffer, const size_t size );
bool SERCOM5_USART_TransmitterIsReady( void );
bool SERCOM5_USART_TransmitComplete( void );
void SERCOM5_USART_WriteByte( int data );
bool SERCOM5_USART_Read( void *buffer, const size_t size );
bool SERCOM5_USART_ReceiverIsReady( void );
int SERCOM5_USART_ReadByte( void );
USART_ERROR SERCOM5_USART_ErrorGet( void );
uint32_t SERCOM5_USART_FrequencyGet( void );
```

SERCOM USART Tx Polling Code Example

```
…

int main (void)
{
    SYS_Initialize ( NULL );
    …

    while( true )
    {
        …
        SERCOM5_USART_Write( "Hello world!\r\n", 14 );
    }
}
```

Terminal Console Software

- Tera Term is a terminal console software. (https://ttssh2.osdn.jp/index.html.en)
- Select COMxx: USB Serial Device (COMxx)
- Set 115200-N-8-1.



Lab9 SERCOM - UART Tx Polling

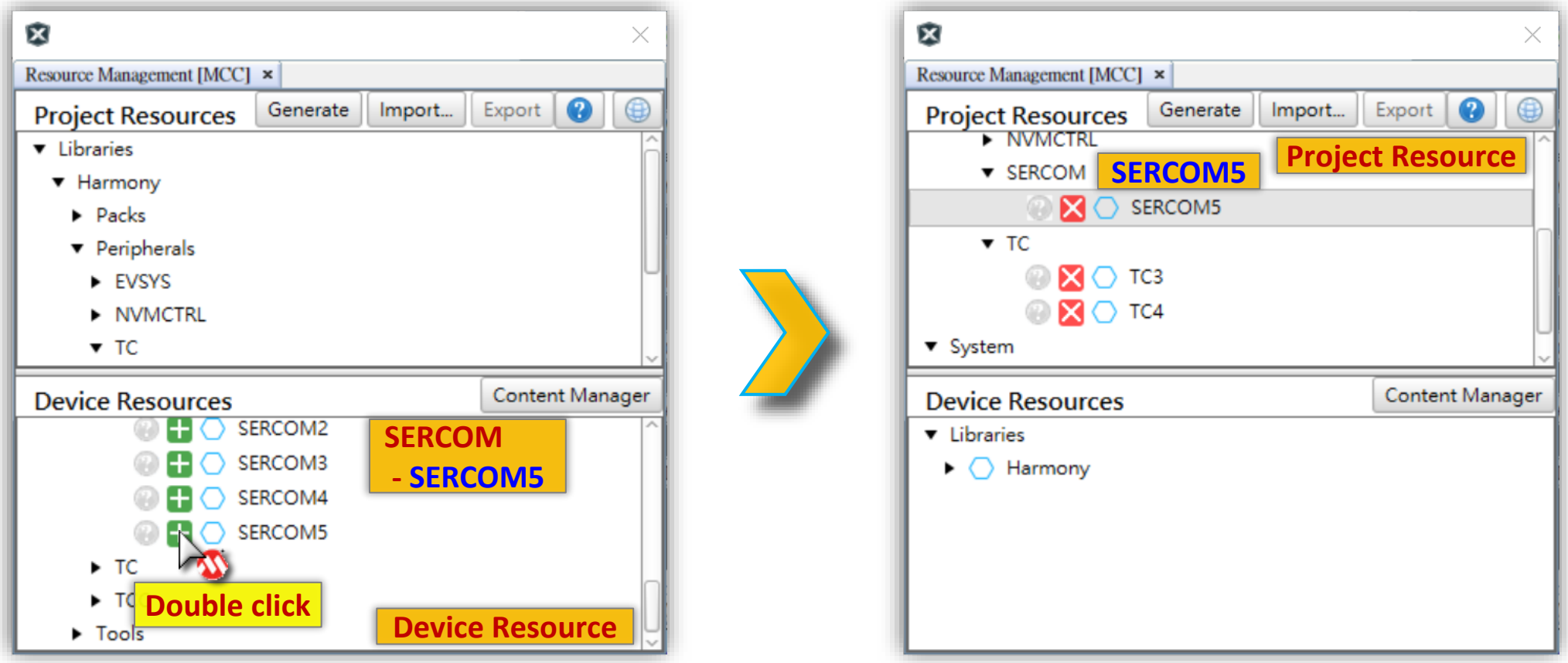
- Try to add SERCOM-USART function to project.
- UART set to 115200-N-8-1, No flow control.
- Send string from UART to PC of one second interval repeated. (Hello World!)
- Character \r for carriage Return (0x0D)
- Character \n for New line (0x0A)

- Let's go!

Lab9 SERCOM - UART Tx Polling

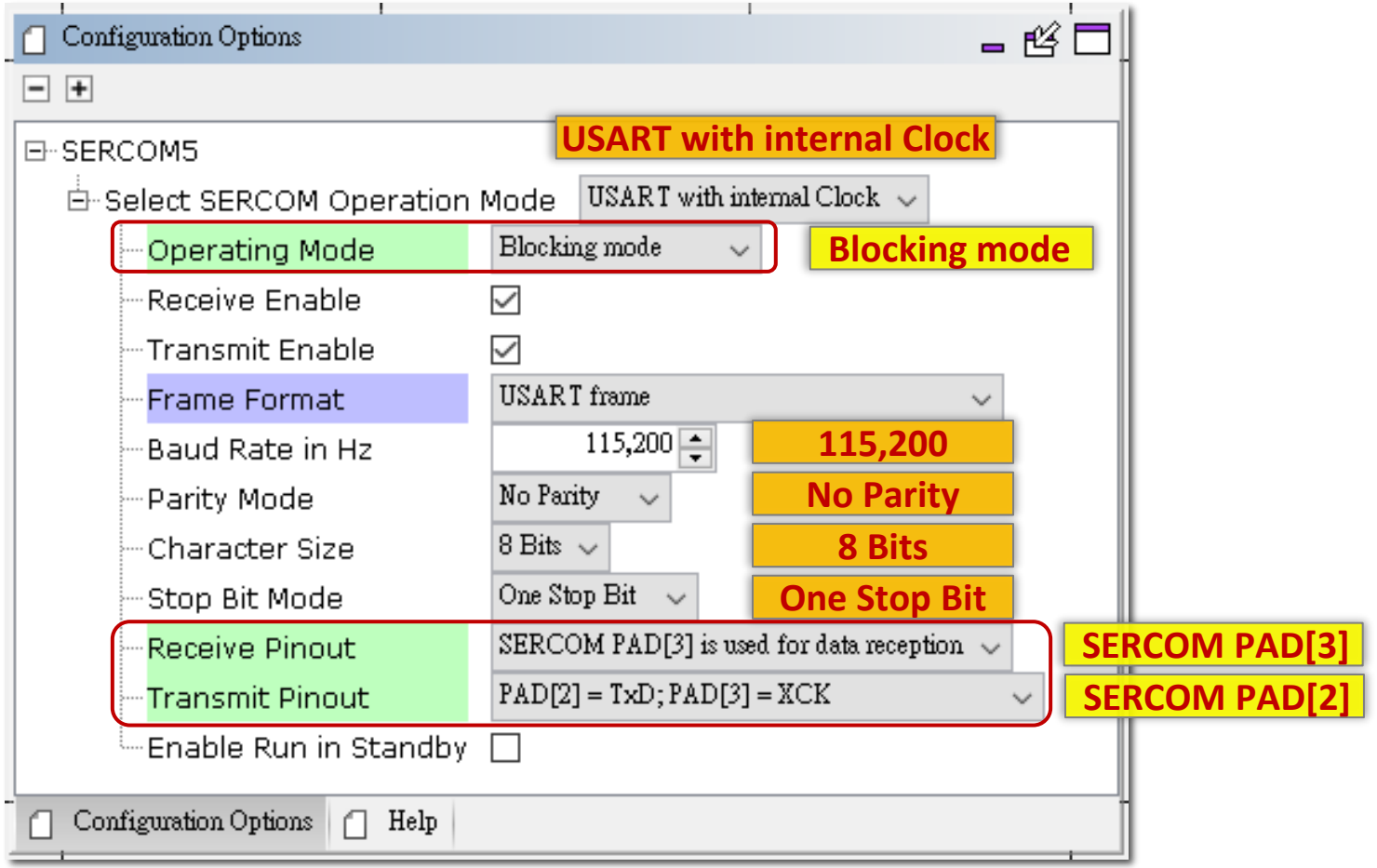
Step 1

- Find SERCOM5 component in Device Resource window.
- Double click SERCOM5 to add to Project Resource window.



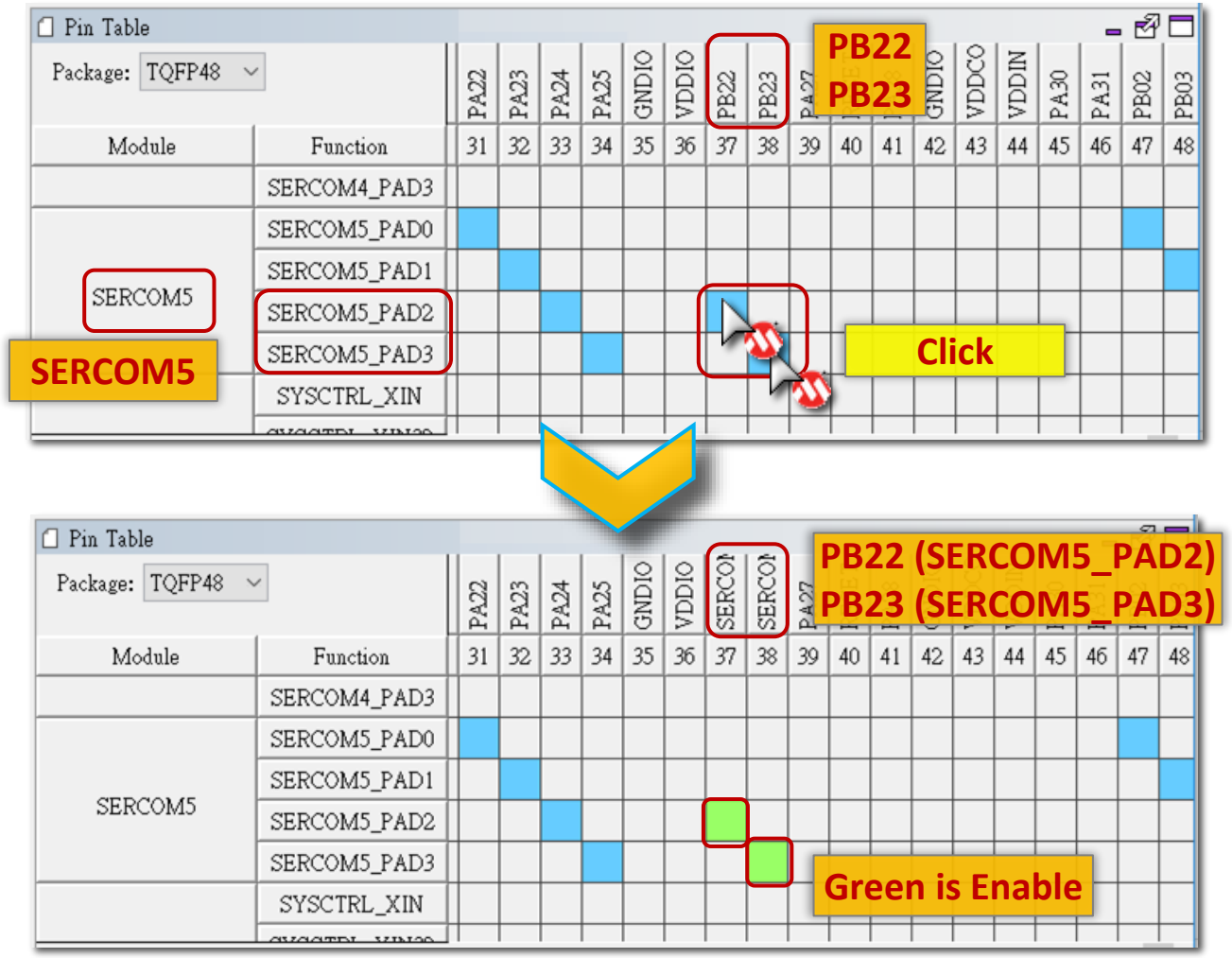
Lab9 SERCOM - UART Tx Polling

Step 2



Lab9 SERCOM - UART Tx Polling

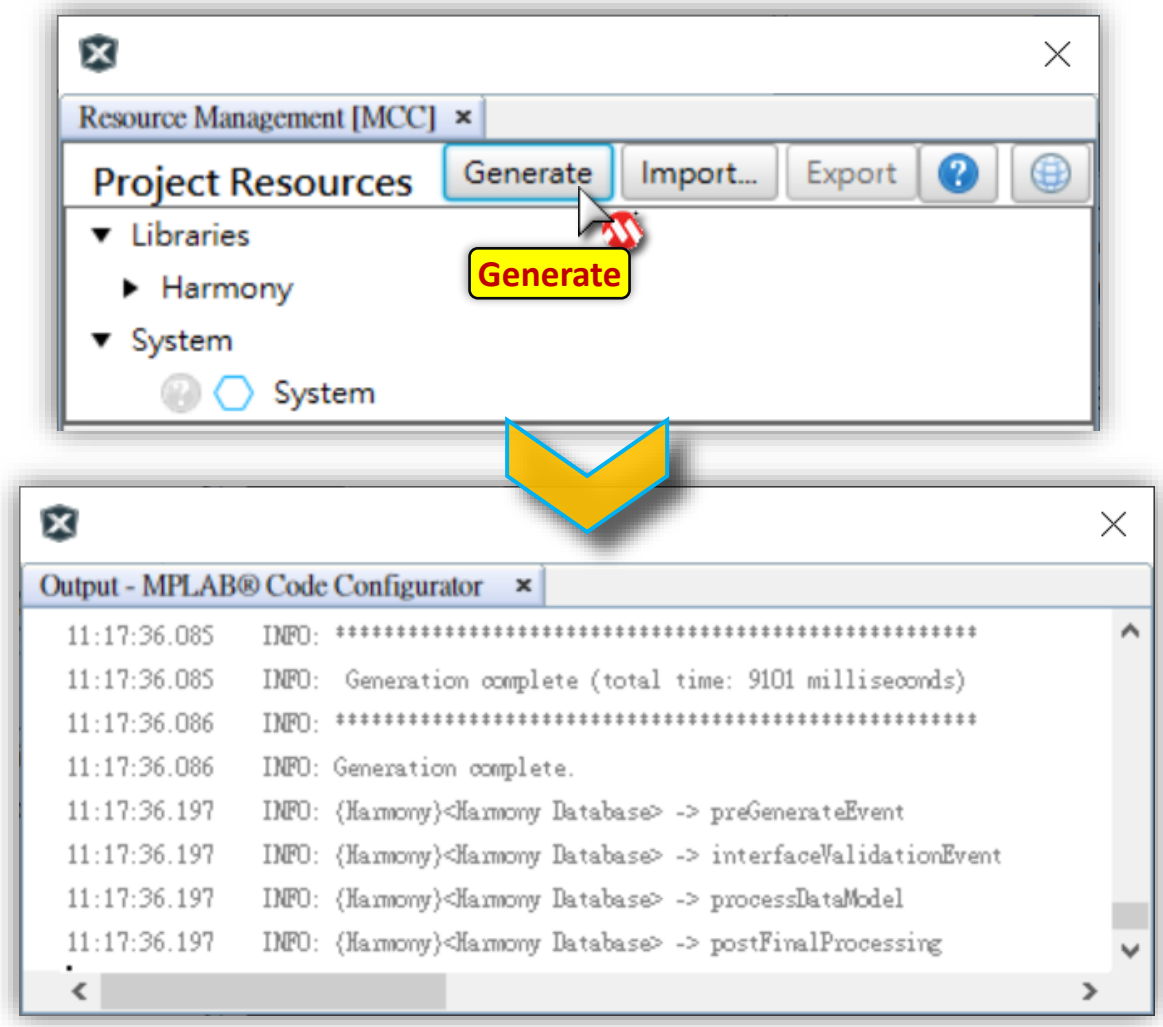
Step 3



Lab9 SERCOM - UART Tx Polling

Step 4

- Click "Generate" Button to Generate your Code.



Lab9 SERCOM - UART Tx Polling

Step 5

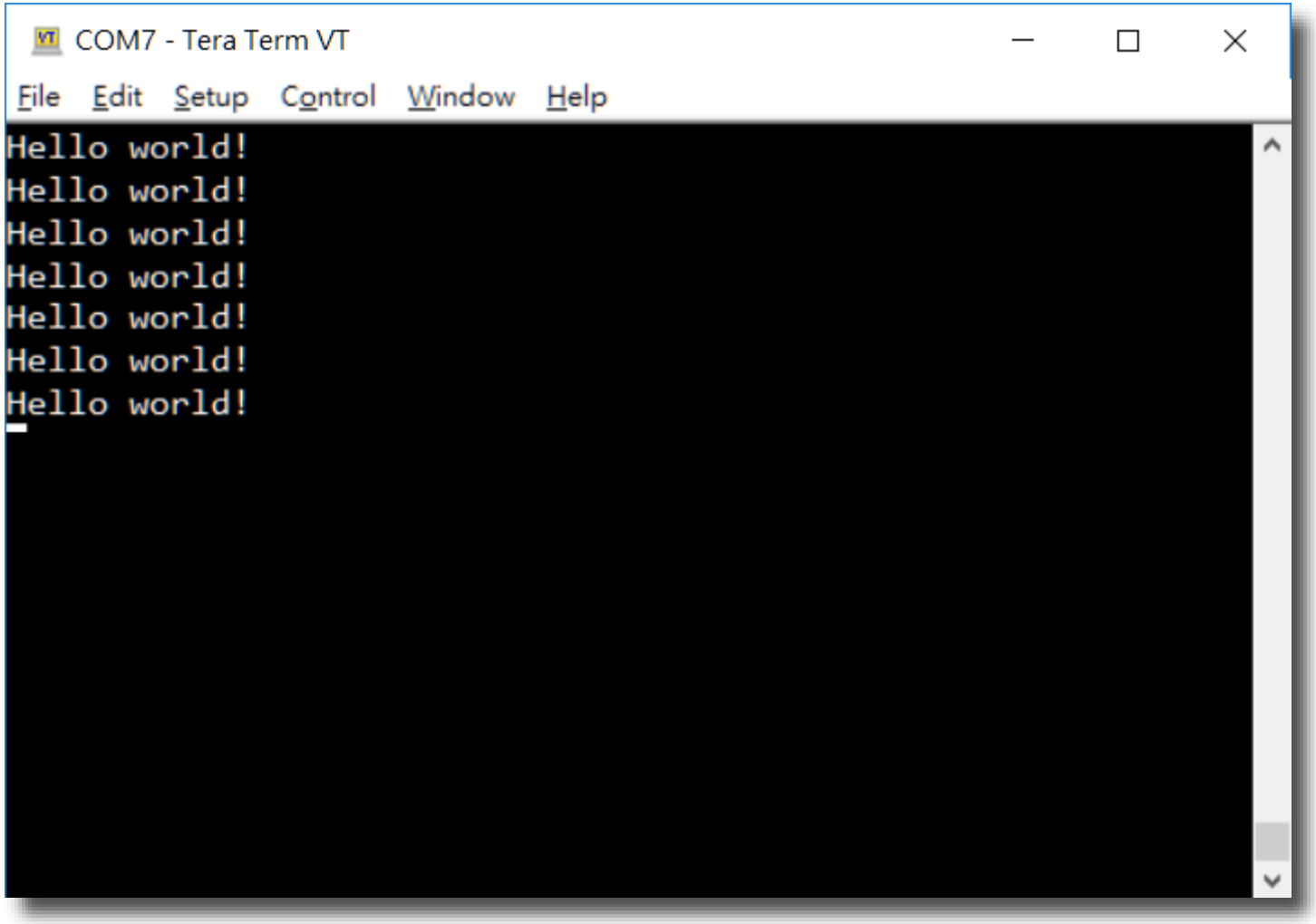
a **Add code segment to your main loop**

```
void TC3_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
      if( status & TC_INTFLAG_Msk )
      {
         LED1_Toggle();

         // TODO 9.01
          SERCOM5_USART_Write( "Hello world!\r\n", 14 );
     }
}

int main (void)
{
   SYS_Initialize ( NULL );

   …

}
```

b **Program firmware to target board then observe result.**

Lab9 SERCOM - UART Tx Polling

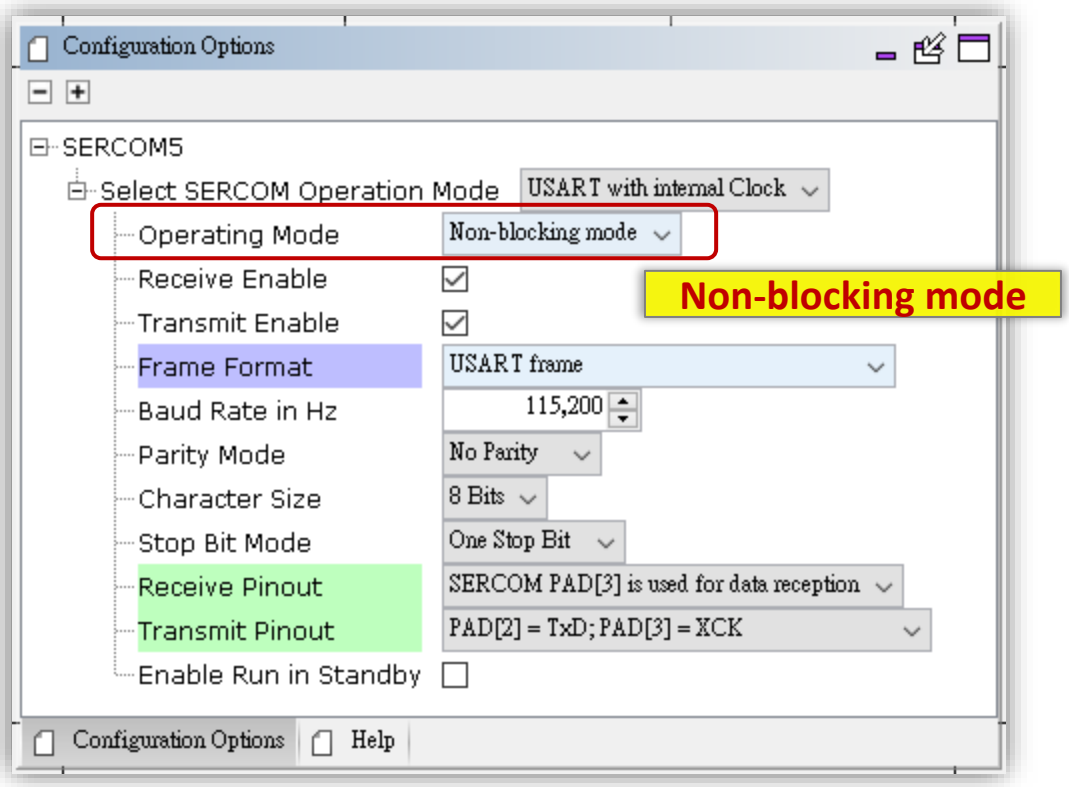
Result

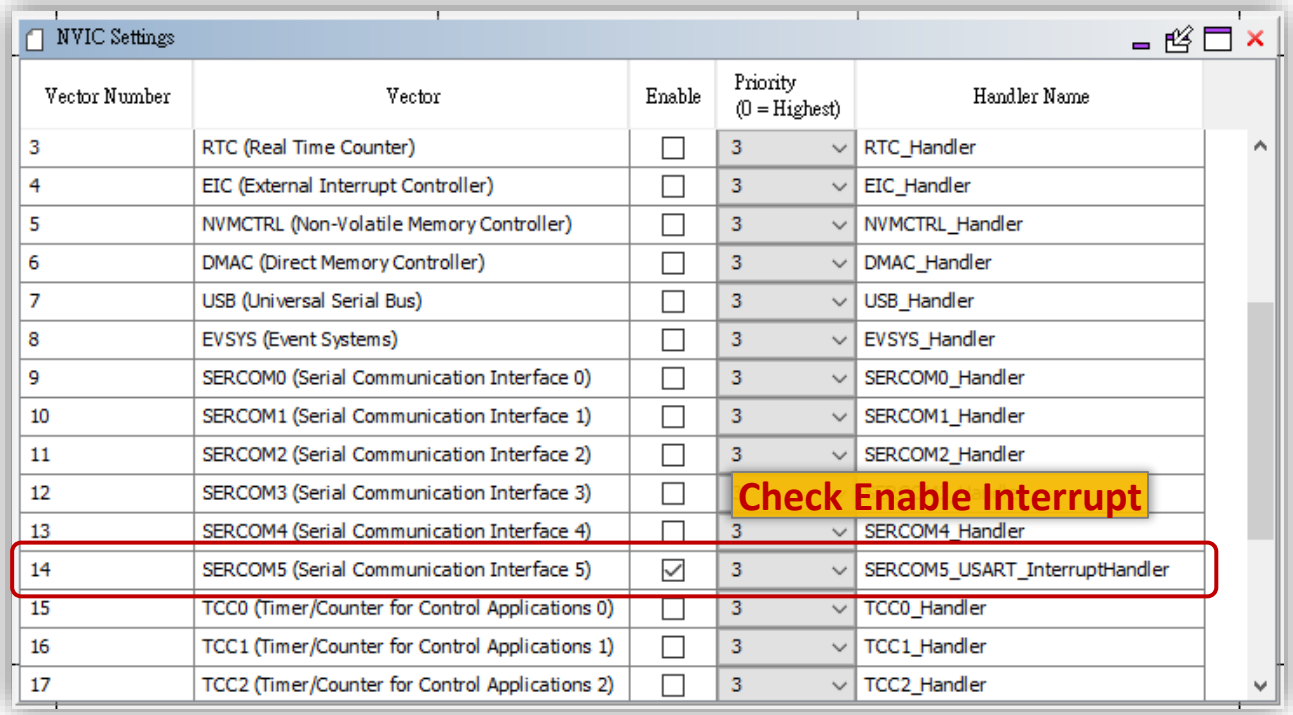


SERCOM USART Interrupt

Configuration Options Example

- **SERCOM provide callback(interrupt) mode, also.**





SERCOM USART Interrupt Callback

Interface Routines

```
void SERCOM5_USART_Initialize( void );
bool SERCOM5_USART_SerialSetup( USART_SERIAL_SETUP * serialSetup, uint32_t clkFrequency );
bool SERCOM5_USART_Write( void *buffer, const size_t size );
bool SERCOM5_USART_WriteIsBusy( void );
size_t SERCOM5_USART_WriteCountGet( void );
void SERCOM5_USART_WriteCallbackRegister( SERCOM_USART_CALLBACK callback, uintptr_t context );
bool SERCOM5_USART_Read( void *buffer, const size_t size );
bool SERCOM5_USART_ReadIsBusy( void );
size_t SERCOM5_USART_ReadCountGet( void );
void SERCOM5_USART_ReadCallbackRegister( SERCOM_USART_CALLBACK callback, uintptr_t context );
USART_ERROR SERCOM5_USART_ErrorGet( void );
uint32_t SERCOM5_USART_FrequencyGet( void );
```

USART TxRx Interrupt Code Example

```
uint8_t USART5_ReceiveData[1];
void USART5_Receive( uintptr_t context )
{
   SERCOM5_USART_Write( USART5_ReceiveData, 1 );
   SERCOM5_USART_Read( USART5_ReceiveData, 1 );
}

void USART5_ Transmit( uintptr_t context ) { }

int main (void)
{
   SYS_Initialize ( NULL );
   …
   SERCOM5_USART_ReadCallbackRegister( USART5_Receive, (uintptr_t )NULL );
   SERCOM5_USART_WriteCallbackRegister( USART5_Transmit, (uintptr_t )NULL );
   SERCOM5_USART_Read( USART5_ReceiveData, 1 );
   while( true )
   { …
     SERCOM5_USART_Write( "Hello world!\r\n", 14 );
   }
}
```

One-Shot Event

Callback Register

About String Functions

- UART generally to used for text string communication,
  We can use C provided string functions to convert multi valuables to an output string.
  Here to introduce two string functions sprintf( ) and strlen( ).
- int sprintf(char *s, const char *format, ...);
  Formatting values to target char type string buffer.
  * Must include <stdio.h>
- size_t strlen(const char *s);
  Calculate string length, not include the end of string 0x00('\0').
  * Must include <string.h>
- For example

```
uint8_t USARTRTxBuffer[100];
uint16_t USART5_ReceiveData;
sprintf((char *) USARTRTxBuffer, "Received Data : %1c\r\n", USART5_ReceiveData);
SERCOM5_USART_Write( USARTRTxBuffer, strlen((char *)USARTRTxBuffer));
```

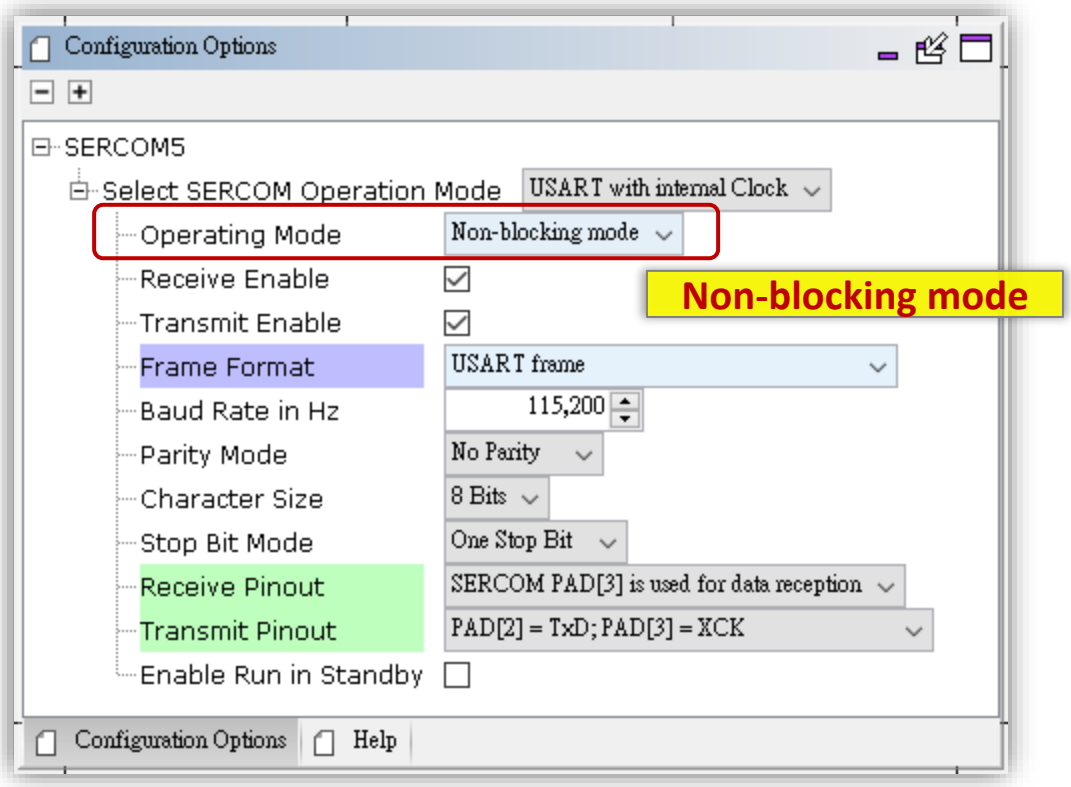
Lab10 SERCOM - UART TxRx Interrupt Callback

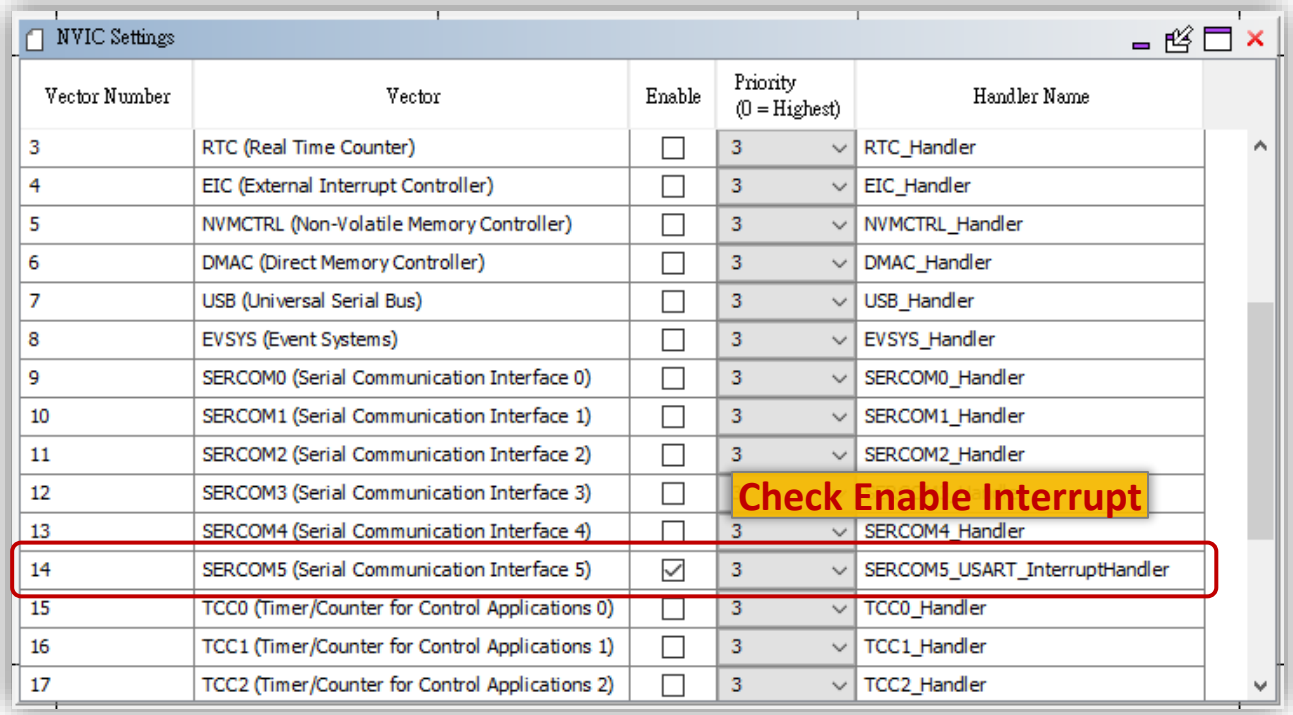
- Try to enable SERCOM-USART Interrupt Callback driver.
- Modify polling transmit function to asynchronous function.
- Add new USART receive function base on interrupt callback function.
- Try to receive character from PC and loopback to TeraTerm as string format "Received Data : x" .
- SERCOM - UART setting same as Lab9

- Let’s go!

Lab10 SERCOM - UART TxRx Interrupt Callback

Step 1

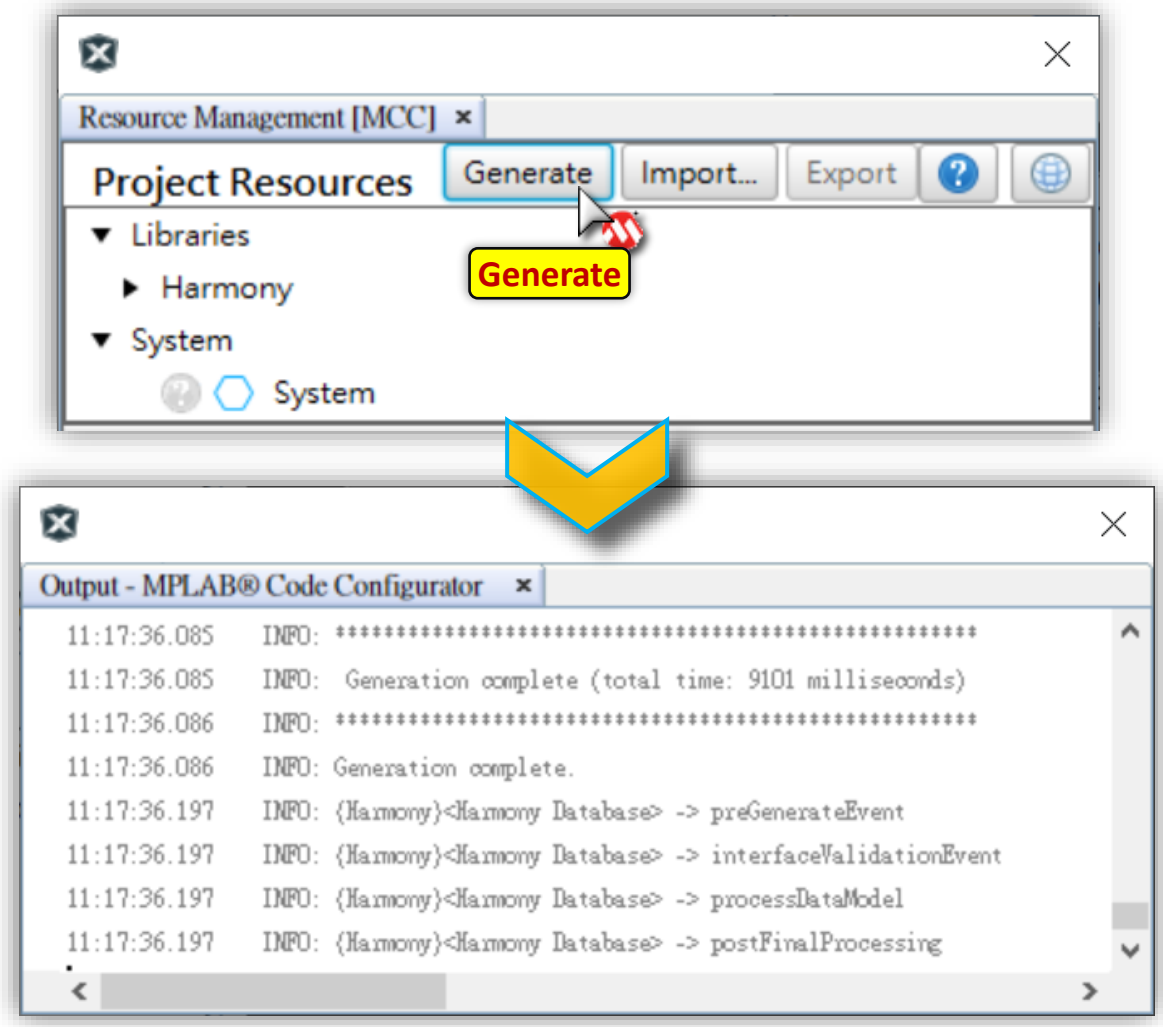




Lab10 SERCOM - UART TxRx Interrupt Callback

Step 2

- Click "Generate" Button to Generate your Code.



Lab10 SERCOM - UART TxRx Interrupt Callback

Step 3

a. Create UART TxRx Callback function, related buffer and

```
// TODO 10.01
#include <stdio.h>
#include <string.h>

// TODO 10.02
uint8_t USARTRTxBuffer[100];
uint8_t USART5_ReceiveData[1];
volatile uint8_t USART5_IsReceived = 0;
volatile uint8_t USART5_IsTransmitted = 1;

void USART5_Transmit( uintptr_t context )
{
  USART5_IsTransmitted = 1;
}

void USART5_Receive( uintptr_t context )
{
  USART5_IsReceived = 1;
}

int main (void)
{  ...  }
```

Lab10 SERCOM - UART TxRx Interrupt Callback

Step 4

a **Modify TC3 Callback for UART Tx**

```
void TC3_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
      if( status & TC_INTFLAG_OVF_Msk )
      {
         LED1_Toggle();

         // TODO 10.03
          sprintf((char *) USARTRTxBuffer, "Hello world!\r\n" );
          SERCOM5_USART_Write( USARTRTxBuffer, strlen((char*)USARTRTxBuffer) );
     }
}

int main (void)
{
   SYS_Initialize ( NULL );

   …

}
```

b **Program firmware to target board then observe result.**

MICROCHIP

Lab10 SERCOM - UART TxRx Interrupt Callback

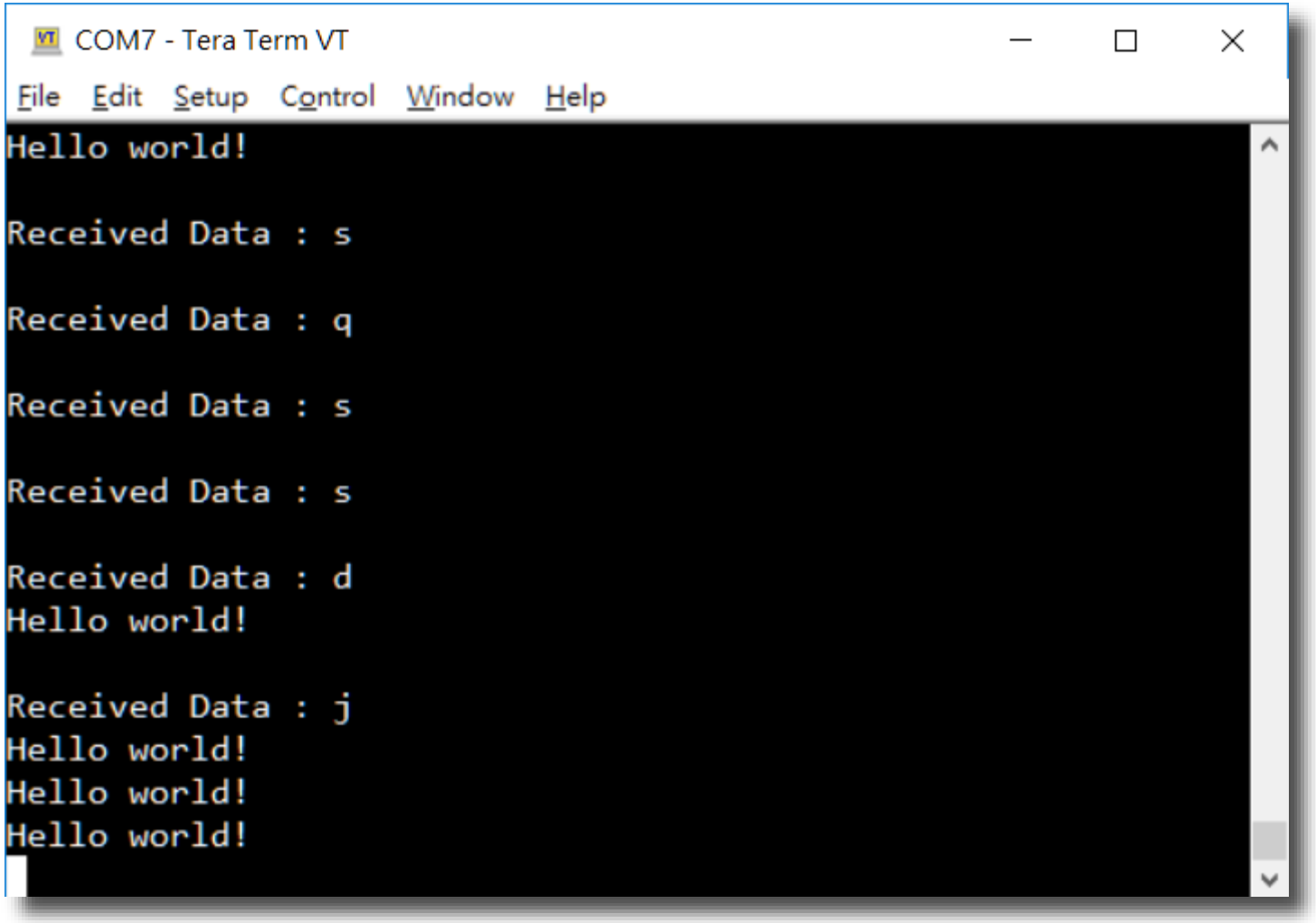
Step 5

a **Add code segment to your main loop**

```
int main (void)
{
  ...
  // TODO 10.04
  SERCOM5_USART_ReadCallbackRegister( USART5_Receive, (uintptr_t )NULL );
  SERCOM5_USART_WriteCallbackRegister( USART5_Transmit, (uintptr_t )NULL );
  SERCOM5_USART_Read( USART5_ReceiveData, 1 );
  while( true )
  {
    ...
    // TODO 10.05
    if( USART5_IsReceived )
    {
      USART5_IsReceived = 0;
      sprintf((char *) USARTRTxBuffer,
                    "\r\nReceived Data : %1c\r\n", USART5_ReceiveData[0] );
      SERCOM5_USART_Write( USARTRTxBuffer, strlen((char*)USARTRTxBuffer) );
      while( SERCOM5_USART_WriteIsBusy() );
      SERCOM5_USART_Read( USART5_ReceiveData, 1 );
    }
  }
}
```

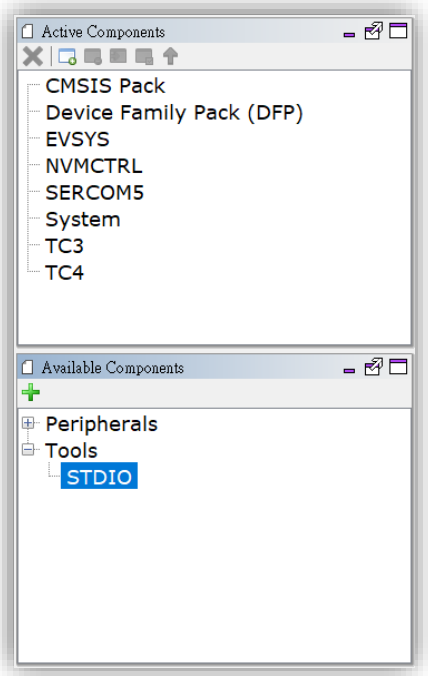
Lab10 SERCOM - UART TxRx Interrupt Callback

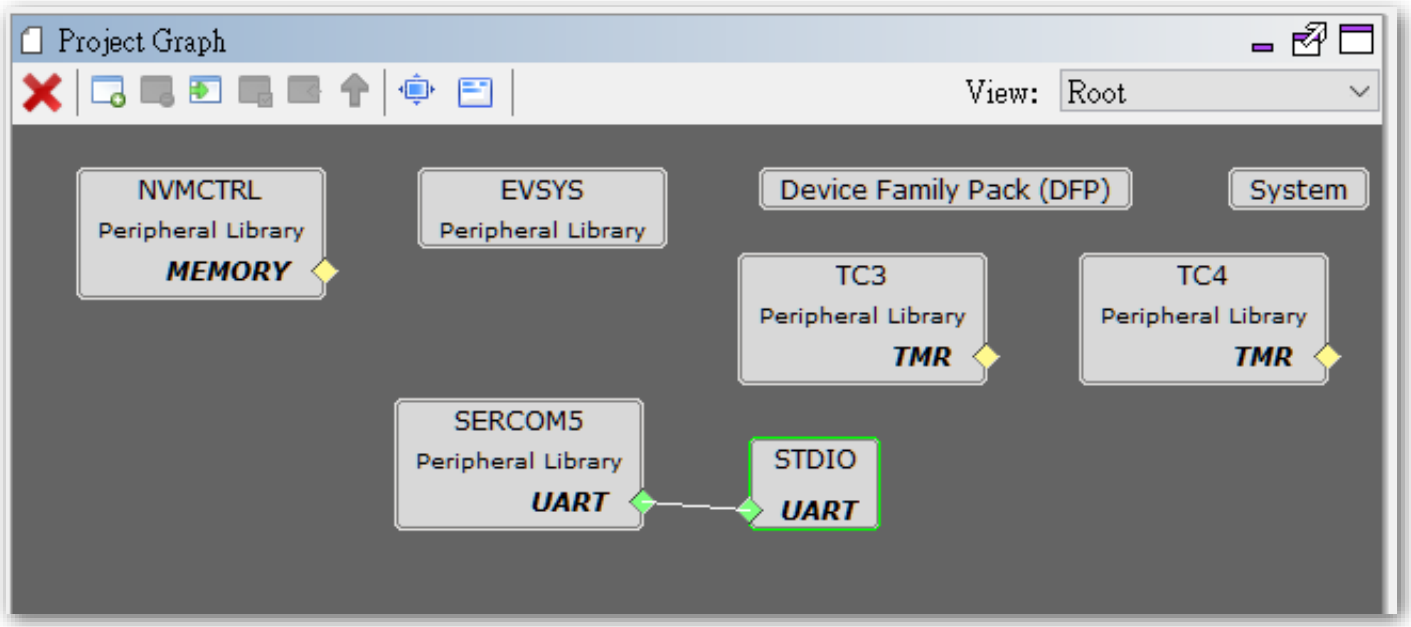
Result



The STDIO limitation

- Harmony support the standard input/output (STDIO) could be easy to use printf() function to output UART message. But the mechanism of STDIO module is based on polling mode (blocking mode). It will conflict when selected SERCOM-UART Non-blocking mode and try to use printf().
- Let ‘s try implement our myprintf() function to use interrupt method but have convenient use as the C printf() function.

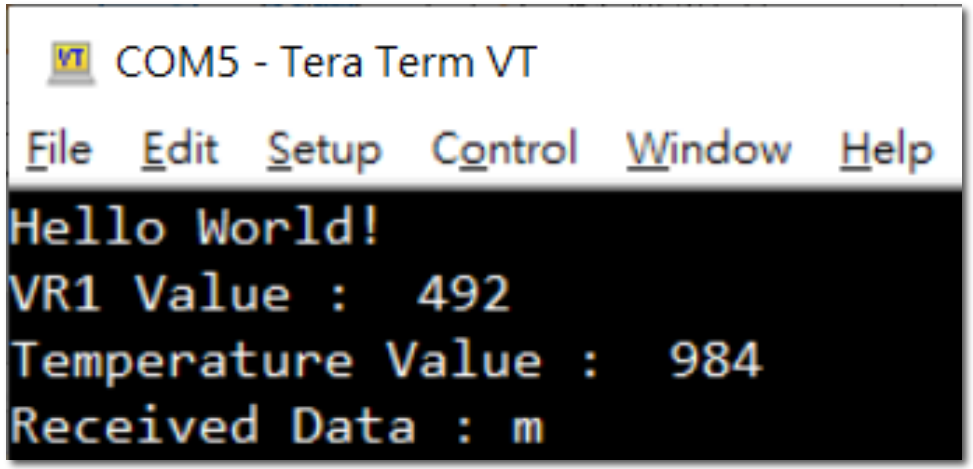




MICROCHIP

VT100 Console Control

- **Use VT100 command to control Tera Term UART output as**




```
myprintf("\033[2J");    // Clear screen
myprintf("\033[?25l"); // Hide cursor
myprintf("\033[y;xH"); // Set cursor to (x,y)
                       // Left-up corner is from (1,1)
```

- **Let's go!**

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

- Try add myprintf code for user code.
- After done this, you could use myprintf() function to instead of USART interface routines.
- SERCOM - UART setting same as Lab10

- Let's go!

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

Step 1

a **Add software flag control of TC3 and TC4.**

```
// TODO 11.01
#include <stdarg.h>

// TODO 11.02
#define SYS_CONSOLE_PRINT_BUFFER_SIZE 200
static char consolePrintBuffer[SYS_CONSOLE_PRINT_BUFFER_SIZE];
volatile uint8_t TC3_HasExpired= 0;
volatile uint8_t TC4_HasExpired= 0;
…
void TC3_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
   if( status & TC_INTFLAG_OVF_Msk )
   {
      // TODO 11.03
       TC3_HasExpired= 1;
   }
}
void TC4_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
   if( status & TC_INTFLAG_OVF_Msk )
   {
      // TODO 11.04
       TC4_HasExpired= 1;
   }
}
```

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

Step 2

a **Add code segment to user code.**

```
void TC4_TimerExpired(TC_TIMER_STATUS status, uintptr_t context)
{
  …
}

// TODO 11.05
void myprintf(const char *format, ...)
{
    size_t len = 0;
    va_list args = {0};

    va_start(args, format);
    len = vsnprintf(consolePrintBuffer, SYS_CONSOLE_PRINT_BUFFER_SIZE, format , args);
    va_end(args);

    if ((len > 0) && (len < SYS_CONSOLE_PRINT_BUFFER_SIZE))
    {
        consolePrintBuffer[len] = '\0';
        SERCOM5_USART_Write(consolePrintBuffer, len);
        while (SERCOM5_USART_WriteIsBusy());
    }
}
```

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

Step 3

a **Add code segment to your main while loop.**

```
int main ( void )
{
  ...
  // TODO 11.06
  myprintf("\033[2J");
  myprintf("\033[?25l");
  while( true )
  {
    // TODO 11.07
    if (TC3_HasExpired)
    {
      TC3_HasExpired= 0;
      LED1_Toggle();
      myprintf( "\033[1;1HHello World!" );
    }

    if (TC4_HasExpired)
    {
      TC4_HasExpired= 0;
      LED2_Toggle();
    }
  }
}
```

MICROCHIP

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

Step 4

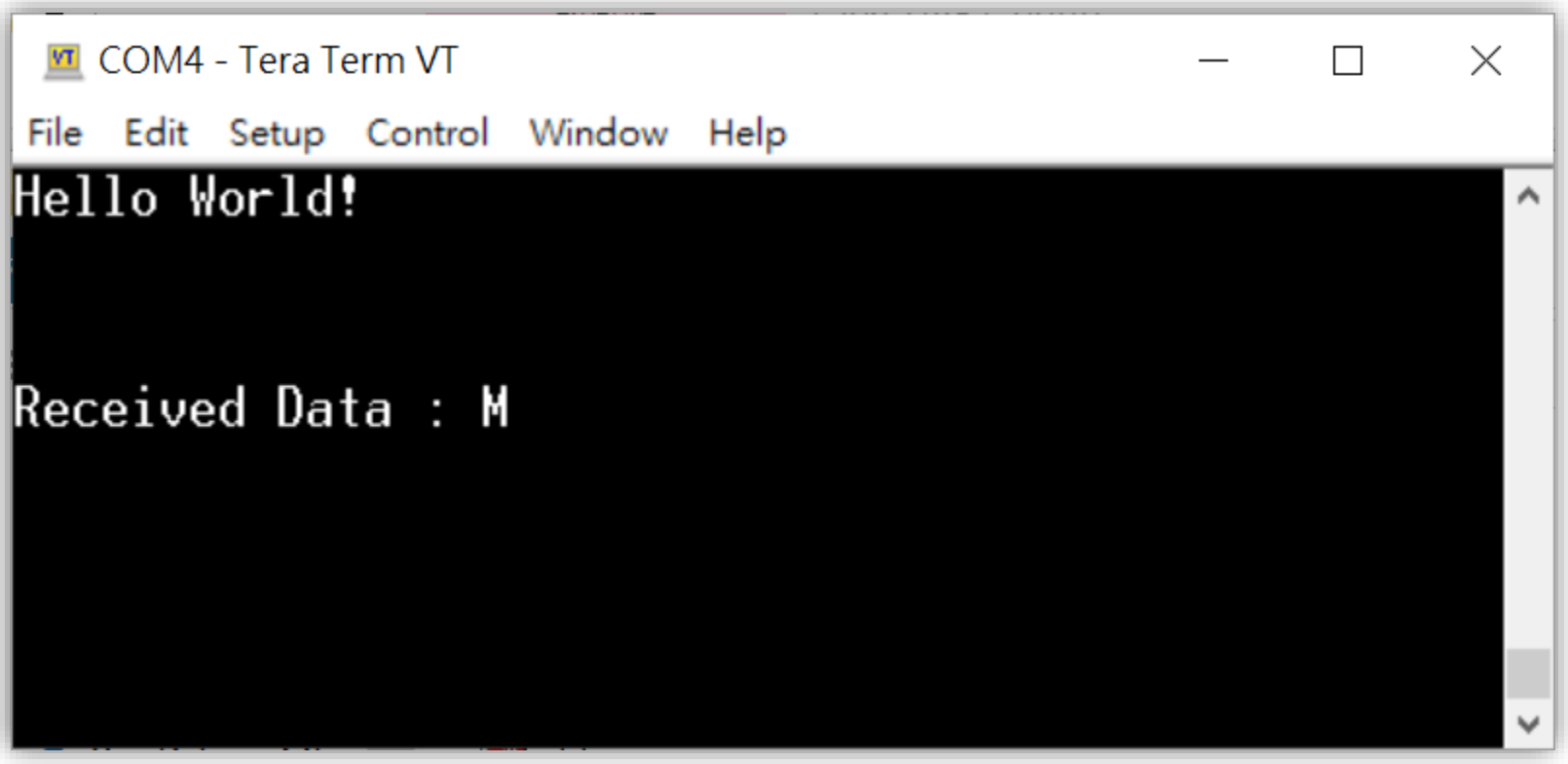
a **Add code segment to your main while loop.**

```
int main ( void )
{
   …
   while( true )
   {
      if (TC4_HasExpired)
      {
         TC4_HasExpired= 0;
         LED2_Toggle();
      }

      if( USART5_IsReceived )
      {
         USART5_IsReceived = 0;

         // TODO 11.08
         myprintf("\033[6;1HReceived Data : %1c", USART5_ReceiveData[0] );
         SERCOM5_USART_Read( USART5_ReceiveData, 1 );
      }
   }
}
```

MICROCHIP

Lab11 SERCOM - UART TxRx Interrupt Callback with myprintf

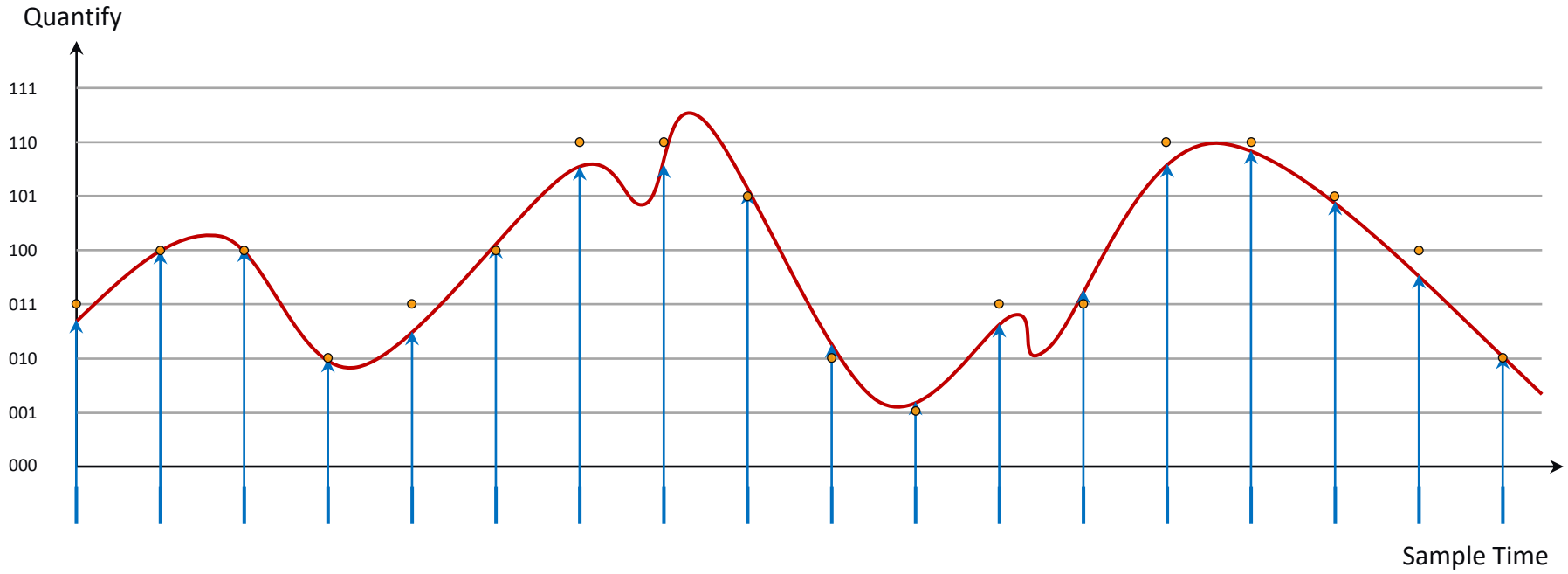
Result



High Speed ADC Architecture

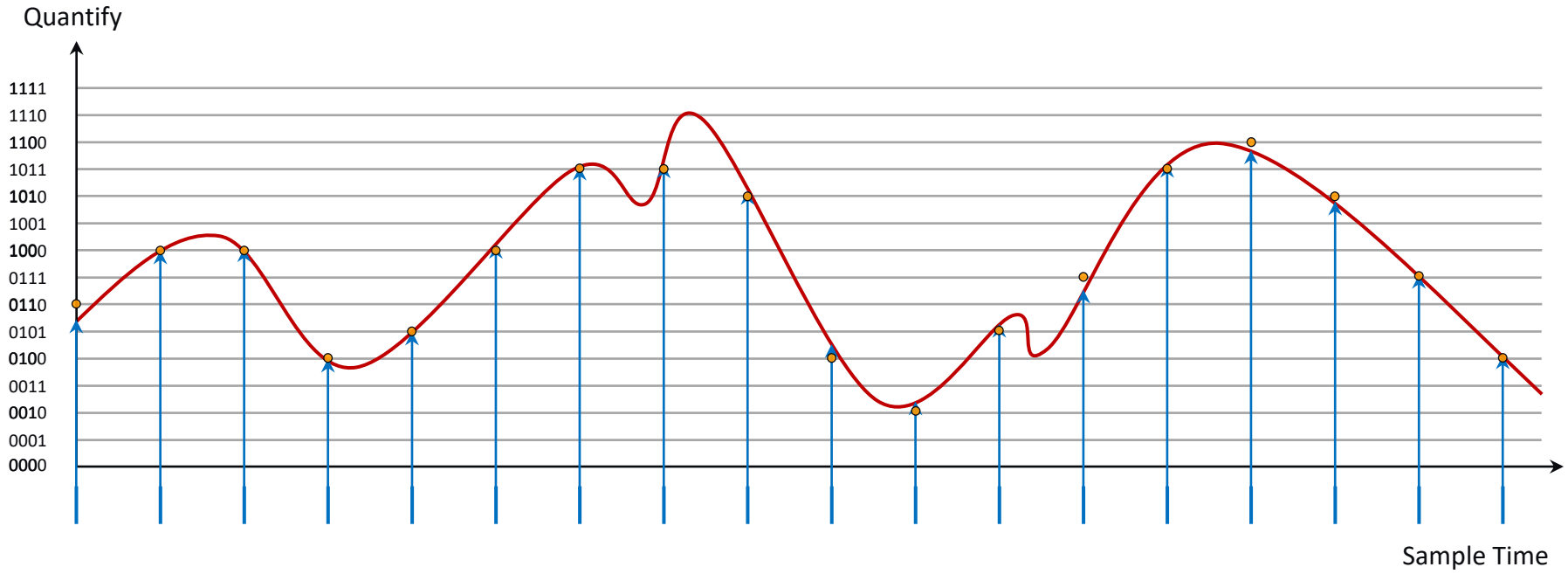
What’s ADC ?

- **The Analog-to-Digital Converter(ADC) converts a signal from the time continuous/amplitude continuous domain into a time discrete/amplitude discrete domain.**



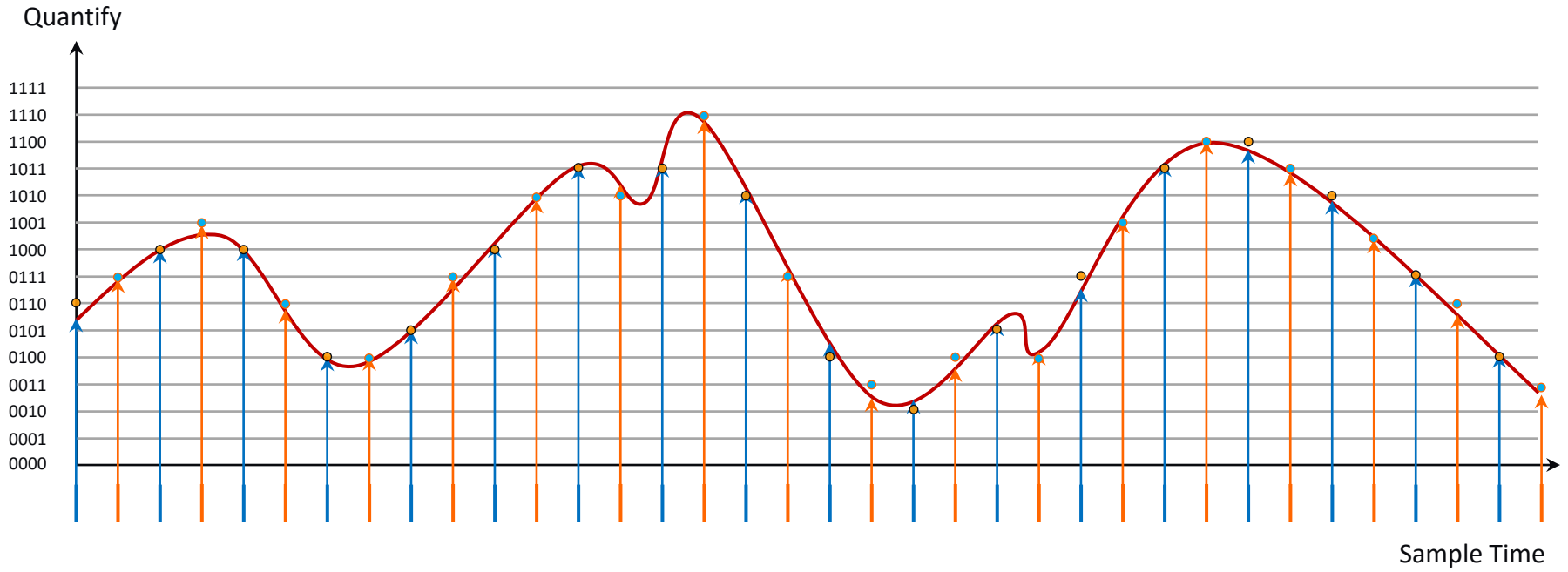
Resolution

- **The resolution of the converter indicates the number of discrete values. The resolution determines the magnitude of the quantization error. (wiki)**



Sample Rate

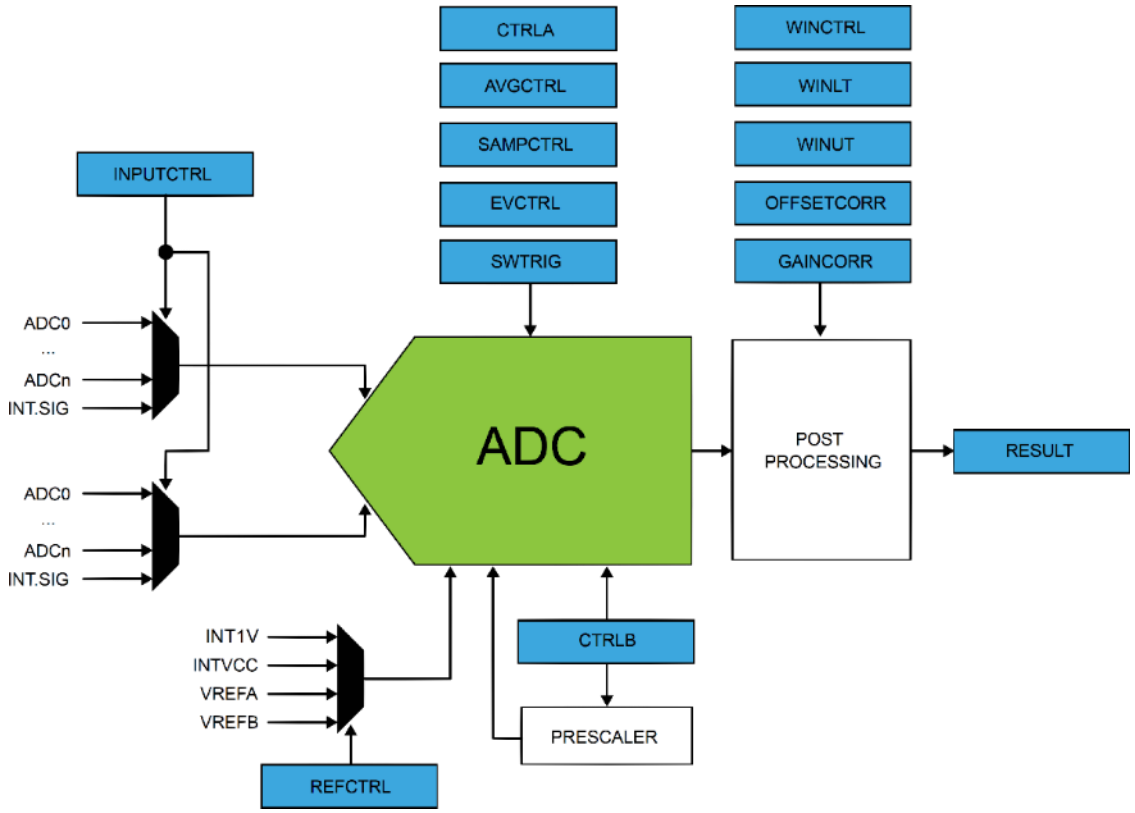
- The analog signal is required to define the rate at which new digital values are sampled from the analog signal.
- This faithful reproduction is only possible if the sampling rate is higher than twice the highest frequency of the signal. (wiki)



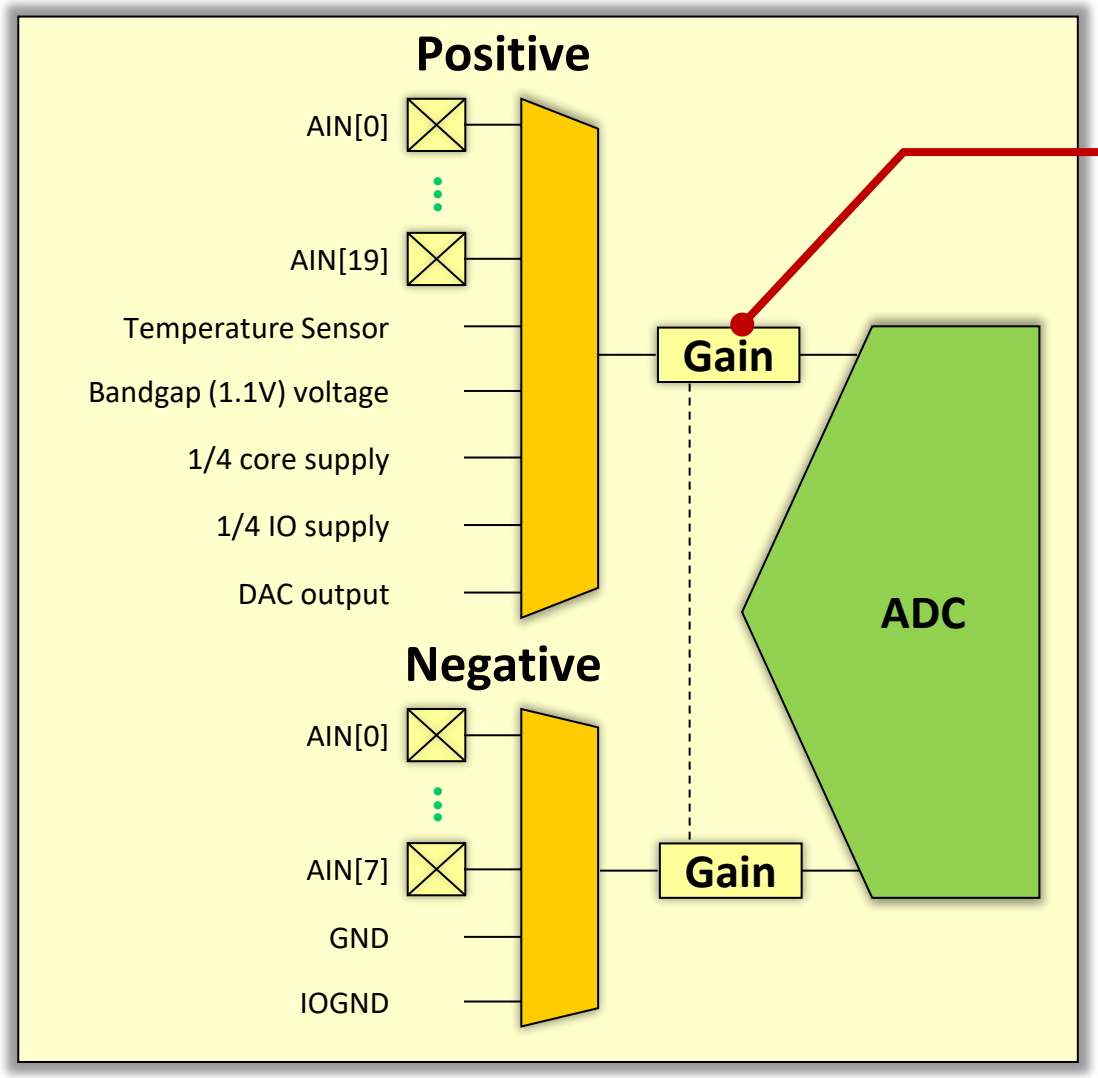
ADC Block Diagram

- Up to 32 analog input, 8, 10 or 12 bits resolution.
- Differential and single-ended inputs.
- 1/2x to 16x gain. Up to 350ksps.
- Support Event-triggered and pin scan.
- Support averaging and oversampling.
- External or Internal reference voltage.
- Oversample accumulation average and window monitor feature.

$$Reusult_{AD} = \left(\frac{AN_{+} - V_{Ref-}}{V_{Ref+} - V_{Ref-}} \times 2^{n}\right) - 1$$

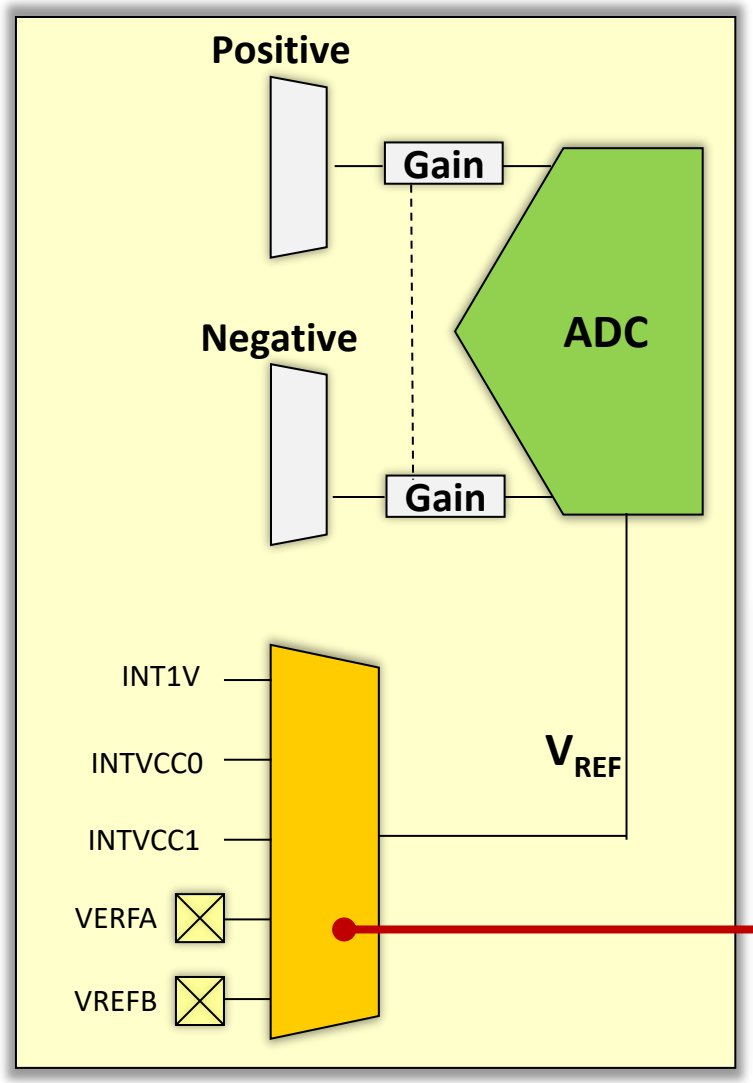


ADC Channel Selection & Gain



GAIN[3:0]	Name
0x0	1X
0x1	2X
0x2	4X
0x3	8X
0x4	16X
0x5-0xE	Reserved
0xF	1/2x

ADC Reference Voltage Selection



VREFA and VREFB range

$1.0V \sim (V_{DDANA} - 0.6V)$

Conversion range:

– Single-ended mode

$0V \sim V_{REF}/Gain$

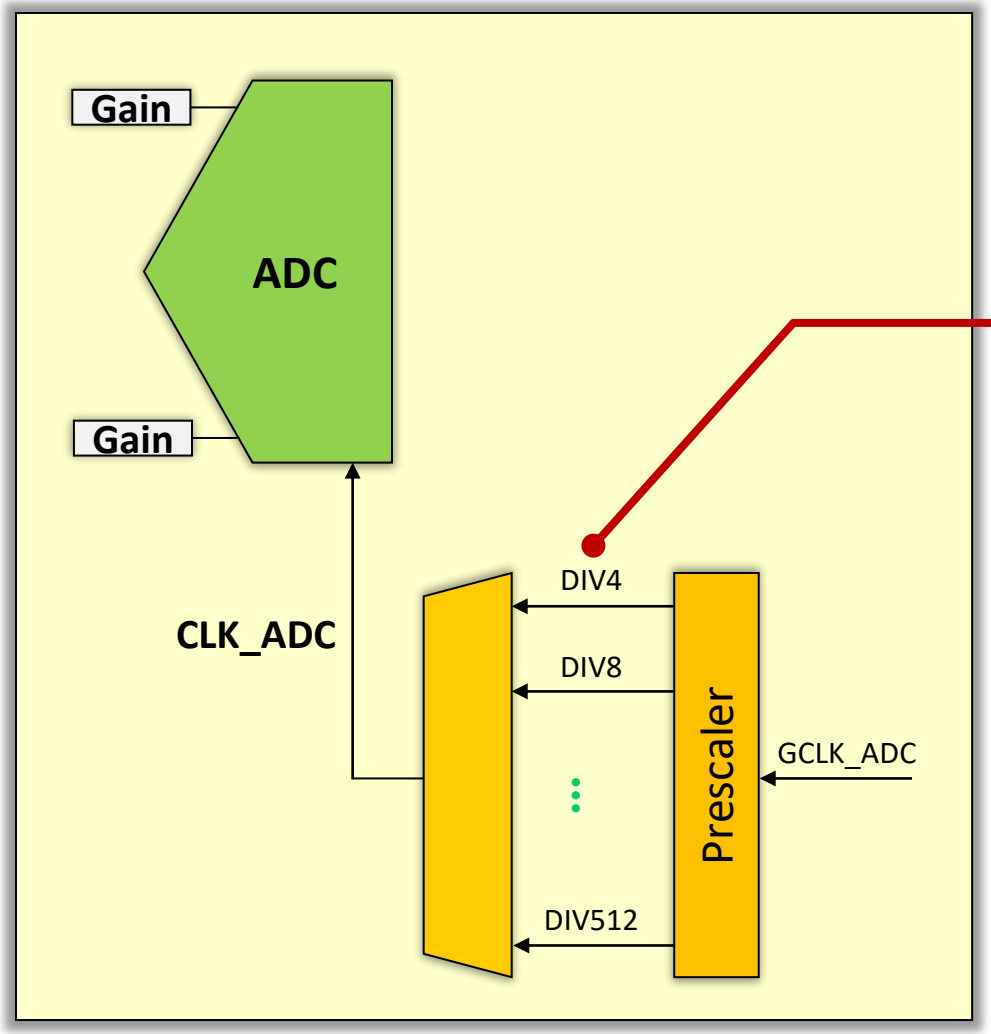
– Differential mode

$-V_{REF}/Gain \sim V_{REF}/Gain$

REFSEL[3:0]	Name	Description
0x0	INT1V	1.0V voltage reference
0x1	INTVCC0	1/1.48 VDDANA
0x2	INTVCC1	1/2 VDDANA (only for VDDANA > 2.0V)
0x3	VREFA	External reference
0x4	VREFB	External reference
0x5-0xF		Reserved

VDDANA = 3.3V
½ VDDANA = 1.65V

ADC Prescaler



PRESCALER[2:0]	Name
0x0	DIV4
0x1	DIV8
0x2	DIV16
0x3	DIV32
0x4	DIV64
0x5	DIV128
0x6	DIV256
0x7	DIV512

ADC Trigger Source

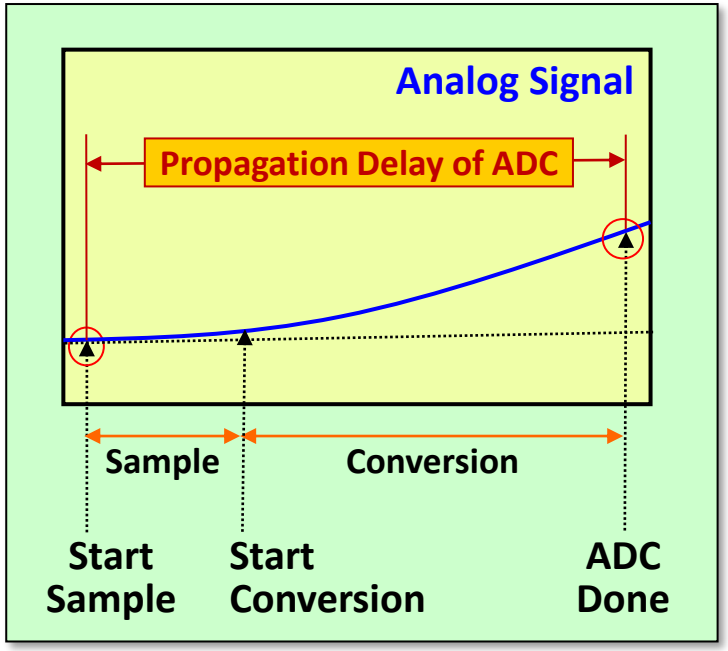
- **There are three way to be started data conversion.**
  - **Software Trigger**
    One shot conversion control via software.
  - **Free Run**
    A free-running mode can be used to continuously convert an input channel. When using free-running mode the first conversion must be started, while subsequent conversions will start automatically at the end of previous conversions.
  - **HW Event Trigger**
    Through Event System peripheral to automatically conversion.

ADC Characteristics

- **Maximum Sampling Rate :**

  Single-shot : 2.1M/Round(6+0.5) = 300k samples/second.

  Free-running : 2.1M/6 = up to 350k samples/second.

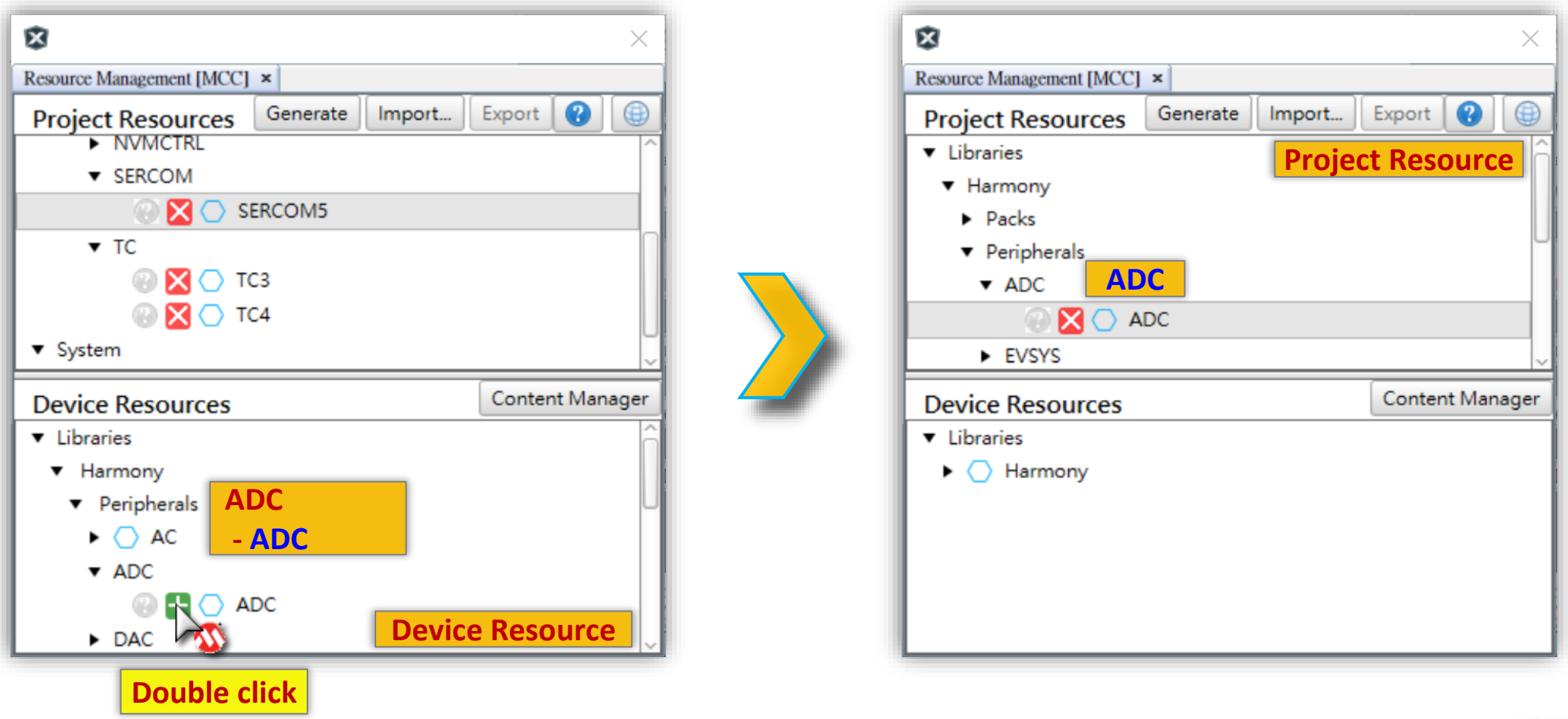


Symbol	Parameter	Conditions	Min.	Max.	Units
RES	Resolution		8	12	bits
f_{CLK_ADC}	ADC Clock frequency		30	2100	kHz
	Sample rate	Single shot	5	300	ksps
		Free running	5	350	ksps
	Sampling time		0.5	-	cycles
	Conversion time	1x Gain	6	-	cycles

MICROCHIP

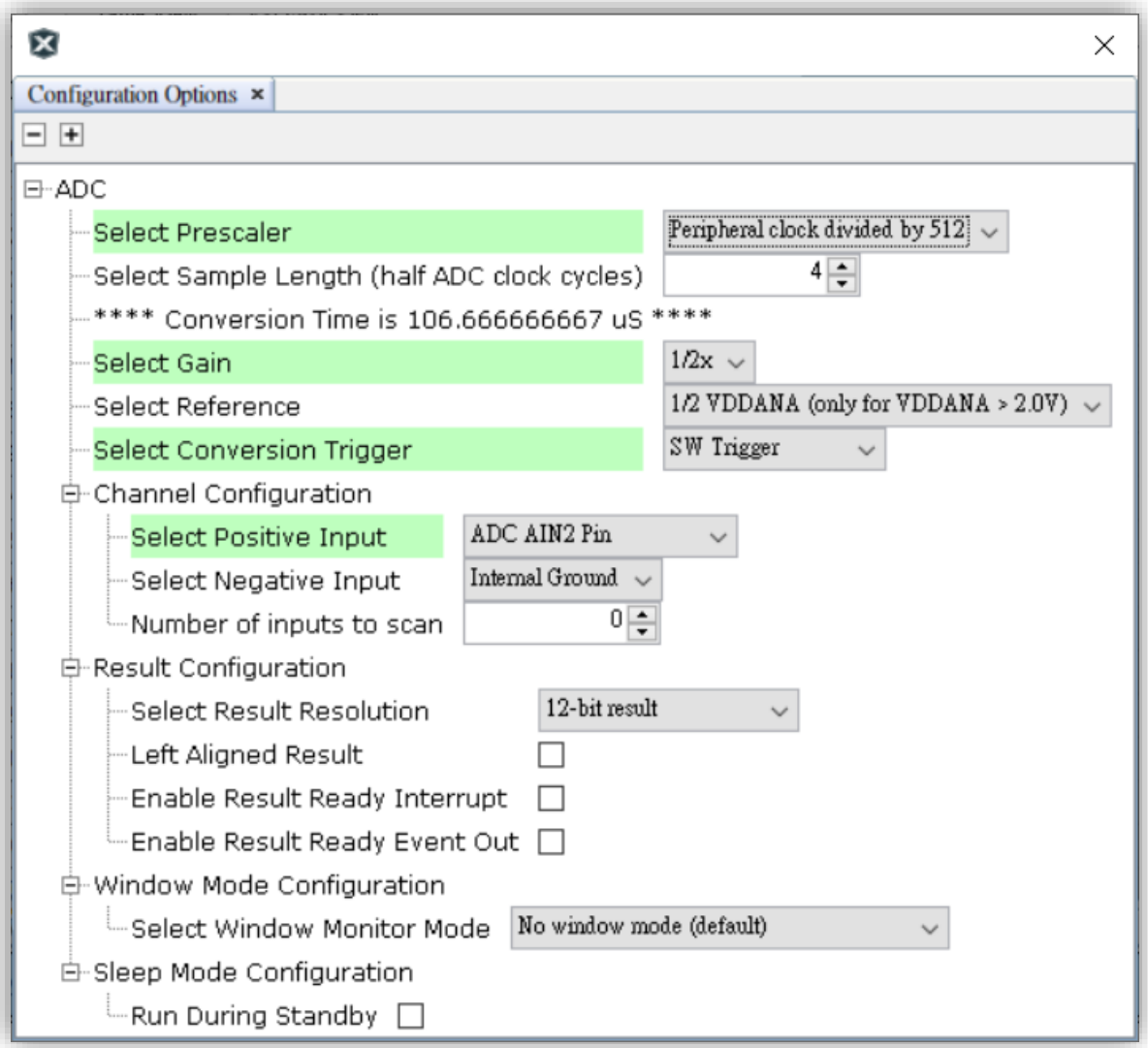
Add ADC Function using MCC Harmony

- Find ADC component in Device Resource window.
- Double click ADC to add to Project Resource window.



ADC Polling

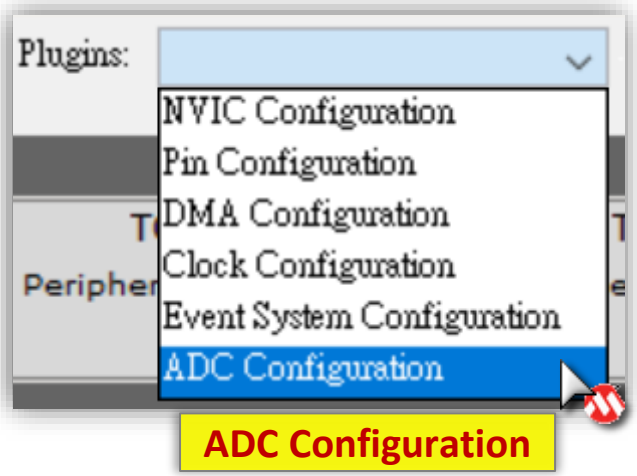
Configuration Options Example

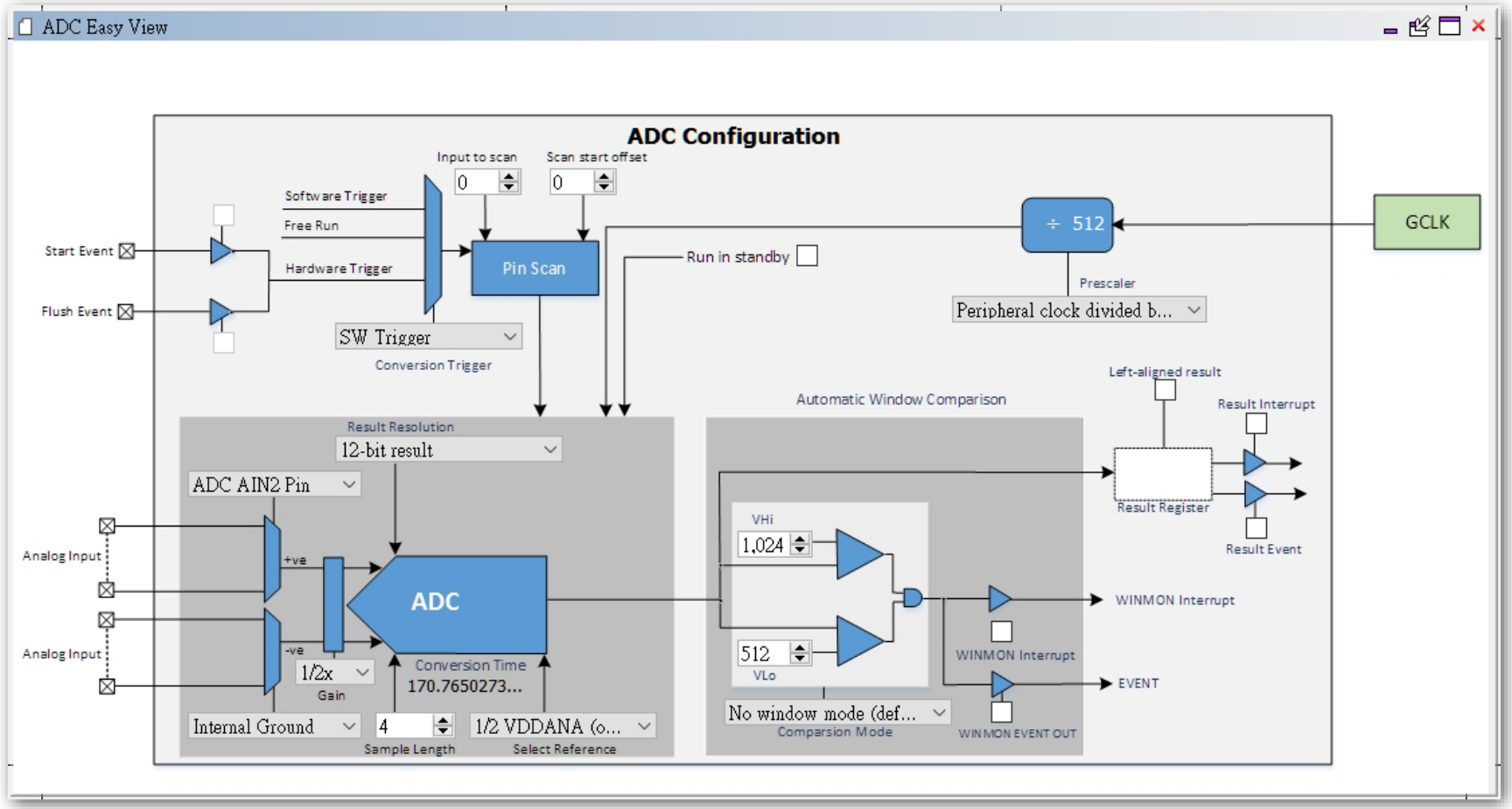


MICROCHIP

ADC Polling

Easy View Configuration Example





ADC Polling

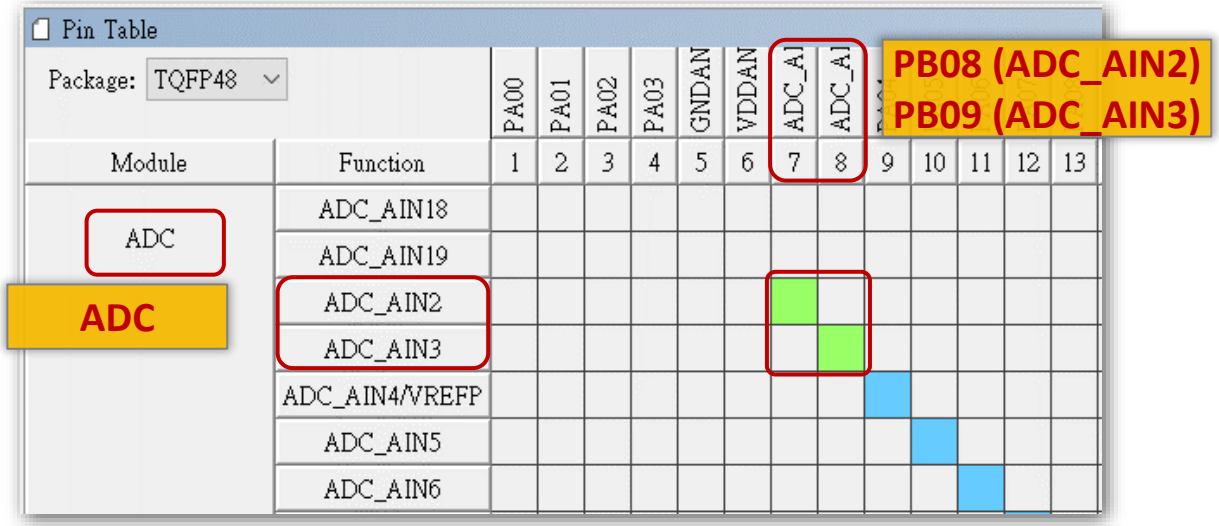
PINMUX Configuration Example

- **Analog pins** will all belong to **PINMUX function group B**.
- For example : **PB08** as **AIN[2]** (Analog input Channel 2)
  PB09 as **AIN[3]** (Analog input Channel 3)

Pin(1)			I/O Pin	Supply	A	B(2)(3)				C	D	E	F	G	H
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC	SERCOM(2)(3)	SERCOM-ALT	TC(4) /TCC	TCC	COM	AC/ GCLK
	7	11	PB08	VDDANA	EXTINT[8]		AIN[2]		Y[14]			SERCOM4/ PAD[0]	TC4/WO[0]	TCC3/ WO[6]		
	8		PB09	VDDANA	EXTINT[9]		AIN[3]					SERCOM4/ PAD[1]	TC4/WO[1]	TCC3/ WO[7]		

PB08
PB09

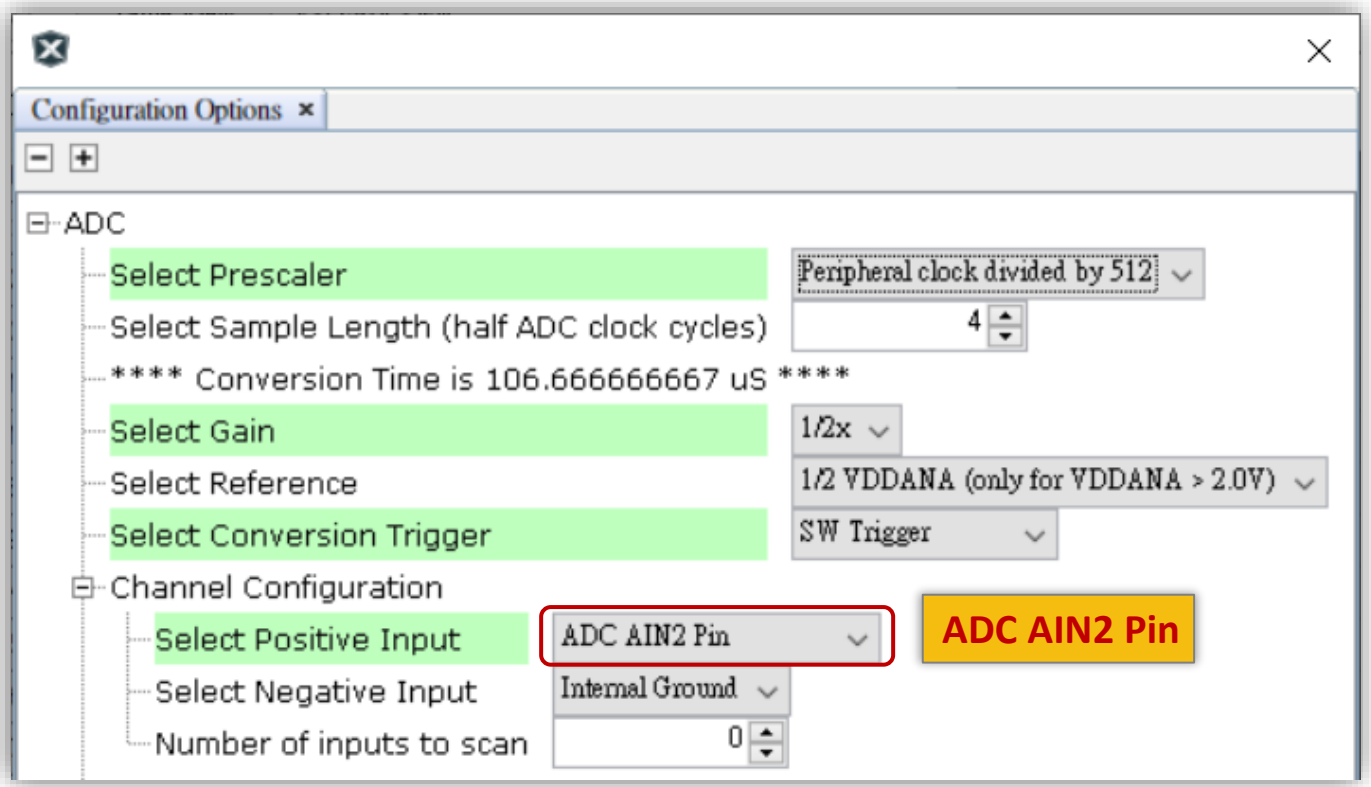
AIN[2]
AIN[3]



ADC Polling

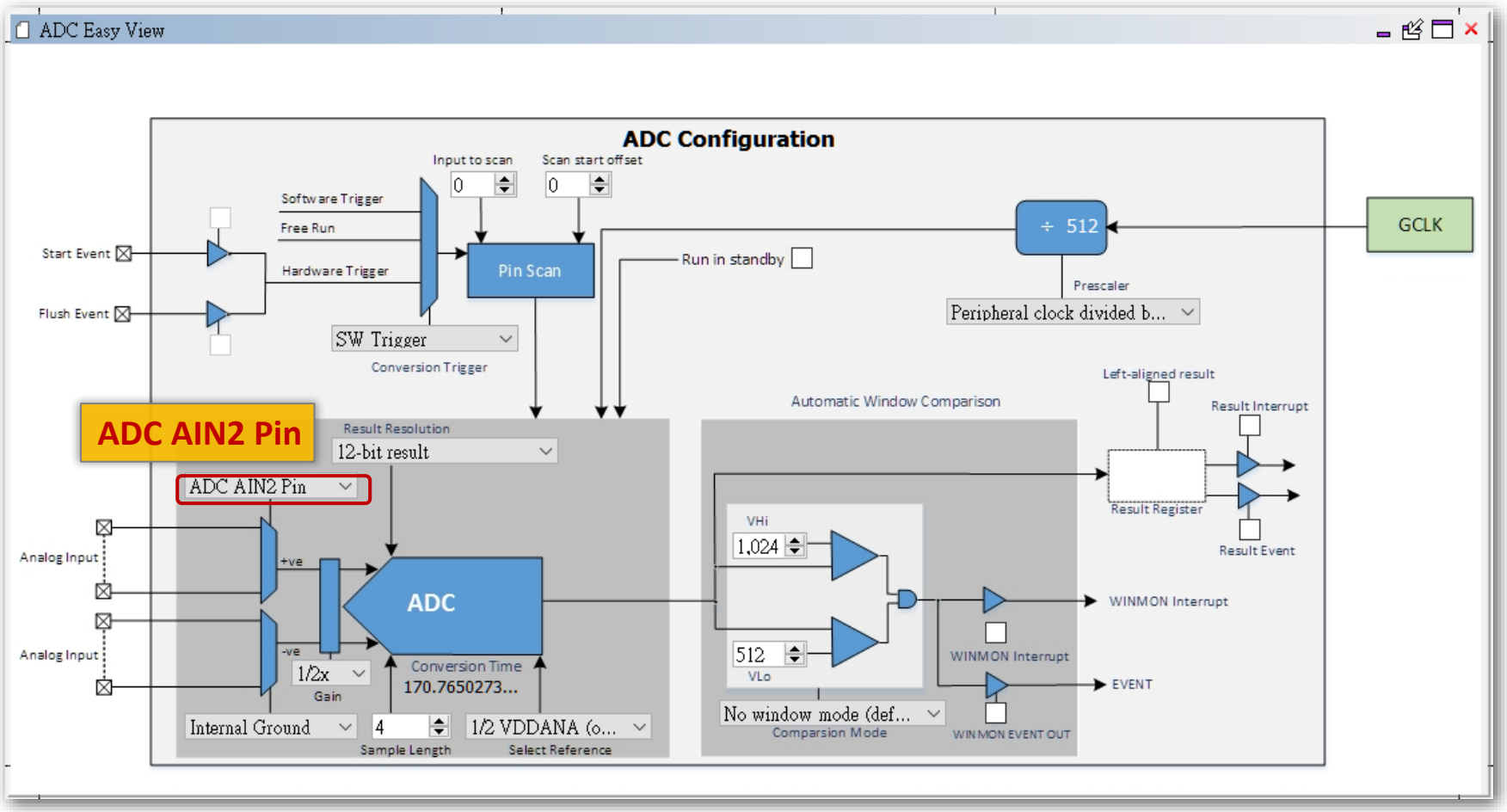
PINMUX Configuration Example

- Remember assign **Positive Input** pin in ADC module.
- For example : **ADC AIN2 Pin** as Positive Input Pin (**PB08**)



ADC Polling

Easy View PINMUX Configuration Example



ADC Polling

Interface Routines

```
void ADC_Initialize( void );
void ADC_Enable( void );
void ADC_Disable( void );
void ADC_ChannelSelect( ADC_POSINPUT positiveInput, ADC_NEGINPUT negativeInput );
void ADC_ConversionStart( void );
uint16_t ADC_ConversionResultGet( void );
bool ADC_ConversionStatusGet( void );
void ADC_ComparisonWindowSet(uint16_t low_threshold, uint16_t high_threshold);
void ADC_WindowModeSet(ADC_WINMODE mode);
```

ADC Polling

Software Trigger Code Example

```
…

int main (void)
{
   SYS_Initialize ( NULL );
   …
   ADC_Enable();
   while( true )
   {
      …
      ADC_ConversionStart();
      while( !ADC_ConversionStatusGet() );
      myprintf( "%d\r\n", ADC_ConversionResultGet() );
   }
}
```

ADC Factory Calibration

- **ADC Factory calibration value will auto load and applicate in MCC Harmony generated ADC initial function.**

plib_adc.c

```
void ADC_Initialize( void )
{ ...
  /* Write linearity calibration and bias calibration */
  ADC_REGS->ADC_CALIB =
    (uint32_t)( ADC_CALIB_LINEARITY_CAL( adc_linearity0 | (adc_linearity1 << 5) ) ) |
    ADC_CALIB_BIAS_CAL( ( ( (*(uint64_t*)OTP4_ADDR + 1) & ADC_BIASCAL_Msk ) >> ADC_BIASCAL_POS) );
}
```

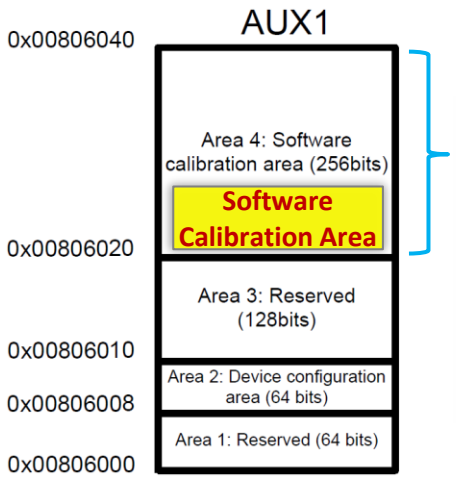


Table 10-5. NVM Software Calibration Area Mapping

Bit Position	Name	Description
34:27	ADC LINEARITY ADC_LINEARITY	ADC Linearity Calibration. Should be written to ADC CALIB register.
37:35	ADC BIASCAL ADC_BIASCAL	ADC Bias Calibration. Should be written to ADC CALIB register.

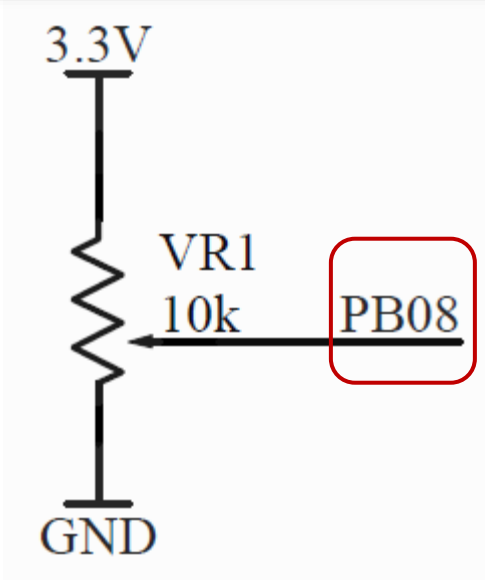
Lab12 ADC Polling Software Trigger

- Try to add ADC function to project.
- Initial ADC and get the conversion value from VR1 (AIN[2]) with one second period, then use UART to output to PC.
- ADC set to Software Trigger, 12 bits resolution, Single-End mode.

- Let's go!

Lab12 ADC Polling Software Trigger

Pin[1]			I/O Pin	Supply	A	B[2][3]				
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC
	7	11	PB08	VDDANA	EXTINT[8]		AIN[2]		Y[14]	
	8	12	PB09	VDDANA	EXTINT[9]		AIN[3]		Y[15]	

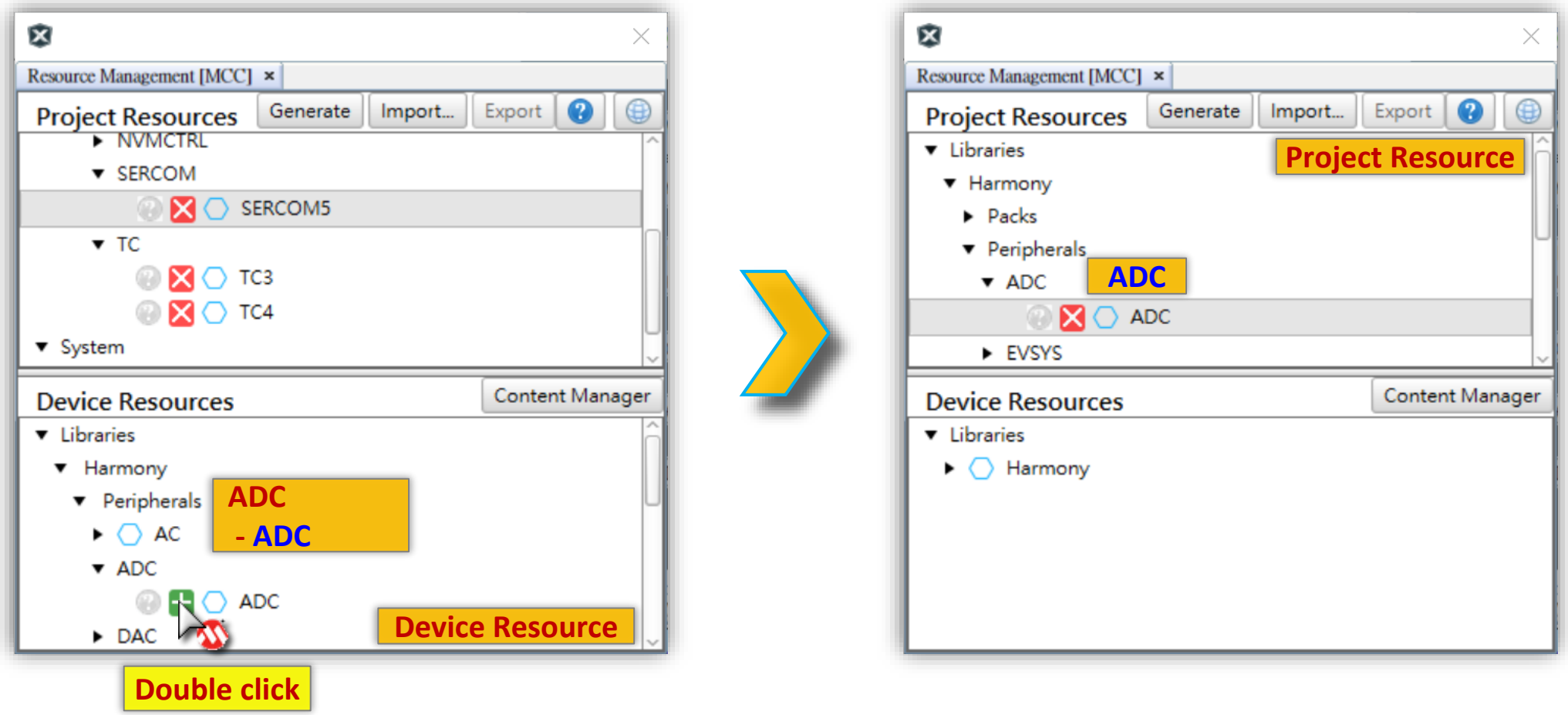


MICROCHIP

Lab12 ADC Polling Software Trigger

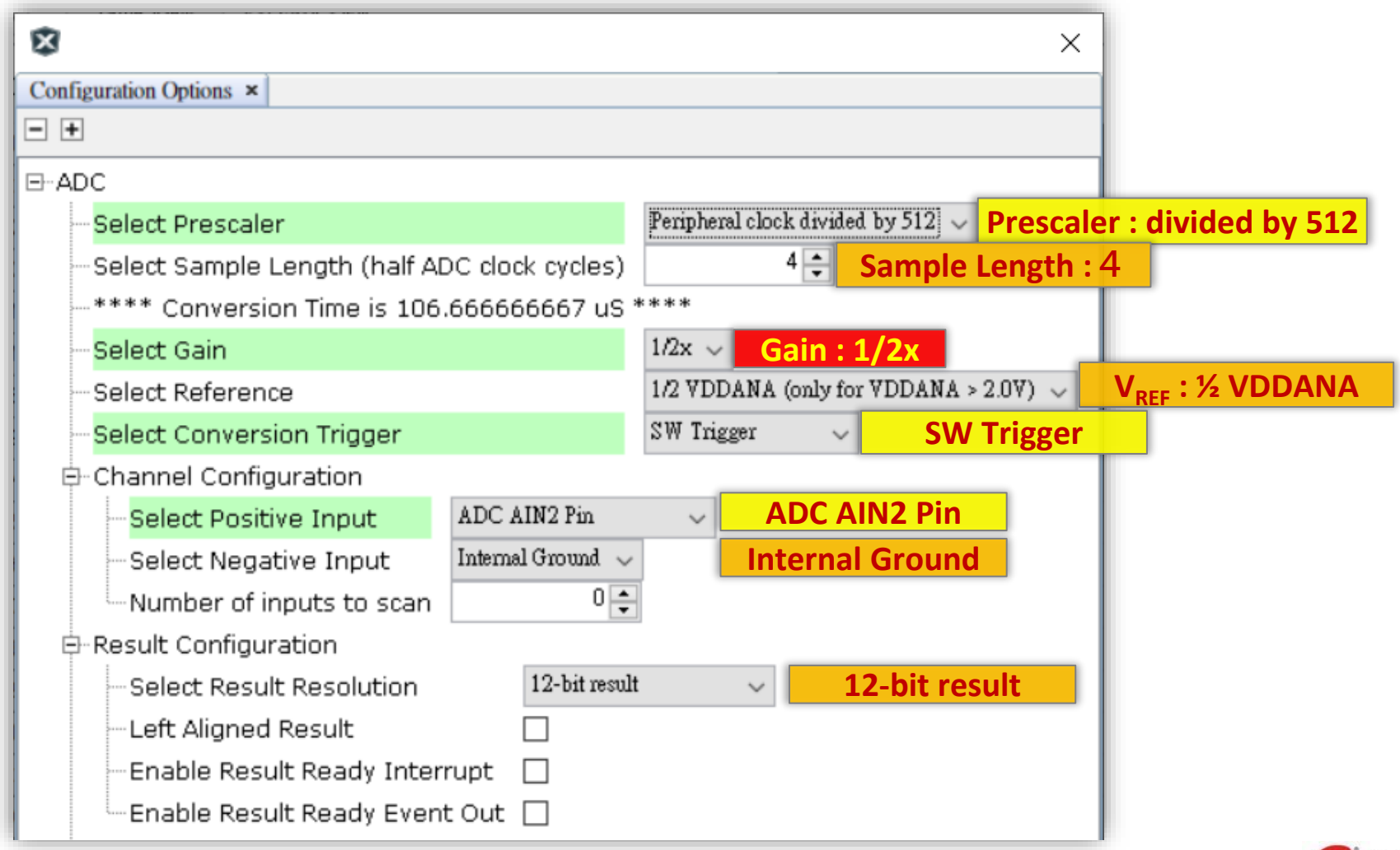
Step 1

- Find ADC component in Device Resource window.
- Double click ADC to add to Project Resource window.



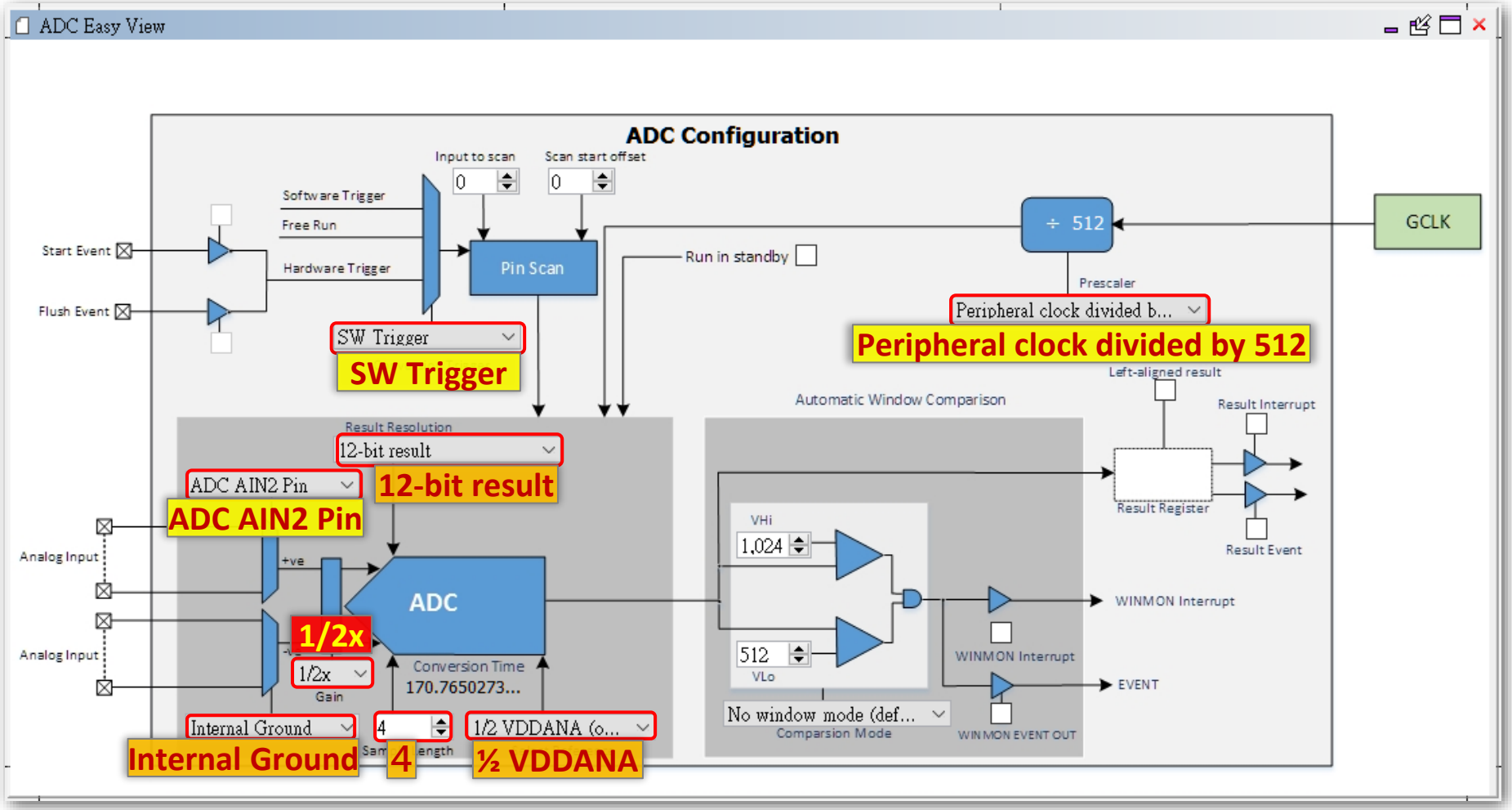
Lab12 ADC Polling Software Trigger

Step 2 (Use Configuration Options)



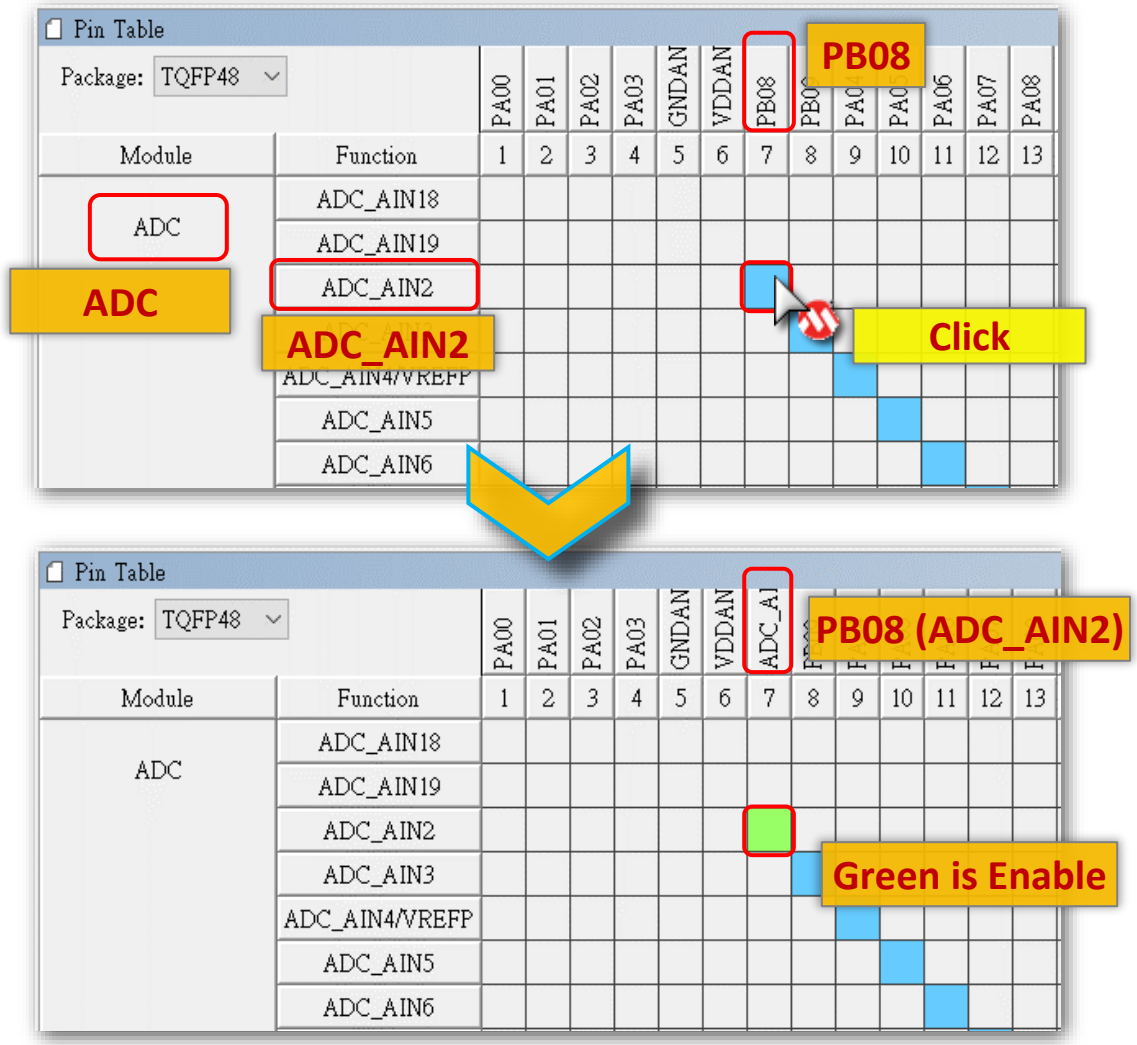
Lab12 ADC Polling Software Trigger

Step 2 (Use Easy View)



Lab12 ADC Polling Software Trigger

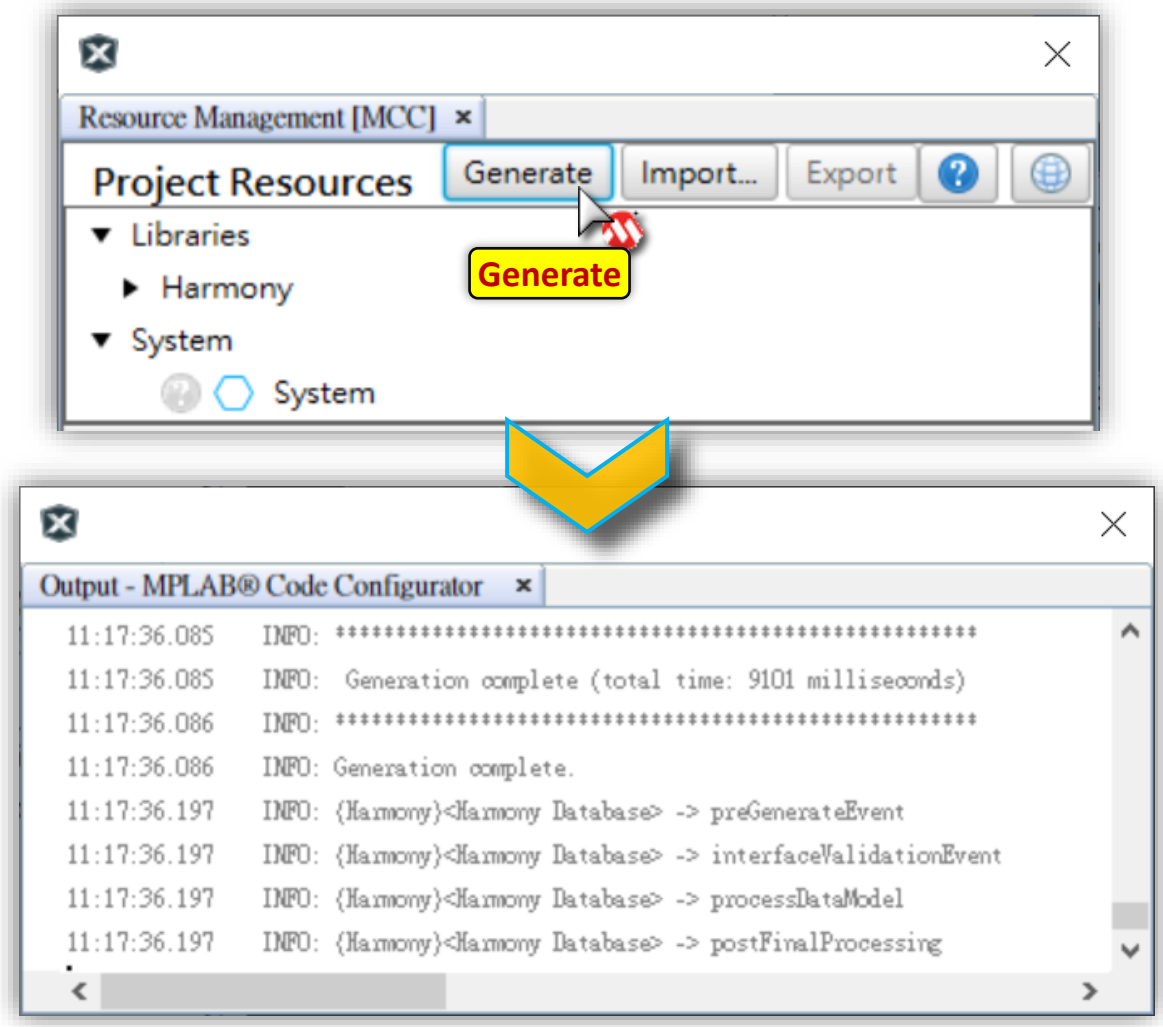
Step 3



Lab12 ADC Polling Software Trigger

Step 4

- Click "Generate" Button to Generate your Code.



Lab12 ADC Polling Software Trigger

Step 5

a. **Add code segment to your main.c**

```
// TODO 12.01
uint16_t ADC_Result;

int main (void)
{  …
   // TODO 12.02
   ADC_Enable();

   while( true )
   {  …
      if( TC3_HasExpired)
      {  …
         myprintf( "\033[1;1HHello World!\r\n" );

         // TODO 12.03
         ADC_ConversionStart();
         while( !ADC_ConversionStatusGet() );
         ADC_Result = ADC_ConversionResultGet();
         myprintf("\033[2;1HVR : %4d", ADC_Result );
      }
      …
   }
 }
```

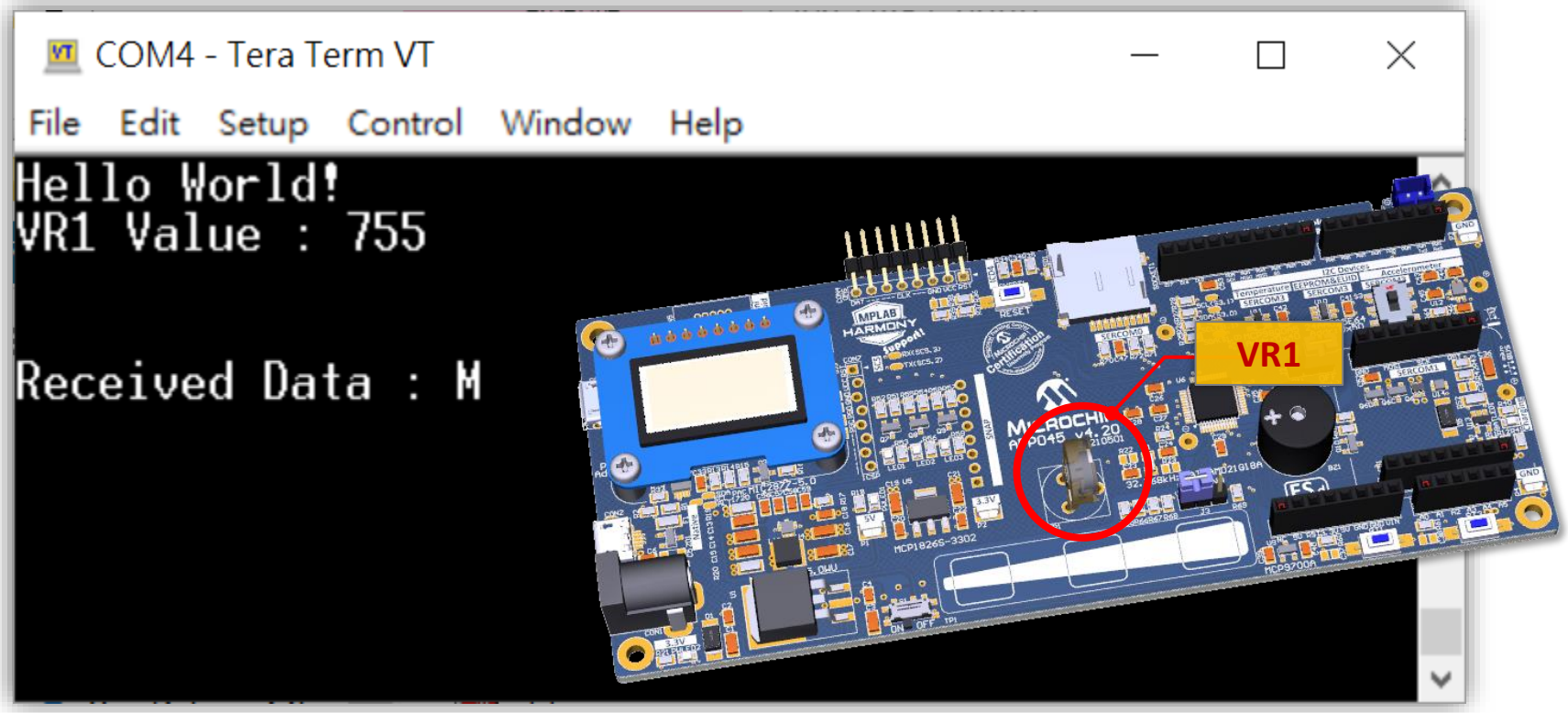
b. **Program firmware to target board then observe result.**

MICROCHIP

Lab12 ADC Polling Software Trigger

Result

- **"Hello World!" string and VR1 ADC value will output to terminal with one second period.**



ADC Interrupt Callback and Pin Scan

ADC Pin Scan

- The ADC support analog channel switch call Pin Scan function.
- Pin scan switch analog channel sequential after a conversion automatically.
- Start Pin : Positive Input + Scan Start Offset
- End Pin : Start Pin + Number of Inputs to Scan

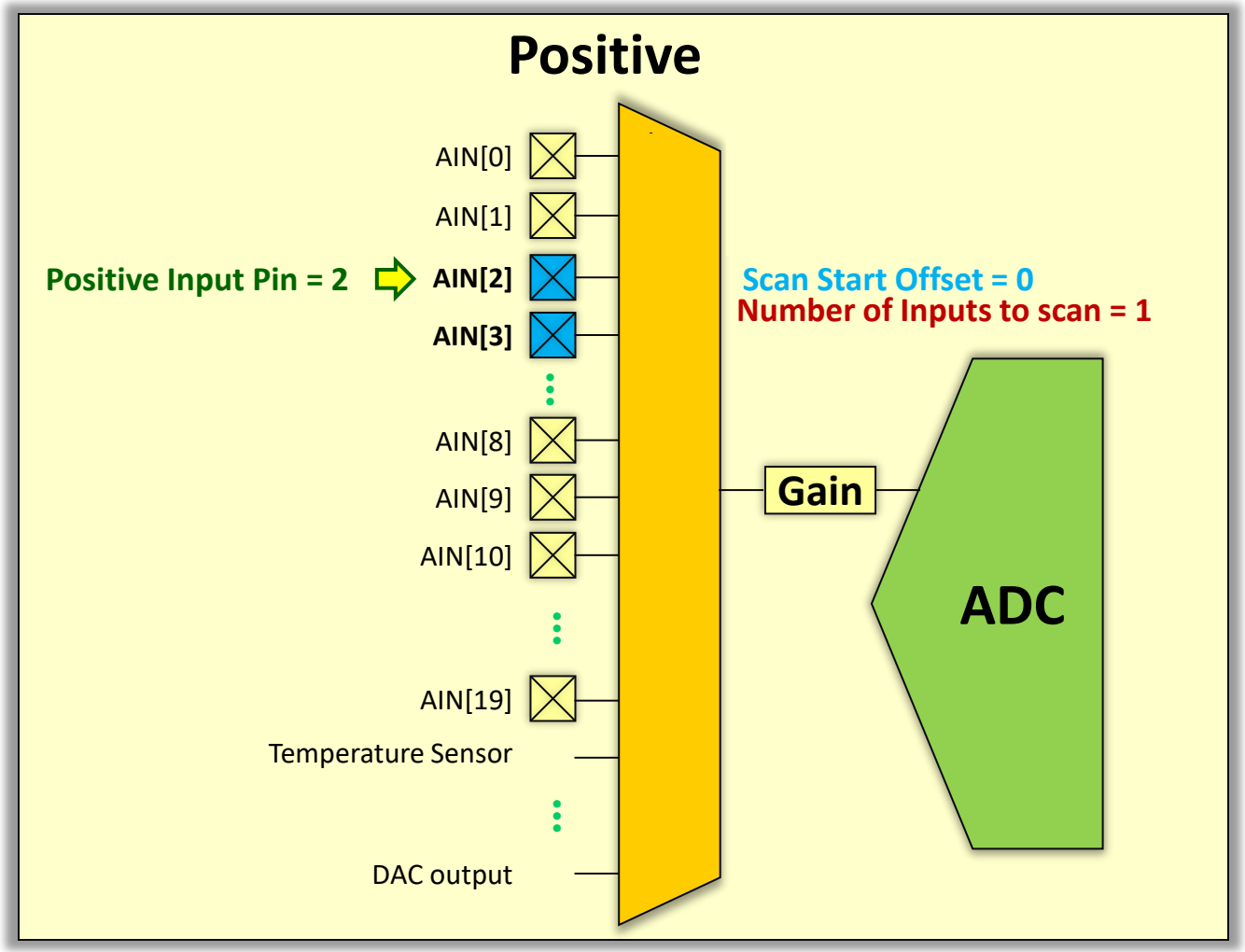
For Example : To do ADC Pin Scan from AIN[2] to AIN[3].

Positive Input Pin = AIN[0] Scan Start Offset = 2 Start Pin = AIN[0+2] = AIN[2]	OR	Positive Input Pin = AIN[2] Scan Start Offset = 0 Start Pin = AIN[2+0] = AIN[2]

Number of Inputs to scan = 1

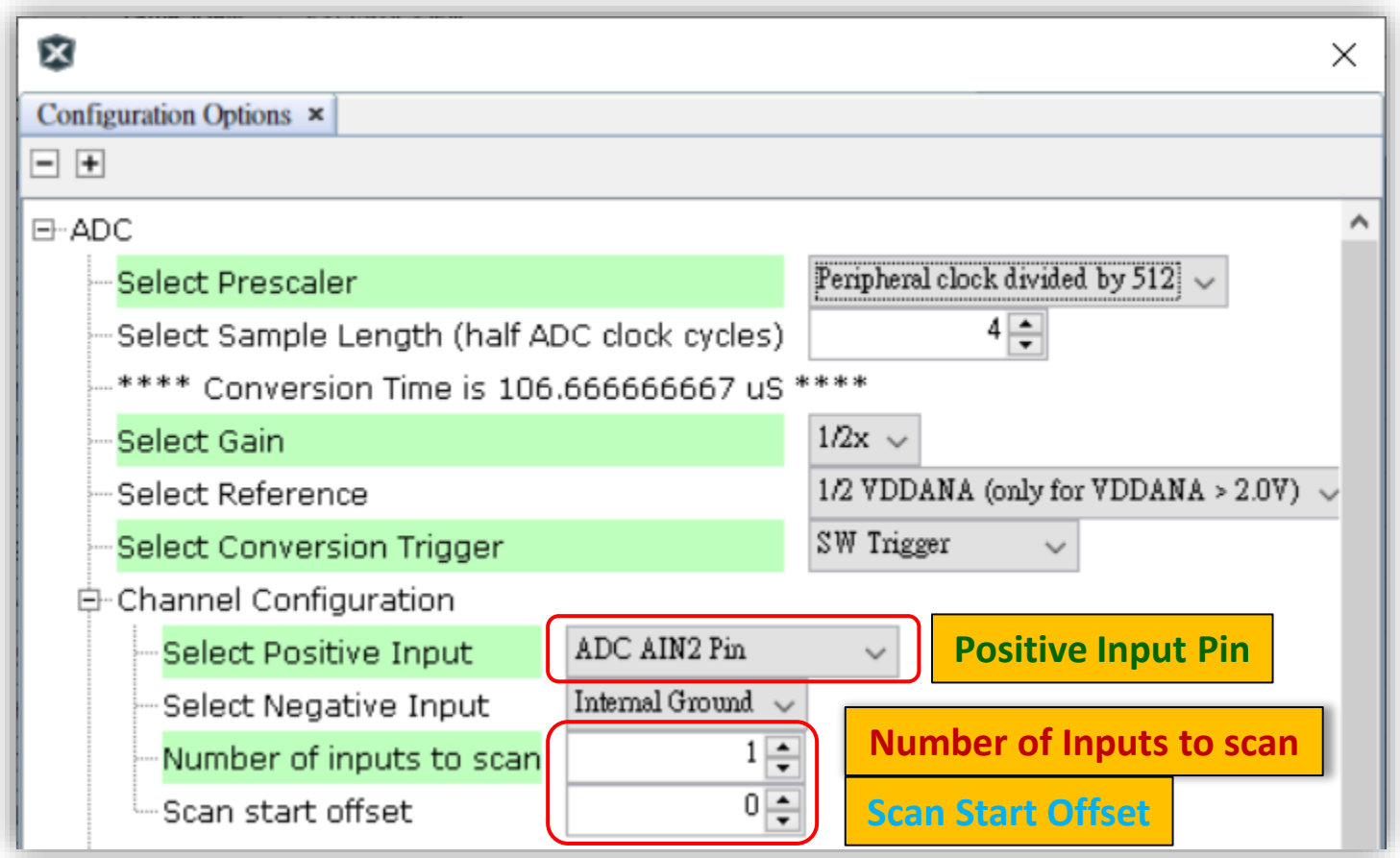
End Pin = AIN[2+1] = AIN[3]

ADC Pin Scan


Positive
AIN[0]
AIN[1]
Positive Input Pin = 2
AIN[2]
AIN[3]
AIN[8]
AIN[9]
AIN[10]
AIN[19]
Temperature Sensor
DAC output
Scan Start Offset = 0
Number of Inputs to scan = 1
Gain
ADC

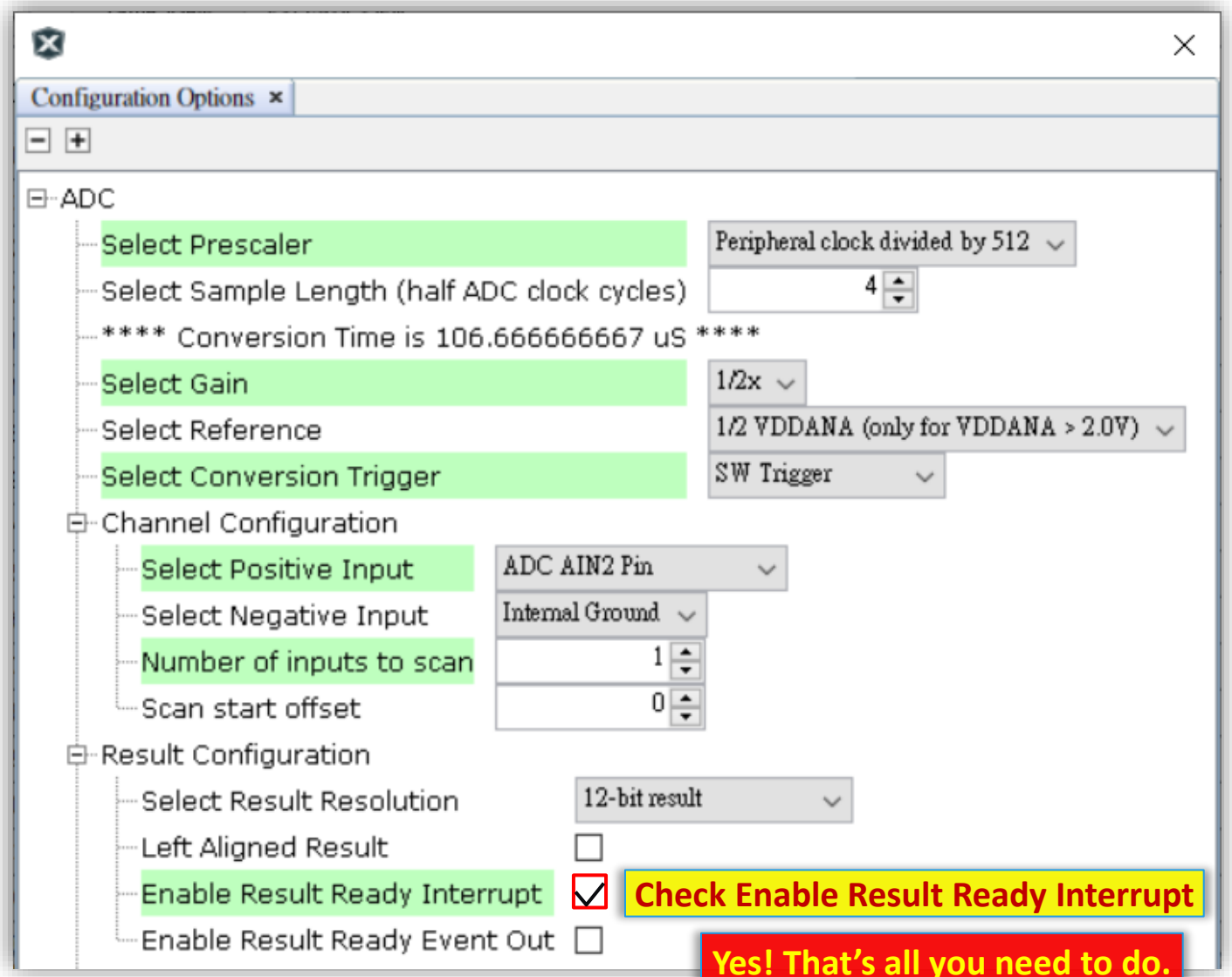
ADC Pin Scan

Configuration Options Example



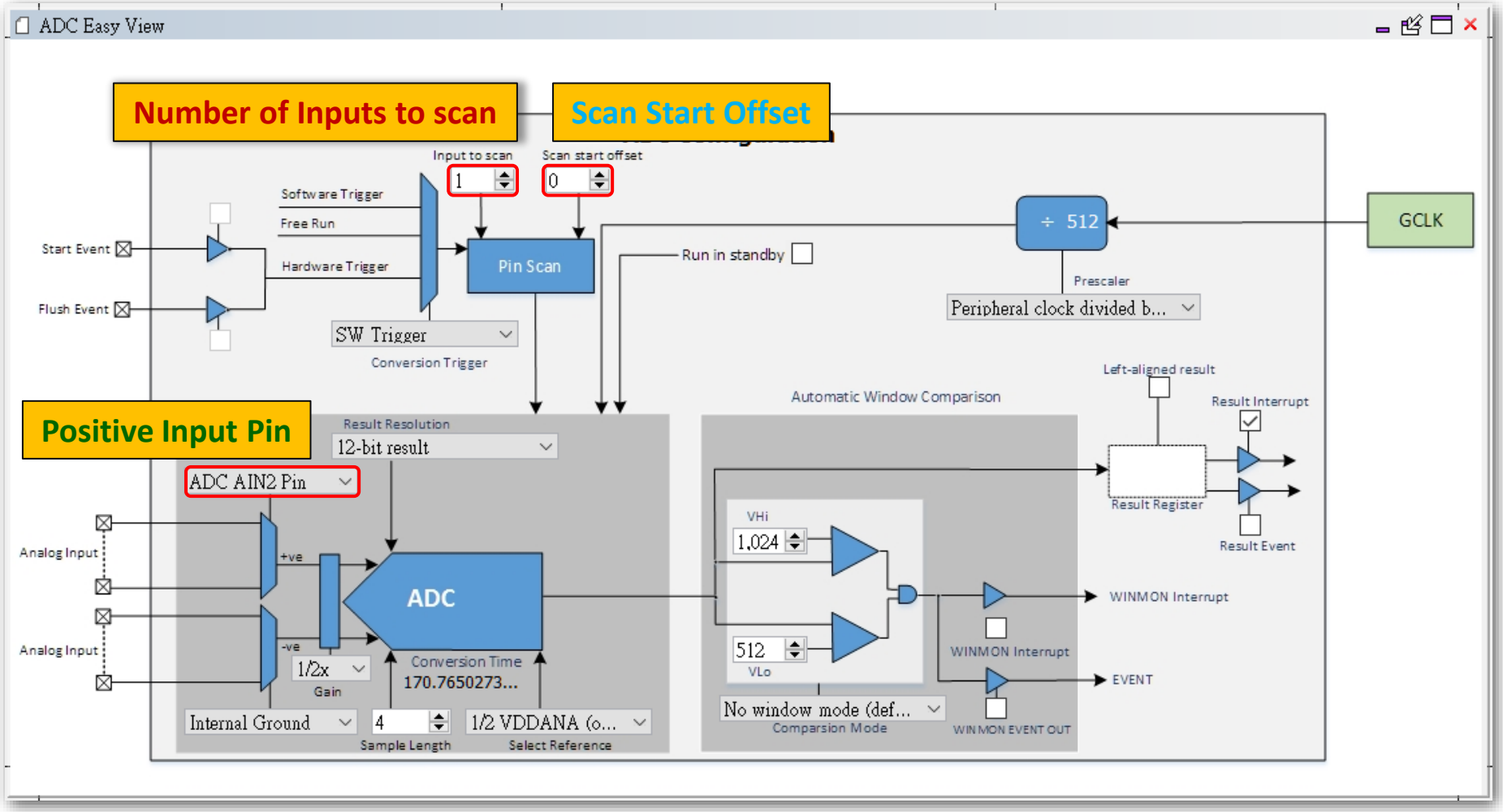
ADC Interrupt

Configuration Options Example



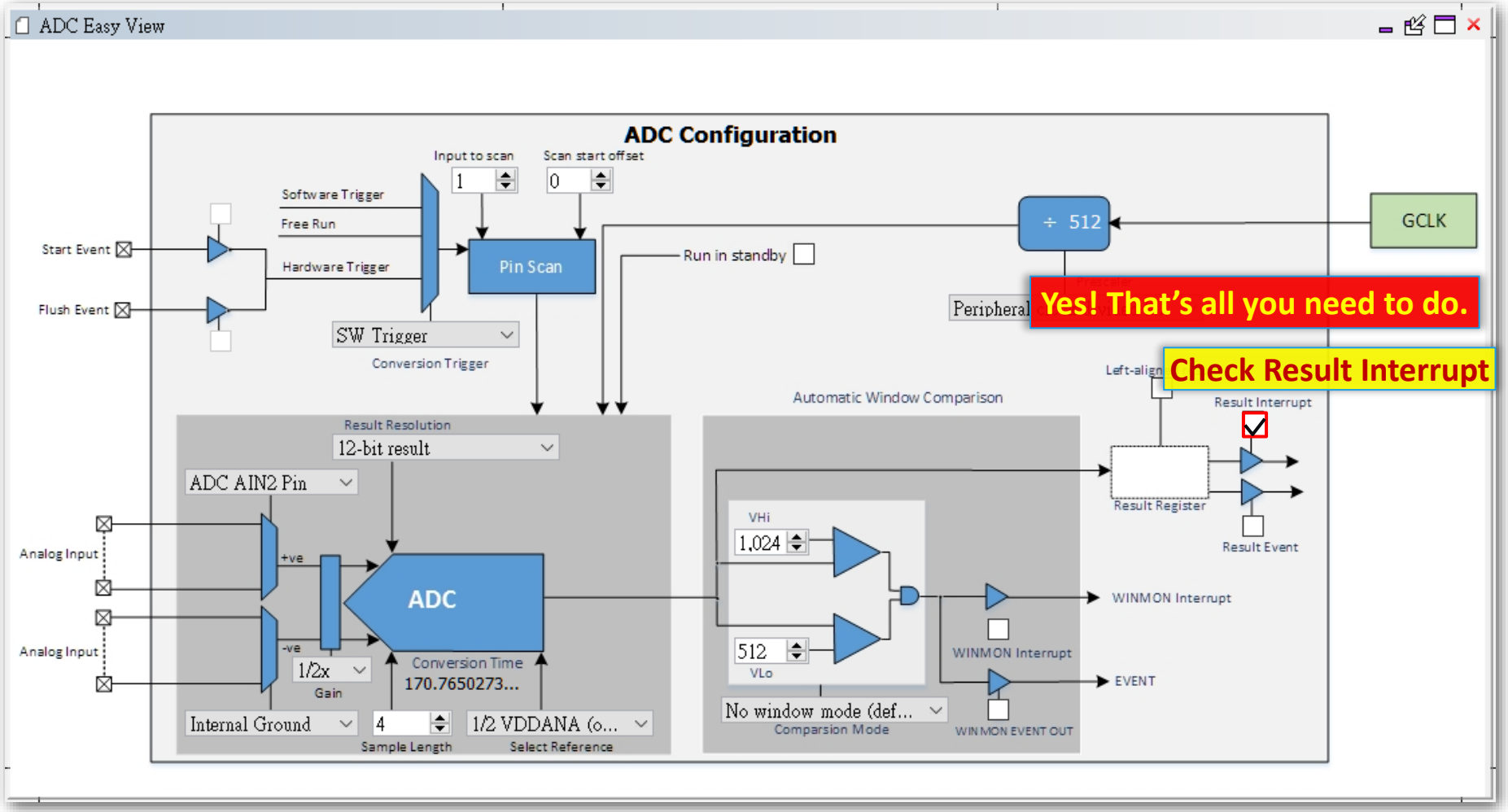
ADC Pin Scan

Easy View Configuration Example



ADC Interrupt

Easy View Configuration Example



ADC Interrupt Callback

Interface Routines

```
/*** ADC Interface Routines***/
void ADC_Initialize( void );
void ADC_Enable( void );
void ADC_Disable( void );
void ADC_ChannelSelect( ADC_POSINPUT positiveInput,  ADC_NEGINPUT negativeInput );
void ADC_ConversionStart( void );
uint16_t ADC_ConversionResultGet( void );
void ADC_ComparisonWindowSet(uint16_t low_threshold, uint16_t high_threshold);
void ADC_WindowModeSet(ADC_WINMODE mode);
void ADC_CallbackRegister( ADC_CALLBACK callback, uintptr_t context );
```

ADC Interrupt Callback

Software Trigger Code Example

```
 …
void ADC_Complete( ADC_STATUS status, uintptr_t context )
{
   if( status & ADC_INTFLAG_RESRDY_Msk )
   {
      myprintf( "%d\r\n", ADC_ConversionResultGet() );
   }
   ADC_ConversionStart();
}

int main (void)
{  …
   ADC_CallbackRegister( ADC_Complete, (uintptr_t )NULL );
   ADC_Enable();
   ADC_ConversionStart();
   while( true )
   {   …
   }
}
```

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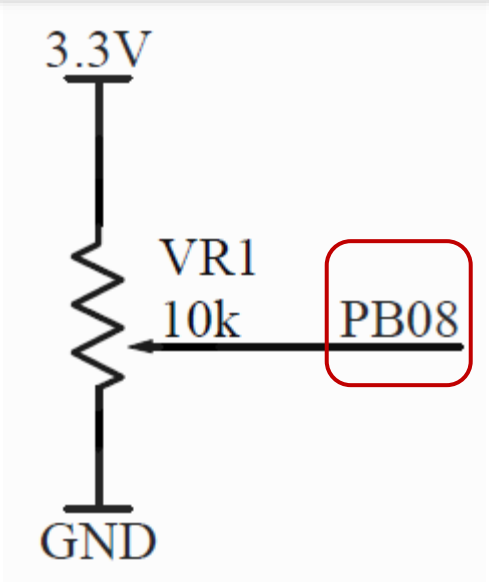
Lab13 ADC Pin Scan

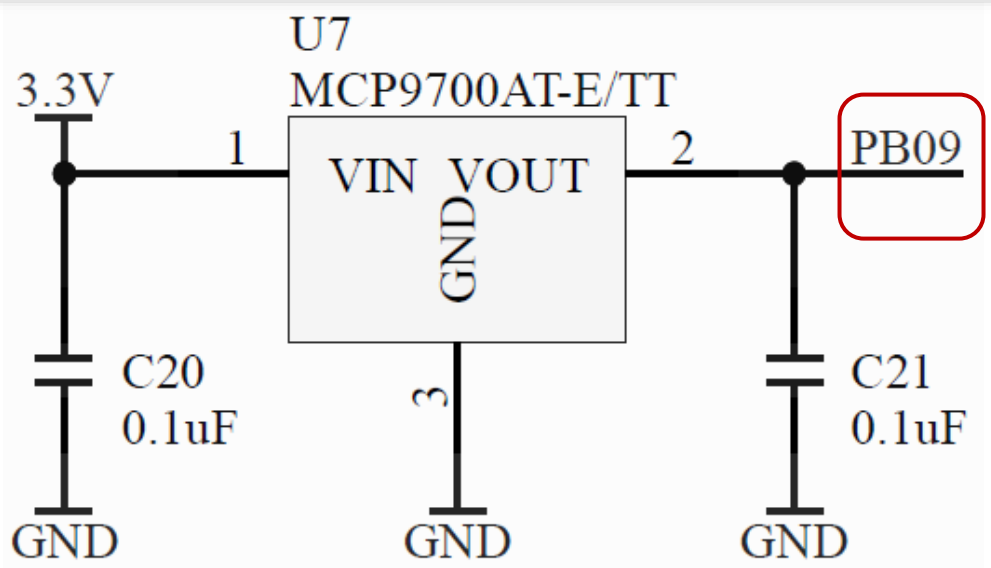
- Change ADC polling to Interrupt callback mode and enable pin scan function.
- Get the ADC conversion value from VR1(AIN[2]) and Analog Temperature Sensor(AIN[3]) with one second period and then use UART to output ADC values to PC.

- Let's go!

Lab13 ADC Pin Scan

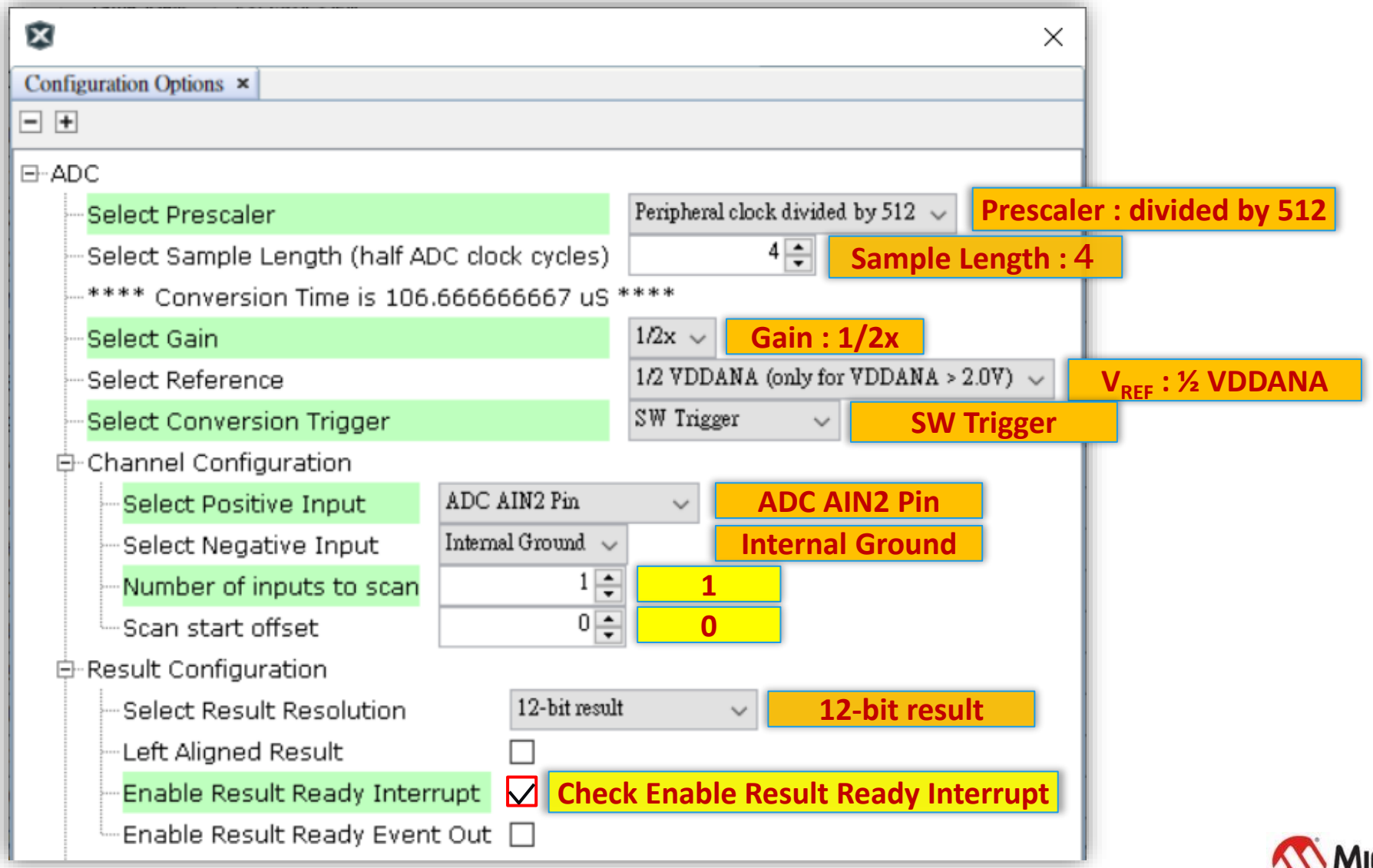
Pin[1]			I/O Pin	Supply	A	B[2][3]				
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC
	7	11	PB08	VDDANA	EXTINT[8]		AIN[2]		Y[14]	
	8	12	PB09	VDDANA	EXTINT[9]		AIN[3]		Y[15]	





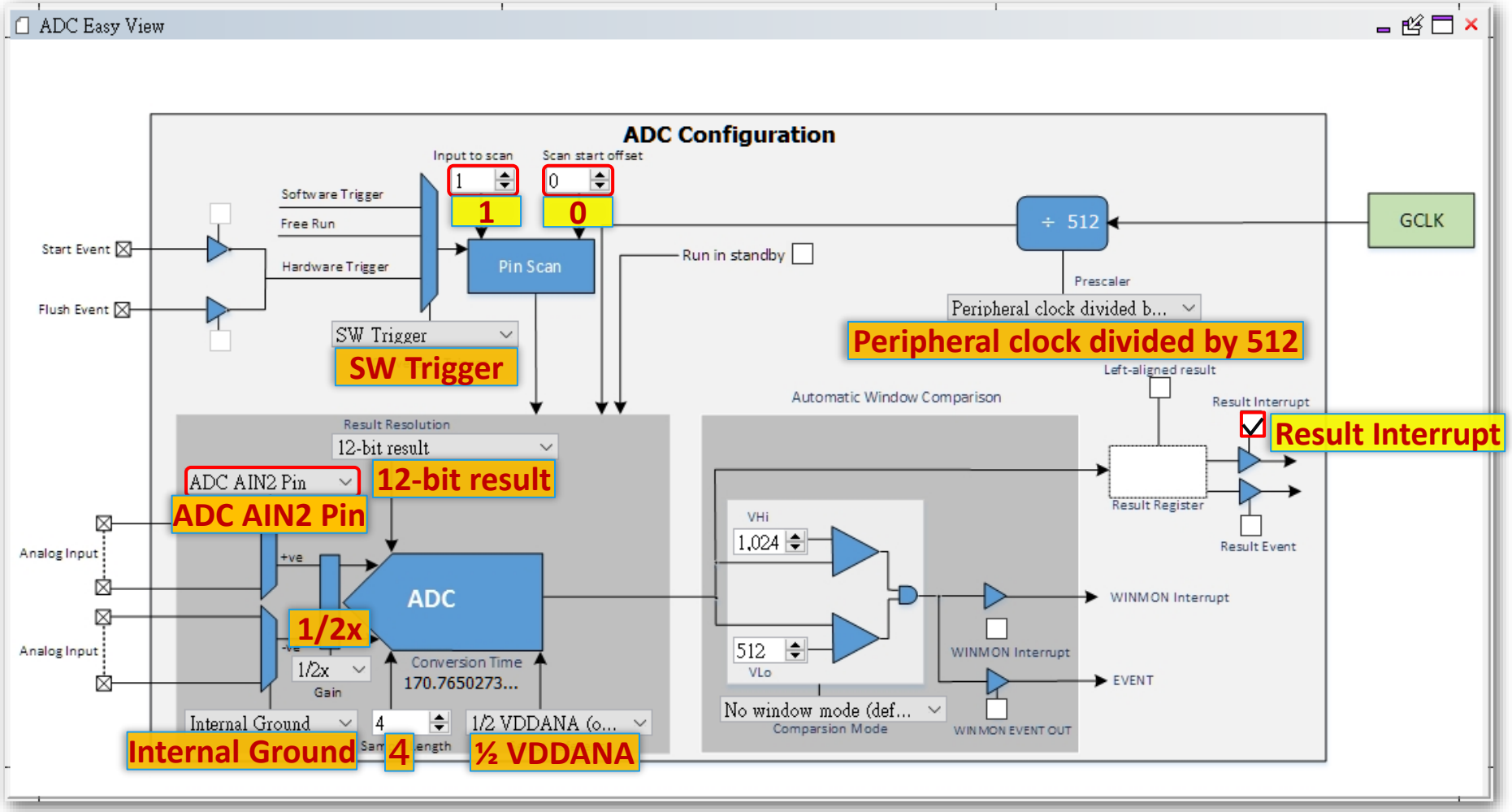
Lab13 ADC Pin Scan

Step 1 (Use Configuration Options)



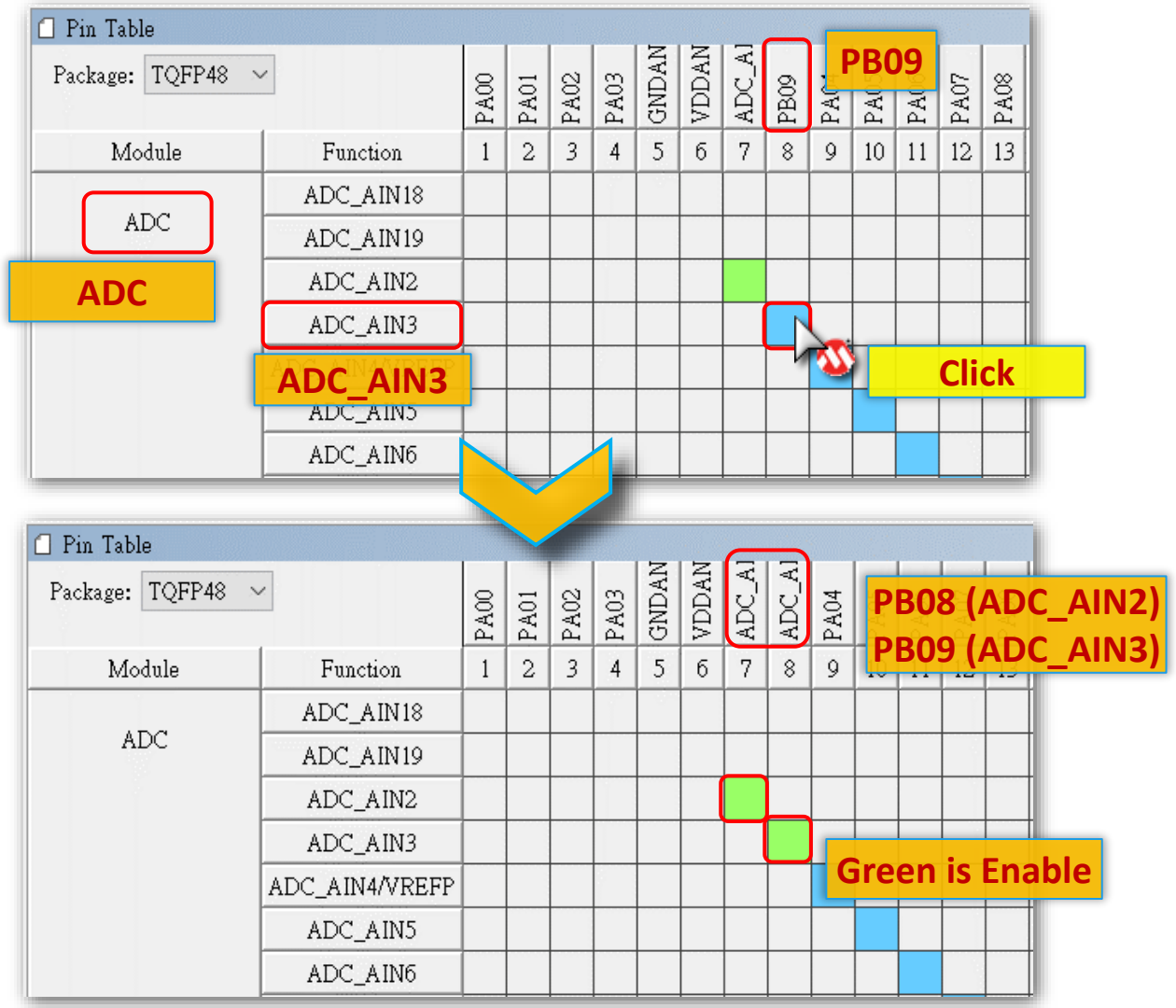
Lab13 ADC Pin Scan

Step 1 (Use Easy View)



Lab13 ADC Pin Scan

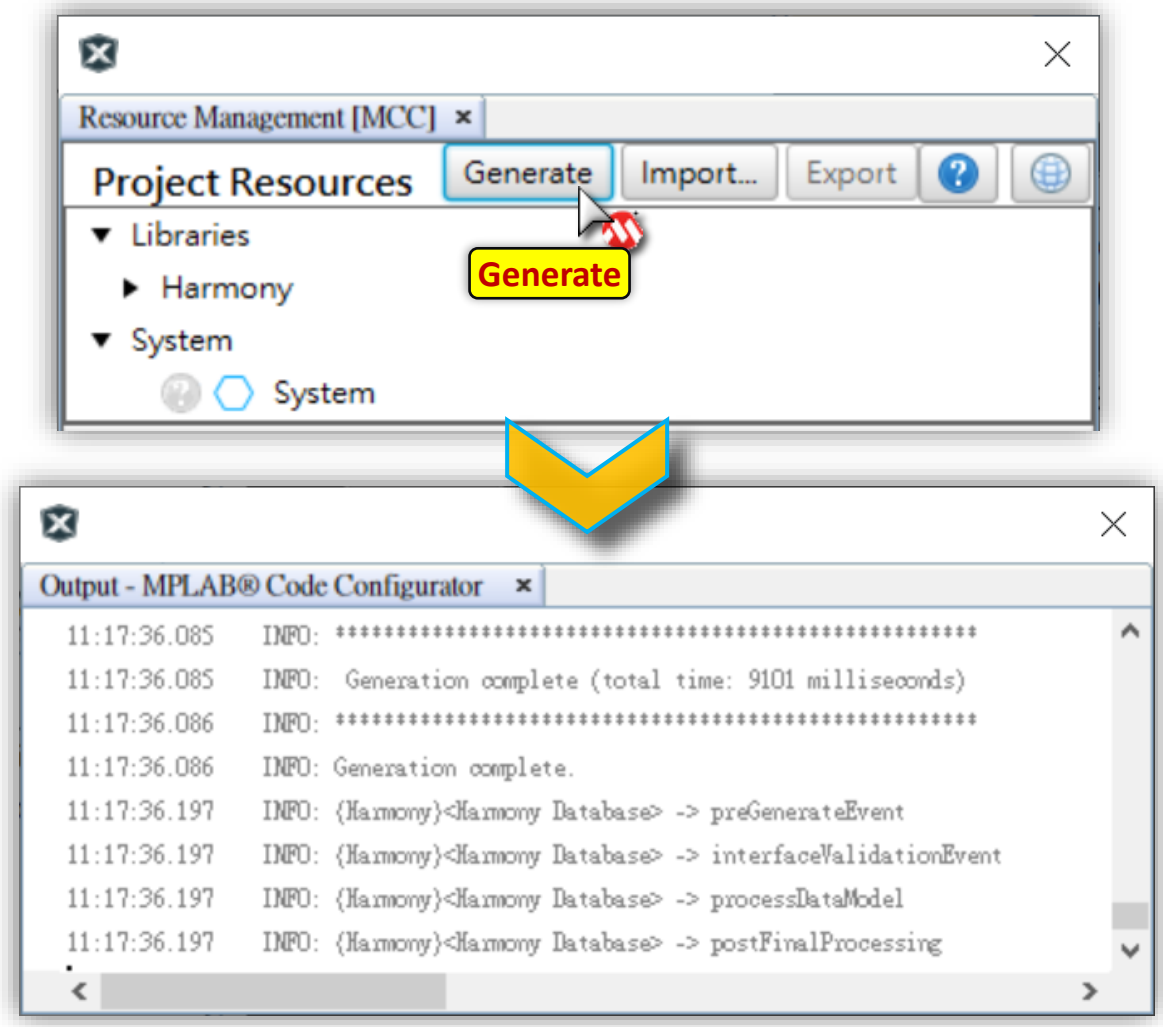
Step 2



Lab13 ADC Pin Scan

Step 3

- Click "Generate" Button to Generate your Code.



Lab13 ADC Pin Scan

Step 4

a. **Add code segment to your main.c**

```
// TODO 13.01
uint16_t ADC_Result[2];
volatile uint8_t ADC_IsCompleted = 0;
volatile int8_t ADC_ChannelIdx = 0;

// TODO 13.02
void ADC_Complete( ADC_STATUS status, uintptr_t context )
{
  if( status & ADC_INTFLAG_RESRDY_Msk )
  {
    ADC_Result[ADC_ChannelIdx] = ADC_ConversionResultGet();
    ADC_ChannelIdx = ( ADC_ChannelIdx + 1 ) % 2;
    if( ADC_ChannelIdx == 0 )
    {
        ADC_IsCompleted = 1;
    }
  }
}
…

int main (void)
{  …
```

Lab13 ADC Pin Scan

Step 5

a **Add code segment to your main.c**

```
…

int main (void)
{
   …

   // TODO 13.03
   ADC_CallbackRegister( ADC_Complete, (uintptr_t )NULL );
   ADC_Enable();

   while( true )
   {
      …
      if( TC3_HasExpired)
      {
         // TODO 13.04
          ADC_ConversionStart();
      }
      …
   }
}
```

Lab13 ADC Pin Scan

Step 6

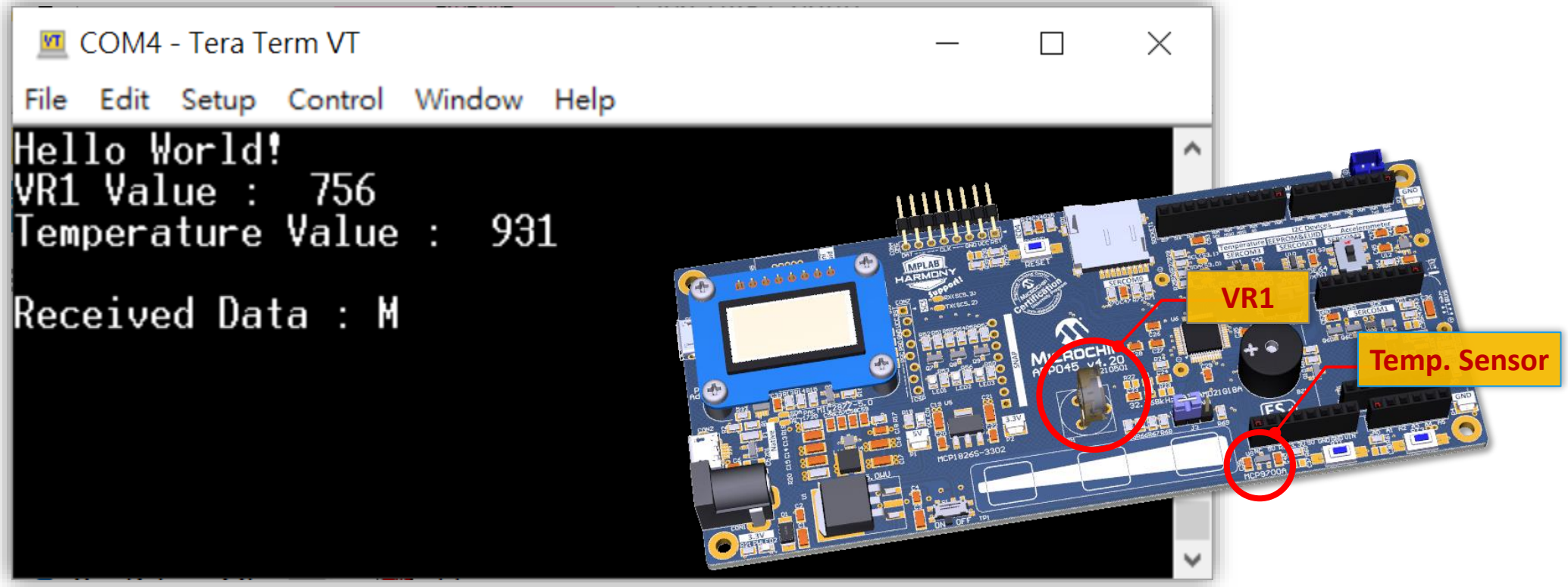
a **Add code segment to your main.c**

```
…

int main (void)
{
   …

   while( true )
   { …

      if( USART5_IsReceived )
      { … }

      // TODO 13.05
       if( ADC_IsCompleted )
       {
         ADC_IsCompleted = 0;

         myprintf( "\033[2;1HVR1 Value : %4d", ADC_Result[0] );
         myprintf( "\033[3;1HTemperature Value : %4d", ADC_Result[1] );
       }
   }
}
```

Lab13 ADC Pin Scan

Result

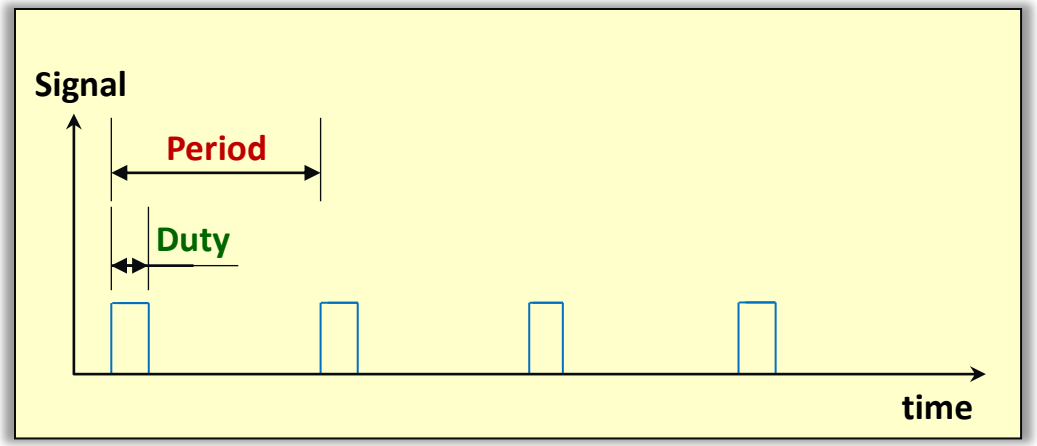
- **"Hello World!!" string and VR1 / Temperature Sensor ADC value will output to terminal with one second period.**



TCC – PWM Architecture

What's PWM

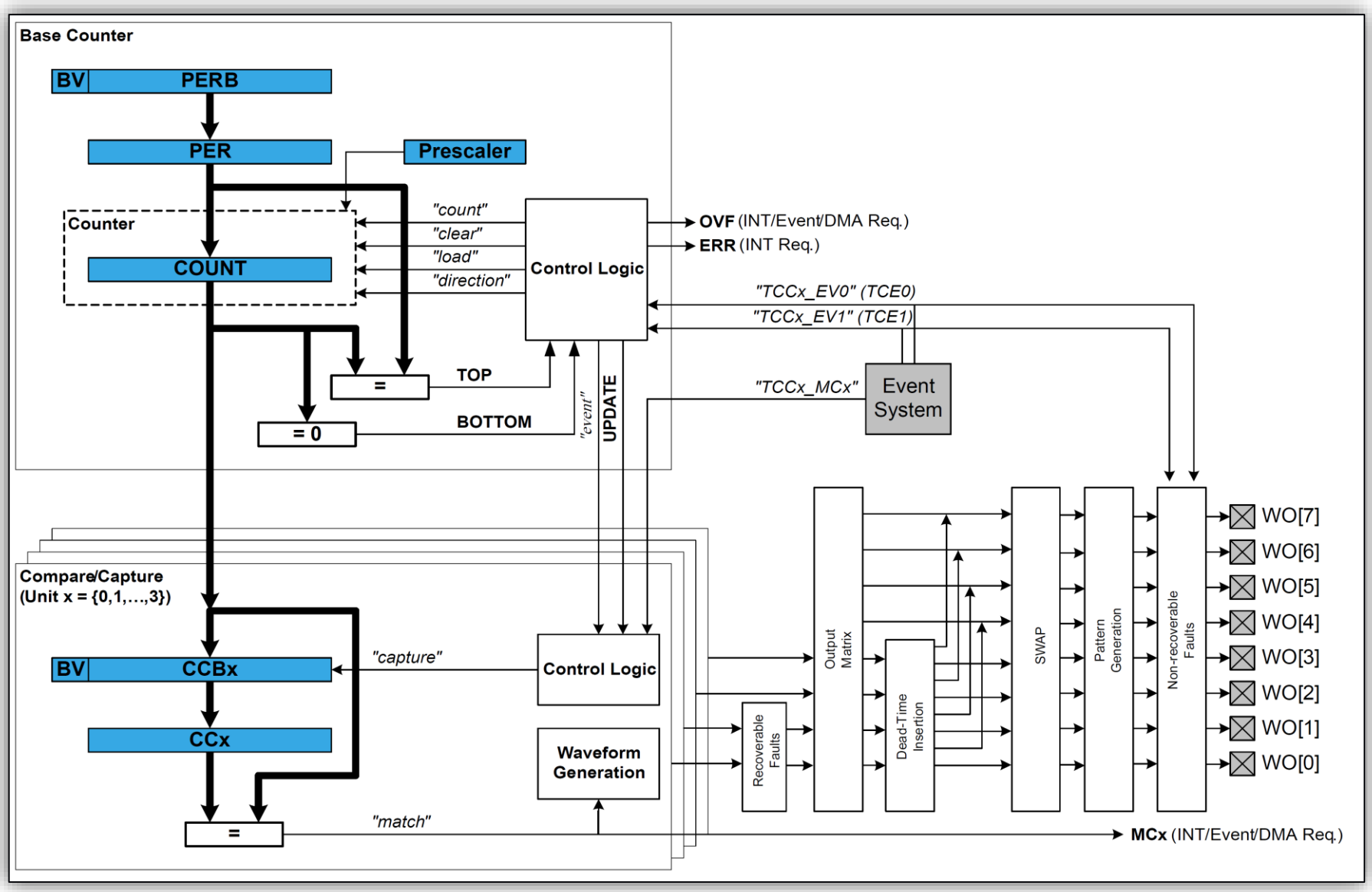
- The Pulse-width modulation (PWM) Waveform is a modulation technique used to encode a message into a pulsing signal.
- Its main use is to allow the control of the power supplied to electrical devices, ex. motor control, ballast, LED, H-bridge, power converters, and other types of power control applications.
- There have two important terms
  - **Period** :
    The single square wave duration.
  - **Duty** :
    The proportion of active time to the regular interval



SAMD21 TCC

- **Timer/Counter for Control, TCC is the TC Enhanced version.**
- **TCC provide below feature**
  - Up to four compare/capture channels
  - Waveform (PWM, Frequency generation)
  - Input capture (Event, Frequency, PWM Capture)
  - Fault protection for safe disabling
  - 3 input Event, 3 output Event
  - Support Interrupt, DMA, Event

TCC Block Diagram



TCCx, Channel and WO[x]

- **TCCx : Timer Counter for Control peripheral**
  - TCC0, TCC1, TCC2

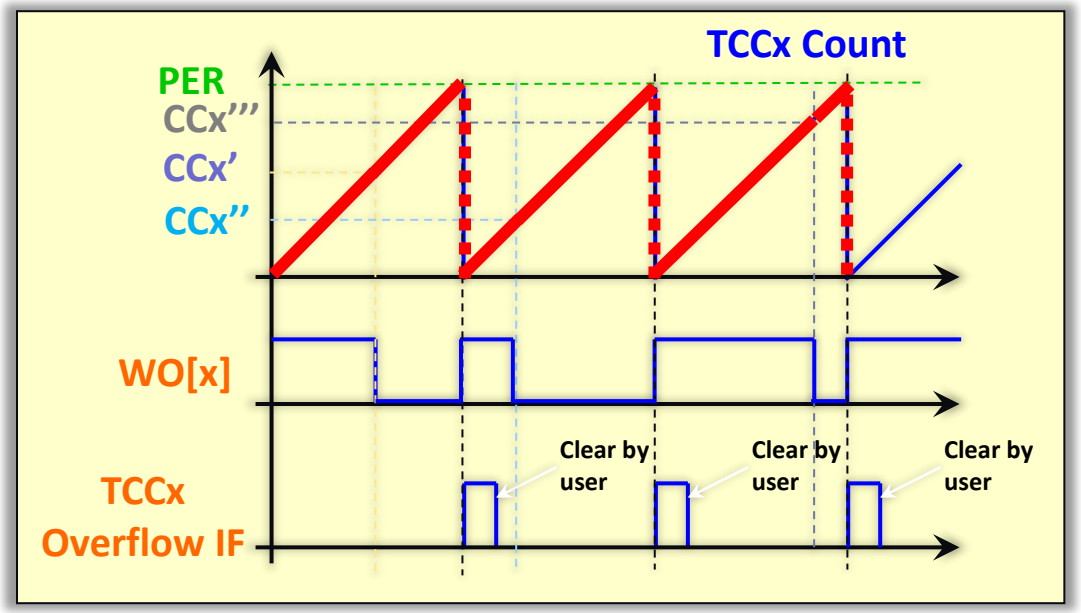
- **Channel : Compare Channel CCx**
  - TCC0 : 4 channel
  - TCC1 : 2 channel
  - TCC2 : 2 channel

- **WO[x] : Waveform Output Pins**
  - TCC0 : 8 pins ➔ WO[0] ~ WO[7] ➔ Channel [0, 1, 2, 3, **0, 1, 2, 3**]
  - TCC1 : 4 pins ➔ WO[0] ~ WO[3] ➔ Channel [0, 1, **0, 1**]
  - TCC2 : 2 pins ➔ WO[0] ~ WO[1] ➔ Channel [0, 1]

Normal Pulse-Width Modulation

NPWM Mode

- **For Normal Pulse-Width Modulation , the period time (T) is controlled by the PER register. WO[x] is set at start and cleared on compare match.**



Rule

1.TCCx Counter == CCx -> WO[x] Clear to low

2.TCCx Counter == PER -> WO[x] Set to high

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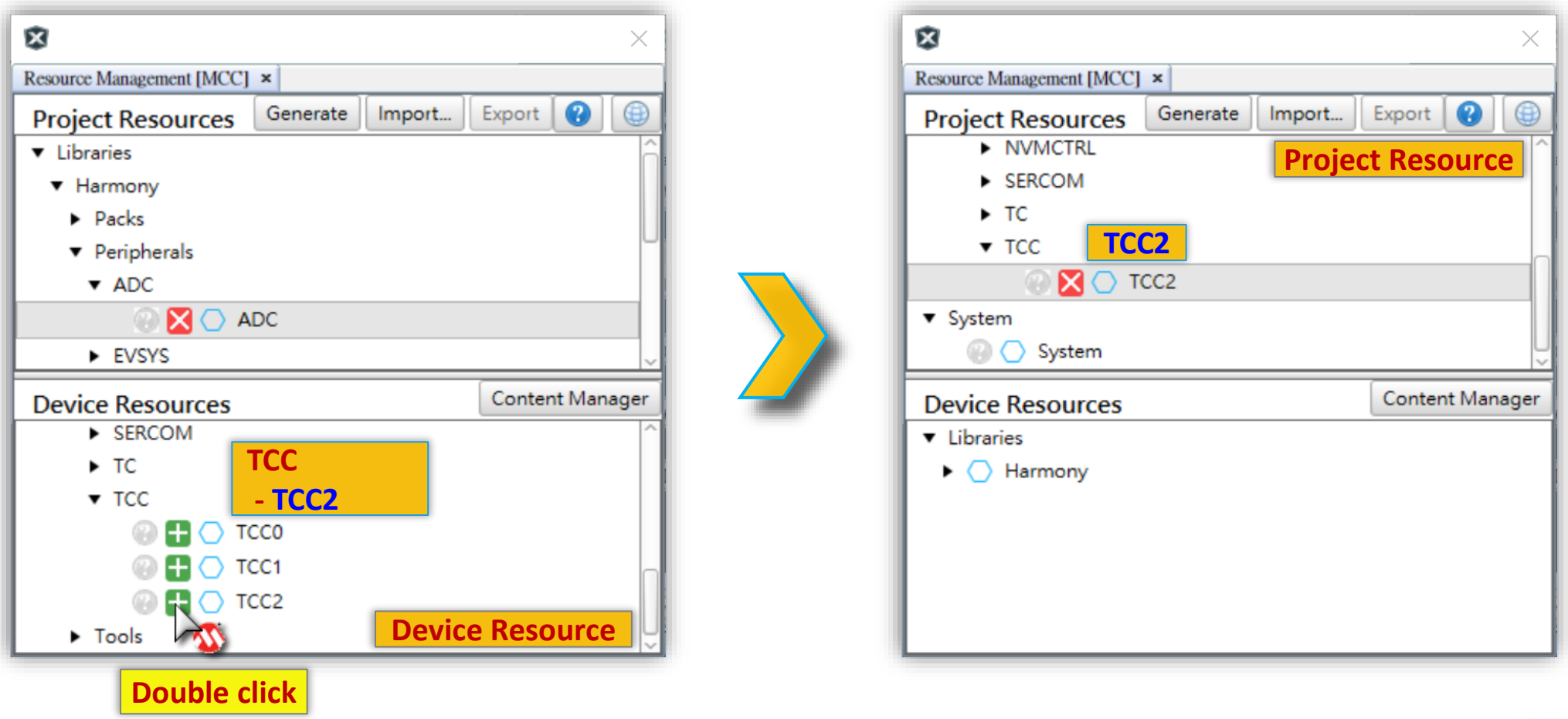
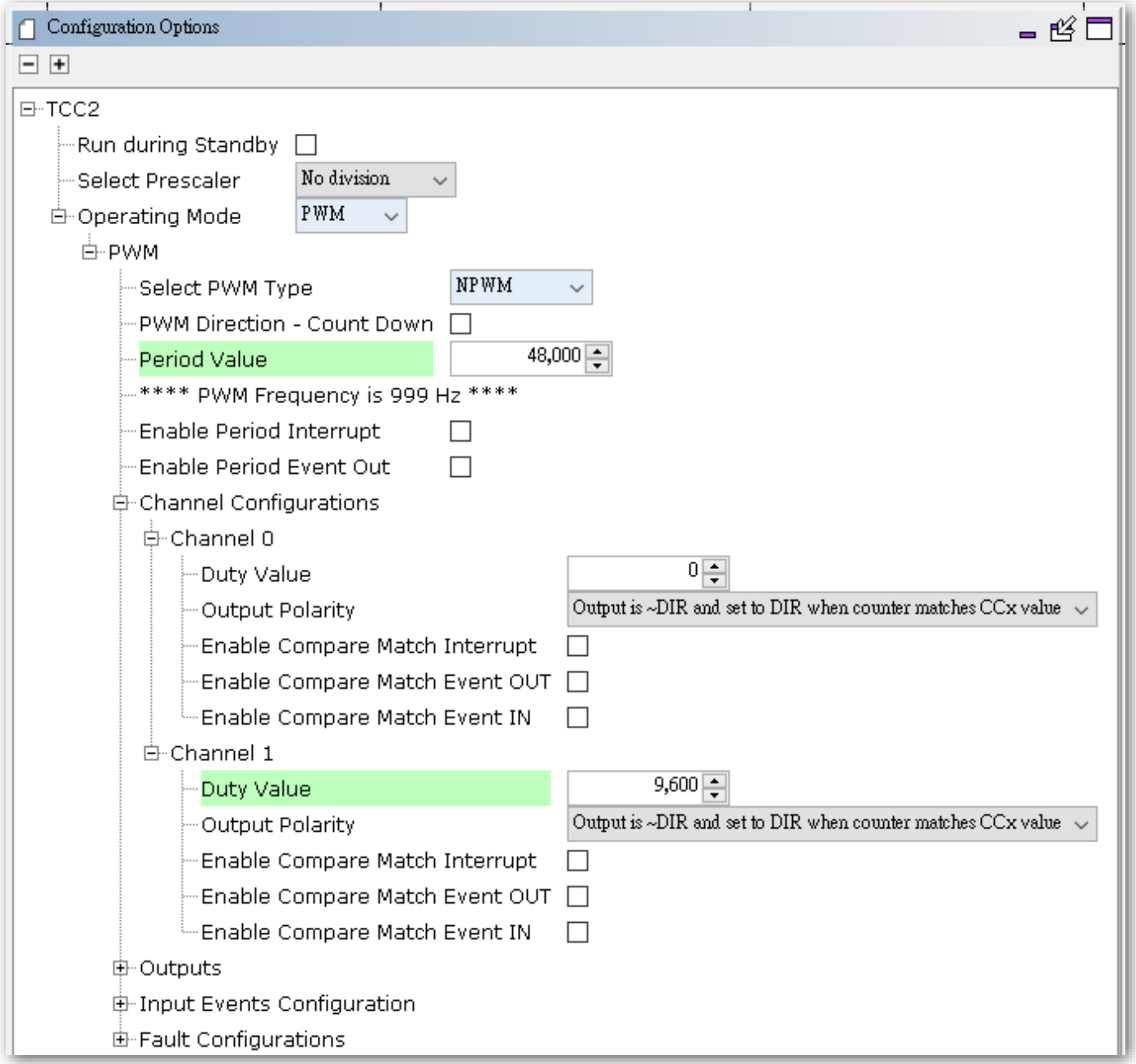
Add TCC Function using MCC Harmony

- Find TCC component in Device Resource window.
- Double click TCC2 to add to Project Resource window.



TCC Configuration Options Example



TCC PMUX Configuration Example

- **TCC could output waveform to corresponds pins of different channel.**
- **For example :**

  PA17 as TCC2/WO[1] (TCC2 Channel 1) or

  TCC0/WO[7] (TCC0 Channel 3)

Pin(1)			I/O Pin	Supply	A	B(2)(3)					C	D	E	F	G	H
SAMD21E	SAMD21G	SAMD21J			EIC	REF	ADC	AC	PTC	DAC	SERCOM(2)(3)	SERCOM-ALT	TC(4) /TCC	TCC	COM	AC/ GCLK
18	26	PA17	PA17	VDDIO	EXTINT[1]				X[5]		TCC2/WO[1]		TCC2/WO[1]	TCC0/WO[7]	TCC0/WO[7]	

PA17

Pin Table

Package: TQFP48

Module	Function	PA10 15	PA11 16	VDDIO 17	GNDIO 18	PB10 19	PB11 20	PA12 21	PA13 22	GCLK_I 23	GCLK_I 24	PA16 25	TCC2_W 26
TCC2	TCC2_WO0												
	TCC2_WO1												

TCC2 TCC2/WO[1]

PA17

Pin Table

Package: TQFP48

Module	Function	PA10 15	PA11 16	VDDIO 17	GNDIO 18	PB10 19	PB11 20	PA12 21	PA13 22	GCLK_I 23	GCLK_I 24	PA16 25	TCC0_W 26
TCC0	TCC0_WO6												
	TCC0_WO7												

TCC0 TCC0/WO[7]

MICROCHIP

TCC Polling

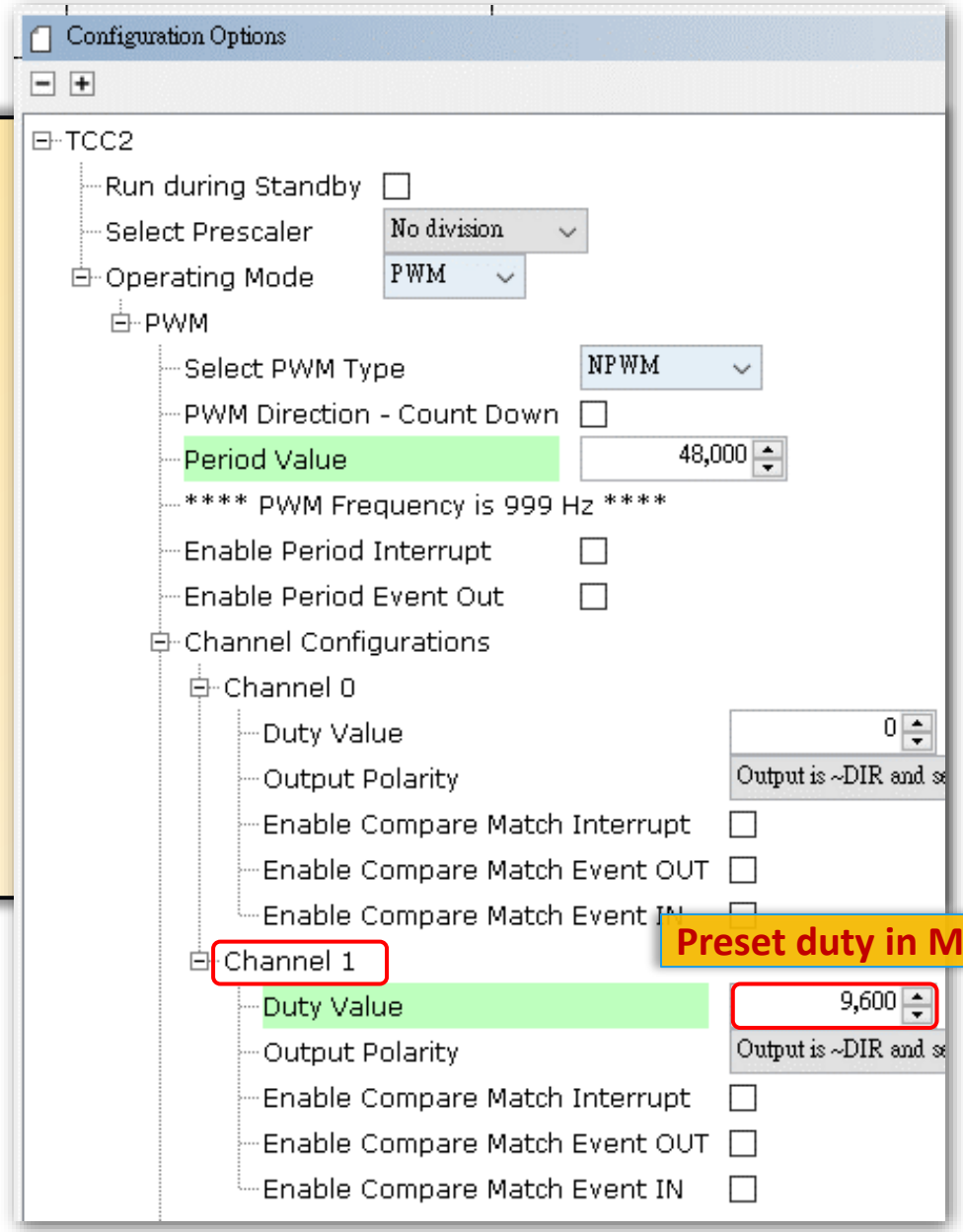
Interface Routines

```
void TCC2_PWMInitialize(void);
void TCC2_PWMStart(void);
void TCC2_PWMStop(void);
void TCC2_PWMForceUpdate(void);
void TCC2_PWMPeriodInterruptEnable(void);
void TCC2_PWMPeriodInterruptDisable(void);
uint32_t TCC2_PWMInterruptStatusGet(void);
void TCC2_PWM16bitPeriodSet(uint16_t period);
uint16_t TCC2_PWM16bitPeriodGet(void);
void TCC2_PWM16bitCounterSet(uint16_t count);
__STATIC_INLINE void TCC2_PWM16bitDutySet(TCC2_CHANNEL_NUM channel, uint16_t duty);
```

TCC Polling Code Example

```
...

int main (void)
{
   SYS_Initialize ( NULL );
   ...
   TCC2_PWMStart();
   TCC2_PWM16bitDutySet( 1, 9600 );

   while( true )
   {
      ...
   }
}
```

Runtime update duty Channel 1, Duty 9600



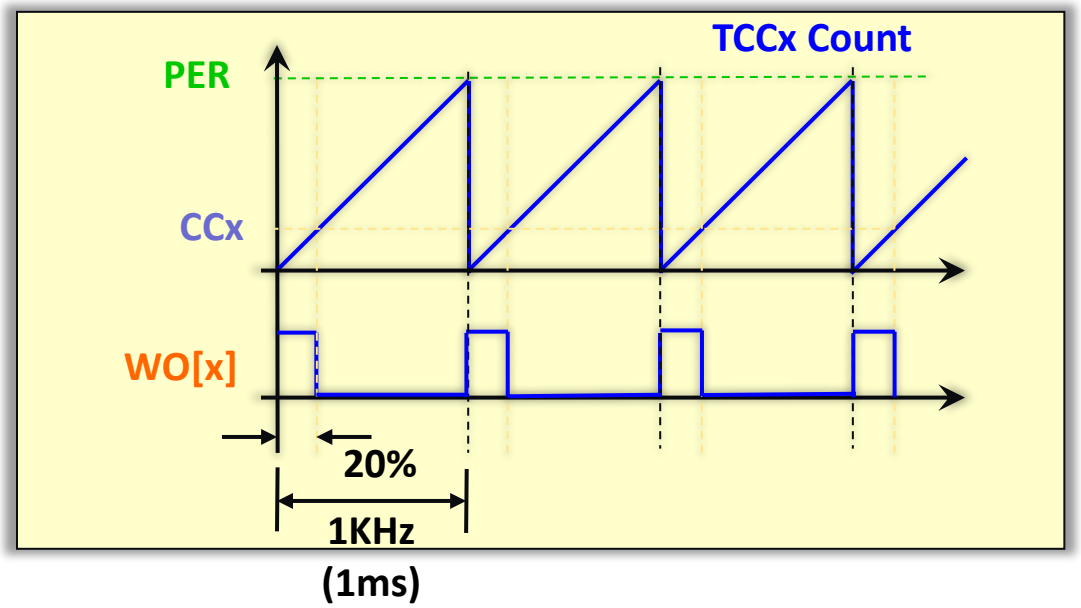
Preset duty in MCC Harmony

MICROCHIP

Lab14 TCC NPWM

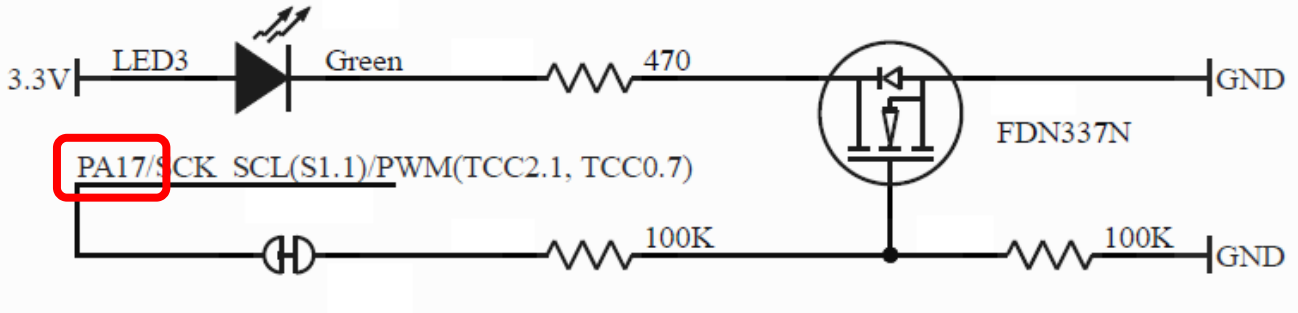
- Add TCC2 NPWM Mode (Single Slope PWM) function to your project.
- Disable LED3(PA17) GPIO function firstly.
- Configure TCC2 to output PWM waveform to LED3(PA17).
- PWM frequency is 1KHz with 20% Duty.

- Let's go!

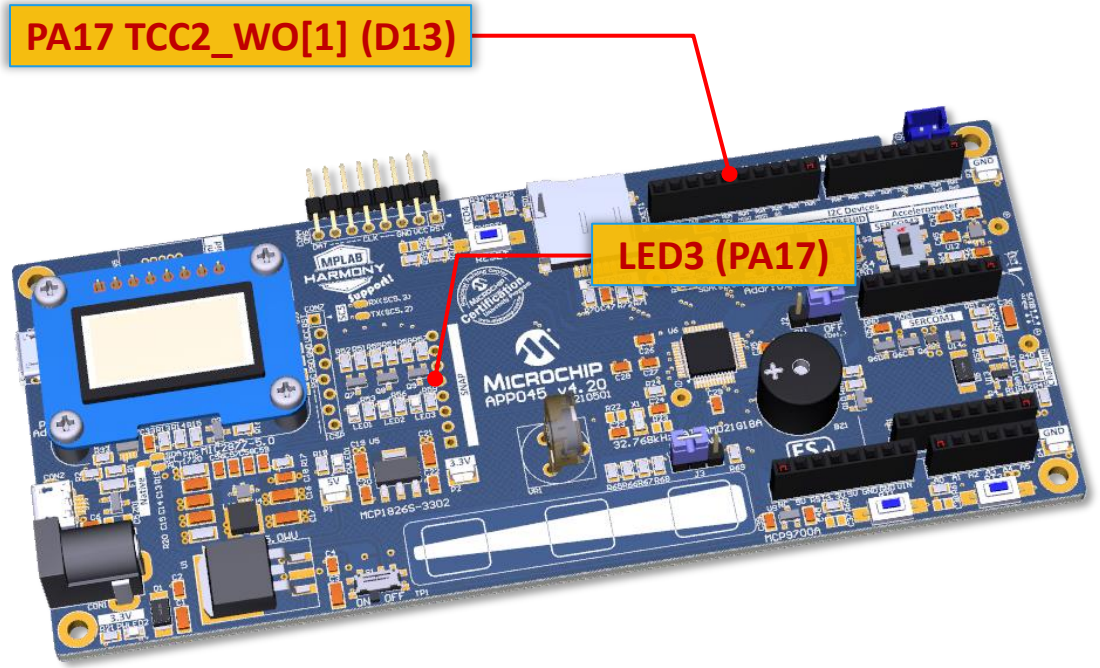


Lab14 TCC NPWM

PA19	27	PA18
PA18	26	PA17
PA17	25	PA16
PA16		



	Arduino UNO Socket
PA06 15	D8
PA07 16	D9/PWM
PA18 17	D10/PWM/SS
PA16 18	D11/PWM/MOSI
PA19 19	D12/MISO
PA17 20	D13/SCK
21	

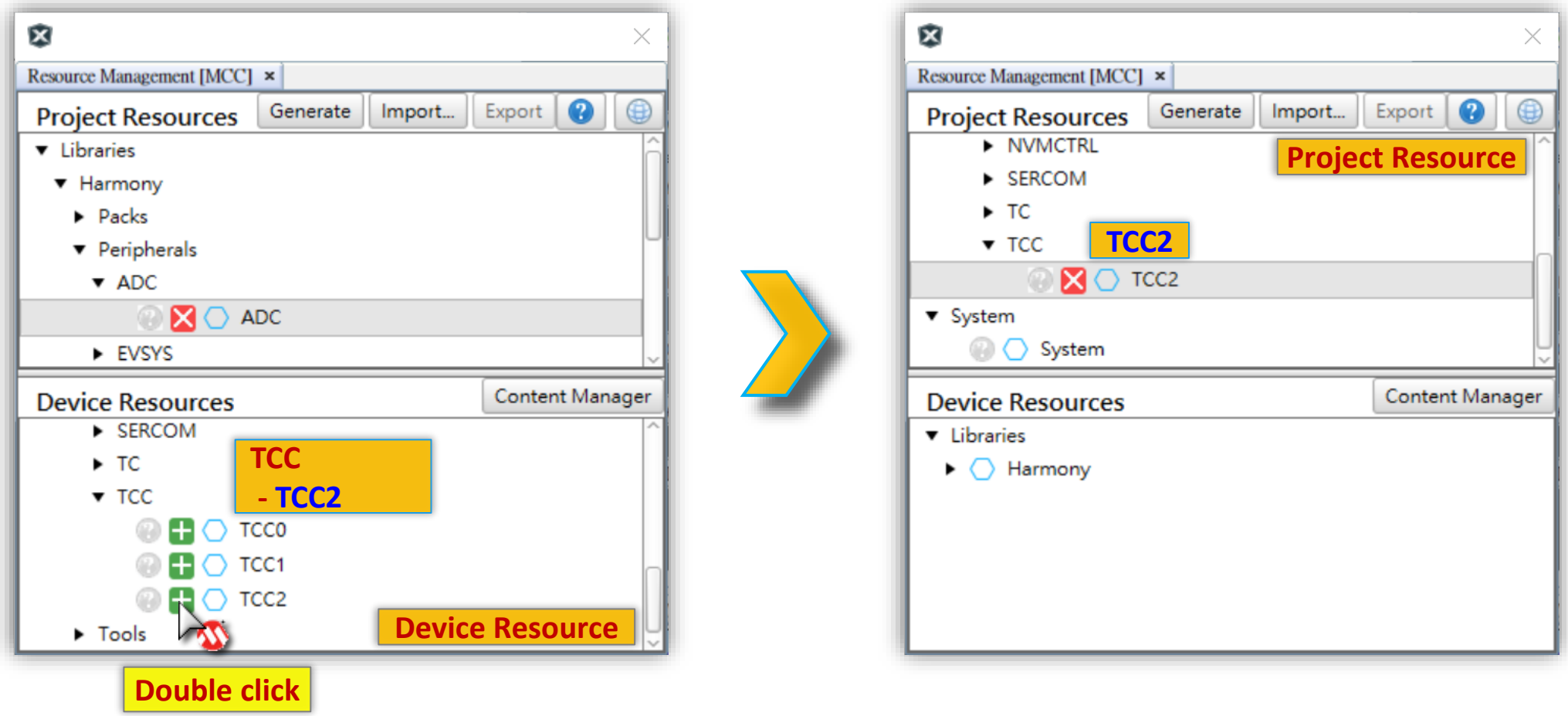


MICROCHIP

Lab14 TCC NPWM

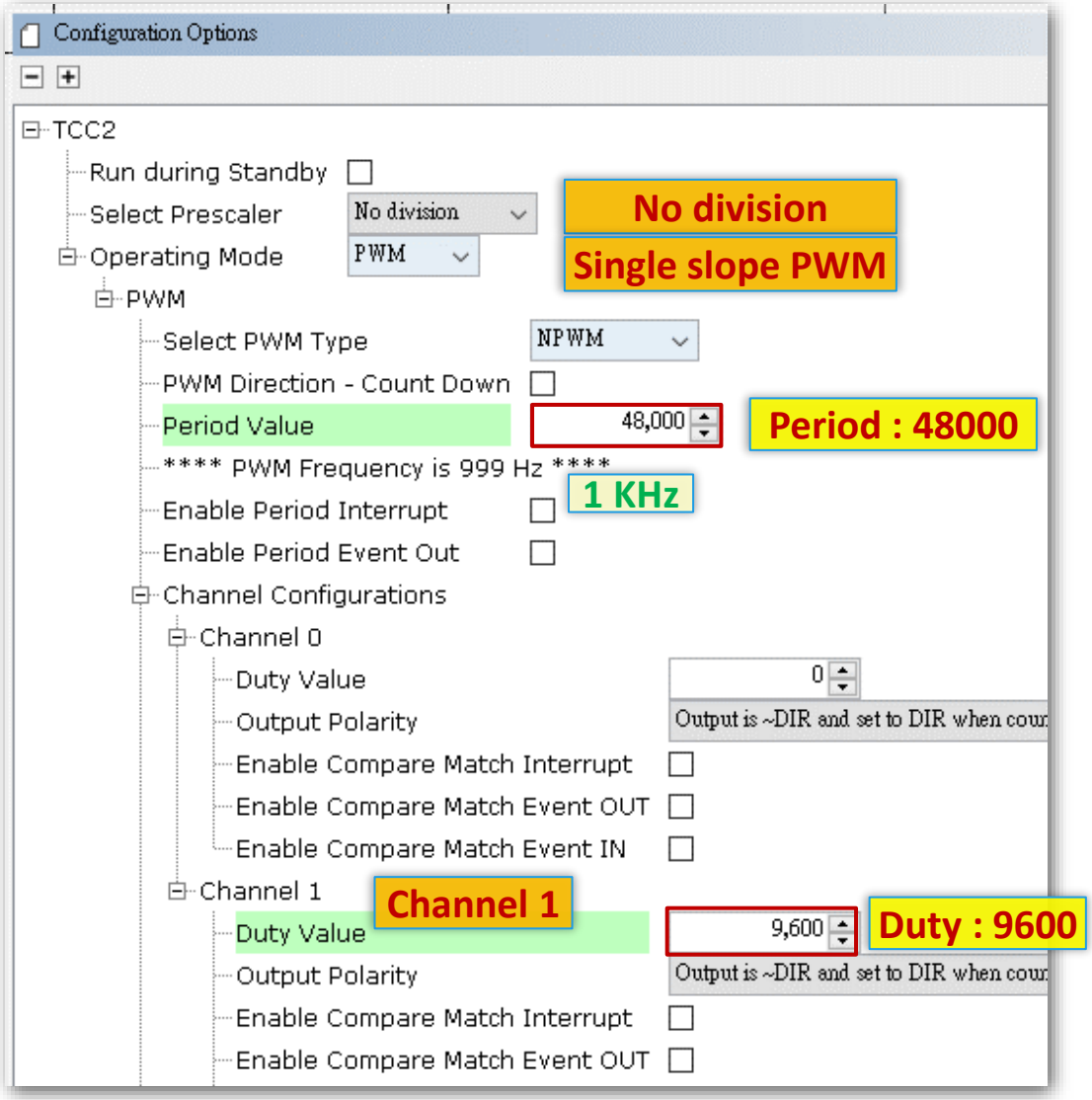
Step 1

- Find TCC component in Available Components window.
- Double click TCC2 to add to Active Components window.



Lab14 TCC NPWM

Step 2



System Clock = 48MHz

One second counts of system clock :

48,000,000 counts

One second counts after Prescaler :

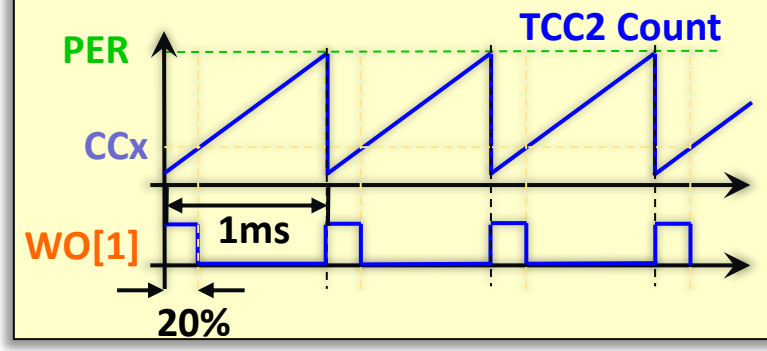
48000000 / 1 48,000,000 counts

1ms counts for LAB14 period target :

48000000 / 1000 48,000 counts

1/5ms counts for LAB14 duty target :

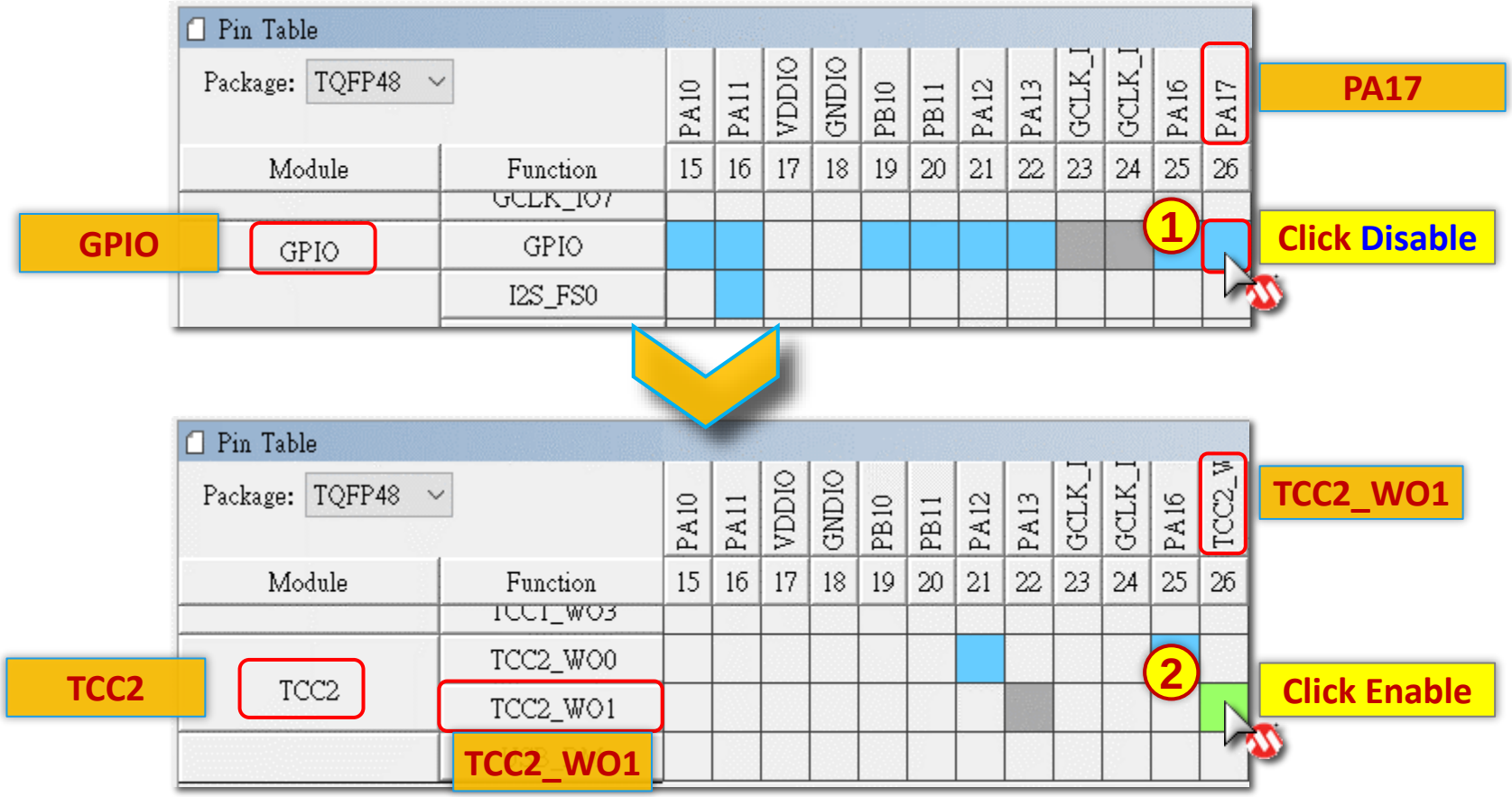
48000 / 5 9,600 counts



Lab14 TCC NPWM

Step 3

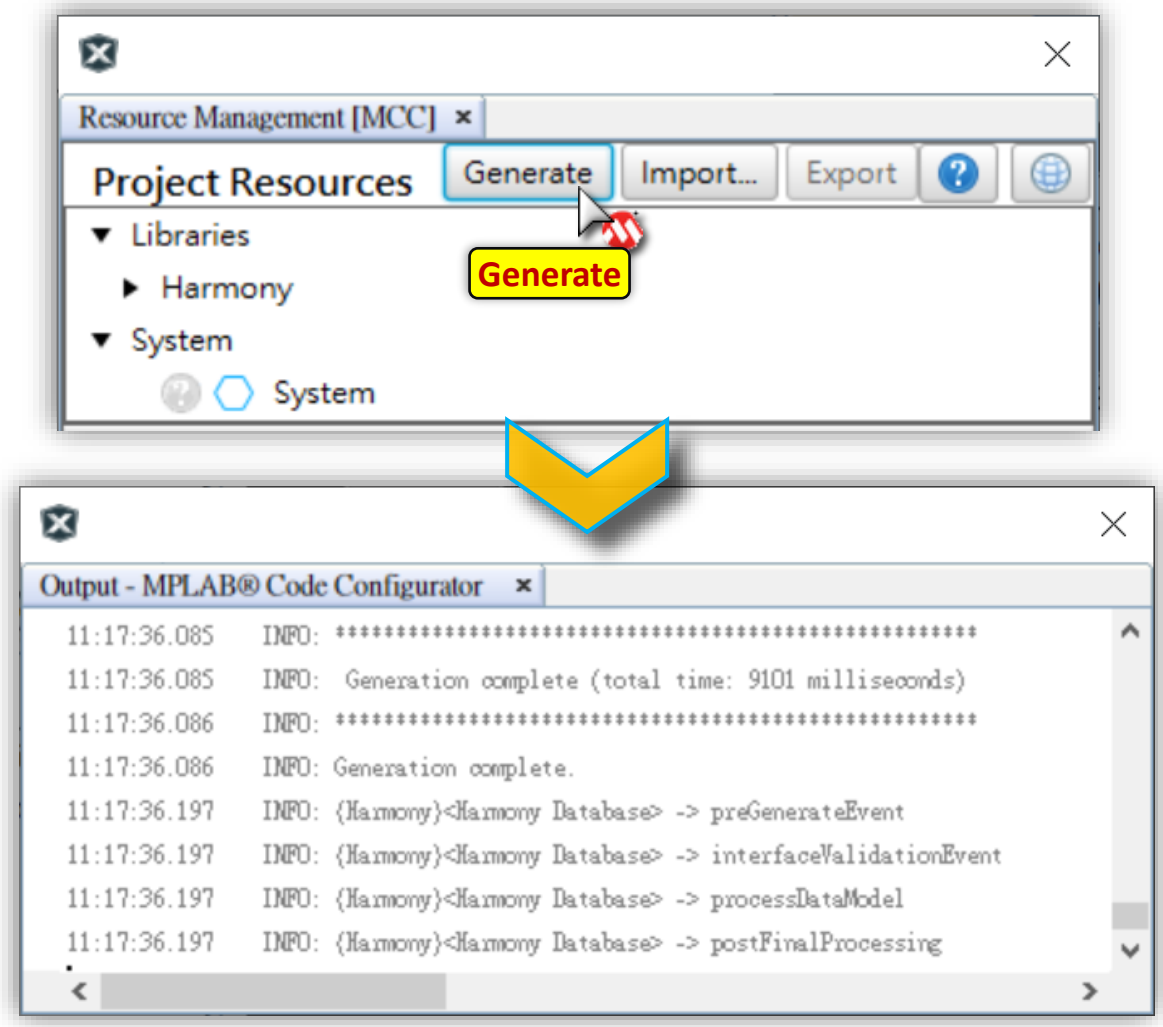
- **Disable LED3(PA17) GPIO function firstly.**
- **Enable TCC2 Waveform Output 1 (TCC2_WO1).**



Lab14 TCC NPWM

Step 4

- Click "Generate" Button to Generate your Code.



Lab14 TCC NPWM

Step 5

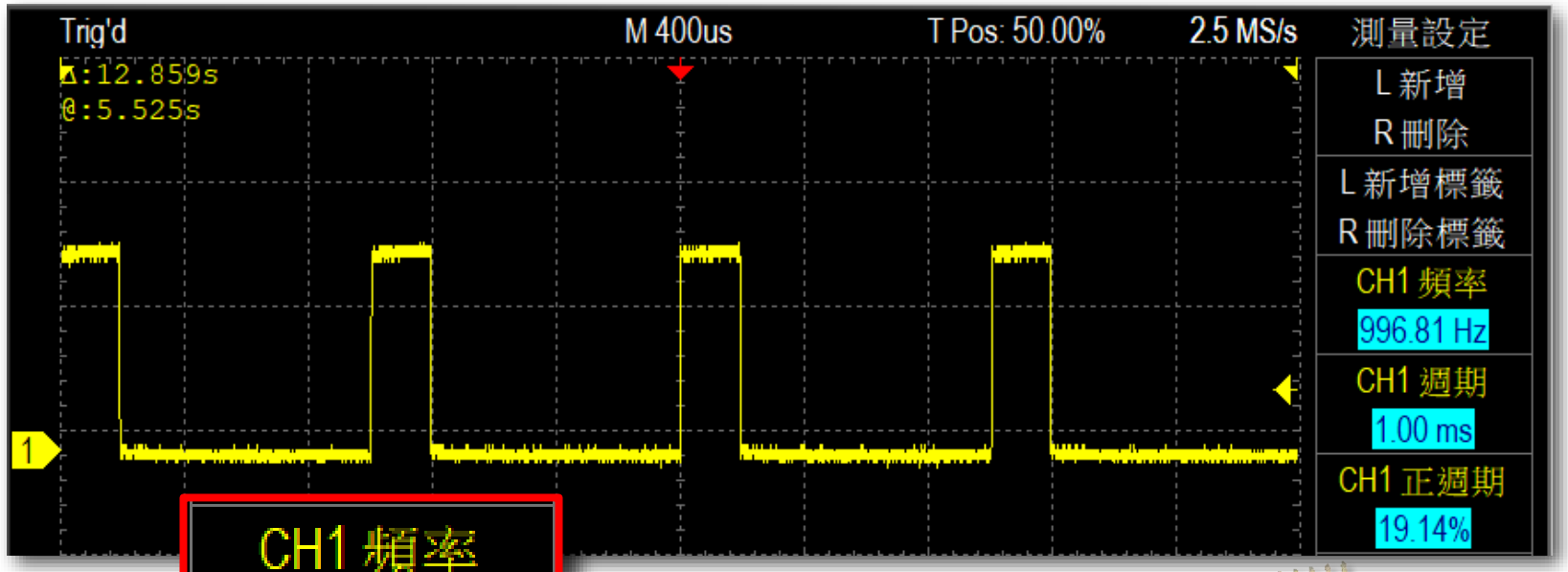
a **Add code segment to your main.c**

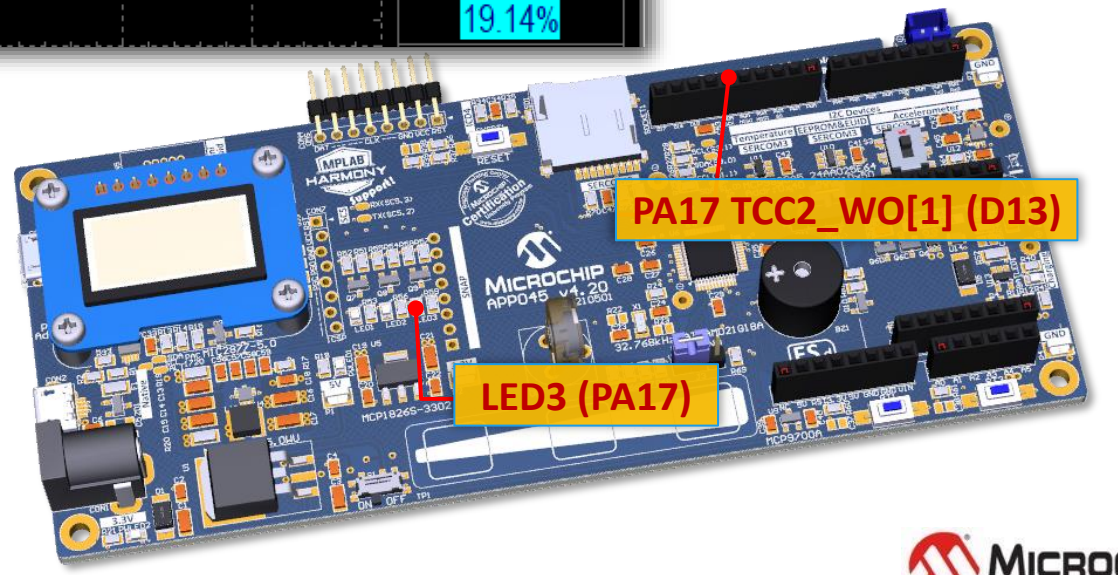
```
…

int main (void)
{
   …

   // TODO 14.01
   TCC2_PWMStart();

   while( true )
   {
      …
   }

}
```

b **Program firmware to target board then observe result.**

Lab14 TCC NPWM

Result

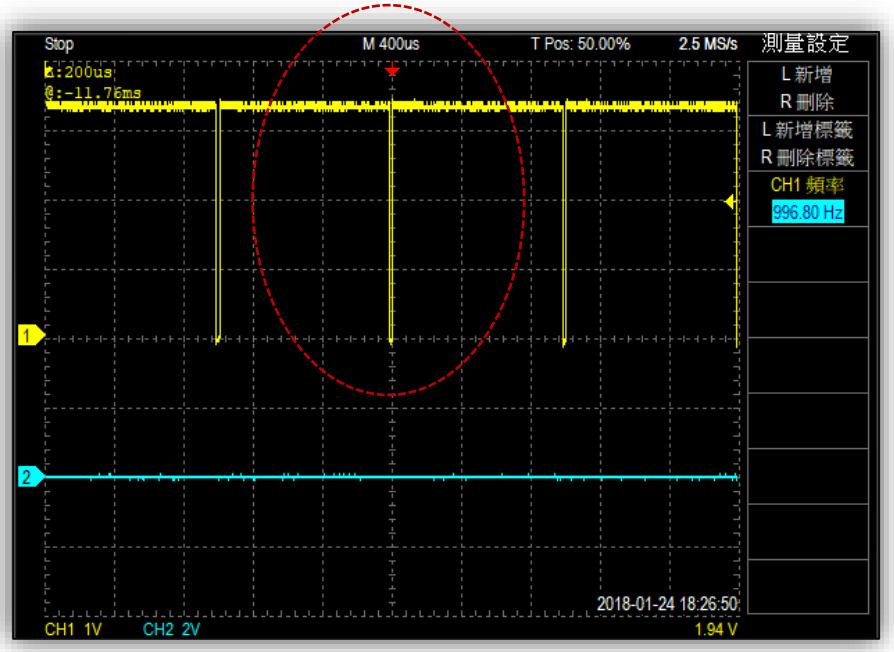




100% Duty Issue

- How to generate 100% duty PWM ?
  - Rule Review
    1.TCCx Counter = CCx -> Output Set to low
    2.TCCx Counter = PER -> Output Set to high
- This means CCx = PER must be set for 100% duty output.
  Which rule be executed ?
  - Result : Glitch !
- To prevent this issue,
  set CCx > PER for 100% duty.

```
if( DutyValue >= PER ) /* 100% duty */
    TCC2_PWM16bitDutySet( 1, PER + 1 );
else
    TCC2_PWM16bitDutySet( 1, DutyValue );
```



Lab15 TCC NPWM ADC Duty Control

- **Use VR1 to adjust TCC2 PWM duty for LED3 dimming control.**
  - VR1 ADC Value = 0 -> TCC2 PWM Duty 0%
  - VR1 ADC Value = 4095 -> TCC2 PWM Duty 100%

```
if( ADC_IsCompleted )
{
   ADC_IsCompleted = 0;

   // TODO 15.01
   if (ADC_Result[0] >= 4095)
     TCC2_PWM16bitDutySet( 1, TCC2_PWM16bitPeriodGet()+1 );
   else
     TCC2_PWM16bitDutySet( 1, (uint32_t)ADC_Result[0] * TCC2_PWM16bitPeriodGet()/4095 );
  ...
}
```

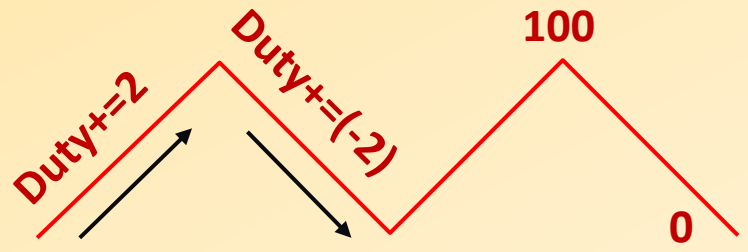
TCC2_ PWM_Peroid = 48000
ADC_Result[0] = 0 ~ 4095
ADC Result[0] / 4095 = 0.0 ~ 1.0
ADC_Result[0] * TCC2_ PWM_Peroid / 4095 = 0 ~ 48000

MICROCHIP

Lab16 TCC NPWM Auto Duty Control

- Use Timer(TC4) to control PWM duty for breathing light effect on LED3.
  Duty change interval 50ms with stepping 2% ~ 5%.
  (Duty 0% -> Duty 100% -> Duty 0% -> … repeat)

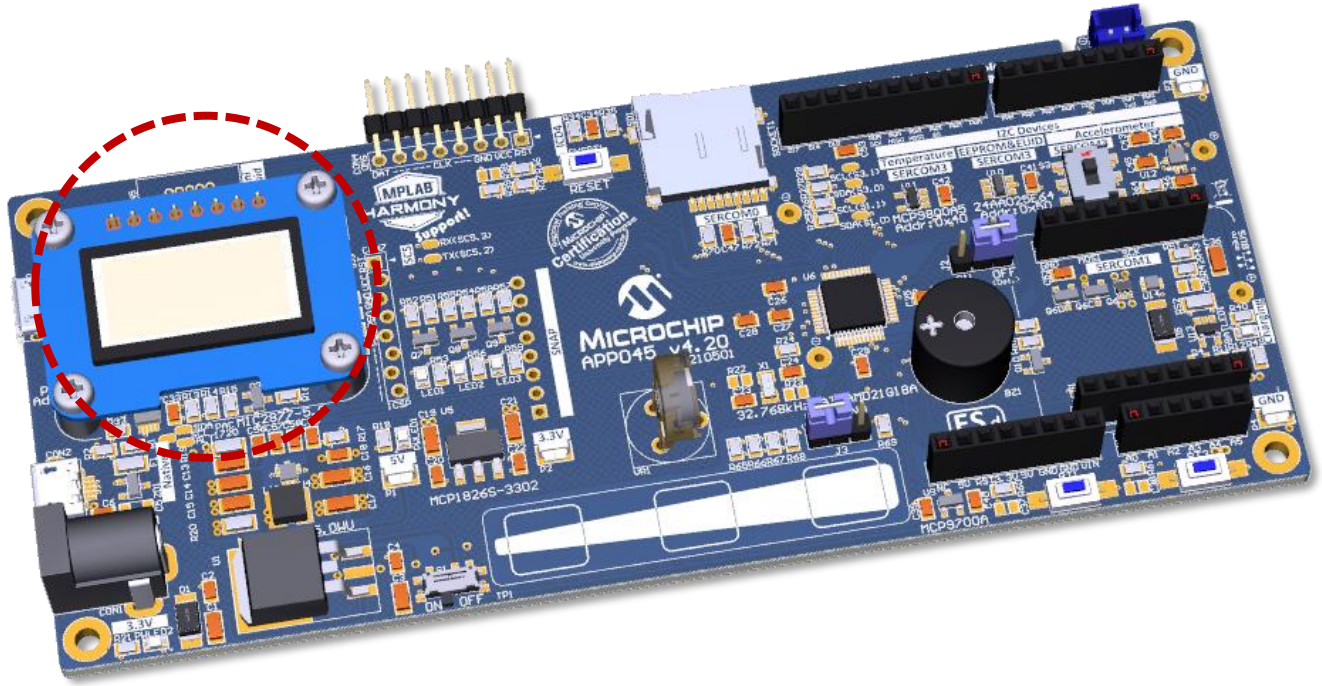
```
// TODO 16.01
uint8_t Duty = 50;
int8_t DutyDistance = 2;

int main (void)
{  …
   if (TC4_HasExpired)
   {
      TC4_HasExpired = 0;
      // TODO 16.02
      Duty += DutyDistance;
      if (Duty >= 100 || Duty <= 0)
        DutyDistance = -DutyDistance;

      if (Duty >= 100)
        TCC2_PWM16bitDutySet( 1, TCC2_PWM16bitPeriodGet() + 1 );
      else
        TCC2_PWM16bitDutySet( 1, ((uint32_t)Duty * TCC2_PWM16bitPeriodGet()) / 100 );
      …
```



SERCOM-SPI (OLED SSD1306)

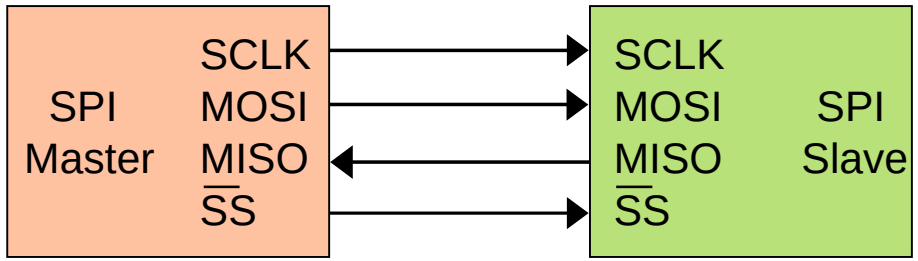
OLED Graphic Display

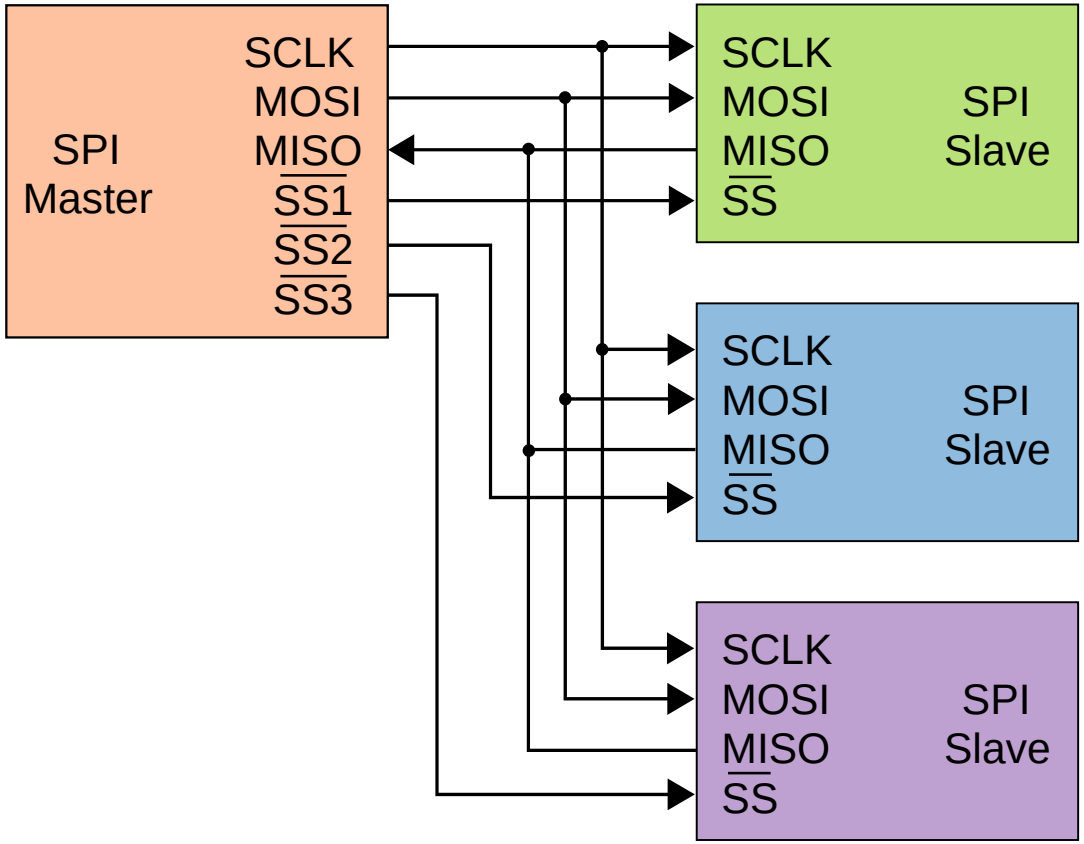
- **SSD1306**
  128 x 64 Dot Matrix OLED/PLED Segment/Common Driver with Controller and SPI communication interface.



What's SPI

- **SPI, Serial Peripheral Interface**
- **It's a serial communication interface.**
  Synchronous, inside-board level, short distance communication.

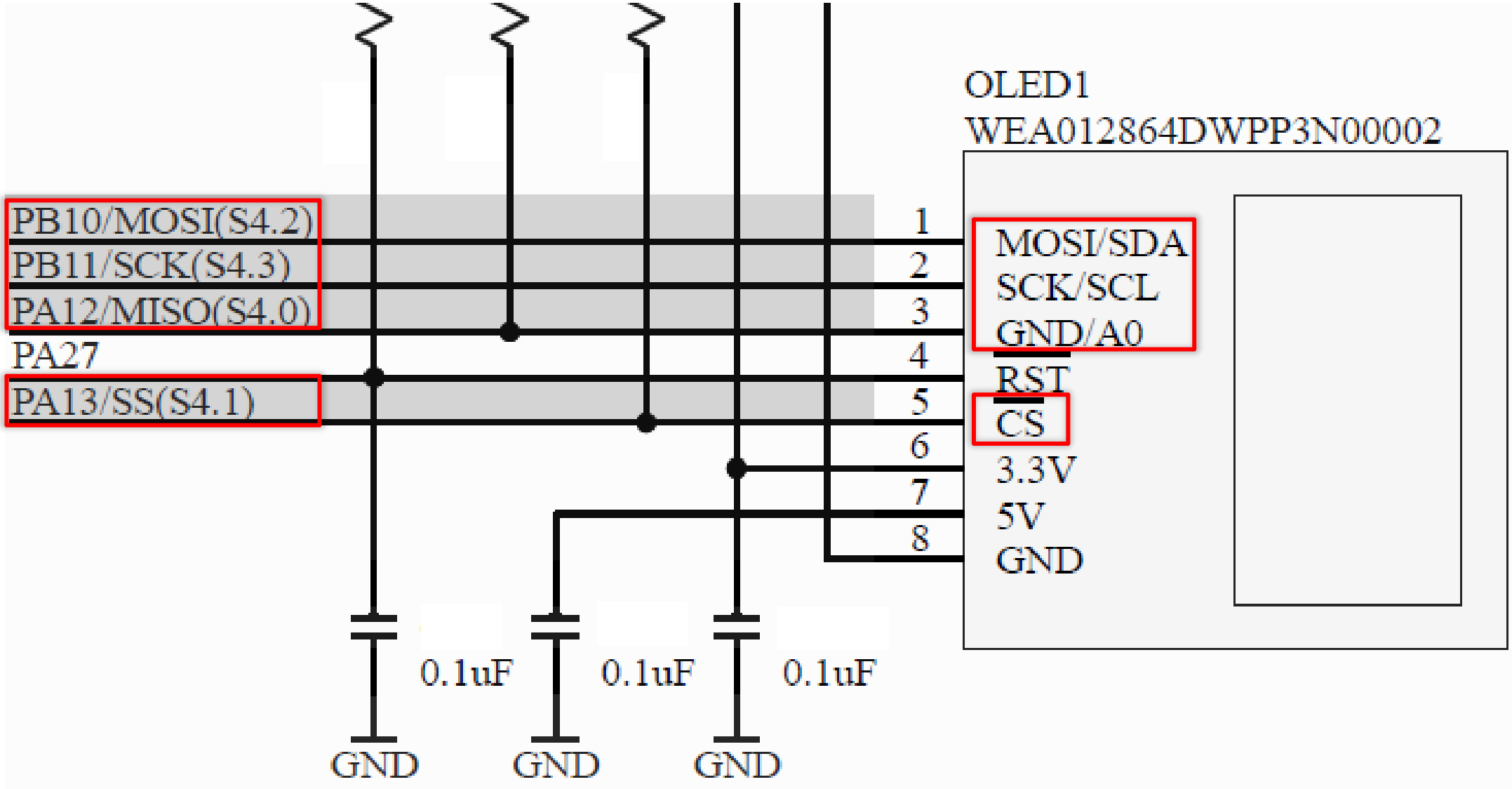




https://zh.wikipedia.org/wiki/%E5%BA%8F%E5%88%97%E5%91%A8%E9%82%8A%E4%BB%8B%E9%9D%A2

MICROCHIP

APP045 OLED SSD1306 Schematic



Lab17 SERCOM - SPI SSD1306 OLED

- Add SERCOM4-SPI module to your project.
- Add OLED control function to shows bitmap logo on your OLED display.
- Create your own Logo and replace original one.
- Pre-build Logo Image and Font header file at

  .\Appendix\LogoFont\Microchip_Logo.h

  .\Appendix\LogoFont\Alphabet_Fonts.h
- Logo image create application at

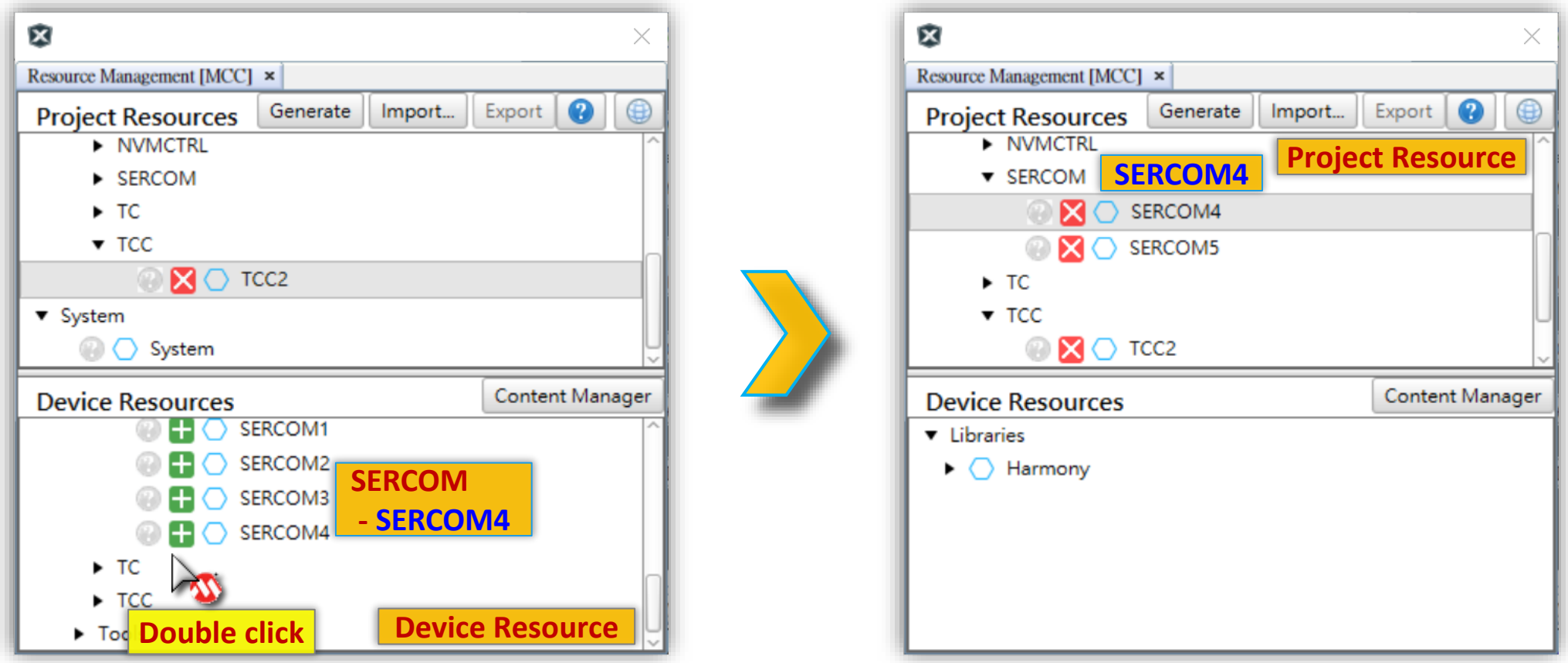
  .\Tools\LCDAssistant.exe

- Let’s go!

Lab17 SERCOM - SPI SSD1306 OLED

Step 1

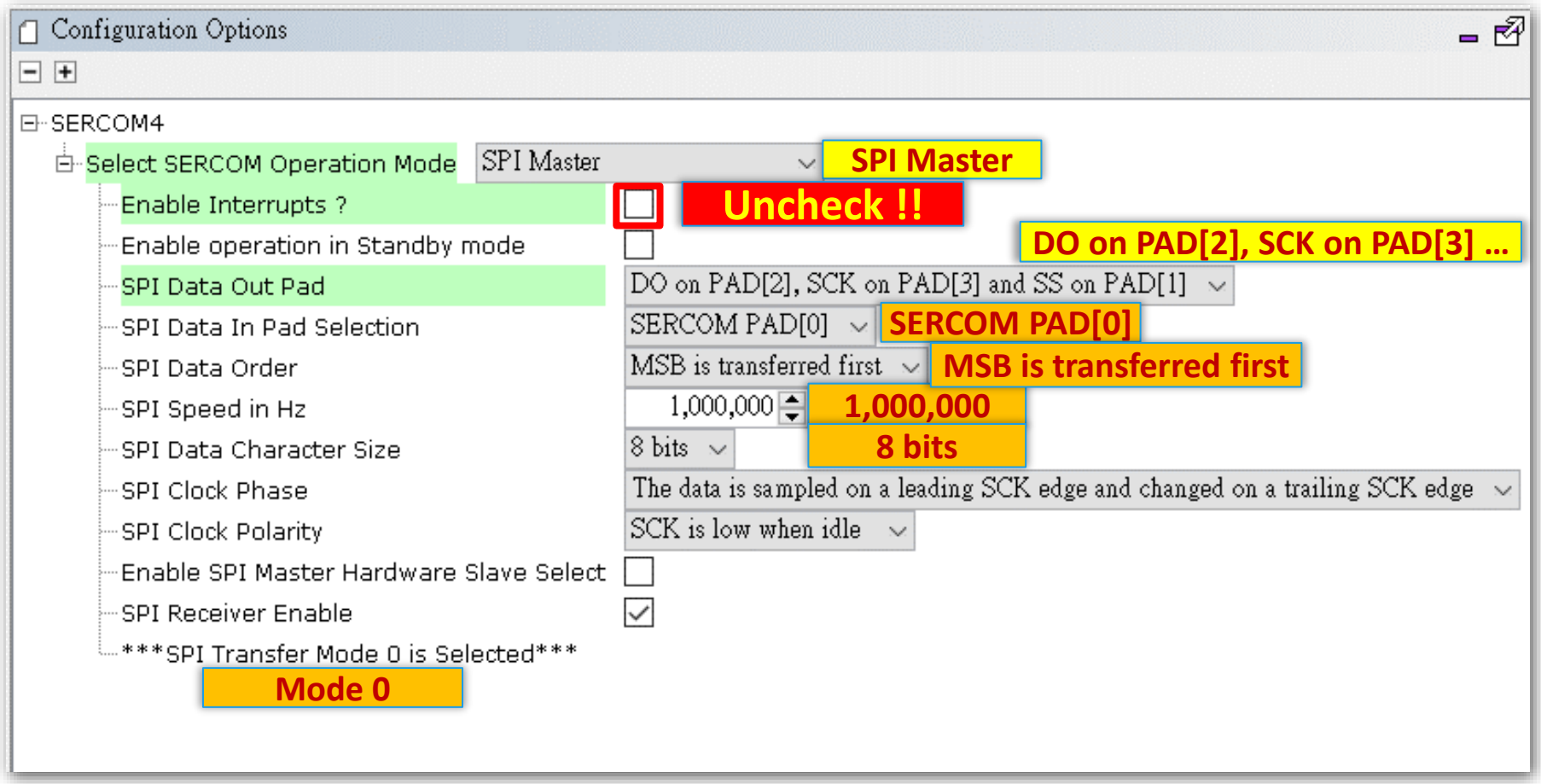
- Find SERCOM4 component in Device Resource window.
- Double click SERCOM4 to add to Project Resource window.



Lab17 SERCOM - SPI SSD1306 OLED

Step 2

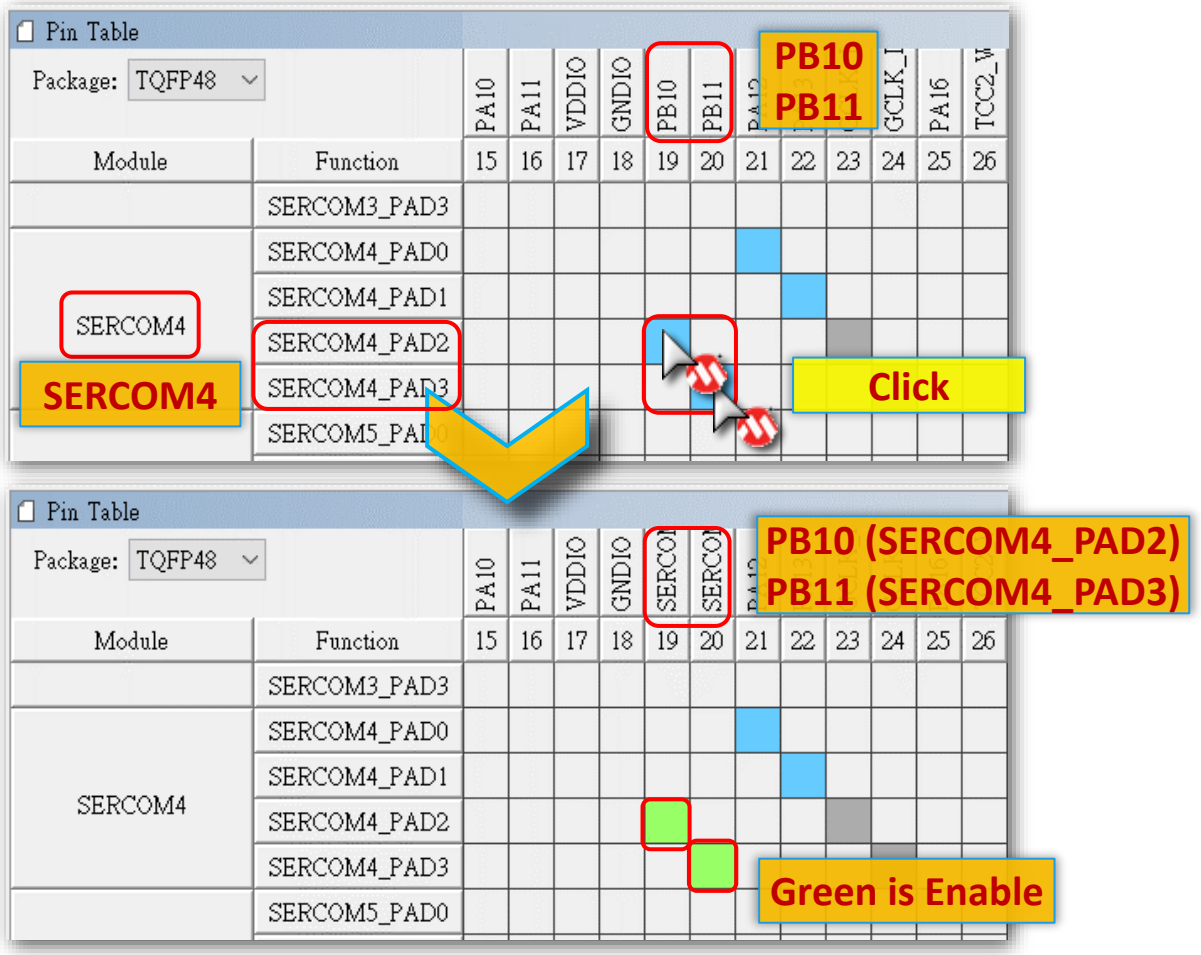
- **Setup SERCOM4 SPI Configuration.**



Lab17 SERCOM - SPI SSD1306 OLED

Step 3

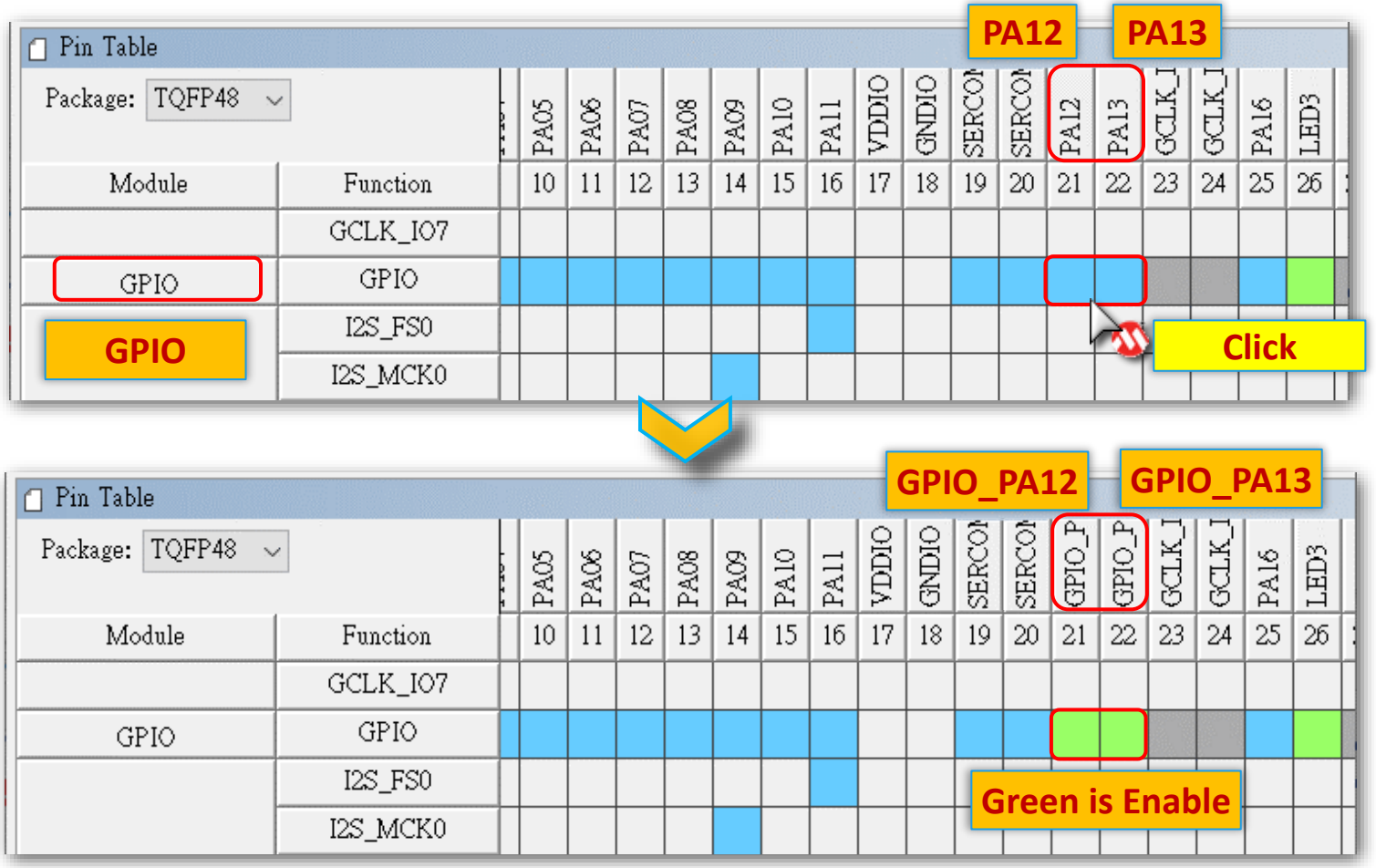
- **Pin Table Configuration of SERCOM4**



Lab17 SERCOM - SPI SSD1306 OLED

Step 4

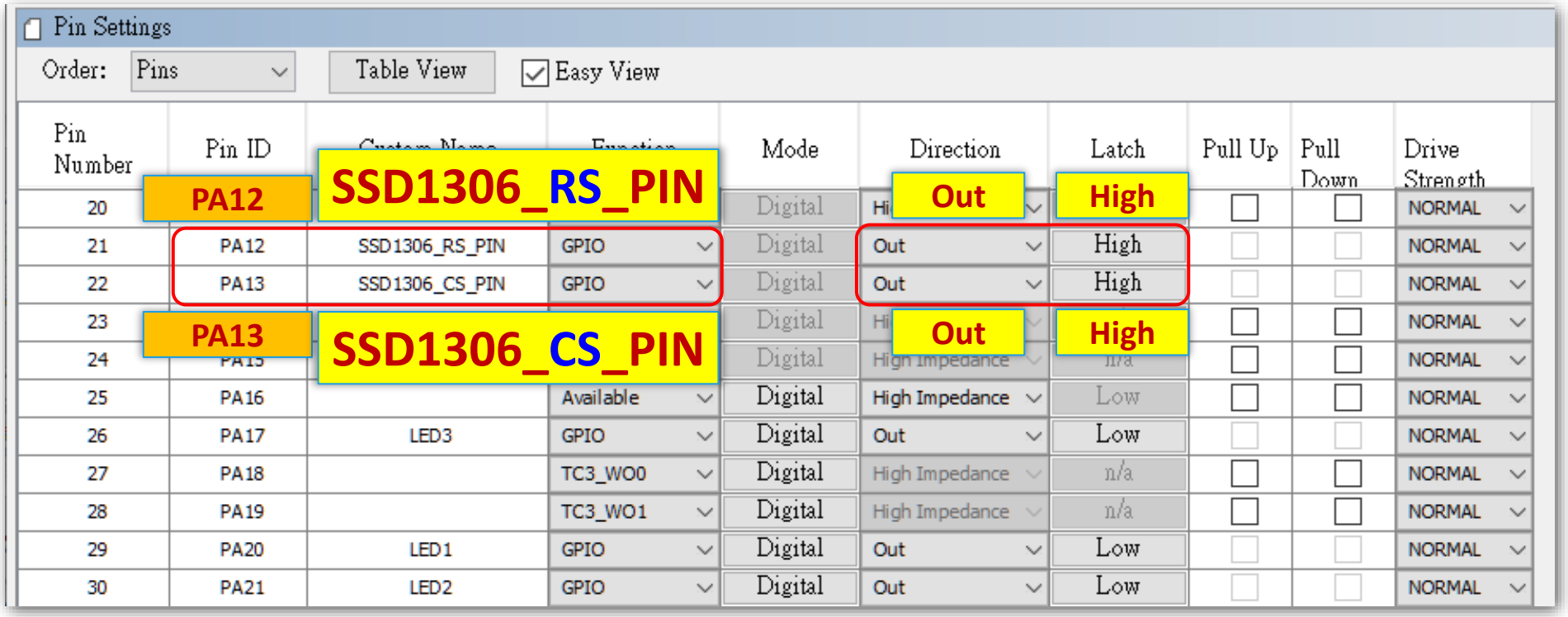
- **Pin Table Configuration of GPIO**



Lab17 SERCOM - SPI SSD1306 OLED

Step 5

- **Pin Setting of GPIO for direction and custom name.**

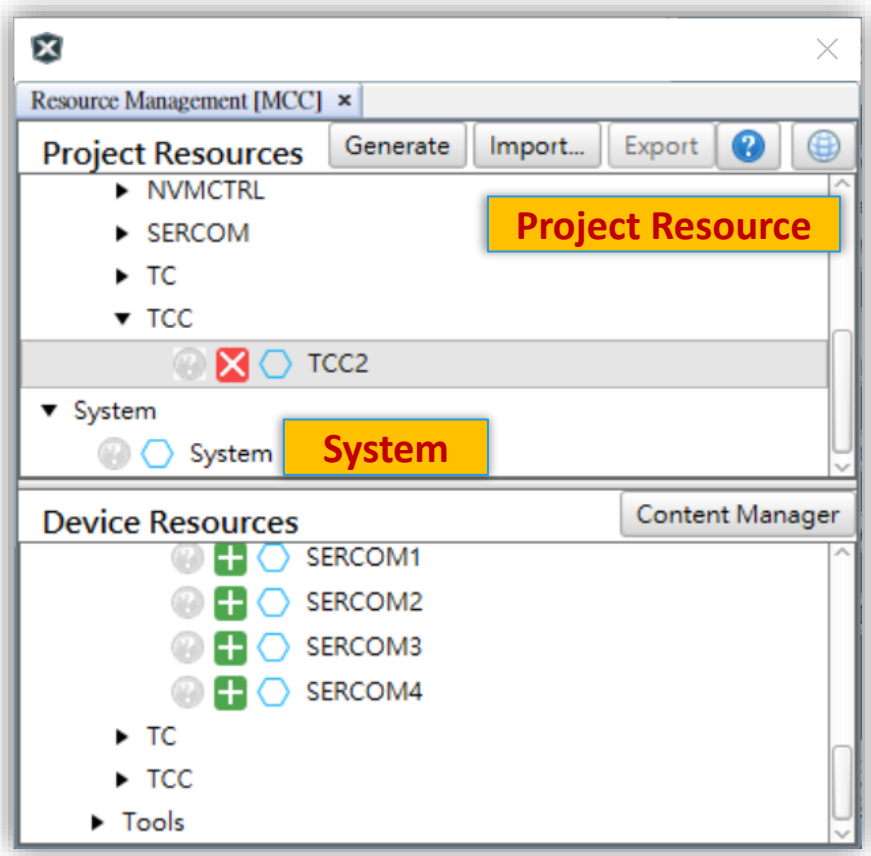


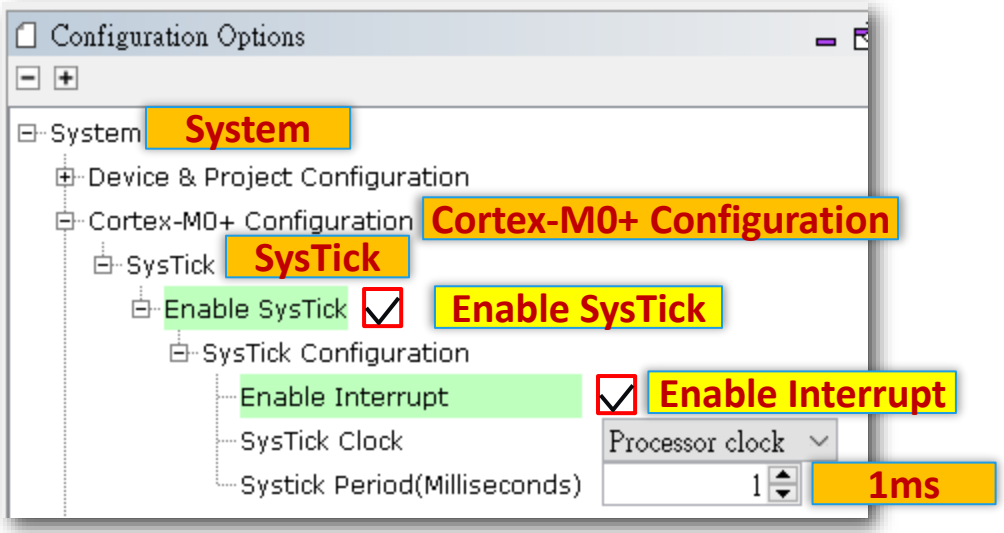
Pin Number	Pin ID	Custom Name	Function	Mode	Direction	Latch	Pull Up	Pull Down	Drive Strength
20	PA12	SSD1306_RS_PIN	GPIO	Digital	Out	High			NORMAL
21	PA12	SSD1306_RS_PIN	GPIO	Digital	Out	High			NORMAL
22	PA13	SSD1306_CS_PIN	GPIO	Digital	Out	High			NORMAL
23	PA13	SSD1306_CS_PIN	GPIO	Digital	Out	High			NORMAL
24	PA15			Digital	High Impedance	n/a			NORMAL
25	PA16		Available	Digital	High Impedance	Low			NORMAL
26	PA17	LED3	GPIO	Digital	Out	Low			NORMAL
27	PA18		TC3_WO0	Digital	High Impedance	n/a			NORMAL
28	PA19		TC3_WO1	Digital	High Impedance	n/a			NORMAL
29	PA20	LED1	GPIO	Digital	Out	Low			NORMAL
30	PA21	LED2	GPIO	Digital	Out	Low			NORMAL

Lab17 SERCOM - SPI SSD1306 OLED

Step 6

- Select exist module System in Project Resource.
- Enable SysTick for Delay Function.

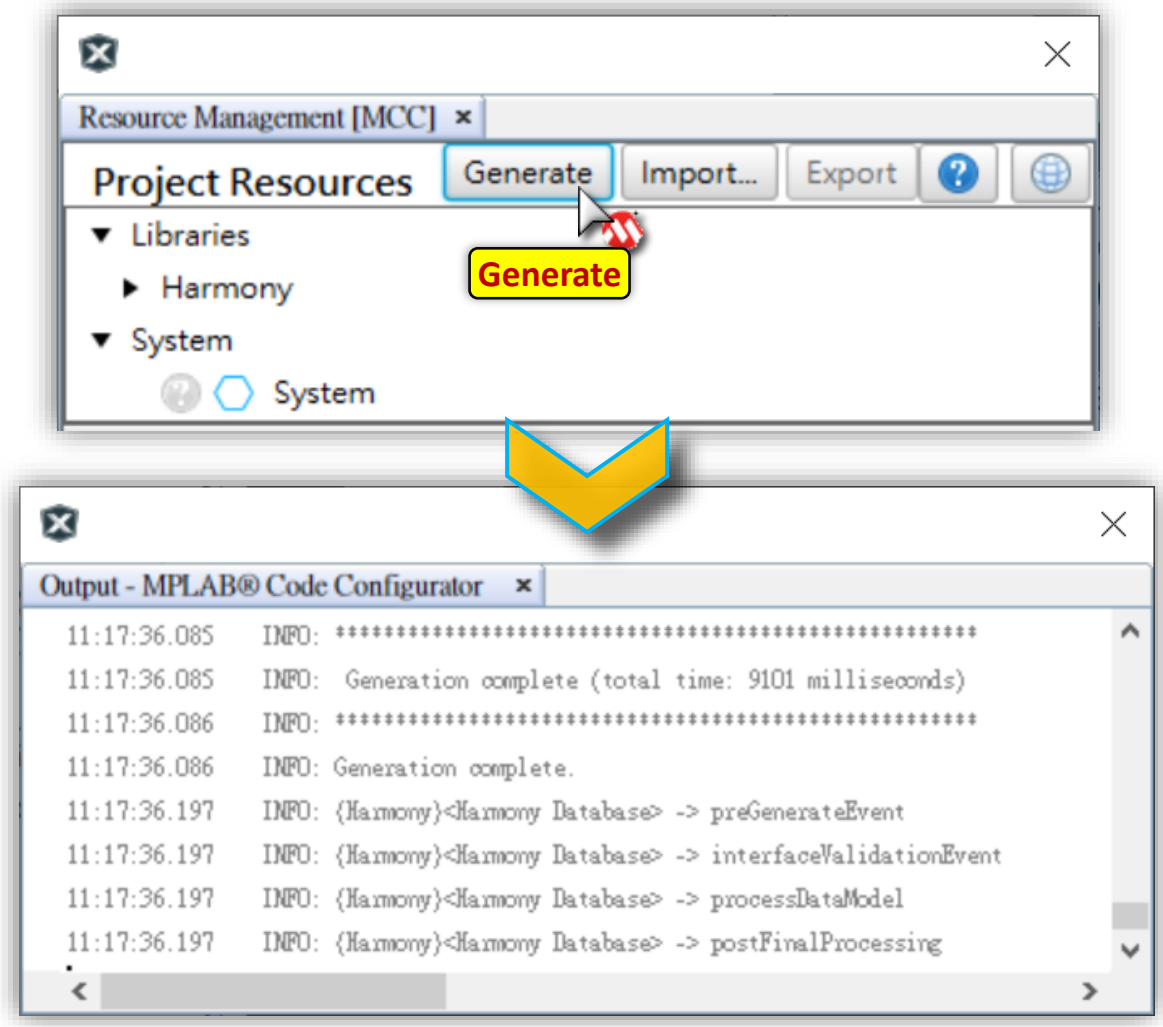




Lab17 SERCOM - SPI SSD1306 OLED

Step 7

- Click "Generate" Button to Generate your Code.



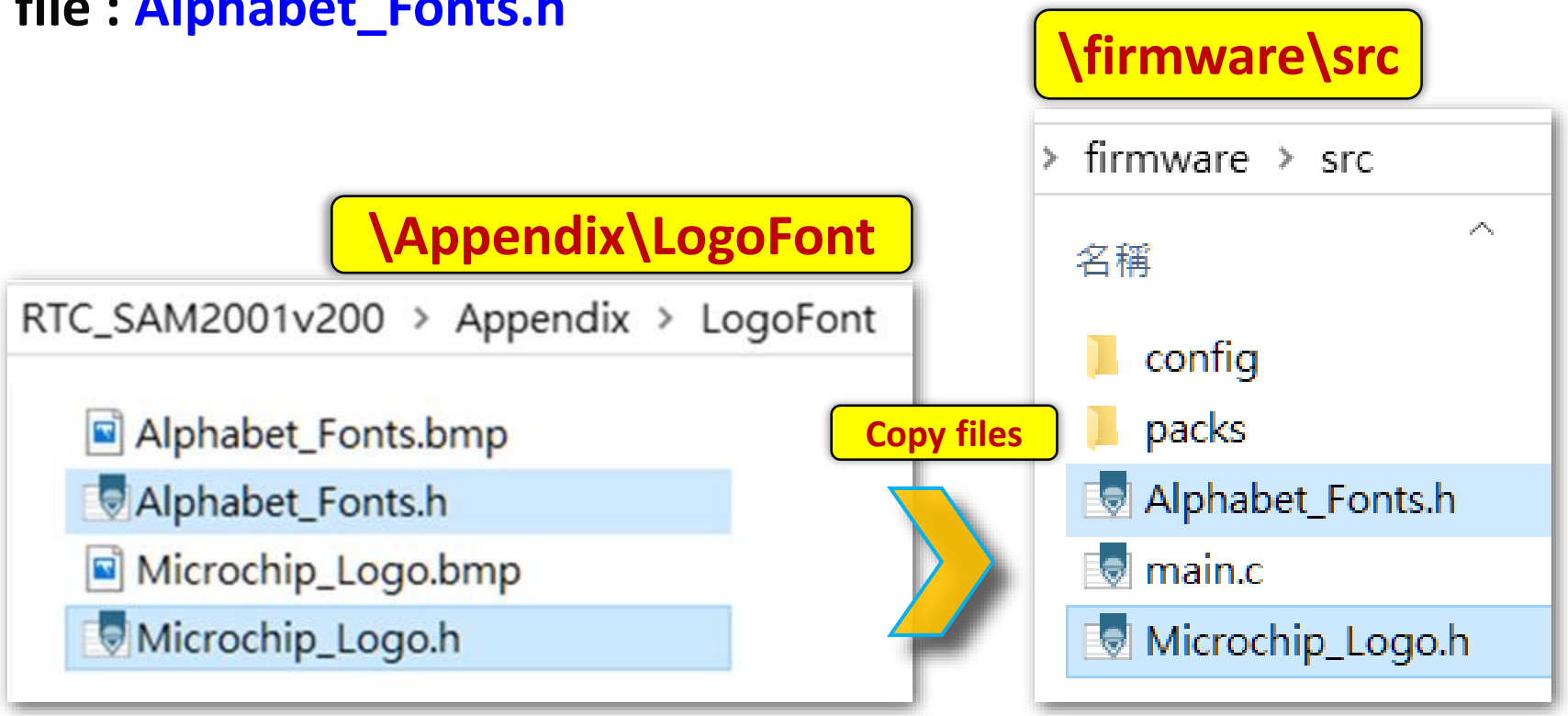
Lab17 SERCOM - SPI SSD1306 OLED

Step 8

- Copy below files to your project's \firmware\src folder

  Logo image file : Microchip_Logo.h

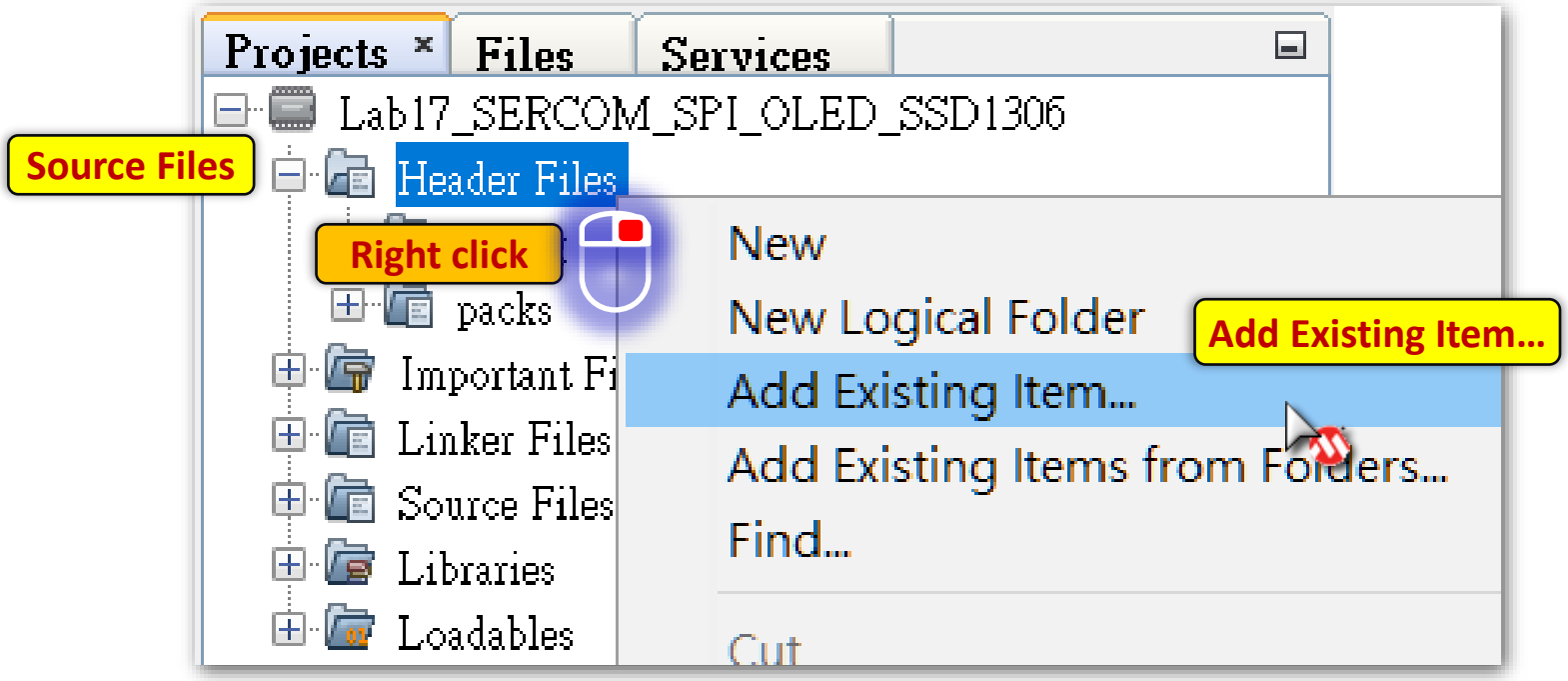
  Font image file : Alphabet_Fonts.h



Lab17 SERCOM - SPI SSD1306 OLED

Step 9

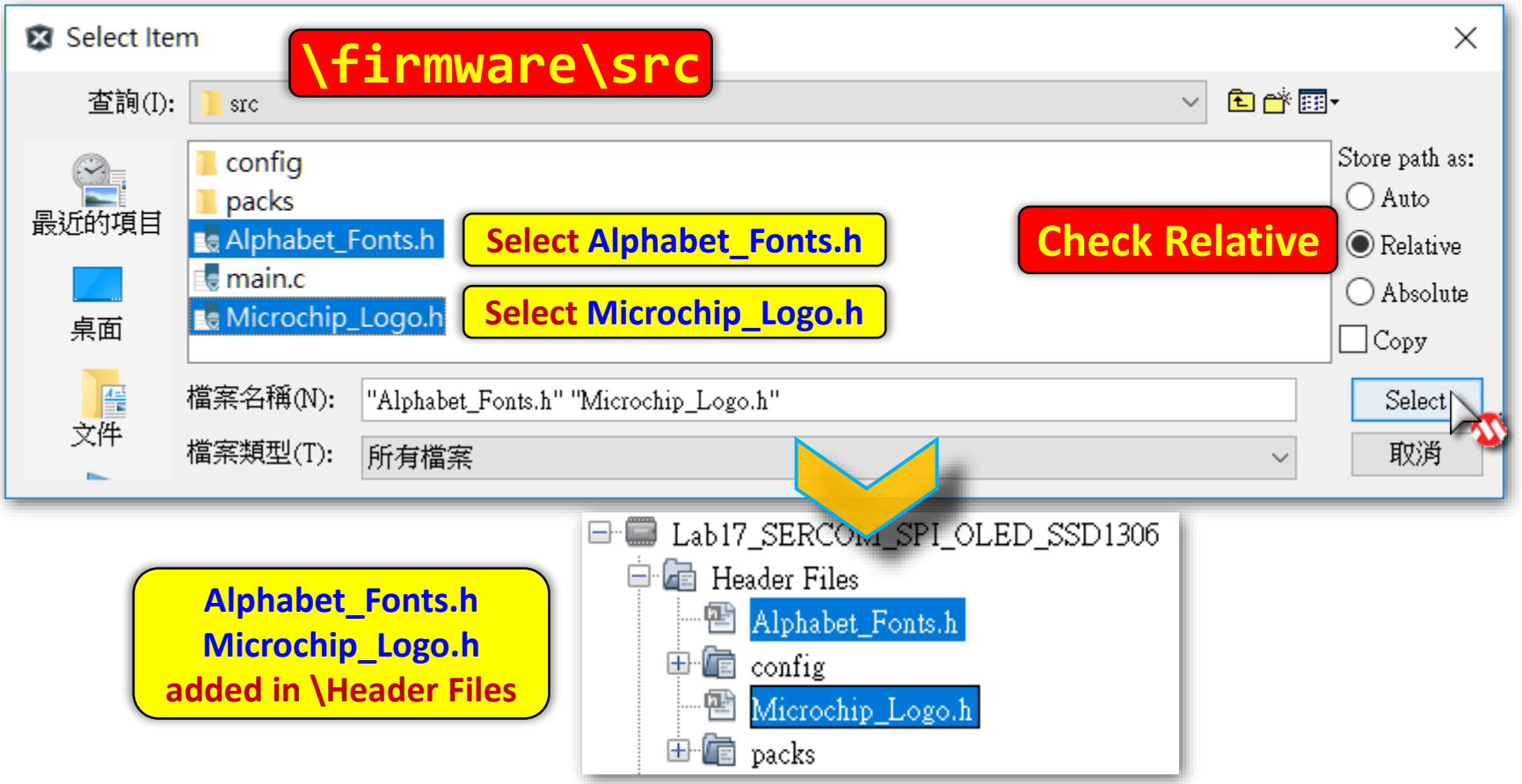
- **Add pre-build logo image header files into project**
  Right click Header Files > Add Existing item…



Lab17 SERCOM - SPI SSD1306 OLED

Step 10

- Select folder in \firmware\src
- Add Alphabet_Fonts.h and Microchip_Logo.h into project.



Lab17 SERCOM - SPI SSD1306 OLED

Step 11

a Add code segment to your project

```
// TODO 17.01
#include "Microchip_Logo.h"
#include "Alphabet_Fonts.h"
...
// TODO 17.02
#define LCM_WIDTH 128
#define LCM_HEIGHT 64
#define FONT_WIDTH  7
#define FONT_HEIGHT 8
uint8_t LogoX, LogoY;
unsigned char LCM_Blank[1024];
char Alphabet[95] = "0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijk\
                     lmnopqrstuvwxyz~!@#$%^&()[]{}_\\|;:,.`'\"<>+-*/=? ";

const uint8_t LCM_InitCMD[] = {
  0xAE, 0xD5, 0x80, 0xA8, 0x3F, 0xD3, 0x00, 0x40, 0x8D, 0x14, 0x20, 0x02,  0xA1,
  0xC8, 0xDA, 0x12, 0x81, 0xCF, 0xD9, 0xF1, 0xDB, 0x40, 0xA4, 0xA6, 0xAF
};
```

Lab17 SERCOM - SPI SSD1306 OLED

Step 12

a Add code segment to your project

```
// TODO 17.02
...
void LCM_SetCursor( uint8_t x, uint8_t y )
{
  uint8_t OUT[3] = { 0x0F & x, 0x10 + (x >> 4), 0xB0 + y };
  SSD1306_RS_PIN_Clear();
  SERCOM4_SPI_Write(( void* )OUT, 3);
}

void LCM_DrawBitmap( uint8_t sx, uint8_t sy, uint8_t width,
                                 uint8_t height, const unsigned char *byte )
{
  for( int y = 0; y < (height/8); y++ )
  {
    LCM_SetCursor(sx, sy + y);
    SSD1306_RS_PIN_Set();
    SERCOM4_SPI_Write(( void* )byte, (width - sx));
    byte += width;
  }
}
```

Lab17 SERCOM - SPI SSD1306 OLED

Step 13

a Add code segment to your project

```
// TODO 17.02
…
void LCM_DrawFont( uint8_t sx, uint8_t row, char ch )
{
  int chIdx = 0;

  while( ch != Alphabet[chIdx] ) { chIdx++; }
  LCM_SetCursor(sx, row);
  SSD1306_RS_PIN_Set();
  SERCOM4_SPI_Write( ( void* )(Alphabet_Font+(chIdx*FONT_WIDTH)),
                     FONT_WIDTH );
}

void LCM_DrawString( uint8_t sx, uint8_t row, char *str )
{
  for( int x=0 ; x<strlen(str); x++ )
  {
    LCM_DrawFont( sx+(x*FONT_WIDTH), row, str[x] );
  }
}
```

Lab17 SERCOM - SPI SSD1306 OLED

Step 14

a **Add code segment to your project**

```
...
int main (void)
{  ...
   TCC2_PWMStart();

   // TODO 17.03
   SYSTICK_TimerStart();
   SSD1306_CS_PIN_Clear();
   SSD1306_RS_PIN_Clear();
   SERCOM4_SPI_Write(( void* )LCM_InitCMD, sizeof (LCM_InitCMD));
   memset(LCM_Blank, 0, 1024);
   LCM_DrawBitmap(0, 0, LCM_WIDTH, LCM_HEIGHT, LCM_Blank);
   LogoX = 127;
   LogoY = 0;
   for( i = 0; i < 128; i += 2 )
   {
     LCM_DrawBitmap(LogoX - i, LogoY, LCM_WIDTH, LCM_HEIGHT, Microchip_Logo);
     SYSTICK_DelayMs((i * i) / 400);
   }
   ...
```

Lab17 SERCOM - SPI SSD1306 OLED

Step 15

a **Add code segment to your project**

```
int main (void)
{ ...
  // TODO 17.03
   ...
  SYSTICK_DelayMs(1000);
  memset(LCM_Blank, 0, 1024);
  LCM_DrawBitmap(0, 0, LCM_WIDTH, LCM_HEIGHT, LCM_Blank);
  sprintf( (char *)USARTRTxBuffer, "SysClock %ld.%-ldMHz",
                                    SYSTICK_TimerFrequencyGet()/1000000,
                                   (SYSTICK_TimerFrequencyGet()%1000000)/1000 );
  LCM_DrawString( 0, 0, (char *)USARTRTxBuffer );
  sprintf( (char *)USARTRTxBuffer, "TC3 period %ldms",
                TC3_Timer16bitPeriodGet()*1000/TC3_TimerFrequencyGet() );
  LCM_DrawString( 0, 1, (char *)USARTRTxBuffer );
  sprintf( (char *)USARTRTxBuffer, "TC4 period %ldms",
                TC4_Timer16bitPeriodGet()*1000/TC4_TimerFrequencyGet() );
  LCM_DrawString( 0, 2, (char *)USARTRTxBuffer );
  sprintf( (char *)USARTRTxBuffer, "Received Data :" );
  LCM_DrawString( 0, 7, (char *)USARTRTxBuffer );
  ...
```

Lab17 SERCOM - SPI SSD1306 OLED

Step 16

a **Add code segment to your project**

```
while ( true )
{  …
   if (TC3_ HasExpired)
   {  …
      LED1_Toggle();

      // TODO 17.04
       sprintf( (char *)USARTRTxBuffer, "Hello World!");
       LCM_DrawString( 0, 3, (char *)USARTRTxBuffer );
       …
   }

   if (TC4_ HasExpired)
   {  …
      // TODO 17.05
       sprintf( (char *)USARTRTxBuffer, "PWM Duty : %3d%%", Duty);
       LCM_DrawString( 0, 4, (char *)USARTRTxBuffer );

     LED2_Toggle();
   }
}
```

Lab17 SERCOM - SPI SSD1306 OLED

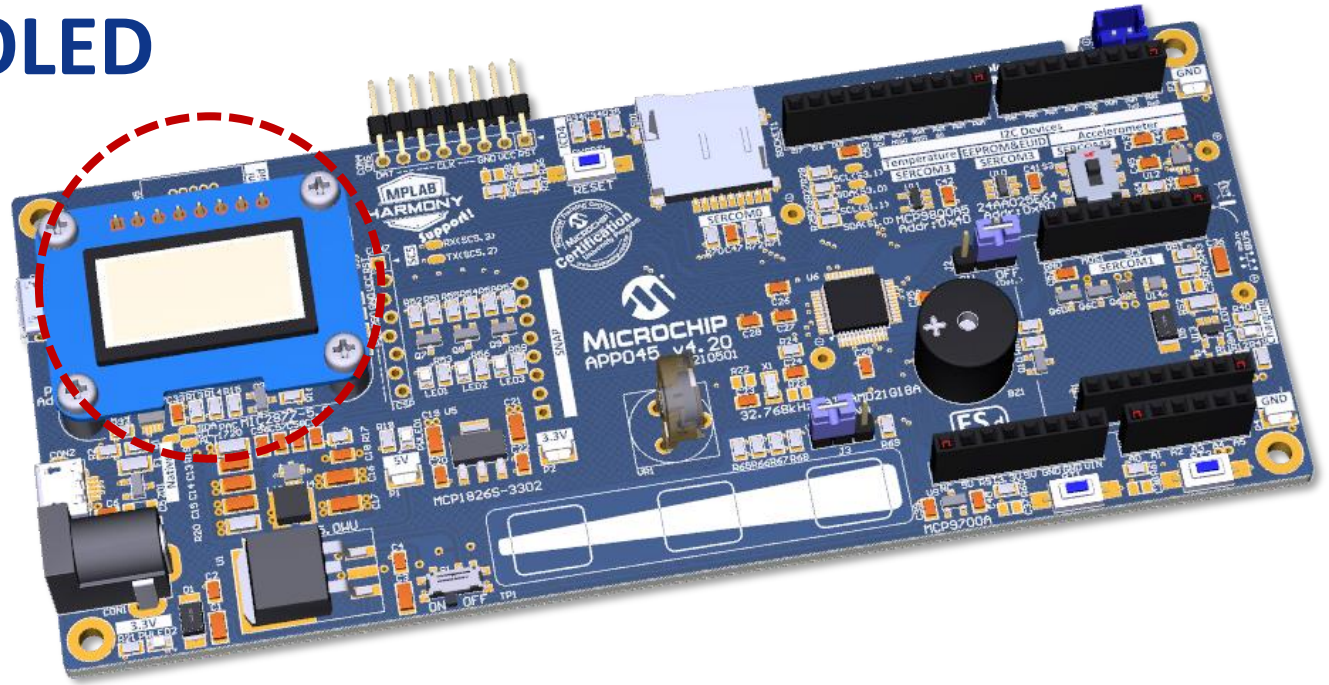
Step 17

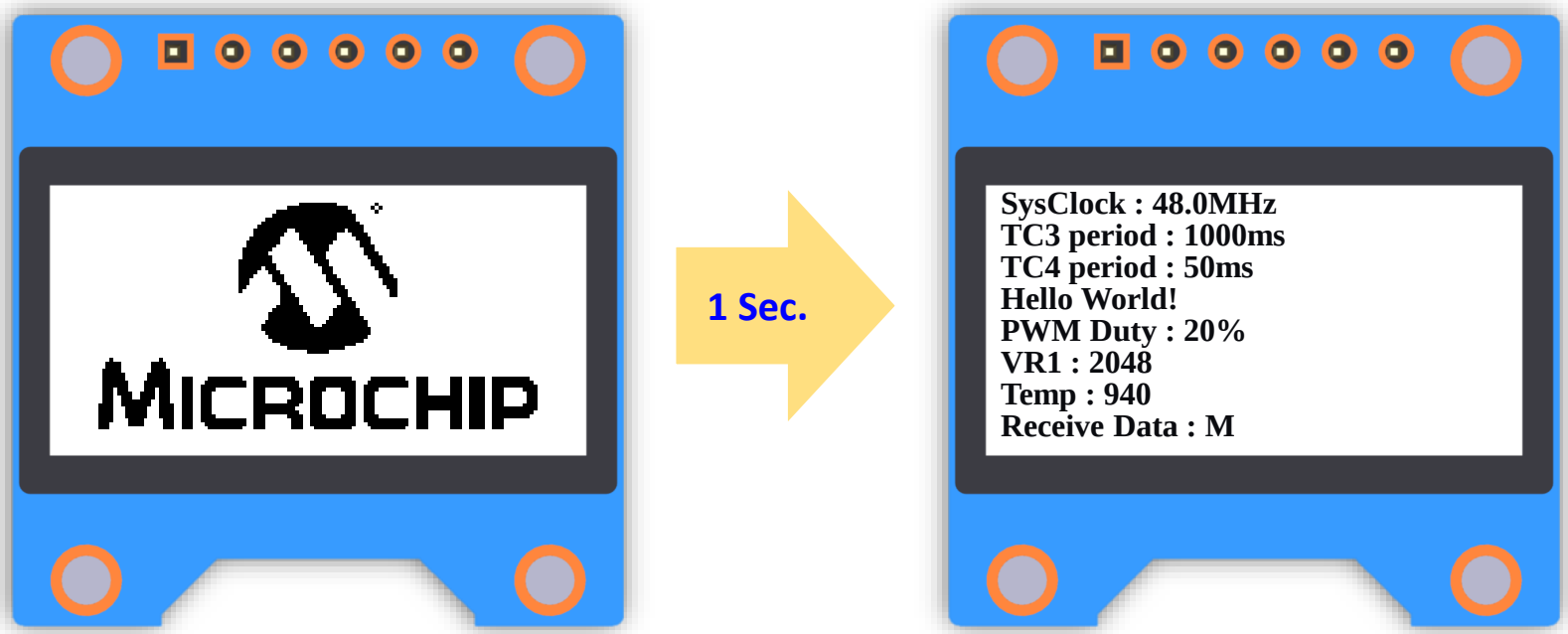
a **Add code segment to your project**

```
while ( true )
{ …
  if (USART5_IsReceived)
  { …
    // TODO 17.06
     sprintf( (char *)USARTRTxBuffer, "Received Data : %1c",
                                                    USART5_ReceiveData[0] );
     LCM_DrawString( 0, 7, (char *)USARTRTxBuffer );
    …
  }

  if (ADC_IsCompleted)
  { …
    // TODO 17.07
     sprintf( (char *)USARTRTxBuffer, "VR1  : %4d", ADC_Result[0]);
     LCM_DrawString( 0, 5, (char *)USARTRTxBuffer );
     sprintf( (char *)USARTRTxBuffer, "Temp : %4d", ADC_Result[1]);
     LCM_DrawString( 0, 6, (char *)USARTRTxBuffer );
    …
  }
}
```

Lab17 SERCOM - SPI SSD1306 OLED

Result





MICROCHIP

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- To create your personally welcome page (logo) !

- Let’s go!

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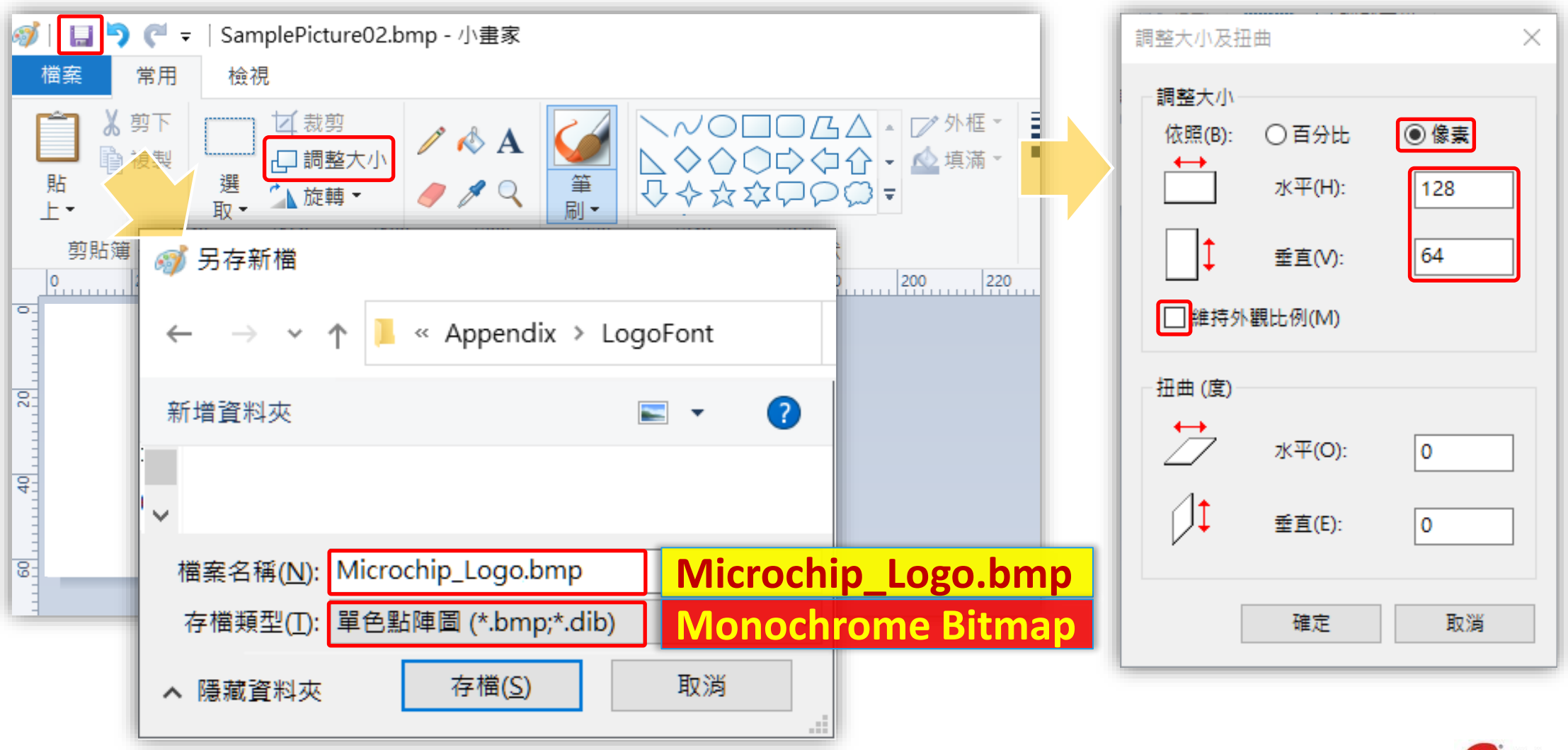
Create your own logo



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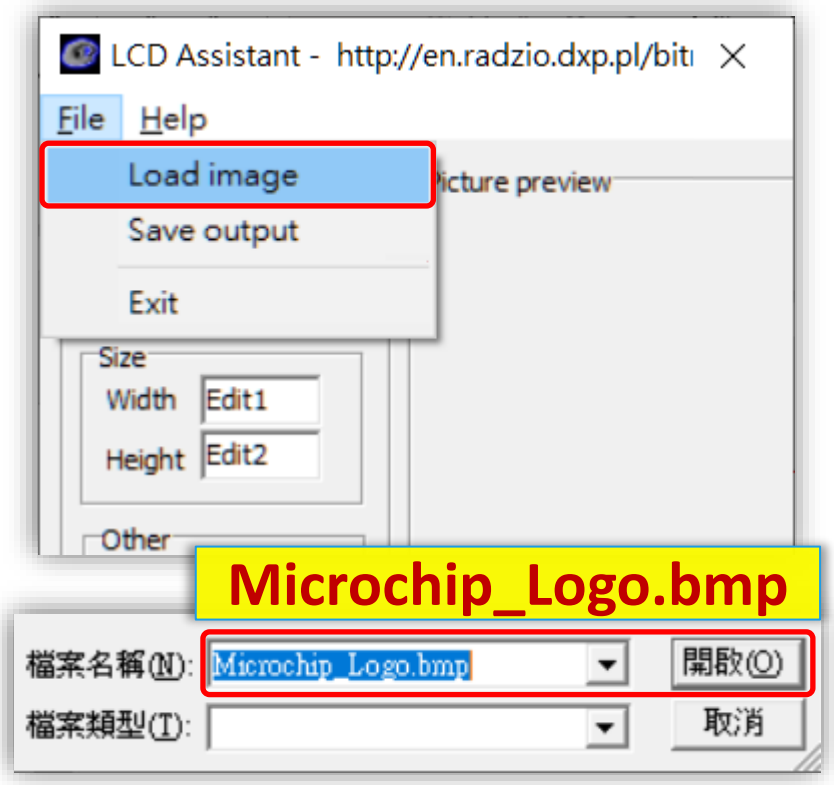
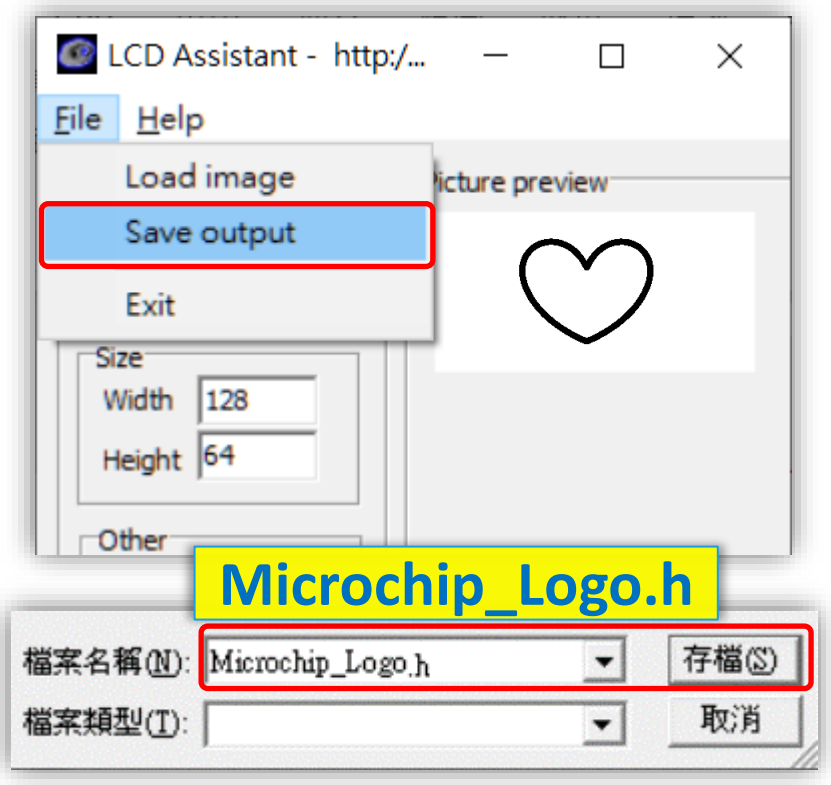
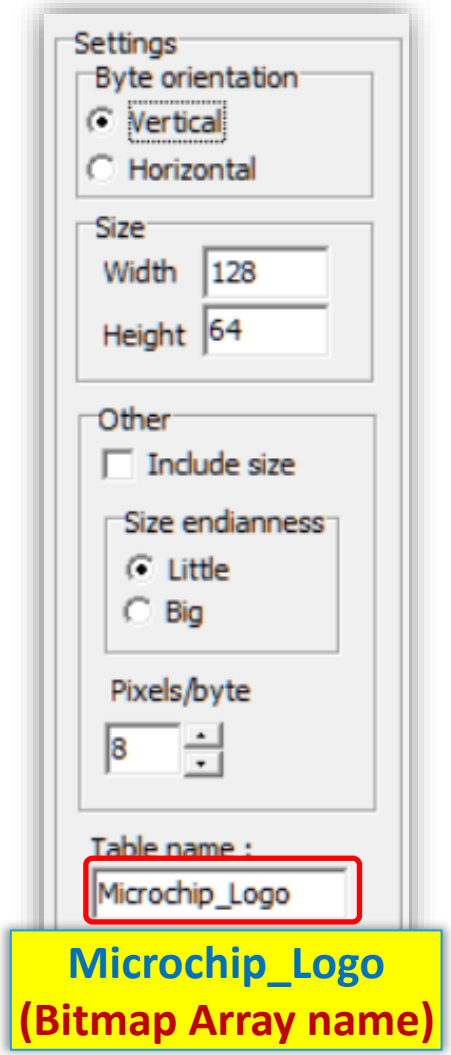
Create your own logo

- **Execute \Tools\LCDAssistant.exe**
  Load Microchip_Logo.bmp and Save output to Microchip_Logo.h







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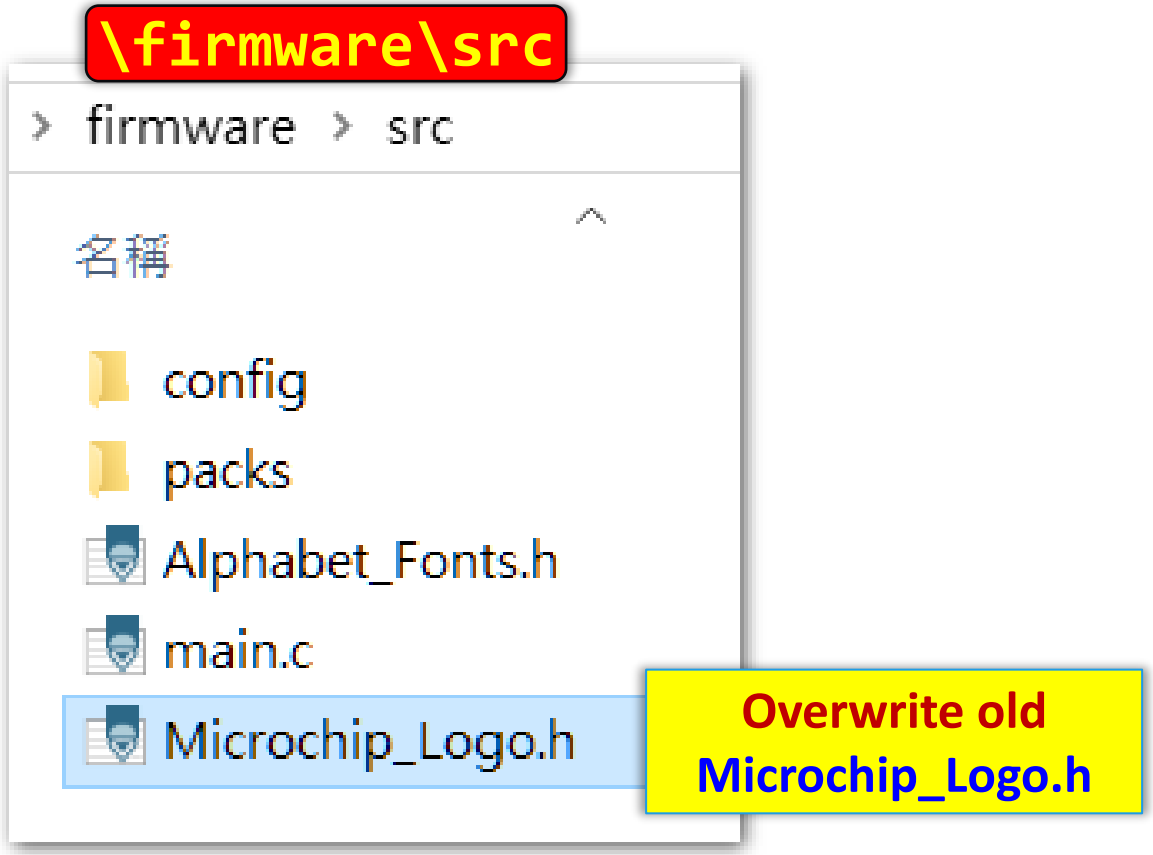
Create your own logo

- Copy new Microchip_Logo.h to overwrite old one in folder \firmware\src\



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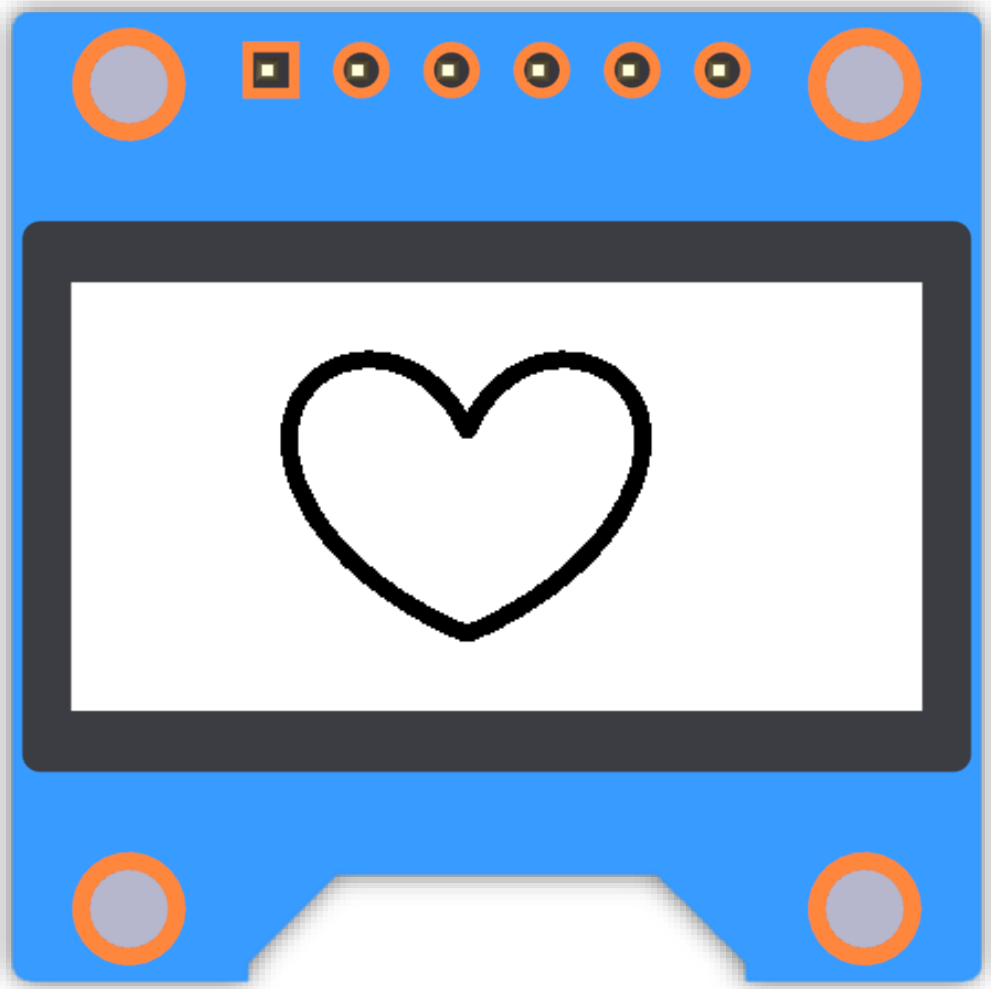
Create your own logo result



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