SAMD21 ARM Cortex-M0+ Microcontroller & MCC Harmony

SAM2001ADV v2.02

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

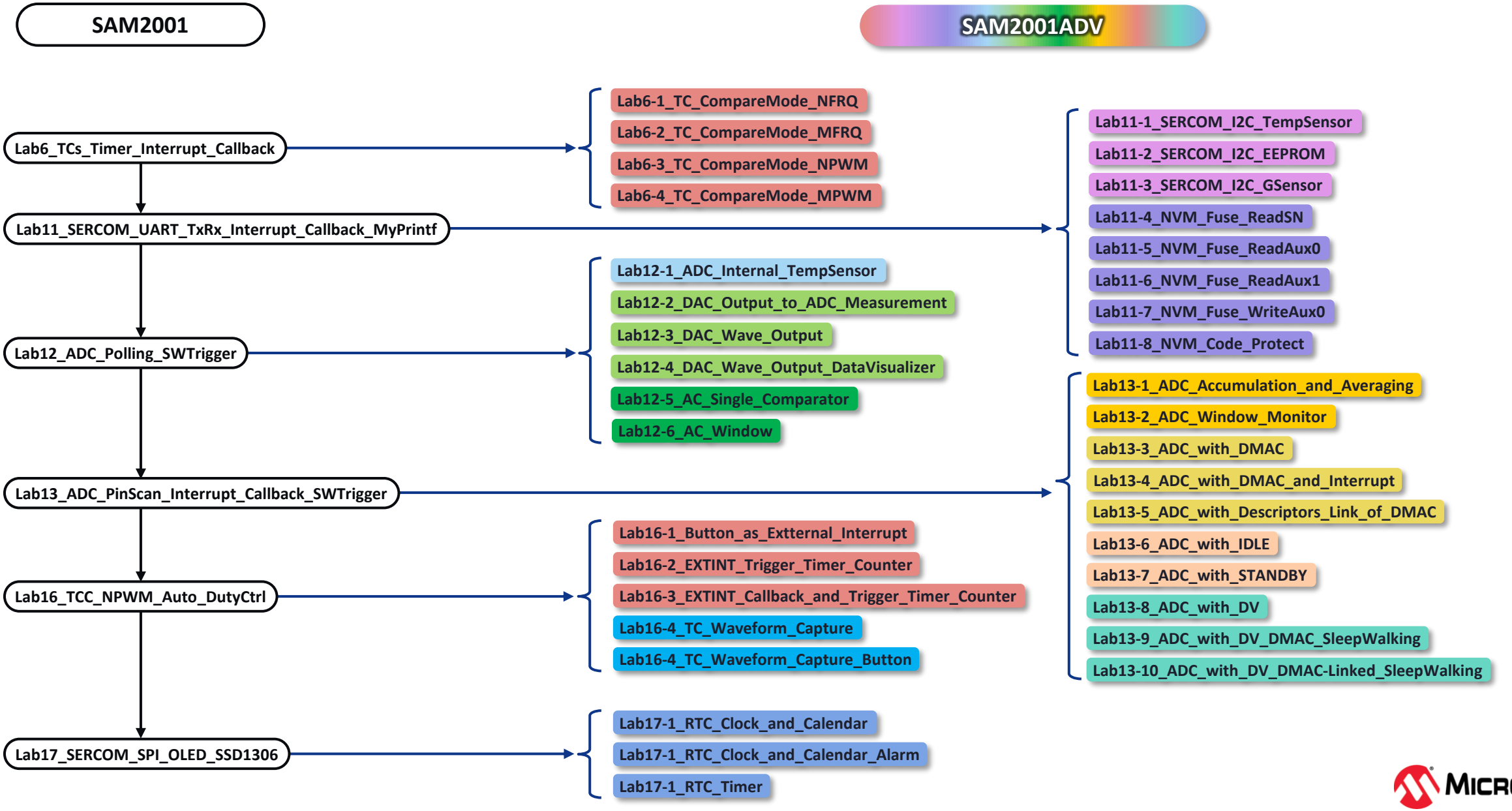
CAE Taiwan Team
Microchip Technology Inc.

2024 March

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.

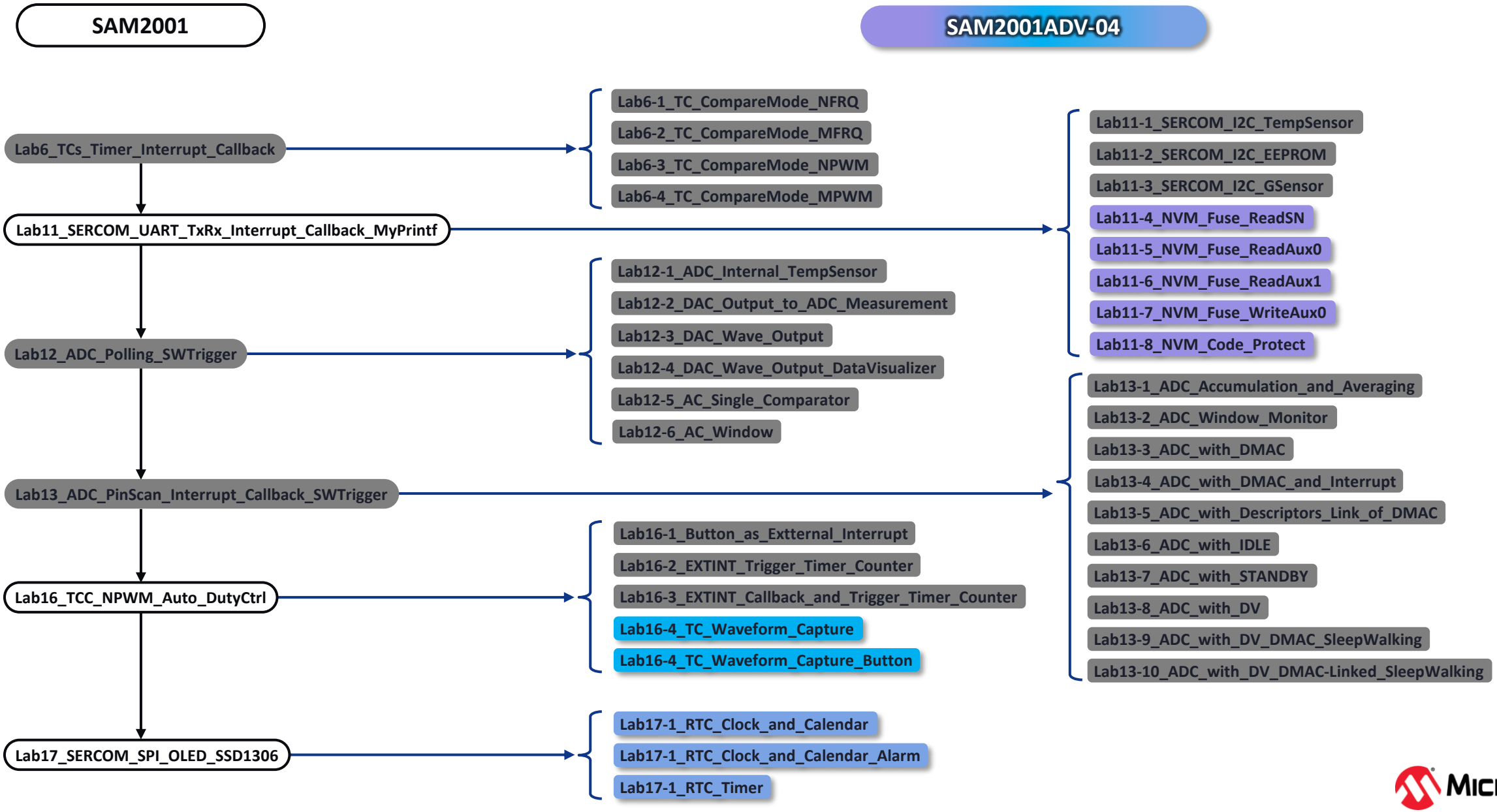
Lab Tree Branch from SAM2001 to SAM2001ADV



Separate Index for SAM2001ADV-04

- SAM2001ADV-04
  - Real Time Counter (RTC)
  - TC Waveform Capture (TC, EIC and Event System)
  - Auxiliary Space of NVM and Fuse Maintains

Separate Labs for SAM2001ADV-04



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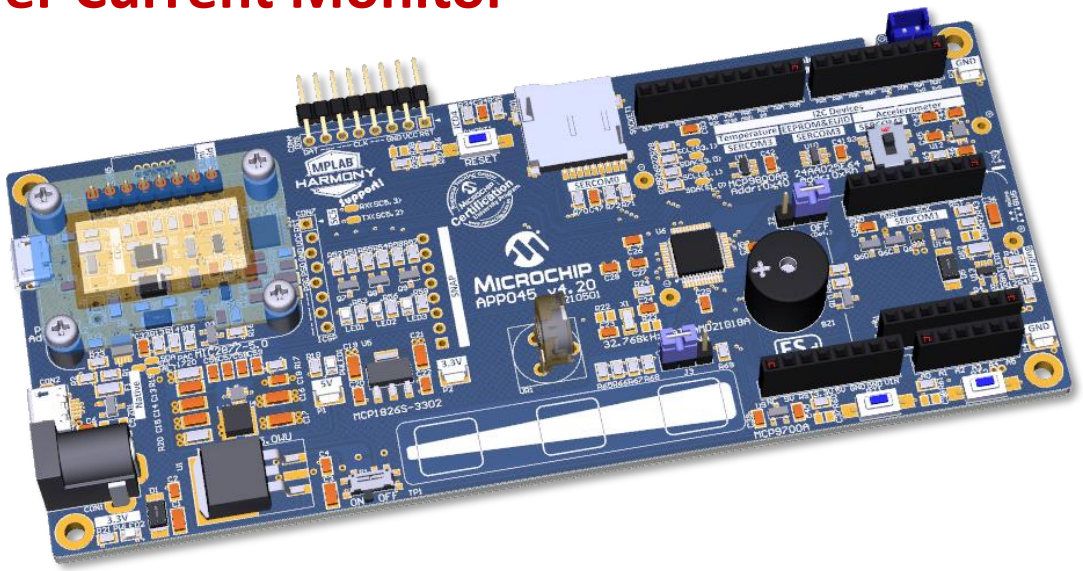
SAMD21 EVB APP045 v4
Introduction

APP045 v4 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)



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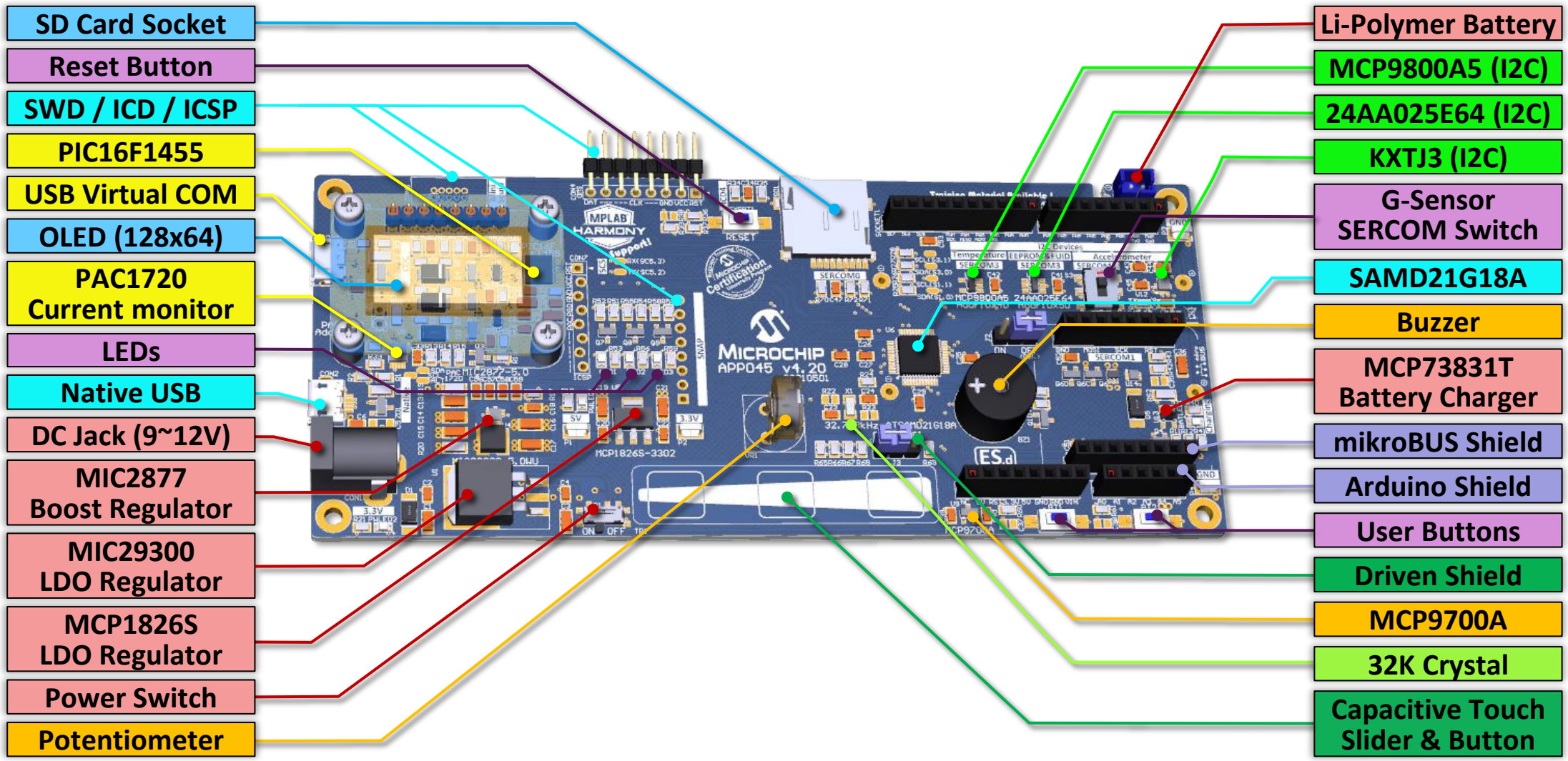
APP045 v4 Overview



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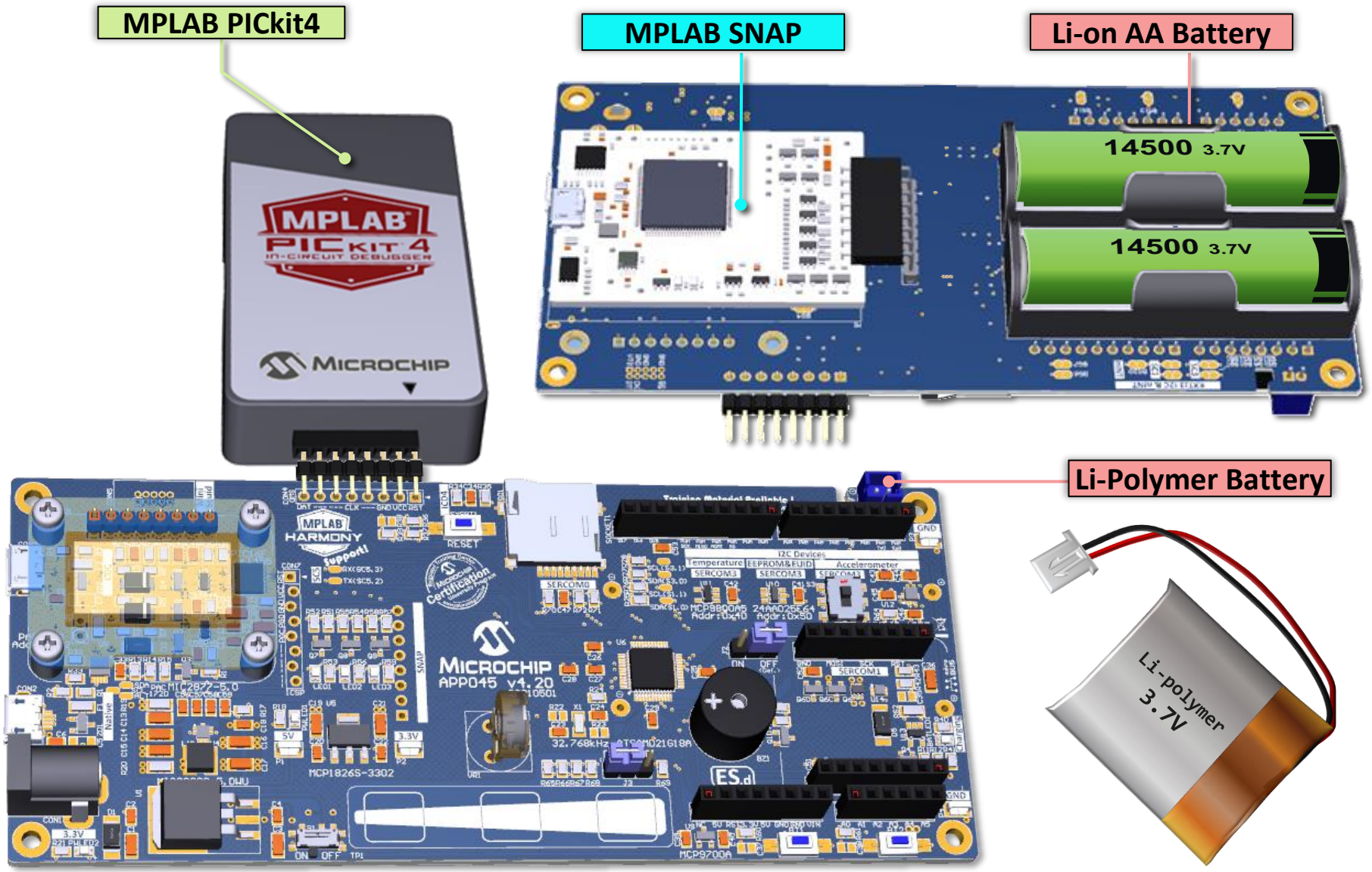
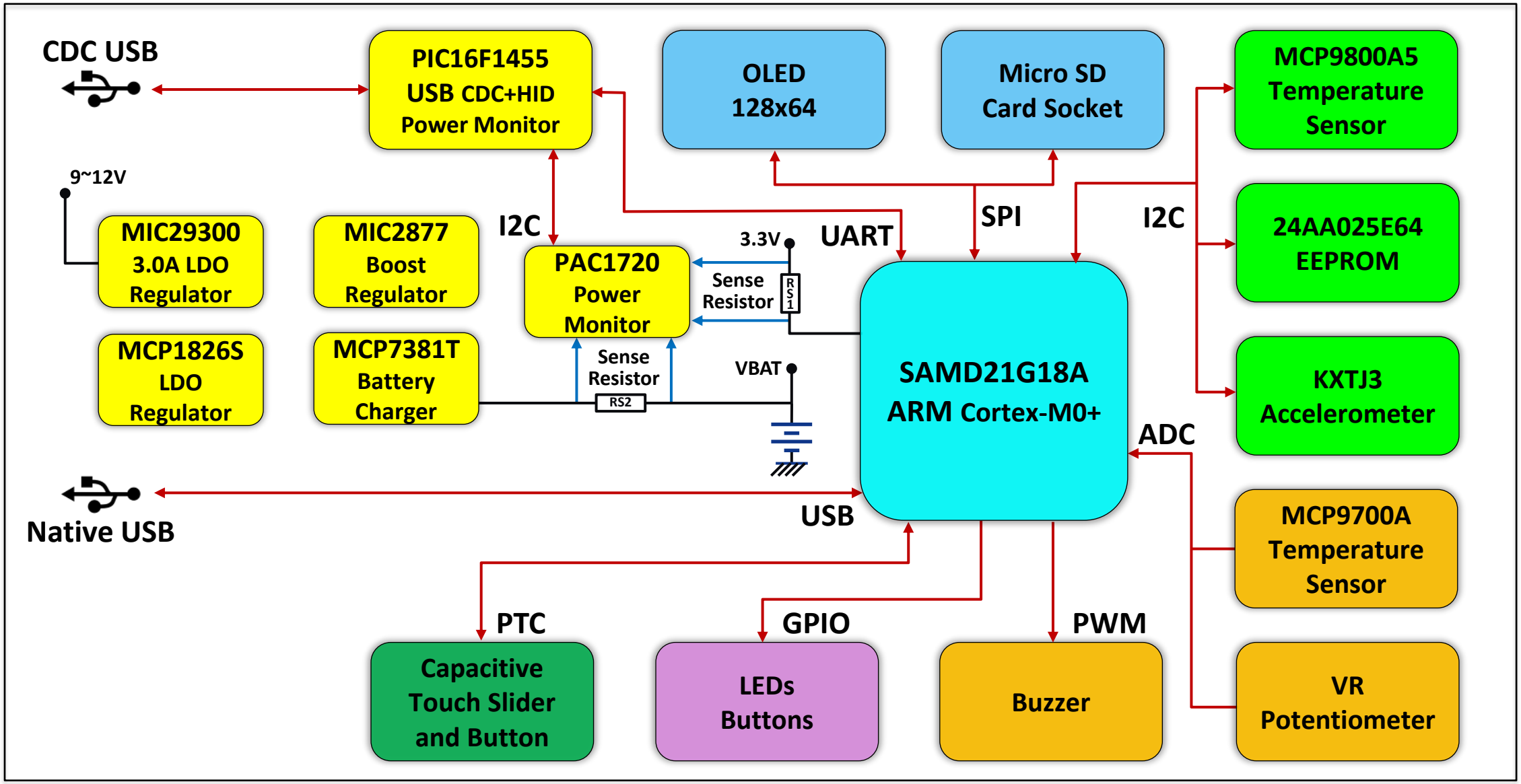
APP045 v4 Programmer and Debugger



APP045 v4 Block Diagram



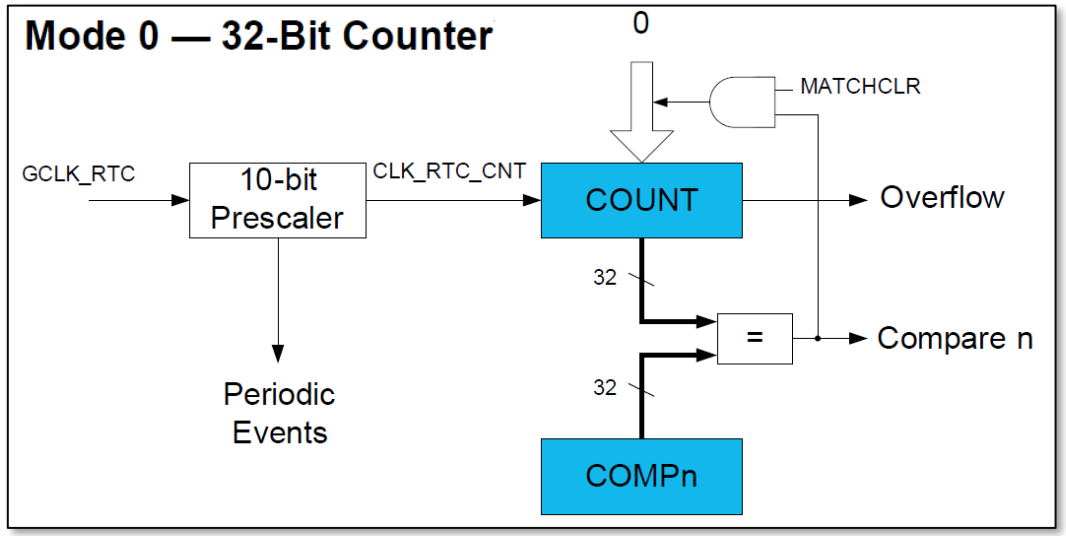
Real Time Counter (RTC)

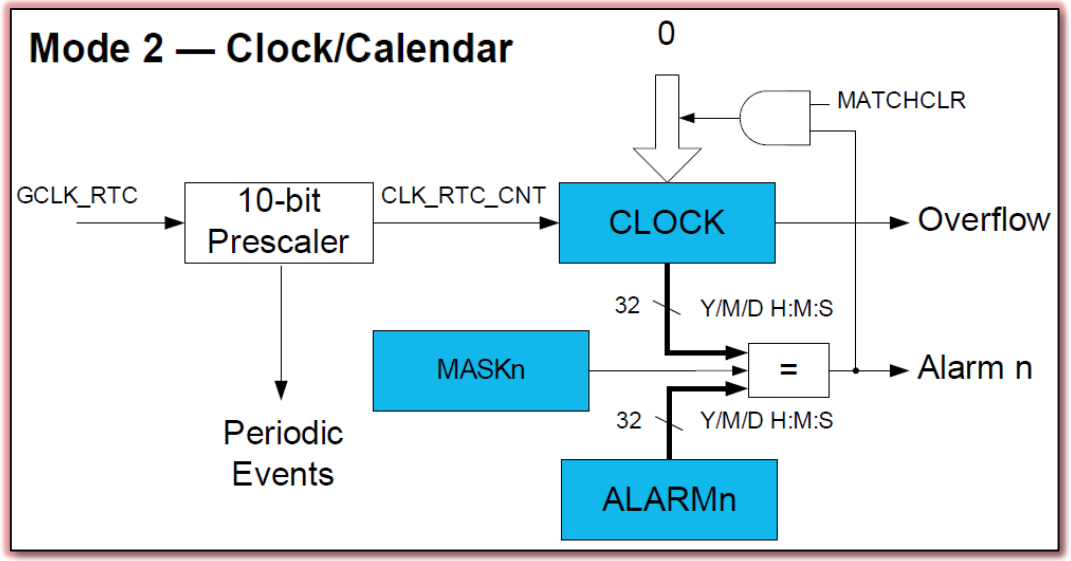
Real Time Counter (RTC)

- The Real-Time Counter (RTC) is a 32-bit counter with a 10-bit programmable prescaler that typically runs continuously to keep track of time.
- The RTC can wake-up the device from Sleep modes using the alarm/compare wake-up, periodic wake-up, or overflow wake-up mechanisms.
- In Clock/Calendar mode, the selected clock source and RTC prescaler must be configured to provide a 1Hz clock to the counter for correct operation in this mode.
- Features
  - 32-bit counter with 10-bit prescaler
  - Multiple clock sources
  - 32-bit or 16-bit Counter mode
    - One 32-bit or two 16-bit compare values
  - Clock/Calendar mode
    – Time in seconds, minutes and hours (12/24)
    – Date in day of month, month and year
    – Leap year correction
  - Digital prescaler correction/tuning for increased accuracy
  - Overflow, alarm/compare match and prescaler interrupts and events
    – Optional clear on alarm/compare match

Real Time Counter (RTC)

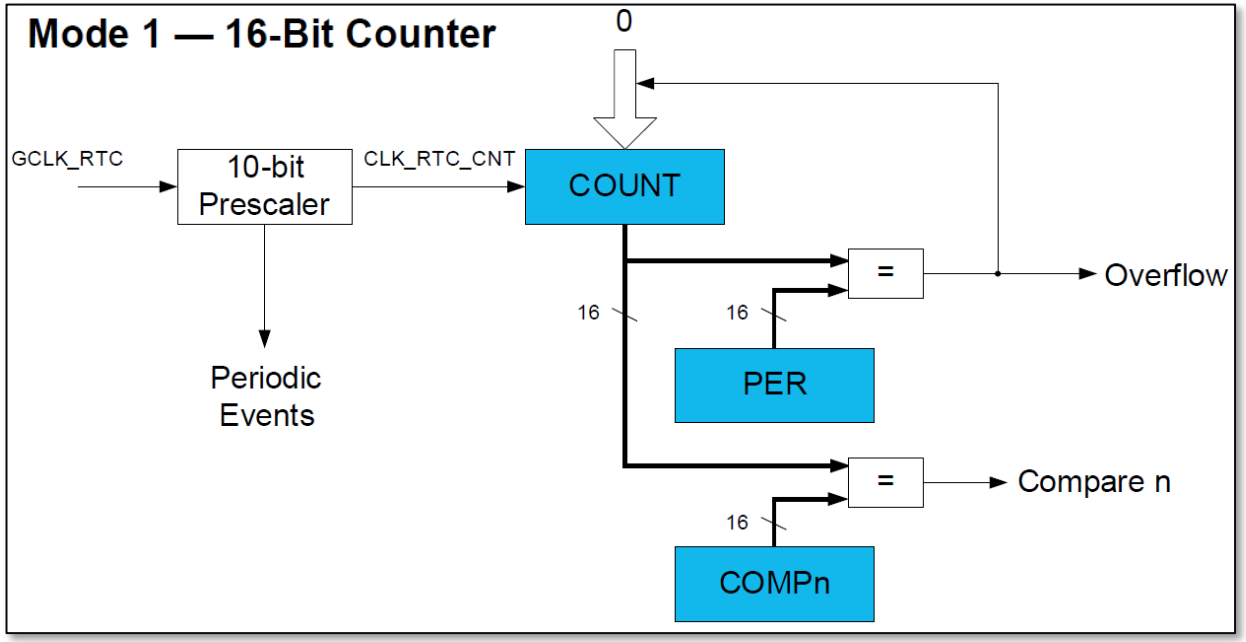
Real Time Counter (RTC) Operation Mode





The RTC can function in one of these modes:

- Mode 0 - COUNT32
  RTC serves as 32-bit counter
- Mode 1 - COUNT16
  RTC serves as 16-bit counter
- Mode 2 – CLOCK
  RTC serves as clock/calendar with alarm functionality



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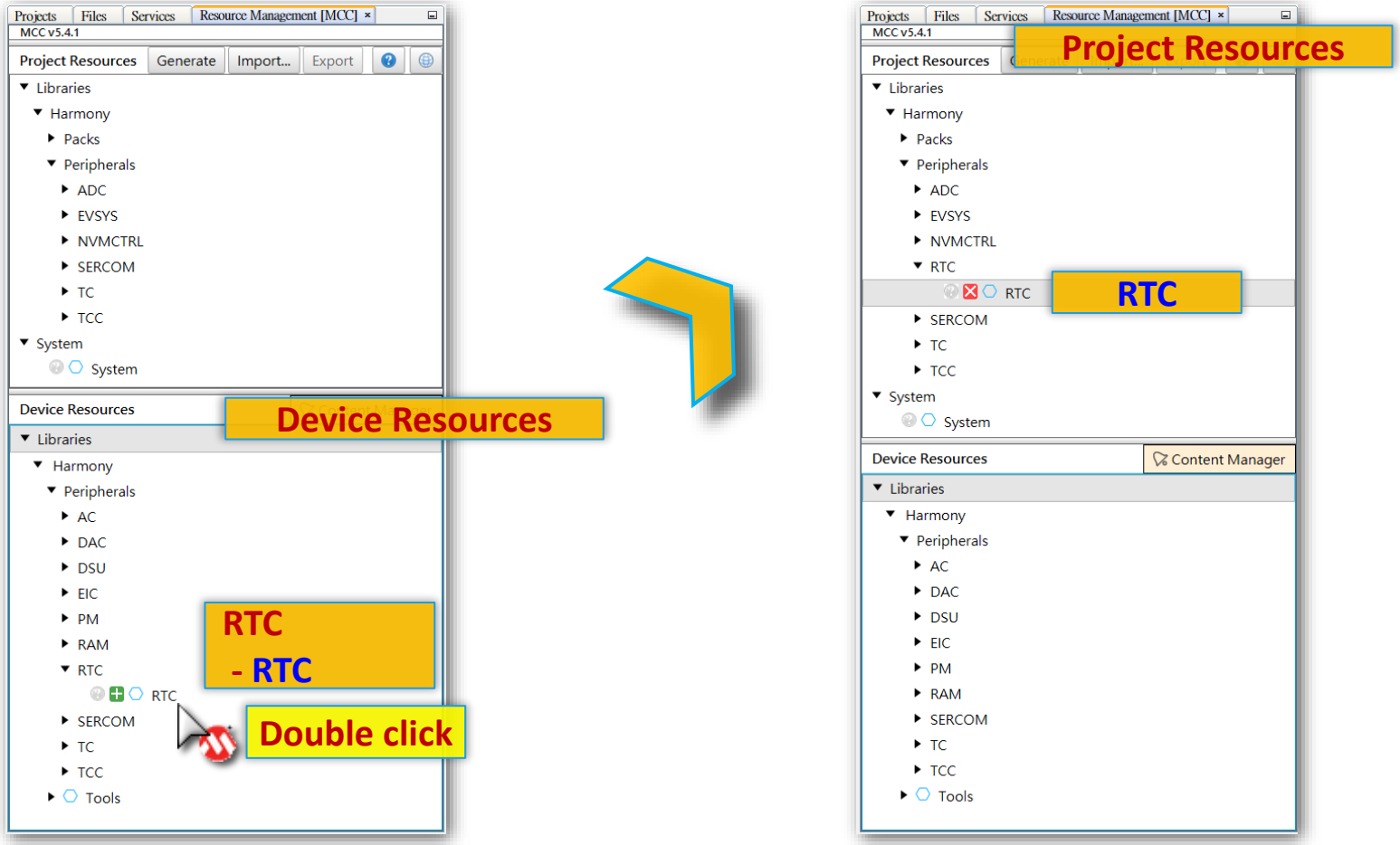
Real Time Counter (RTC)

Add RTC module using MHC

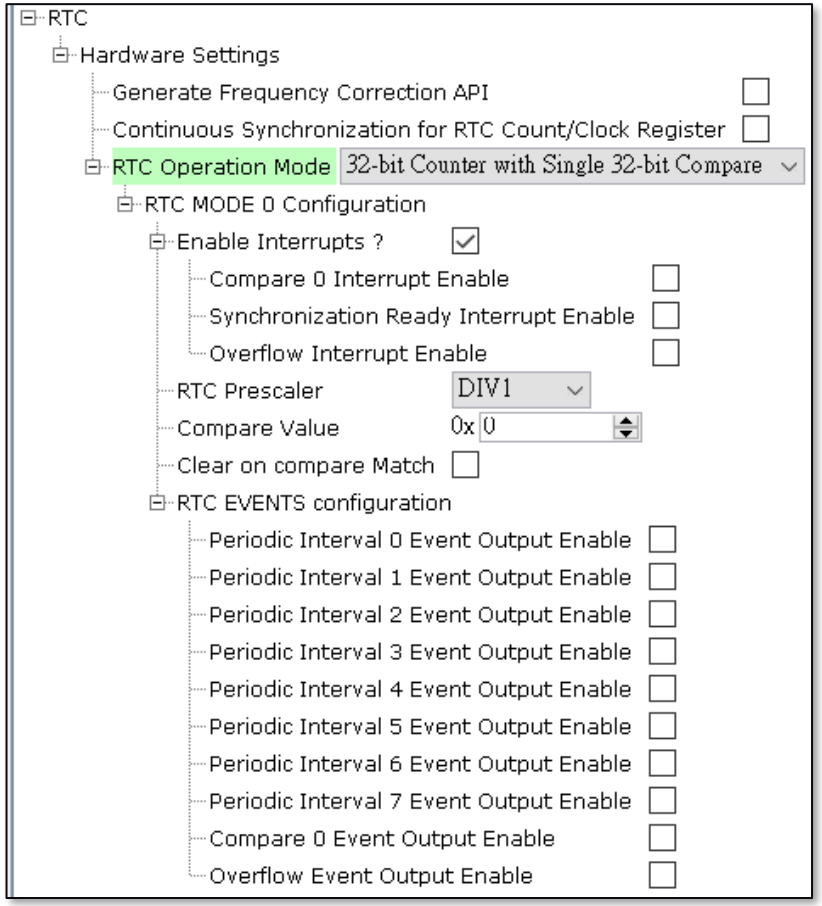
- Find RTC component in Device Resources window.
- Double click RTC to add to Project Resources window.



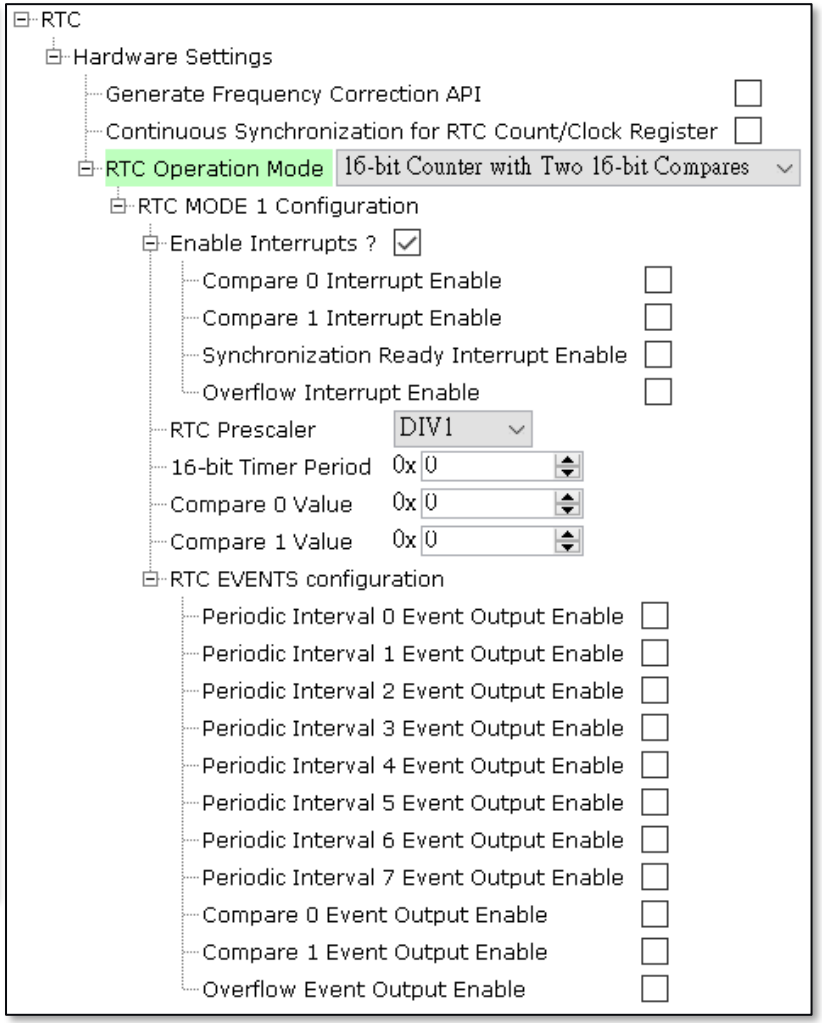
Real Time Counter (RTC)

Configuration Options Example

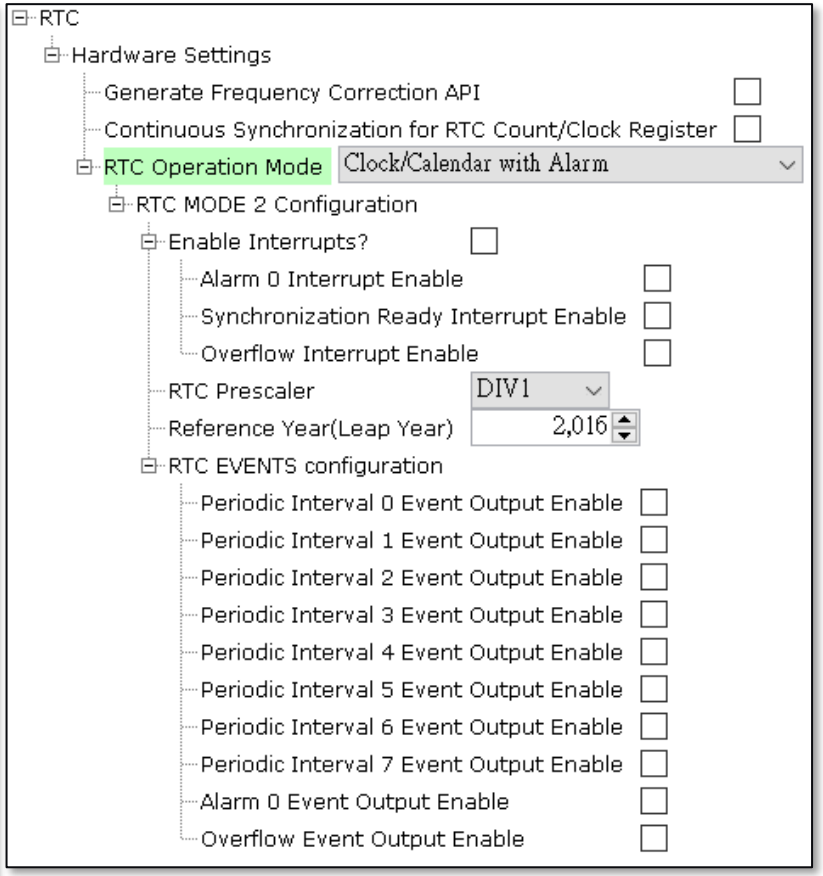
Mode 0 – 32-Bit Counter



Mode 1 – 16-Bit Counter



Mode 2 – Clock/Calendar



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Real Time Counter (RTC)

Interface Routines

void RTC_Initialize(void);

void RTC_InterruptHandler(void);

- **Mode 2 – Clock/Calendar** PLIB_RTC_Clock.c

```
bool RTC_RTCCTimeSet ( struct tm * initialTime );
void RTC_RTCCTimeGet ( struct tm * currentTime );
bool RTC_RTCCAlarmSet (struct tm * alarmTime, RTC_ALARM_MASK mask);
void RTC_RTCCCallbackRegister ( RTC_CALLBACK callback, uintptr_t context);
```

- **Mode 0 – 32-Bit Counter & Mode 1 – 16-Bit Counter** PLIB_RTC_Timer.c

```
void RTC_Timer32Start ( void );
void RTC_Timer32Stop ( void );

void RTC_Timer32CounterSet ( uint32_t count );
uint32_t RTC_Timer32CounterGet ( void );

uint32_t RTC_Timer32PeriodGet ( void );

uint32_t RTC_Timer32FrequencyGet ( void );

void RTC_Timer32CompareSet ( uint32_t compareValue );

void RTC_Timer32InterruptEnable (RTC_TIMER32_INT_MASK interrupt);
void RTC_Timer32InterruptDisable (RTC_TIMER32_INT_MASK interrupt);

void RTC_Timer32CallbackRegister ( RTC_TIMER32_CALLBACK callback, uintptr_t context );
```

```
void RTC_Timer16Start ( void );
void RTC_Timer16Stop ( void );

void RTC_Timer16CounterSet ( uint16_t count );
uint16_t RTC_Timer16CounterGet ( void );

void RTC_Timer16PeriodSet ( uint16_t period );
uint16_t RTC_Timer16PeriodGet ( void );

uint32_t RTC_Timer16FrequencyGet ( void );

void RTC_Timer16Compare0Set ( uint16_t comparisionValue );
void RTC_Timer16Compare1Set ( uint16_t comparisionValue );

void RTC_Timer16InterruptEnable (RTC_TIMER16_INT_MASK interrupt);
void RTC_Timer16InterruptDisable (RTC_TIMER16_INT_MASK interrupt);

void RTC_Timer16CallbackRegister ( RTC_TIMER16_CALLBACK callback, uintptr_t context );
```

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🛠 Lab17-1 RTC Clock and Calendar

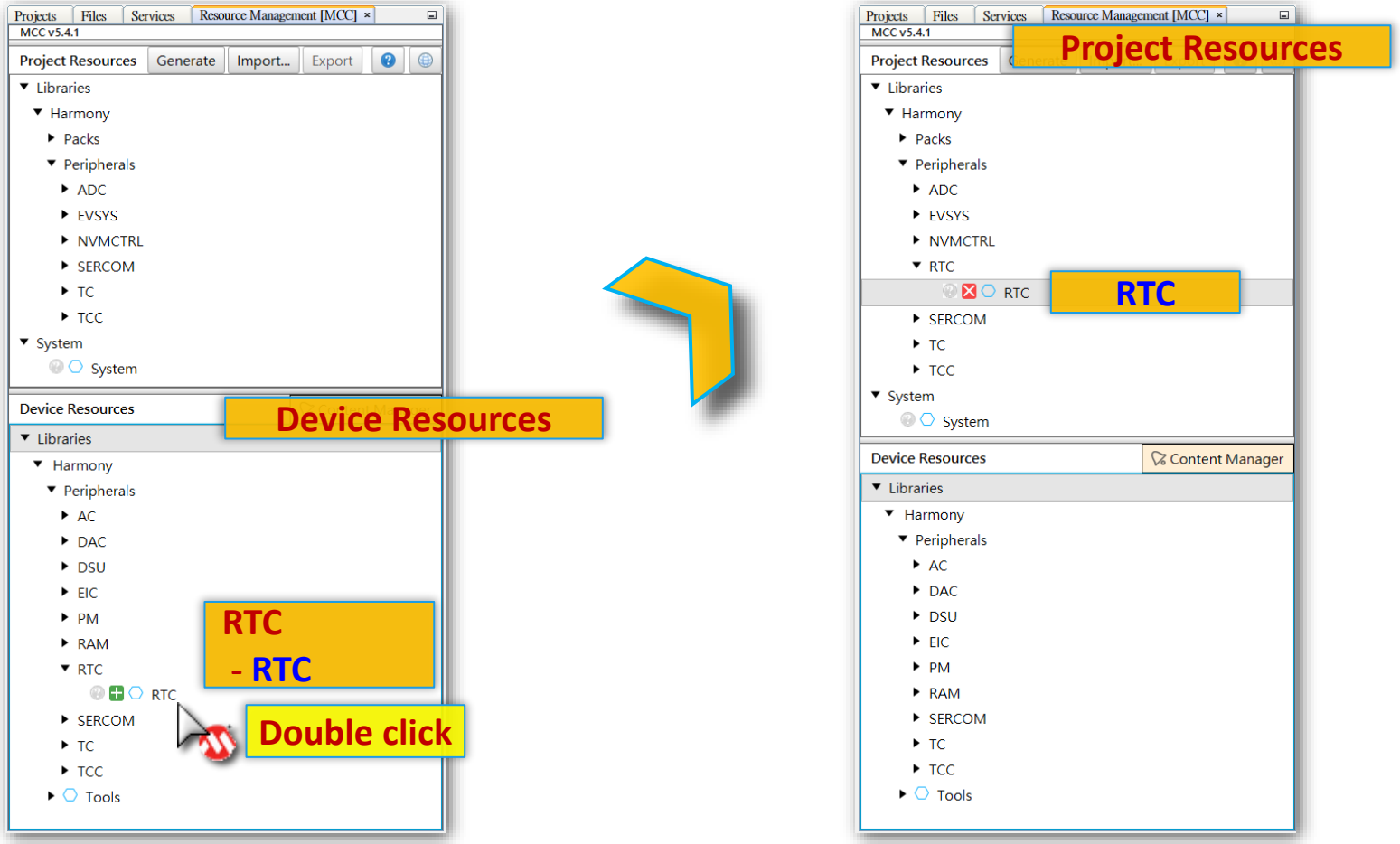
- Please continue from SAM2001 Lab17 (SERCOM - SPI SSD1306 OLED)
- Try add RTC module to current project.
- Select RTC Operation Mode to Clock/Calendar with Alarm (Mode2).
- Select RTC Prescaler to DIV1024.
- Generate a 1024Hz clock through GCLK1 by divide 32 of XOSC32K clock source.
- Due to change of GCLK1, please recalculate DFPLL 48Mhz clock by click Auto Calculate.
- Select RTC clock source in Peripheral Clock Configuration from GCLK1 that is 1024Hz.
- RTC is 1024Hz then after prescaler DIV1024 to get 1024Hz/1024 = 1Hz Clock tick.

- **Let's go !**

🛠 Lab17-1 RTC Clock and Calendar

Step 1

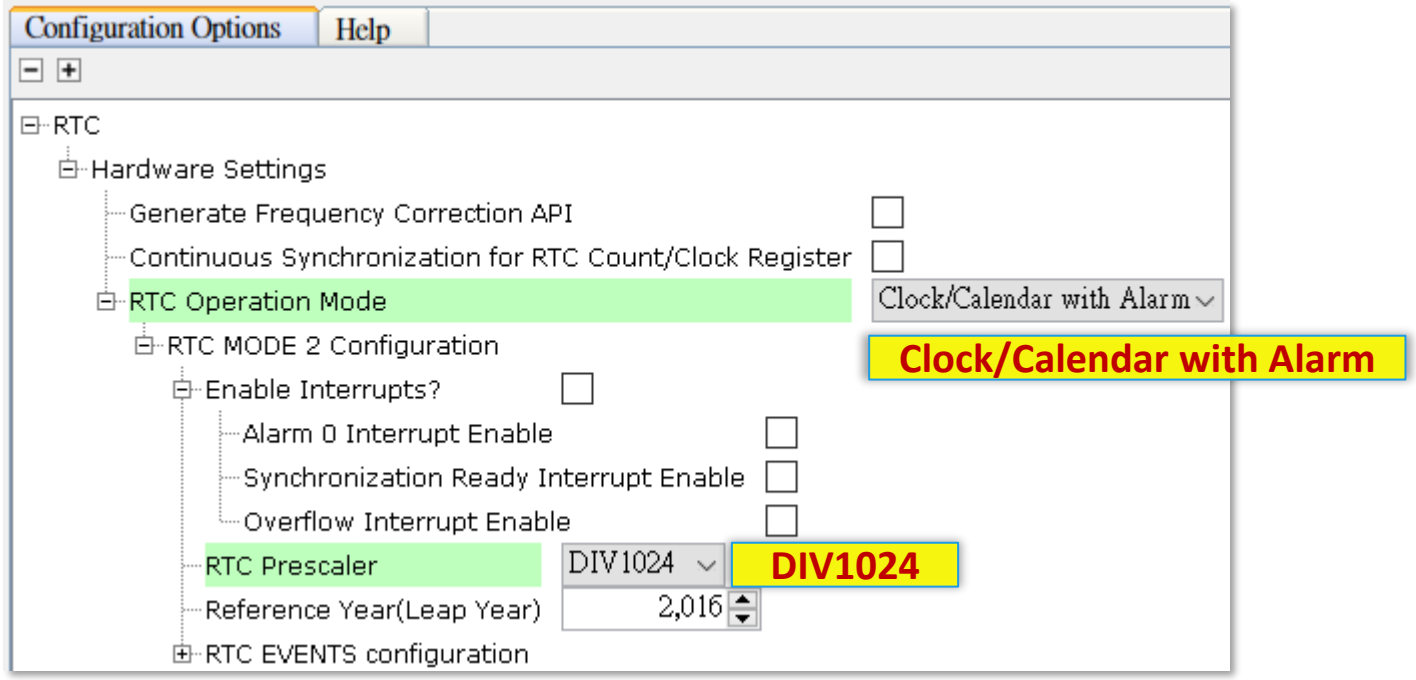
- Find **RTC** component in Device Resources window.
- Double click **RTC** to add to Project Resources window.



🛠 Lab17-1 RTC Clock and Calendar

Step 2

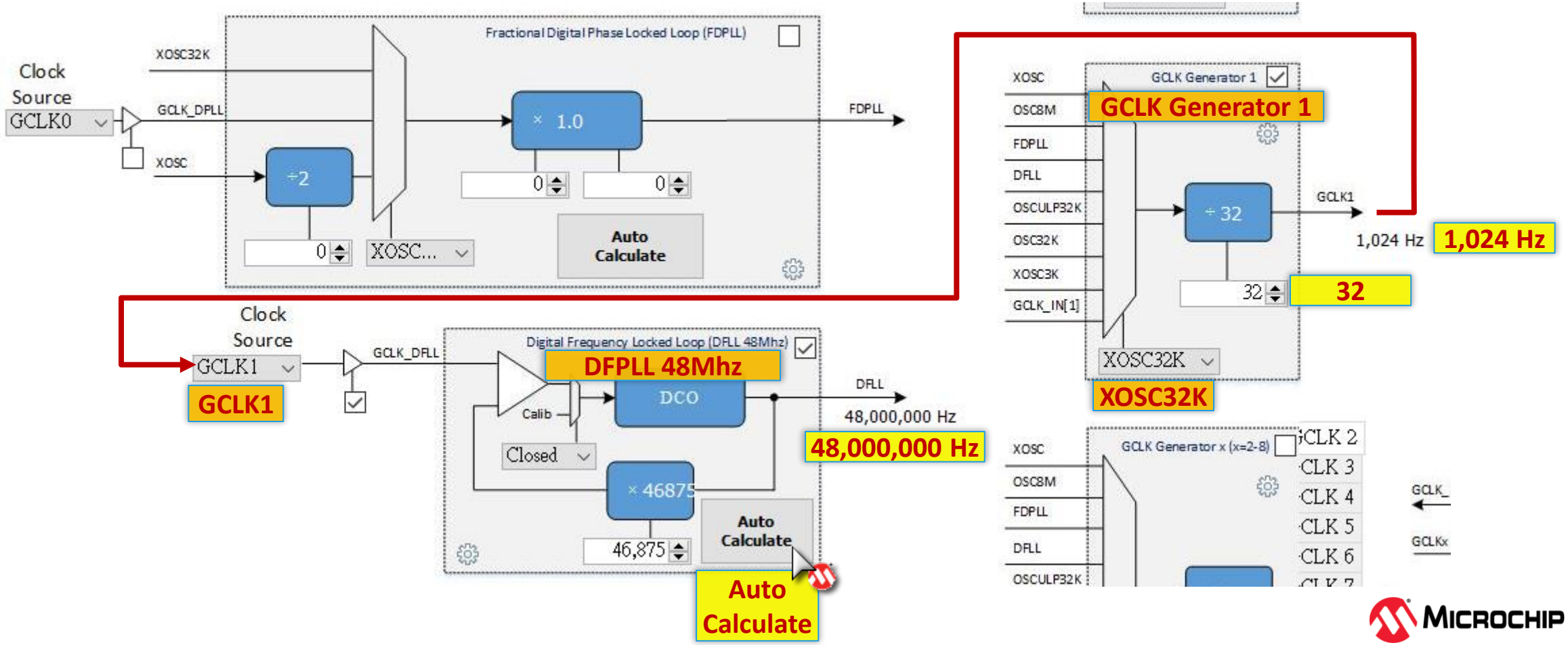
- Select RTC Operation Mode to **Clock/Calendar with Alarm** (Mode2).
- Set RTC Prescaler to **DIV1024**. (We will provide RTC 1024Hz to get **1Hz** clock tick)



🛠 Lab17-1 RTC Clock and Calendar

Step 3 (This step already done in current project)

- In MHC → Tools → Clock Configuration, Select GCLK1 to divided by 32.
- Click on Auto Calculate of DFPLL 48Mhz to recalculate correct 48MHz output.



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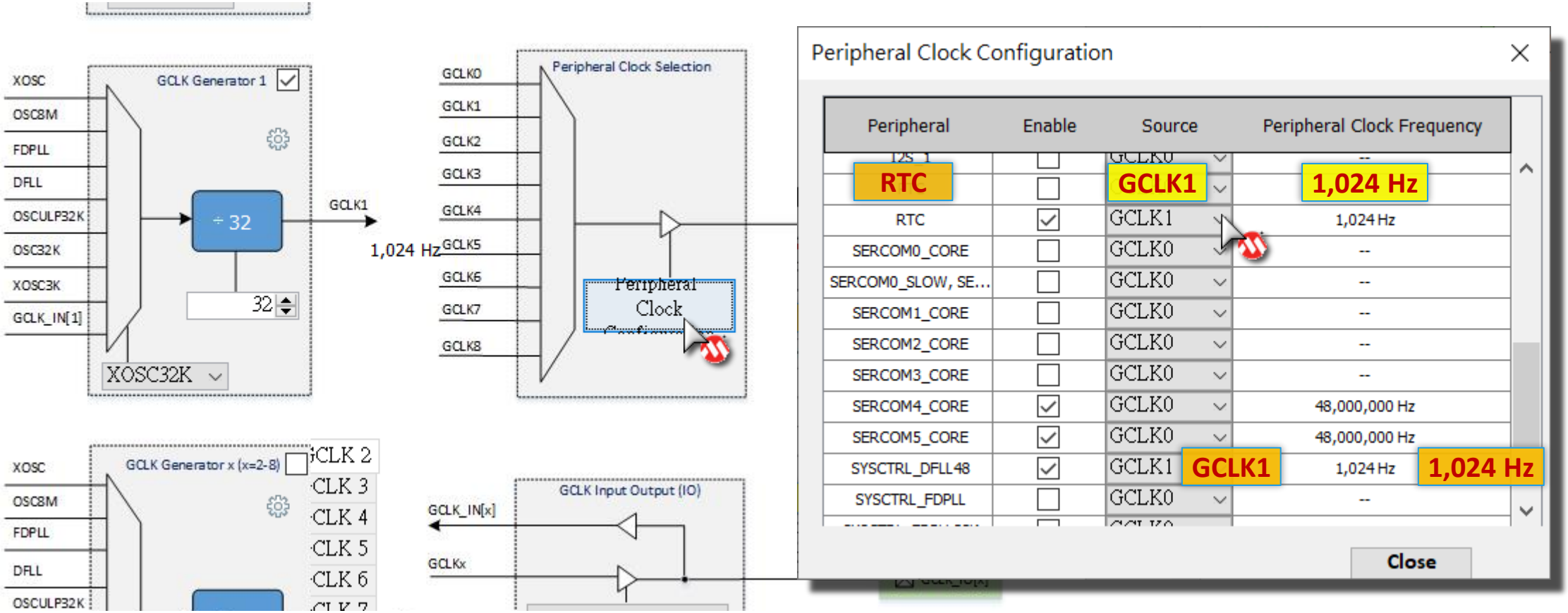
Lab17-1 RTC Clock and Calendar

Step 4

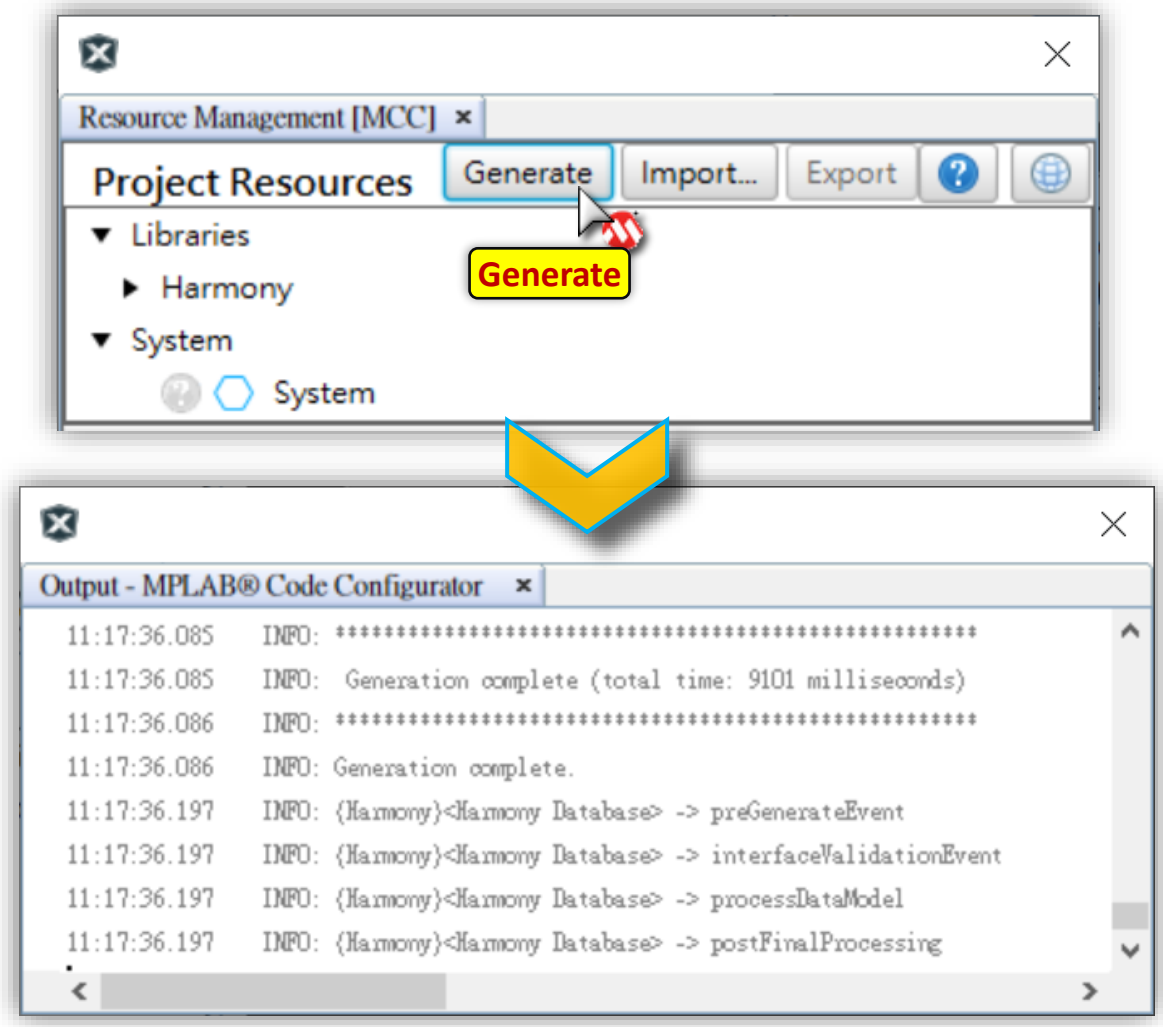
- Click on **Peripheral Clock Configuration** of **Peripheral Clock Selection**.
- Select **GCLK1** (1,024 Hz) as source clock of **RTC**.



Lab17-1 RTC Clock and Calendar

Step 5

- Click "Generate" Button to Generate your Code.



Real Time Counter (RTC)

Time structure in time.h

- **Structure containing a calendar date and time broken down into its components.**

```
struct tm {
  int tm_sec;                 // Seconds , 0 ~ 59          (Seconds after the minute)
  int tm_min;                 // Minutes , 0 ~ 59          (Minutes after the hour)
  int tm_hour;                // Hours   , 0 ~ 23          (Hours since midnight)
  int tm_mday;                // Day     , 1 ~ 31          (Day of the month)
  int tm_mon;                 // Months  , 0 ~ 11          (Months since January)
  int tm_year;                // Year = tm_year + 1900     (Years since 1900)
  int tm_wday;                // WeekDay , 0 ~ 6           (Days since Sunday)
  int tm_yday;                // YearDay , 0 ~ 365         (Days since January 1)
  int tm_isdst;               // Is daylight Saving?       (Daylight Saving Time flag)
  long __tm_gmtoff;           // GMT Off
  const char *__tm_zone;      // Time zone
};
```

Real Time Counter (RTC)

RTC Mode 2 Register

- Implement difference between RTC Mode2 Register and Time structure

RTC MODE2 CLOCK Register		Time structure
RTC_REGS.MODE2.CLOCK[0:5]	// Seconds , 0 ~ 59	(tm_sec)
RTC_REGS.MODE2.CLOCK[11:6]	// Minutes , 0 ~ 59	(tm_min)
RTC_REGS.MODE2.CLOCK[16:12]	// Hours , 0 ~ 23	(tm_hour)
RTC_REGS.MODE2.CLOCK[21:17]	// Day , 1 ~ 31	(tm_mday)
RTC_REGS.MODE2.CLOCK[25:22]	// Months , 1 ~ 12	(tm_mon)
RTC_REGS.MODE2.CLOCK[31:26]	// Year = [31:26] + [Reference Year]	(tm_year)
------ Not implement ------	// WeekDay	(tm_wday)
------ Not implement ------	// YearDay	(tm_yday)
------ Not implement ------	// Is daylight Saving?	(tm_isdst)
------ Not implement ------	// GMT Off	(__tm_gmtoff)
------ Not implement ------	// Time zone	(__tm_zone)

Real Time Counter (RTC)

RTC Mode 2 Register convert between Time structure

- Hamrony Interfaces routines in below will convert between RTC register and struct tm.

  bool RTC_RTCCTimeSet (struct tm * initialTime);

  void RTC_RTCCTimeGet (struct tm * currentTime);

  bool RTC_RTCCAlarmSet (struct tm * alarmTime, RTC_ALARM_MASK mask);

```
/* Reference Year */
#define REFERENCE_YEAR              (2016U)

/* Reference Year in tm structure year (C standard) */
#define TM_STRUCT_REFERENCE_YEAR    (1900U)

/* Adjust user year with respect to tm structure year (C Standard) */
#define ADJUST_TM_YEAR(year)        (year + TM_STRUCT_REFERENCE_YEAR)

/* Adjust user month */
#define ADJUST_MONTH(month)         (month + 1)

/* Adjust to tm structure month */
#define ADJUST_TM_STRUCT_MONTH(mon) (mon - 1)
```

```
RTC_REGS.MODE2.CLOCK[31:26] = TM_STRUCT_REFERENCE_YEAR + tm_year - REFERENCE_YEAR
tm_year = RTC_REGS.MODE2.CLOCK[31:26] + REFERENCE_YEAR - TM_STRUCT_REFERENCE_YEAR
```

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🛠 Lab17-1 RTC Clock and Calendar

Calculate Weekday

- Zeller's congruence (Use Gregorian calendar)

$$h = \left(q + \left\lfloor \frac{13(m+1)}{5} \right\rfloor + K + \left\lfloor \frac{K}{4} \right\rfloor + \left\lfloor \frac{J}{4} \right\rfloor - 2J\right) mod\ 7$$

h : The day of the week (0 = Saturday, 1 = Sunday, 2 = Monday, ..., 6 = Friday)
q : The day of the month.
m : The month (3 = March, 4 = April, 5 = May, ..., 12 = December, **13 = January**, **14 = February**)
K : The year of the century ($year\ mod\ 100$), ex. 19**98** and 20**22** are **98** and **22** respectively.
J : The zero-based century ($\lfloor year/100 \rfloor$), ex. **19**98 and **20**22 are **19** and **20** respectively.
⌊…⌋ : The floor function or integer part.
mod : The modulo operation or remainder after division.

https://en.wikipedia.org/wiki/Zeller%27s_congruence

Lab17-1 RTC Clock and Calendar

Step 6

```
...
char Alphabet[95] =
"0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz~!@#$%^&()[]{}_\\|...

// TODO 17-1.01
struct tm RTC_TimeStruct;
const char *monthArray[] =
          {"Jan", "Feb", "Mar", "Apr", "May", "Jun",
           "Jul", "Aug", "Sep", "Oct", "Nov", "Dec" };
const char *weekArray[] =
          {"SUN", "MON", "TUE", "WED", "THR", "FRI", "SAT"};
int Year, Month, Date, Week;
int Hour, Minute, Second;

void RTC_CalculateWeekday( struct tm *pTimeStruct )
{
    // Zeller's congruence to use Gregorian calendar
    int J = (pTimeStruct->tm_year+1900) / 100;
    int K = (pTimeStruct->tm_year+1900) % 100;
    int m = (pTimeStruct->tm_mon<2?pTimeStruct->tm_mon+13:pTimeStruct->tm_mon+1);
    int q =  pTimeStruct->tm_mday;
    int h = (q + (int)((13*((float)m+1))/5) + K + (int)(K/4) + (int)(J/4) - 2*J) % 7;

    pTimeStruct->tm_wday = (h+7-1)%7; // Convert to Time structure format
}
```

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🛠 Lab17-1 RTC Clock and Calendar

Use C compiler time as Clock Initialize

- **Standard Predefined Macros**

__FILE__
This macro expands to the name of the current input file, in the form of a C string constant.
__LINE__
This macro expands to the current input line number, in the form of a decimal integer constant.

__FILE__ and __LINE__ are useful in generating an error message in line of program.

```
myprintf ( "Exception at line %d of file %s.",  __LINE__, __FILE__ );
```

__DATE__
This macro expands to a string constant that describes the date on which the preprocessor is being run.
The string constant contains eleven characters and looks like "Feb 12 1996".
__TIME__
This macro expands to a string constant that describes the time at which the preprocessor is being run.
The string constant contains eight characters and looks like "23:59:01".

__DATE__ and __TIME__ could be use for output latest built date and time of current application program.

```
myprintf ( "Current program built at %s, %s.",  __TIME__, __DATE__ );
```

https://gcc.gnu.org/onlinedocs/cpp/Standard-Predefined-Macros.html

🛠 Lab17-1 RTC Clock and Calendar

Step 7

```
// TODO 17-1.01
...
void RTC_CalculateWeekday( struct tm *pTimeStruct ) { ... };
void RTC_SetCompilerTime( struct tm *pTimeStruct )
{
    char monthStr[3];
    int year, month, day, hour, min, sec;

    sscanf(__DATE__, "%s %d %d", monthStr, &day, &year );
    sscanf(__TIME__, "%d:%d:%d", &hour, &min, &sec );

    for( month=0 ; month<12 && strcmp(monthStr, monthArray[month]) ; month++ );

    pTimeStruct->tm_year = year-1900;
    pTimeStruct->tm_mon  = month;
    pTimeStruct->tm_mday = day;
    pTimeStruct->tm_hour = hour;
    pTimeStruct->tm_min  = min;
    pTimeStruct->tm_sec  = sec;

    RTC_RTCCTimeSet( pTimeStruct );
    RTC_CalculateWeekday( pTimeStruct );
}

const uint8_t LCM_InitCMD[] = { ... };
```

Lab17-1 RTC Clock and Calendar

Step 8

```
int main ( void )
{   ...
    // TODO 17-1.02
    RTC_SetCompilerTime( &RTC_TimeStruct );

    while ( true )
    {
        if (TC3_HasExpired)
        {   ...
            // TODO 17-1.03
            RTC_RTCCTimeGet( &RTC_TimeStruct );
            RTC_CalculateWeekday( &RTC_TimeStruct );
            Year   = RTC_TimeStruct.tm_year+1900;    Month  = RTC_TimeStruct.tm_mon;
            Date   = RTC_TimeStruct.tm_mday;         Week   = RTC_TimeStruct.tm_wday;
            Hour   = RTC_TimeStruct.tm_hour;         Minute = RTC_TimeStruct.tm_min;
            Second = RTC_TimeStruct.tm_sec;
            sprintf( (char *)USARTRTxBuffer, "%04d-%s-%02d(%s)",
                                        Year, monthArray[Month], Date, weekArray[Week] );
            LCM_DrawString( 0, 2, (char *)USARTRTxBuffer );
            myprintf( "\033[1;1H%s ", USARTRTxBuffer );
            sprintf( (char *)USARTRTxBuffer, "%02d:%02d:%02d", Hour, Minute, Second );
            LCM_DrawString( 0, 3, (char *)USARTRTxBuffer );
            myprintf( "%s", USARTRTxBuffer );

            ADC_ConversionStart();
```

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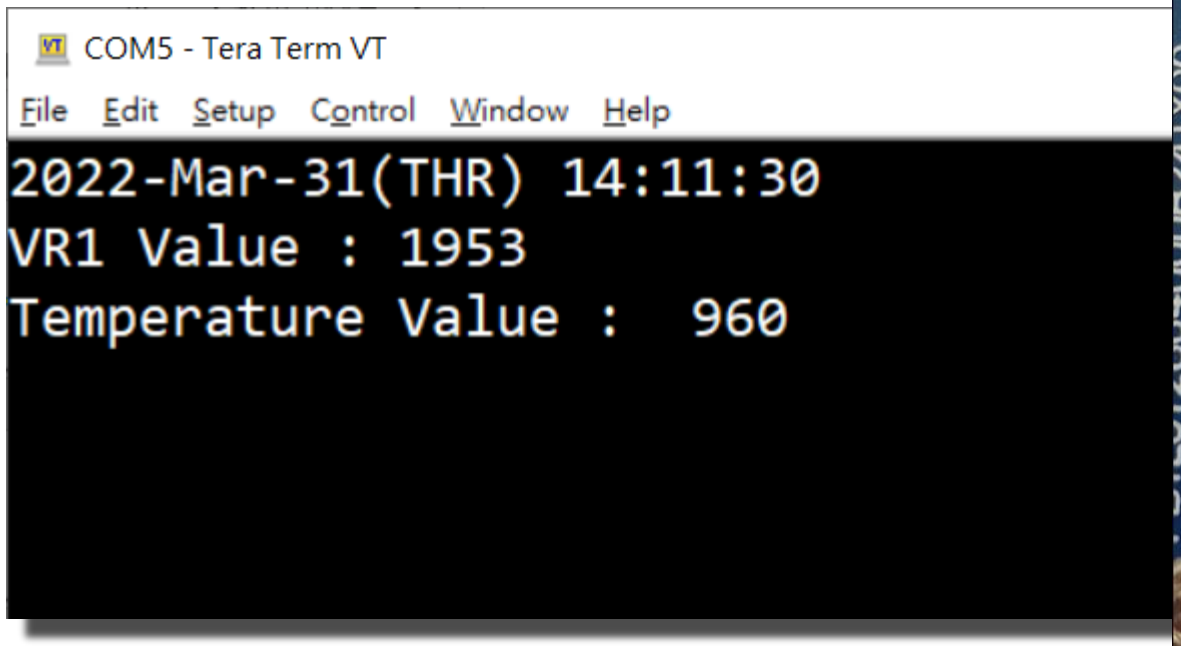
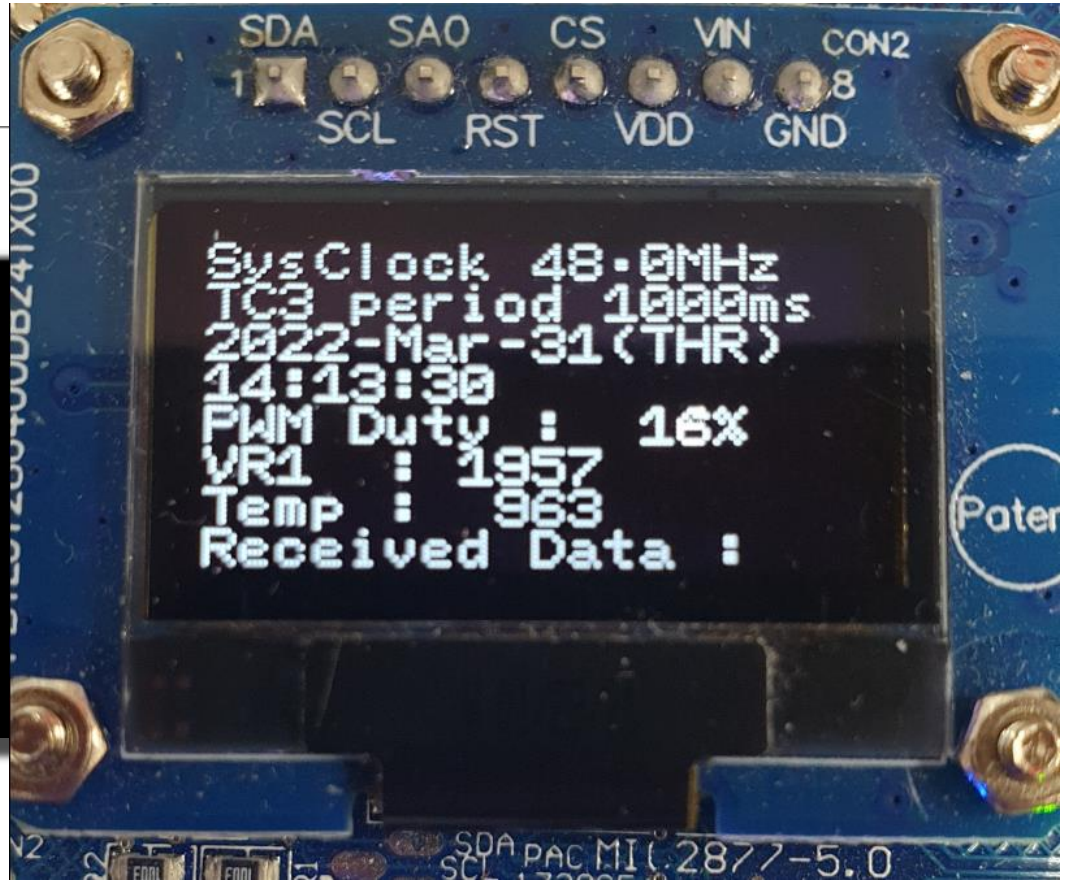
🛠 Lab17-1 RTC Clock and Calendar

Result

- **Calendar and Clock on OLED to use Compiler Time as initialize.**





🛠 Lab17-1 RTC Clock and Calendar

Discuss

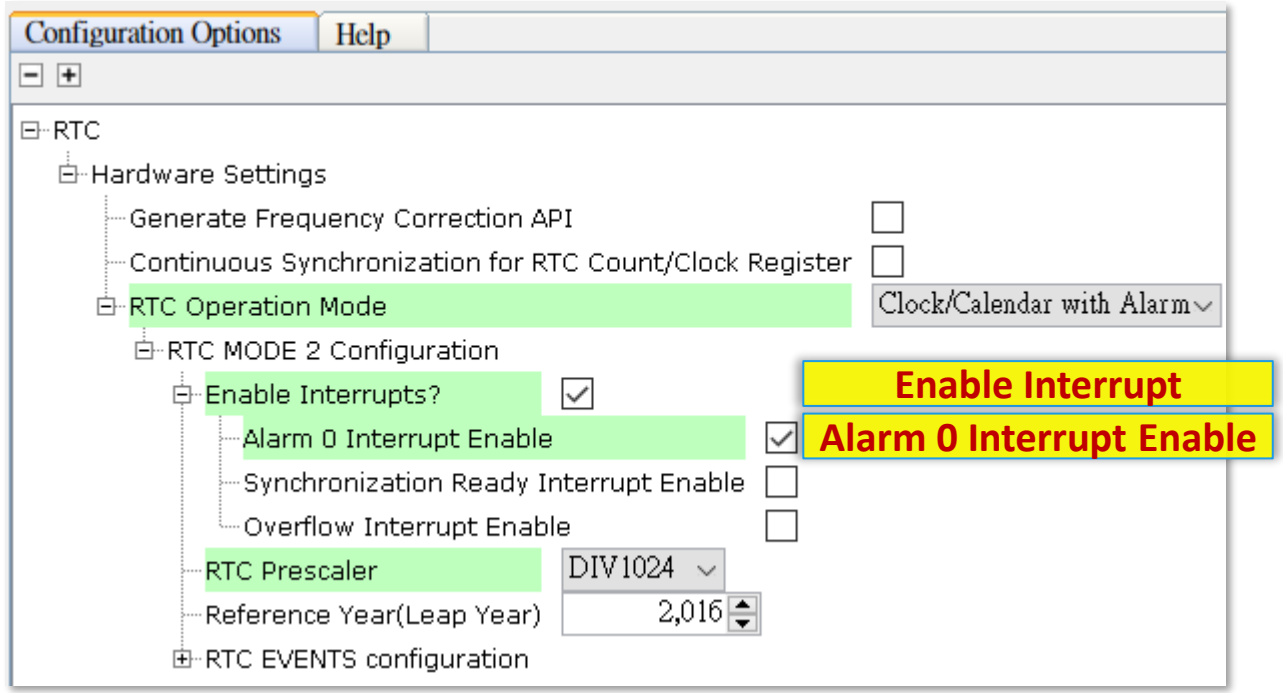
- **How to setup an Alarm ?**

Please Enable Interrupt and set Alarm 0 Interrupt Enable in Harmony.

Two extra interface routines will be generated.

bool RTC_RTCCAlarmSet (struct tm * alarmTime, RTC_ALARM_MASK mask);

void RTC_RTCCCallbackRegister (RTC_CALLBACK callback, uintptr_t context);



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🛠 Lab17-1 RTC Clock and Calendar

Discuss

- **Implement an Alarm in 10 seconds after boot.**

```
int Hour, Minute, Second;
struct tm RTC_AlarmStruct;
volatile int8_t RTC_IsAlarm = 0;
void RTC_AlarmCallback( RTC_CLOCK_INT_MASK intCause, uintptr_t context )
{
    if( intCause & RTC_CLOCK_INT_MASK_ALARM )
        RTC_IsAlarm = 1;
}
...
int main ( void )
{   ...
    RTC_RTCCCallbackRegister( RTC_AlarmCallback, 0 );
    RTC_AlarmStruct = RTC_TimeStruct;
    RTC_AlarmStruct.tm_sec = RTC_AlarmStruct.tm_sec + 10;
    RTC_RTCCAlarmSet( &RTC_AlarmStruct, RTC_ALARM_MASK_YYMMDDHHMMSS );
    while ( true )
    {
        if (TC3_HasExpired)
        {   ...
            sprintf( (char *)USARTRTxBuffer, "%02d:%02d:%02d %s",
                                    Hour, Minute, Second, (RTC_IsAlarm?"!!Alarm!!":"") );
            ...
```

```
typedef enum
{
   RTC_ALARM_MASK_SS = 0x1,          //Alarm every minute
   RTC_ALARM_MASK_MMSS,              //Alarm every Hour
   RTC_ALARM_MASK_HHMMSS,            //Alarm Every Day
   RTC_ALARM_MASK_DDHHMMSS,          //Alarm Every Month
   RTC_ALARM_MASK_MMDDHHMMSS,        //Alarm Every year
   RTC_ALARM_MASK_YYMMDDHHMMSS       //Alarm Once
} RTC_ALARM_MASK;
```

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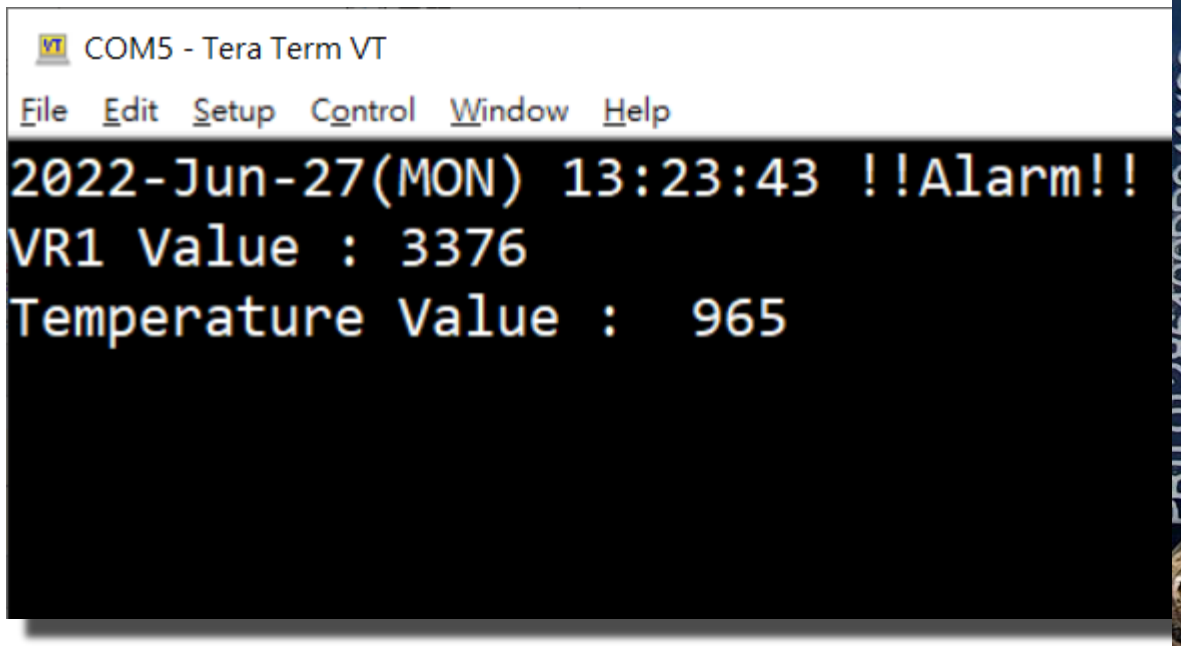
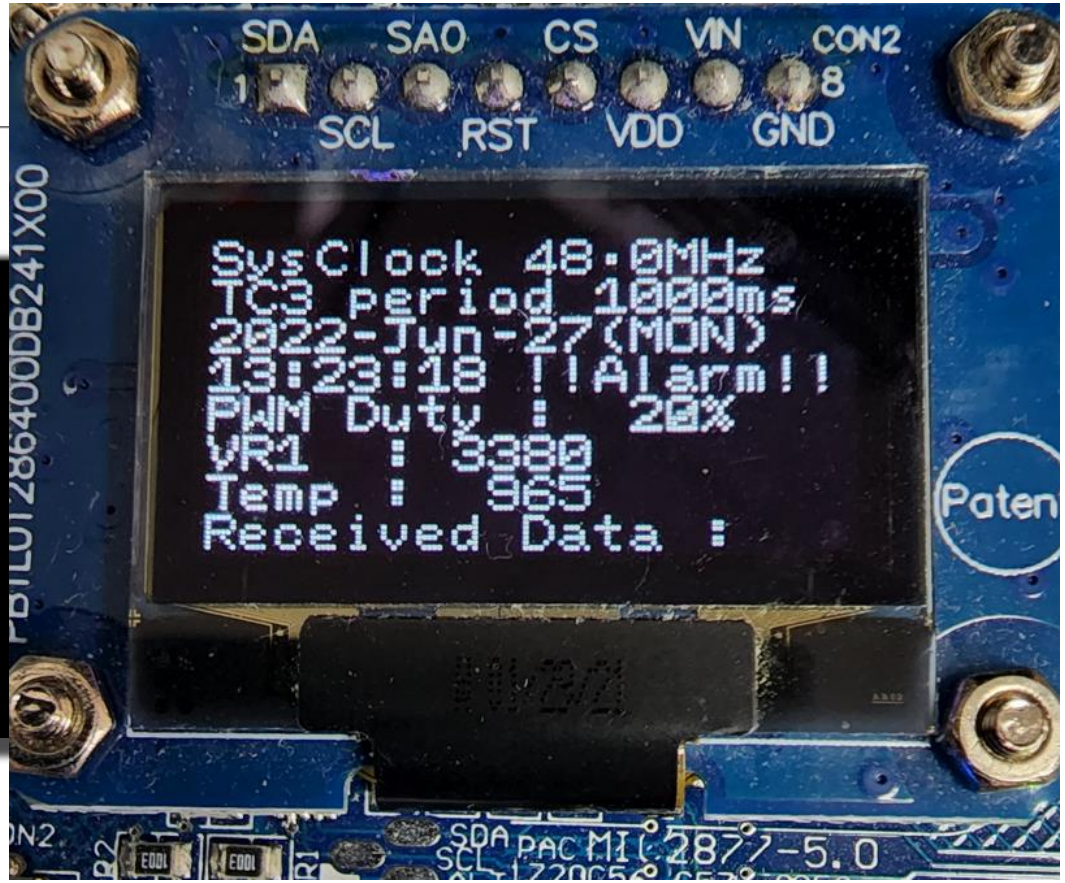
🛠 Lab17-1 RTC Clock and Calendar

Discuss

- **Show the “!!Alarm!!” message after 10 second.**





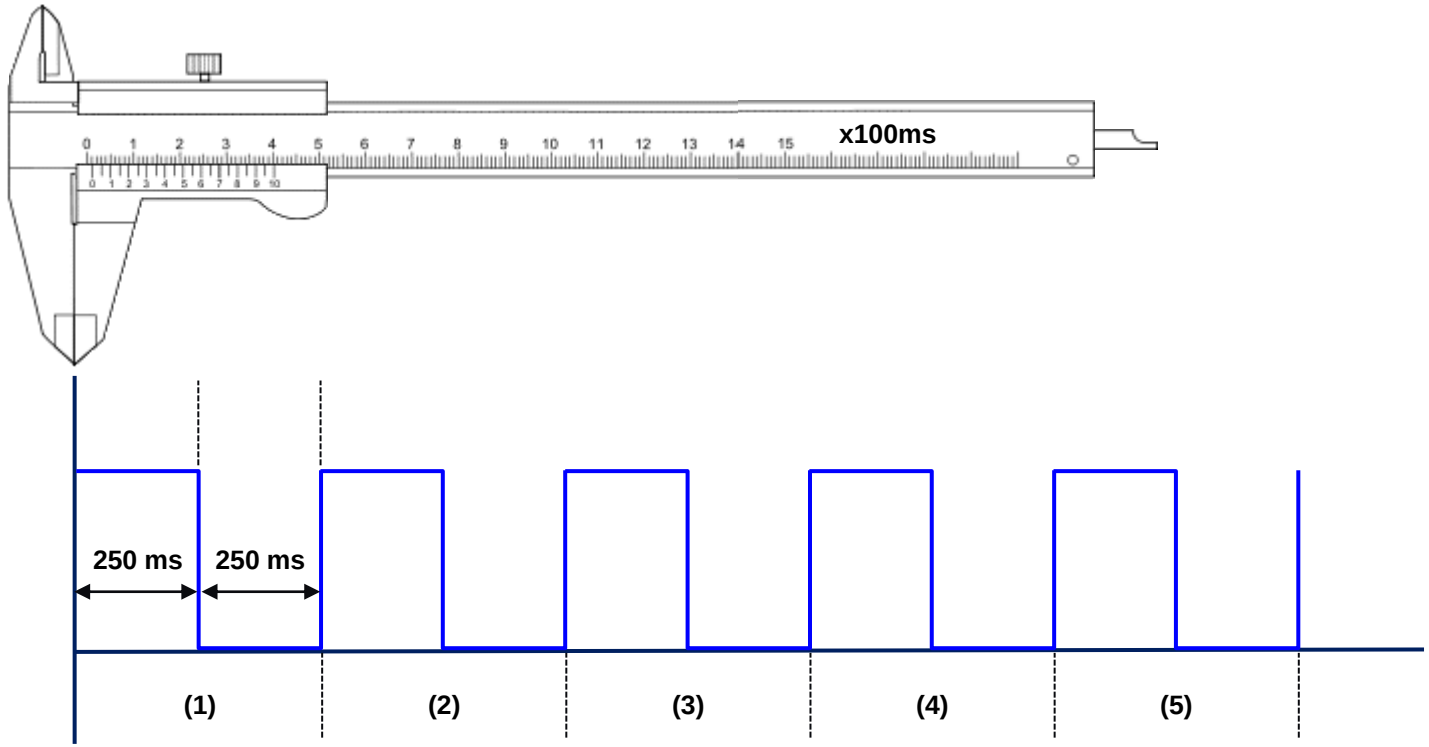
TC Waveform Capture

Integrate TC, EIC and Event System

MICROCHIP

What’s Waveform Capture?

- **Waveform Capture is used to capture a timer value from an independent timer base upon an event on the input pin.**
- **The Capture features are useful in applications requiring frequency (time period) and pulse measurement.**

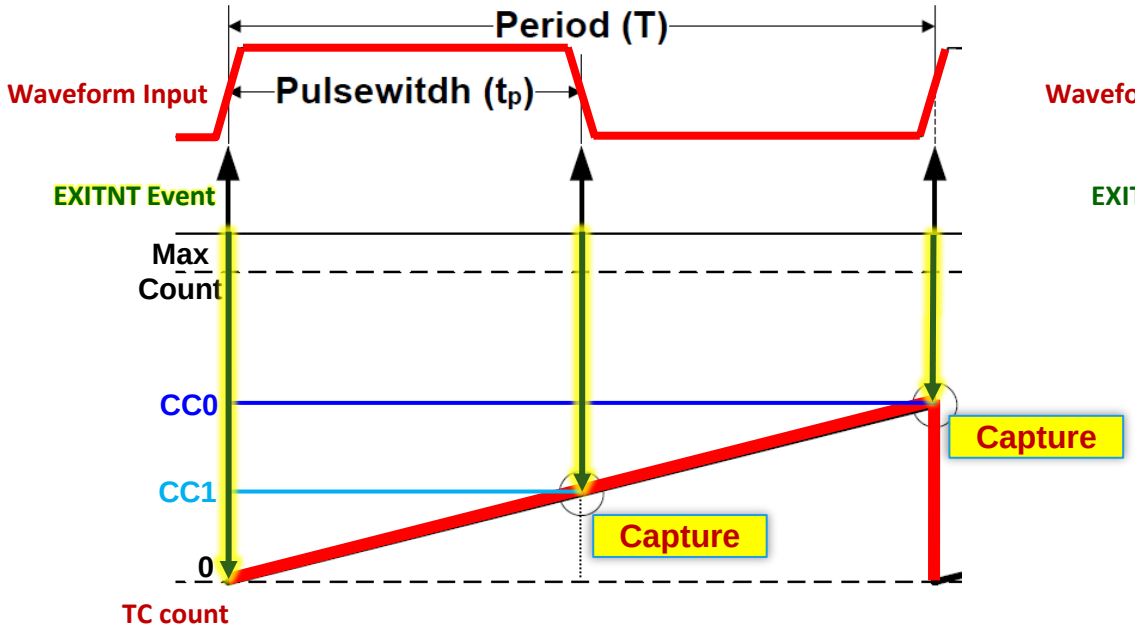


MICROCHIP

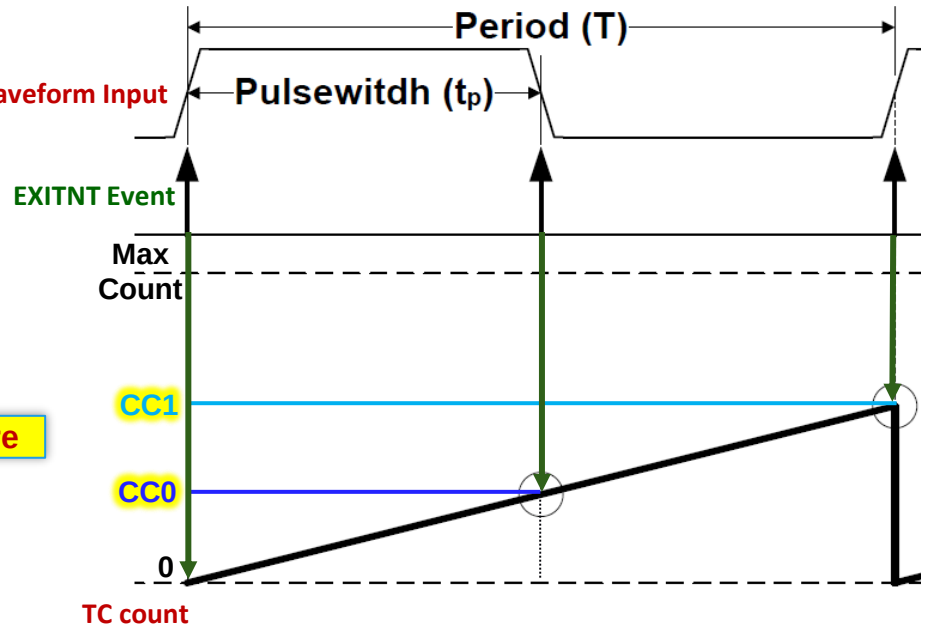
TC Capture with Event System

- The TC compare/capture channels can be used as input capture channels to capture events from the Event System and give them a timestamp.
- The TC can perform two input captures action on the rising and falling edge, counter will restart on one of the edges depend. This enables the TC to measure the pulse width and period and to characterize the frequency and duty cycle of an input signal.

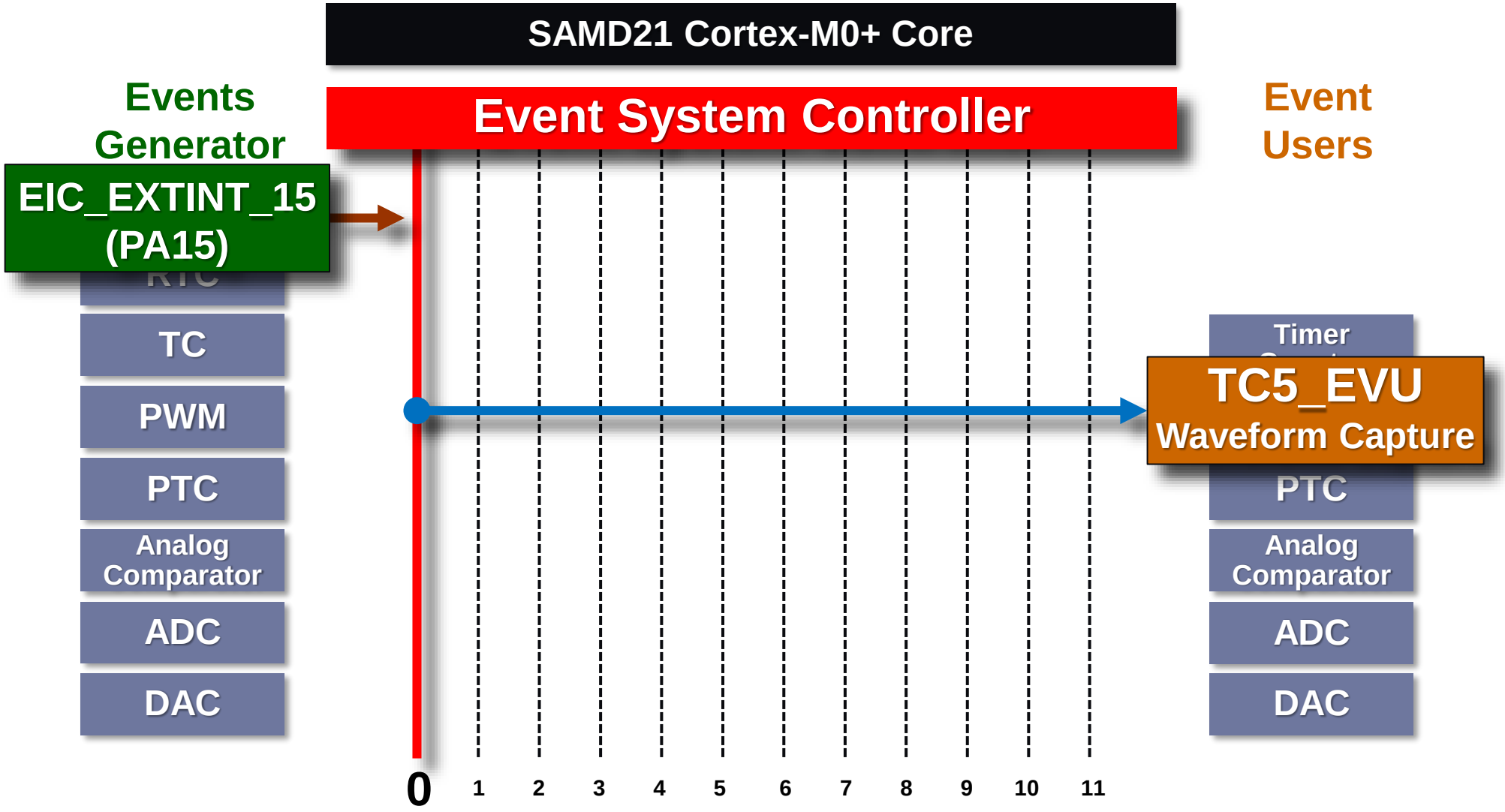
PPW (Period and Pulse-width) :
Period (T) will be captured into CC0,
Pulsewidth (t_p) will be into CC1



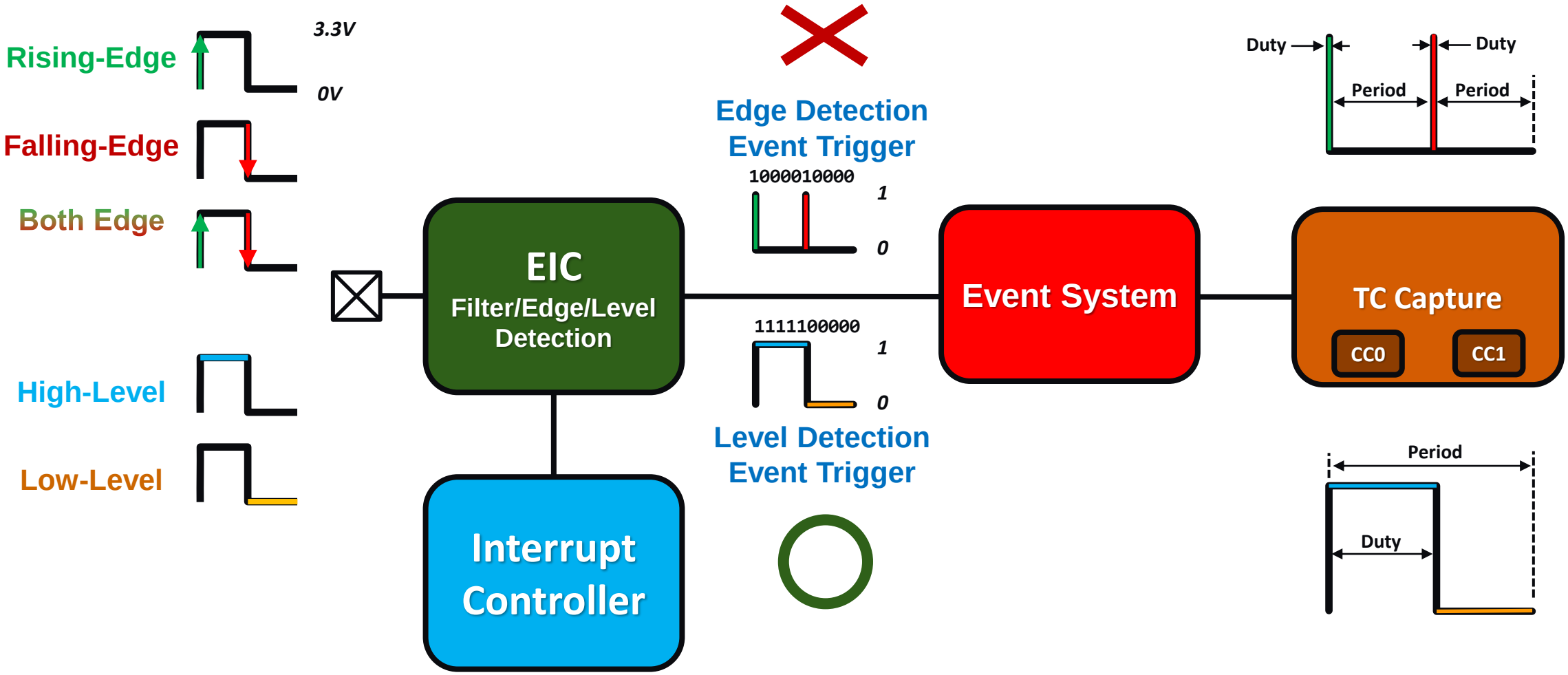
PWP (Pulse-width, Period) :
Period (T) will be captured into CC1,
Pulsewidth (t_p) will be into CC0.



Routing EIC to TC Capture through Event System



Routing EIC to TC Capture through Event System



Lab16-4 TC Waveform Capture

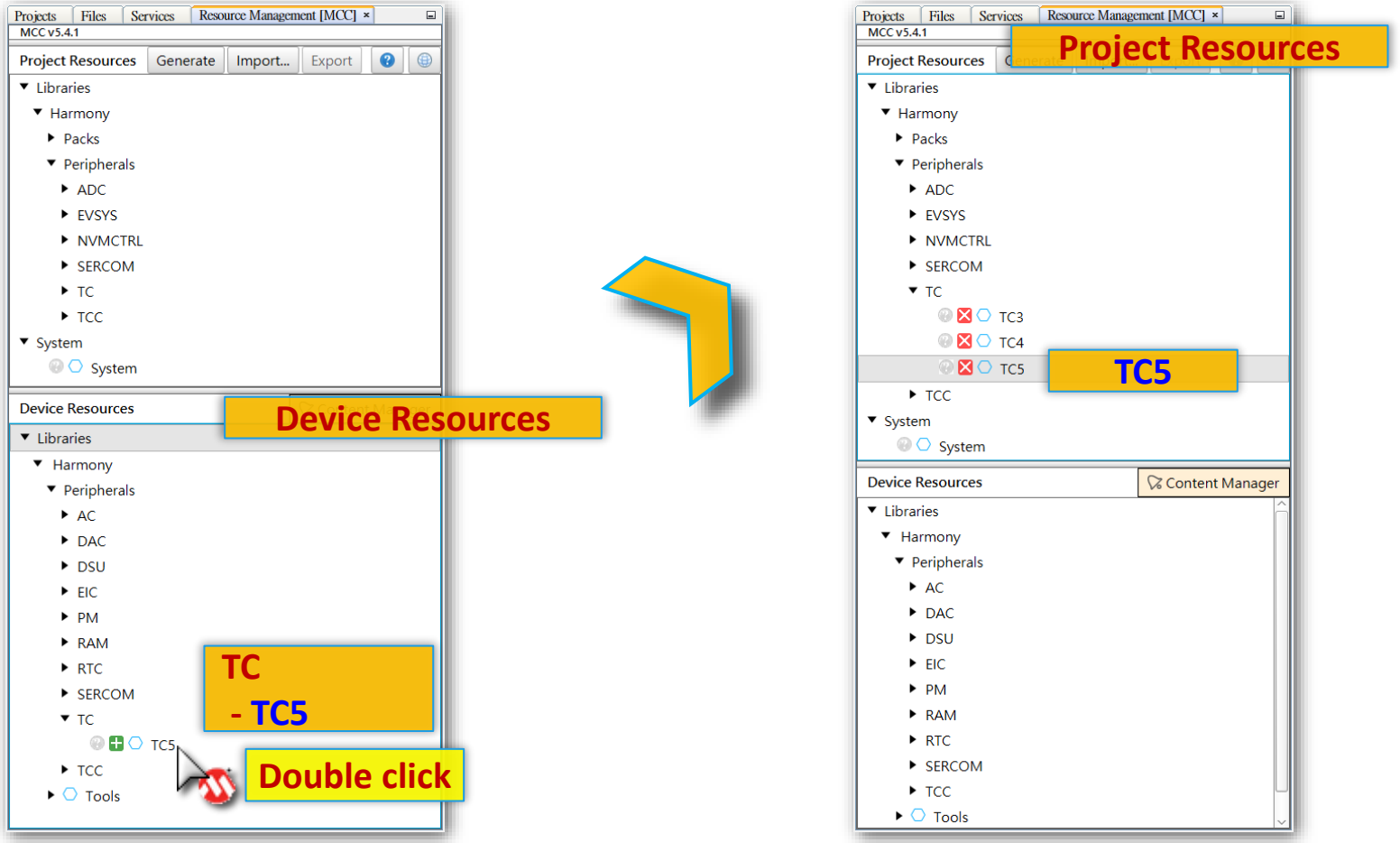
- Please continue from SAM2001 Lab16 (TCC NPWM Auto DutyCtrl)
- Add new TC5 module and configure to Capture mode.
- Add EIC module and enable EIC_EXTINT15(PA15) for Event output.
- Assign EIC_EXTINT15(PA15) as waveform capture input pin and configure it as the Event System Generator.
- Assign TC5 module as Event System User to capture waveform from EIC_EXTINT15(PA15).
- Output measured waveform Period and Duty to UART.

- Let's go!

Lab16-4 TC Waveform Capture

Step 1

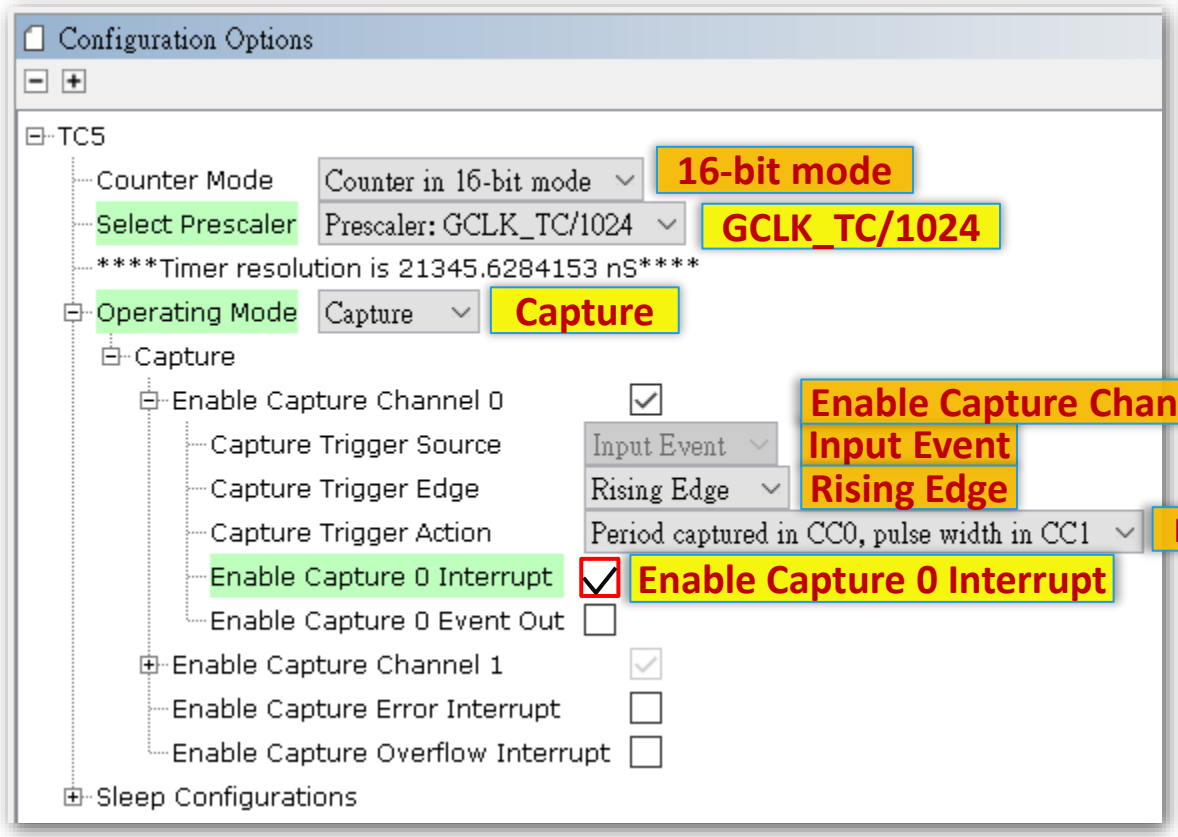
- Find TC5 component in Device Resources window.
- Double click TC5 to add to Project Resources window.



Lab16-4 TC Waveform Capture

Step 2

- **Config TC5 as Capture Mode and enable Interrupt.**

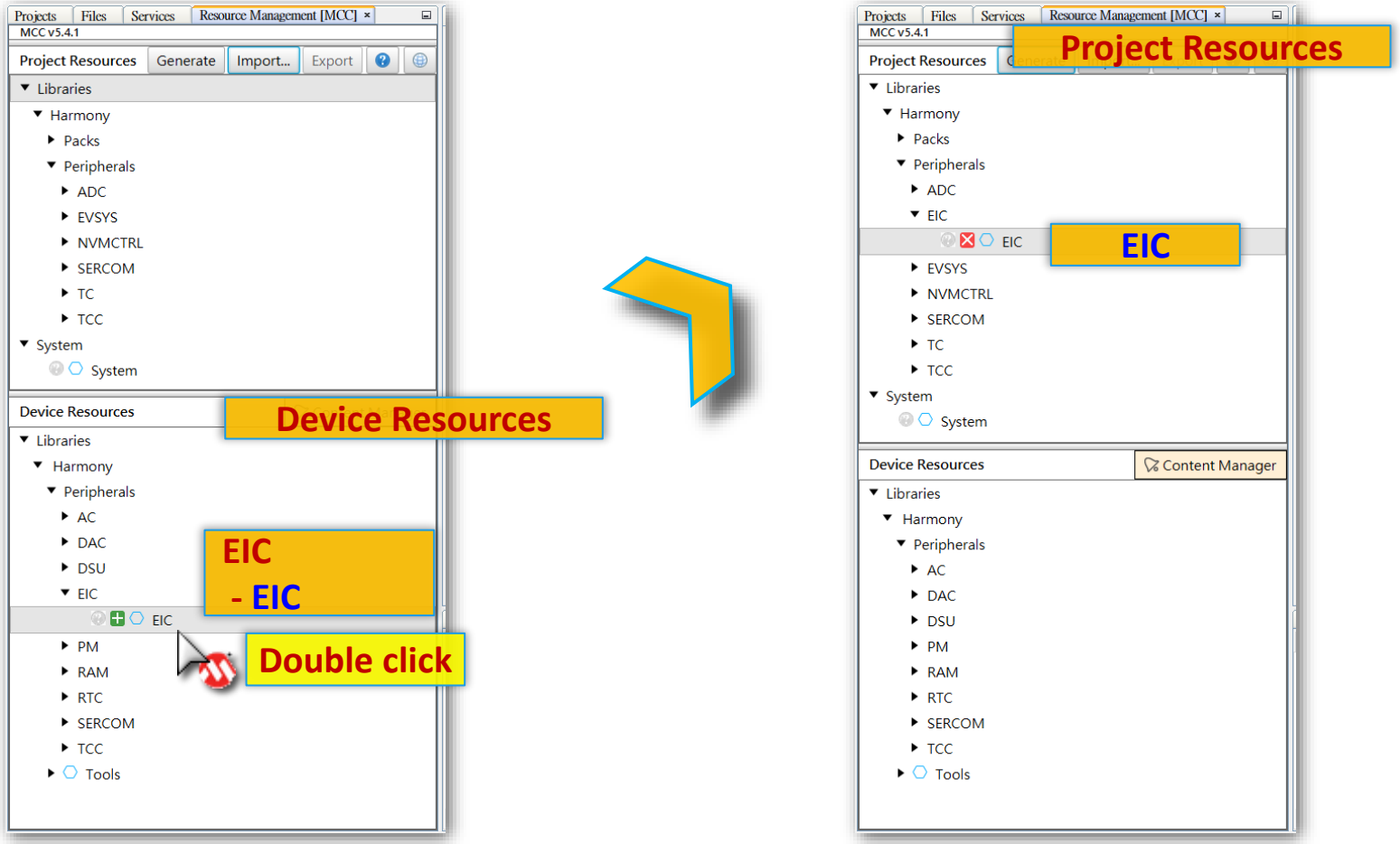


Capture Resolution is :
48M/1024 = 46.875 KHz
Max Capture Count is :
0xFFFF (16bits)
Max Capture Period is :
0xFFFF / 46.875KHz = 1398 ms

Lab16-4 TC Waveform Capture

Step 3

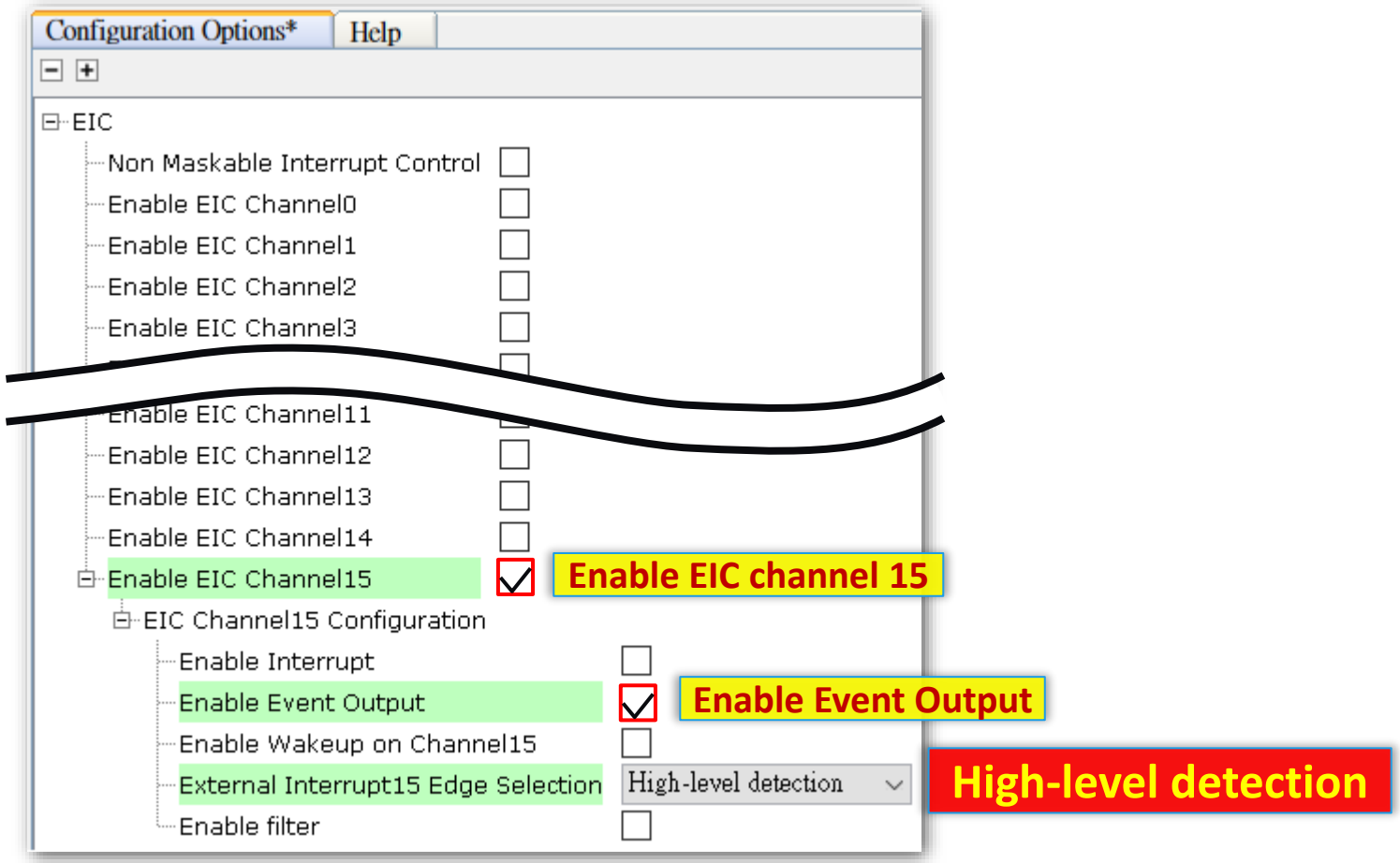
- Find EIC component in Device Resources window.
- Double click EIC to add to Project Resources window.



Lab16-4 TC Waveform Capture

Step 4

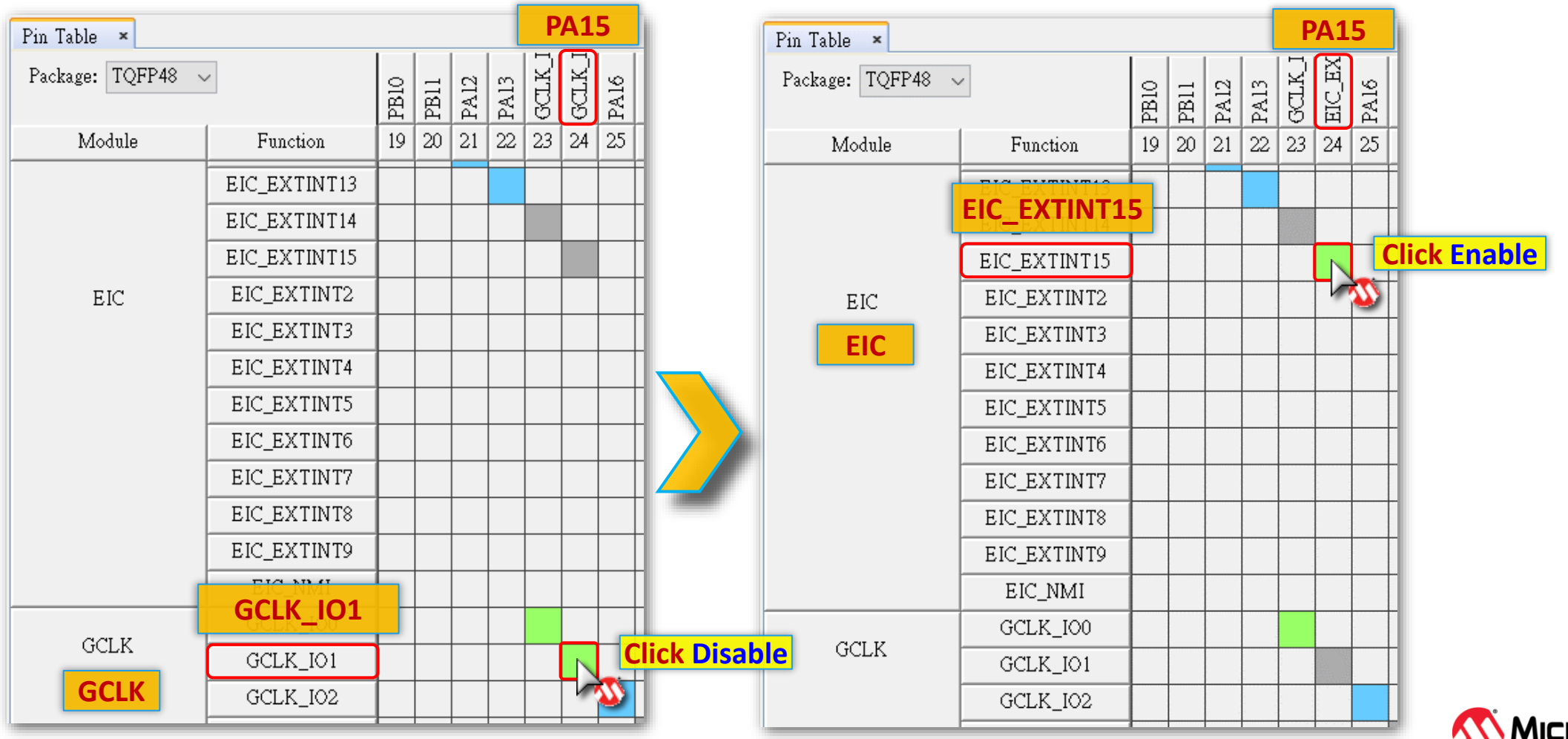
- Enable EIC channel 15 in configuration options, it's corresponding to PA15.
- Enable Event Output and Edge selection to High-level detection.



Lab16-4 TC Waveform Capture

Step 5

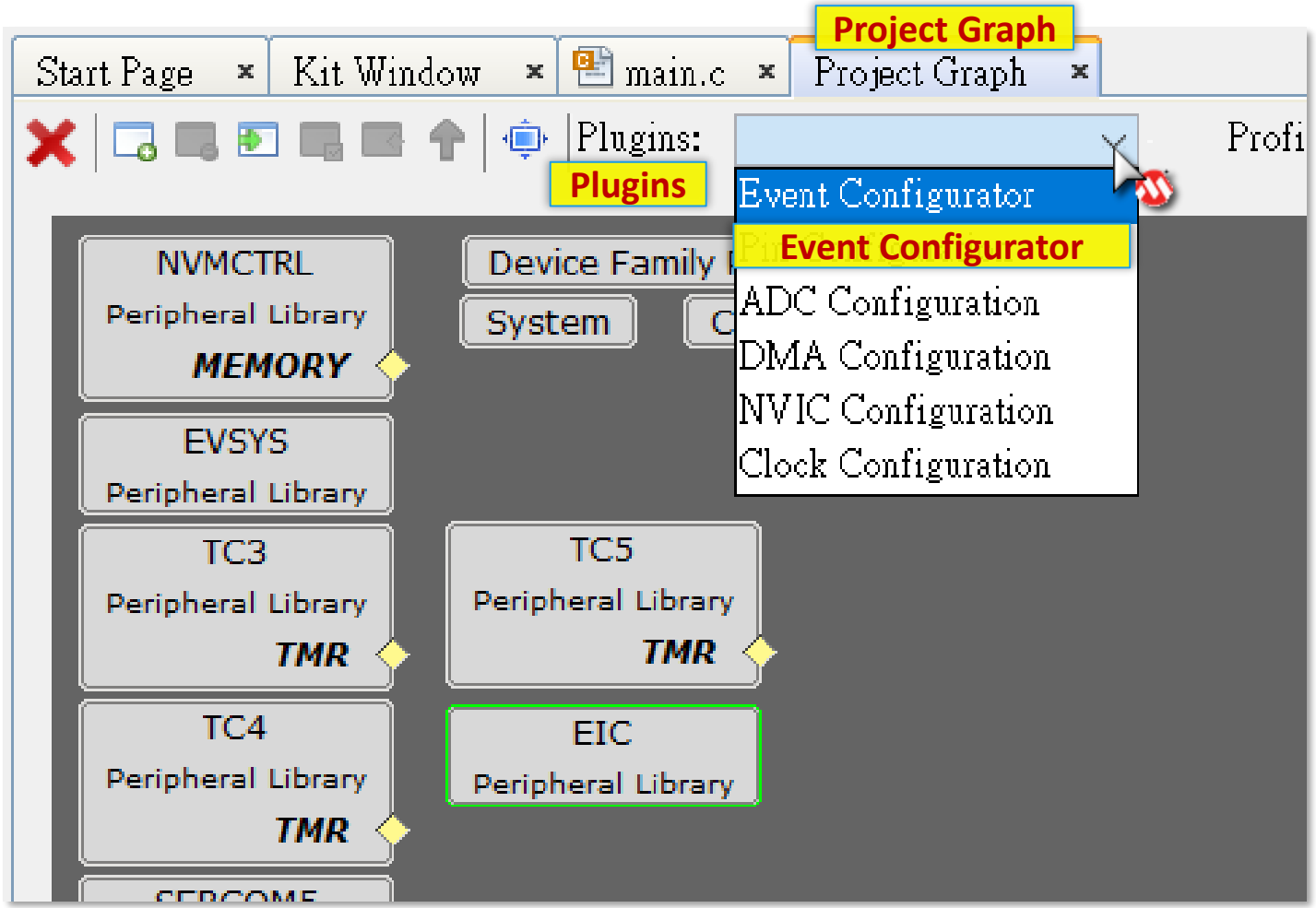
- **Disable GCLK_IO1 on PA15 and Enable it for EIC_EXTINT15 pin function.**



Lab16-4 TC Waveform Capture

Step 6

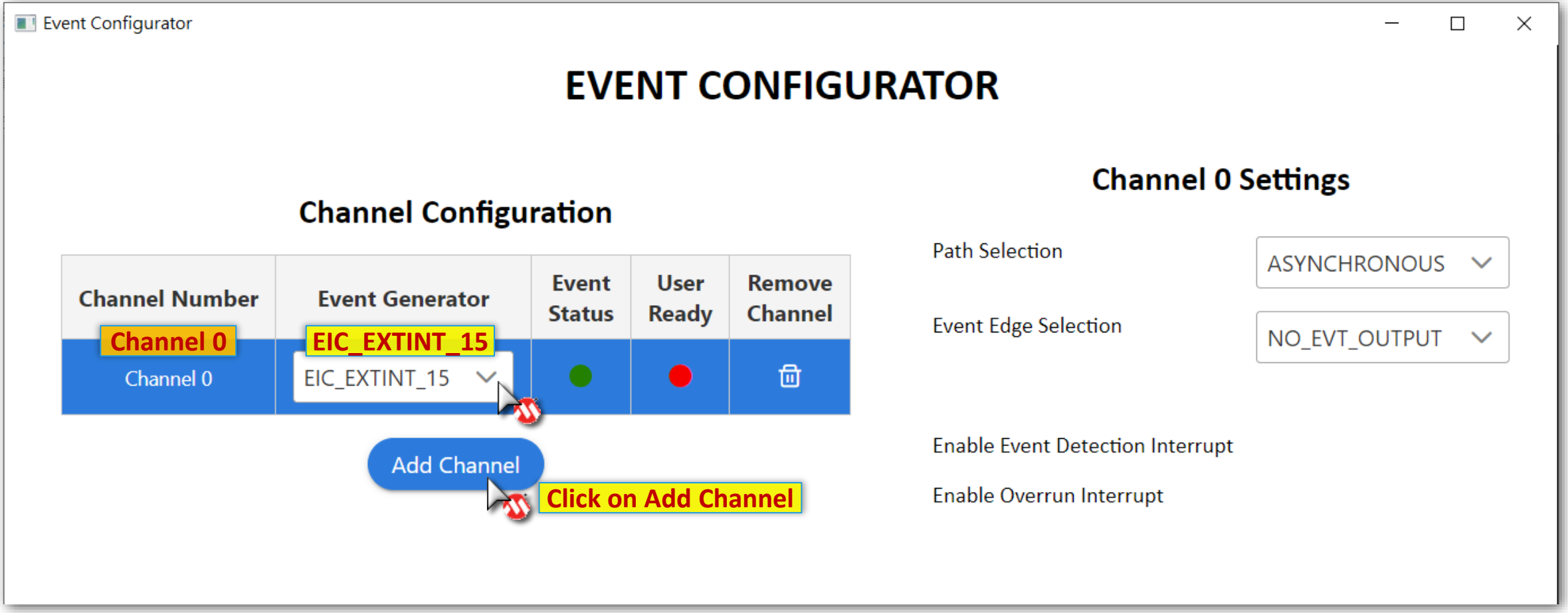
- Find **Event Configurator** in Plugins of **Project Graph** window.



Lab16-4 TC Waveform Capture

Step 7

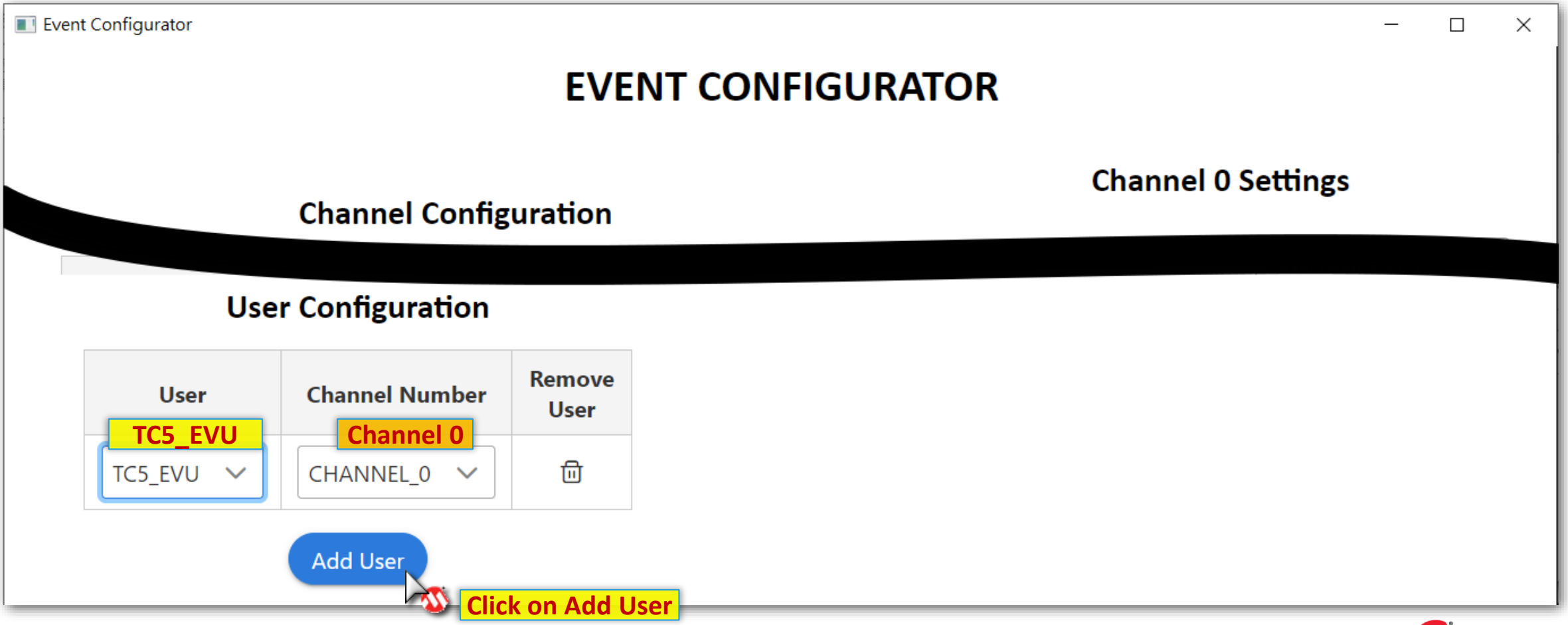
- Add Channel 0 and assign EIC_EXTINT_15 as Event Generator.



Lab16-4 TC Waveform Capture

Step 8

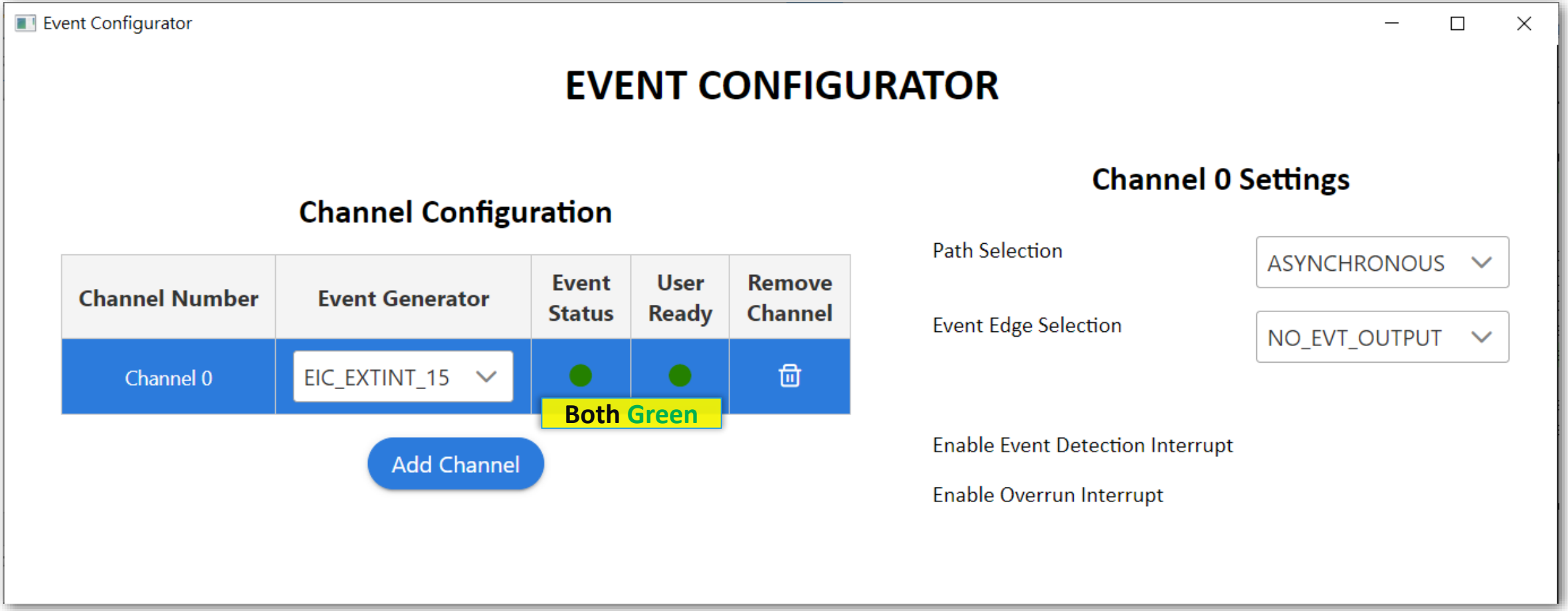
- Add User and assign TC5_EVU as Event User of Channel 0.



Lab16-4 TC Waveform Capture

Step 9

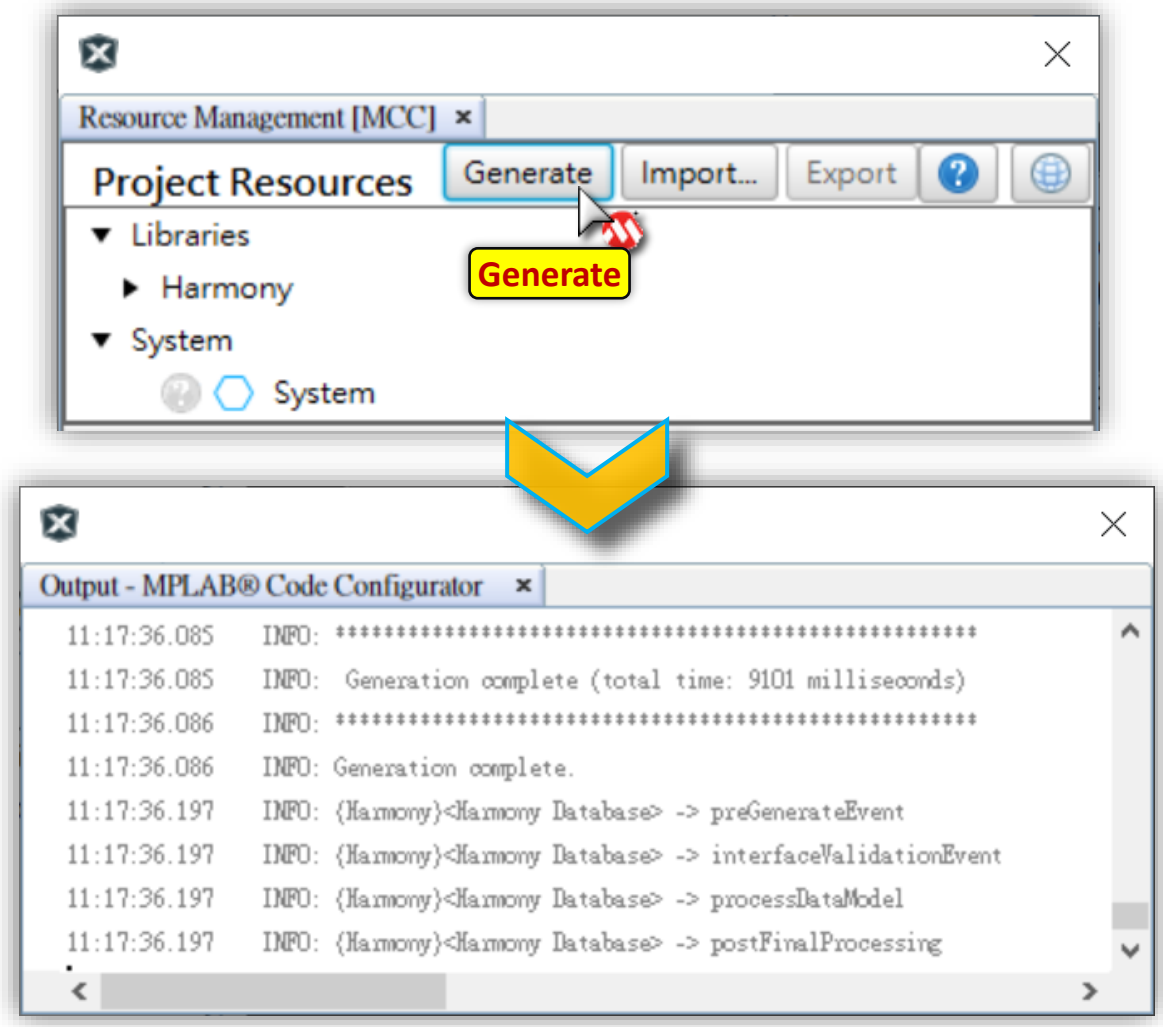
- **Event Status** and **User Ready** turned to **green light** means a good Event configuration.



Lab16-4 TC Waveform Capture

Step 10

- Click "Generate" Button to Generate your Code.



TC Capture

Interface Routines

```
void TC5_CaptureInitialize( void );
void TC5_CaptureStart( void );
void TC5_CaptureStop( void );
uint32_t TC5_CaptureFrequencyGet( void );
uint16_t TC5_Capture16bitChannel0Get( void );
uint16_t TC5_Capture16bitChannel1Get( void );
void TC5_CaptureCallbackRegister( TC_CAPTURE_CALLBACK callback, uintptr_t context );
void TC5_CaptureInterruptHandler( void );
```

Lab16-4 TC Waveform Capture

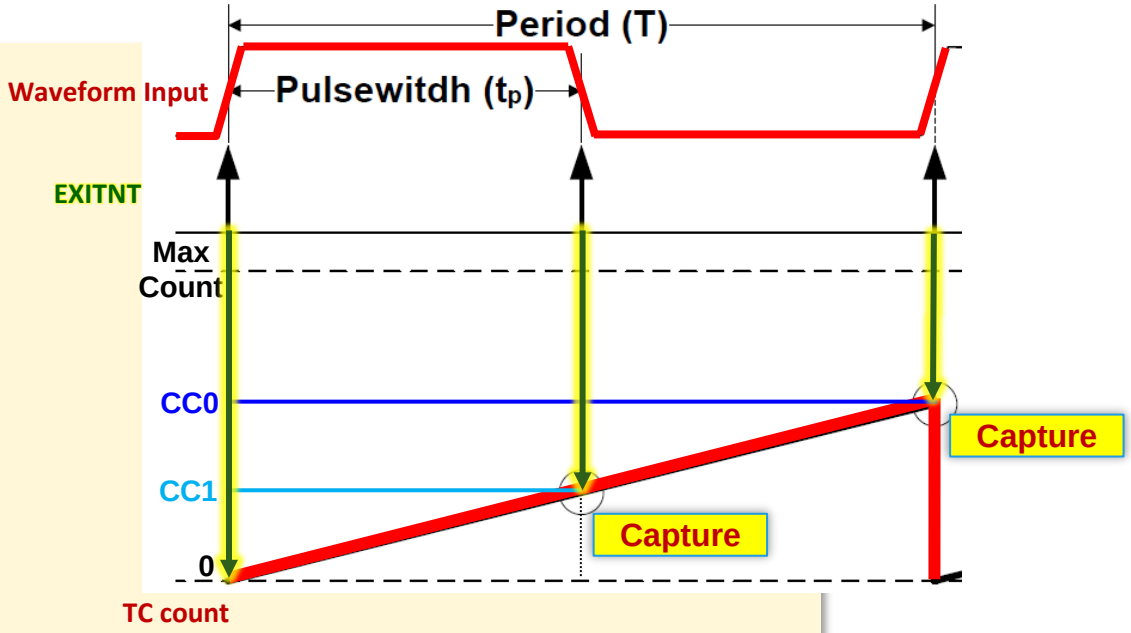
Step 11

```
...
int8_t DutyDistance = 2;
// TODO 16-4.01
volatile uint8_t TC5_IsCaptureReady = 0;
uint16_t TC5_Period = 0;
uint16_t TC5_Duty = 0;

void TC5_CaptureReady(TC_CAPTURE_STATUS status, uintptr_t context)
{
    if( (status & TC_CAPTURE_STAUTS_CAPTURE0_READY) == TC_CAPTURE_STAUTS_CAPTURE0_READY )
    {
        TC5_IsCaptureReady = 1;
    }
}

...
int main ( void )
{   ...
    // TODO 16-4.02
    TC5_CaptureCallbackRegister( TC5_CaptureReady, (uintptr_t)NULL );
    TC5_CaptureStart();

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

Lab16-4 TC Waveform Capture

Step 12

PPW (Period and Pulse-width) :
Period (T) will be captured into CC0,
Pulsewidth (t_p) will be into CC1

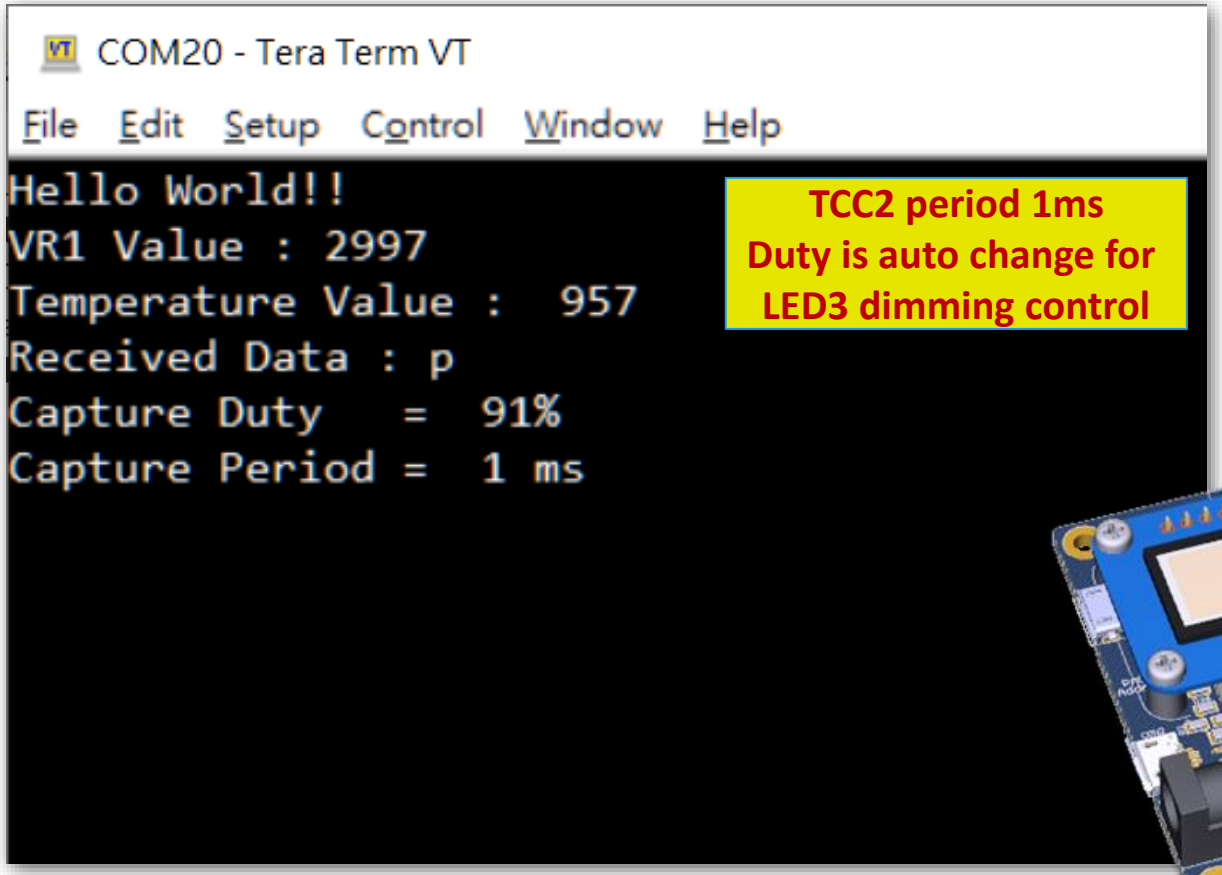


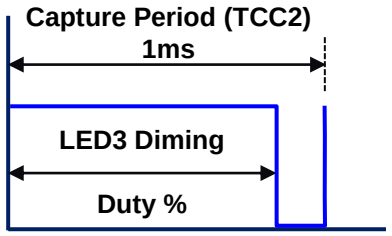

```
...
int main ( void )
{
    ...
    while ( true )
    {
        ...
        if( ADC_IsCompleted )
        { ... }

        // TODO 16-4.03
        if( TC5_IsCaptureReady )
        {
            TC5_IsCaptureReady = 0;
            TC5_Period = TC5_Capture16bitChannel0Get();
            TC5_Duty = TC5_Capture16bitChannel1Get();

            myprintf("\033[5;1H");
            myprintf( "Capture Duty   = %3d%%", (int)(TC5_Duty*100/TC5_Period) );
            myprintf("\033[6;1H");
            myprintf( "Capture Period = %3d ms",
                                        (int)(TC5_Period*1000/TC5_CaptureFrequencyGet()) );
        }
    }
}
```

Lab16-4 TC Waveform Capture

Result 1 (Capture TCC2 PWM output)

- **Wire from PA17(TCC2/WO[1]) to PA15(EIC_EXTINT_15) could measure the period and duty output from TCC2 waveform that is LED3 diming control.**

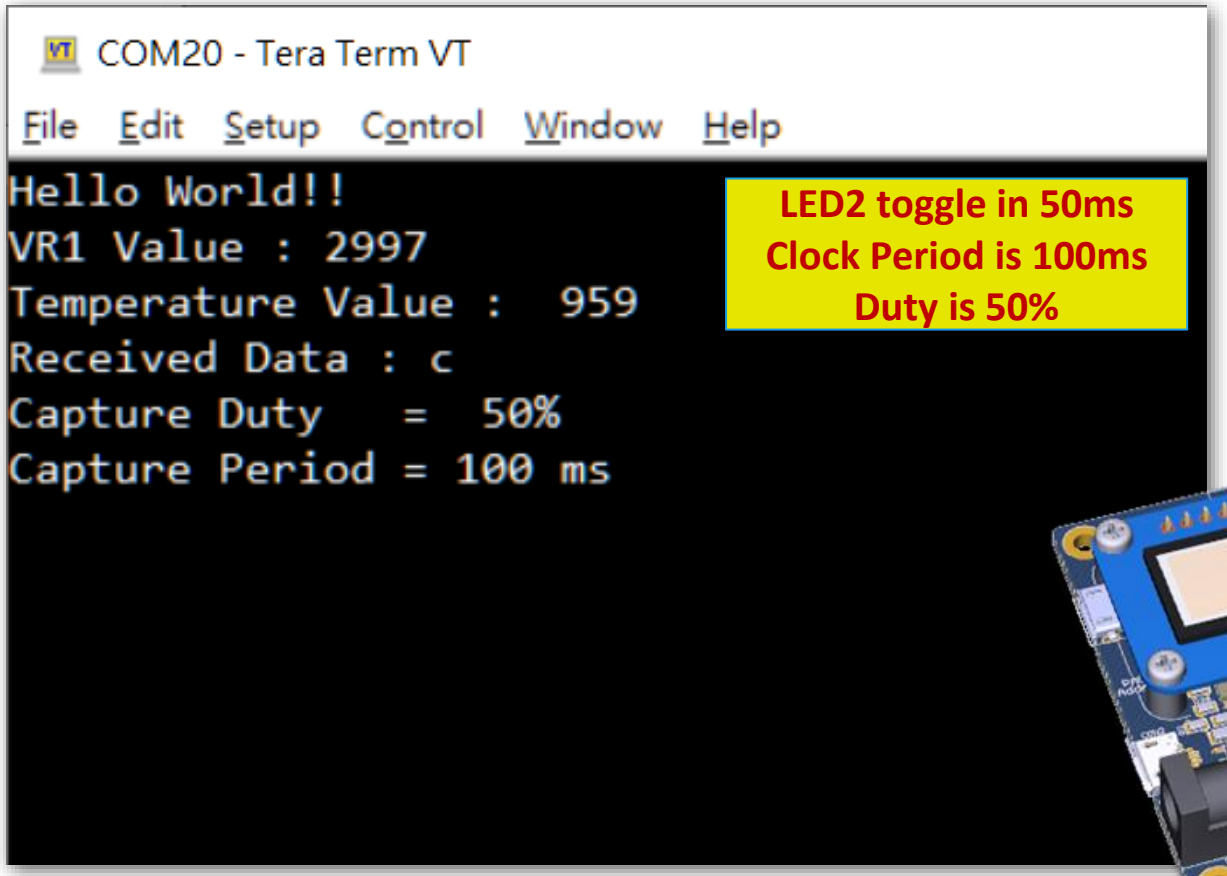


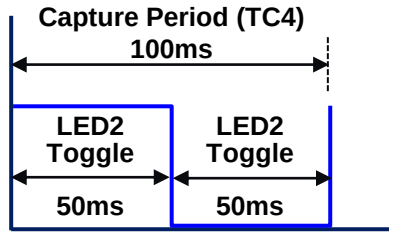


Lab16-4 TC Waveform Capture

Result 2 (Capture LED2 toggle frequency)

- **Wire from PA21(LED2) to PA15(EIC_EXTINT_15) could measure the LED2 toggle frequency that control by TC4 Timer.**

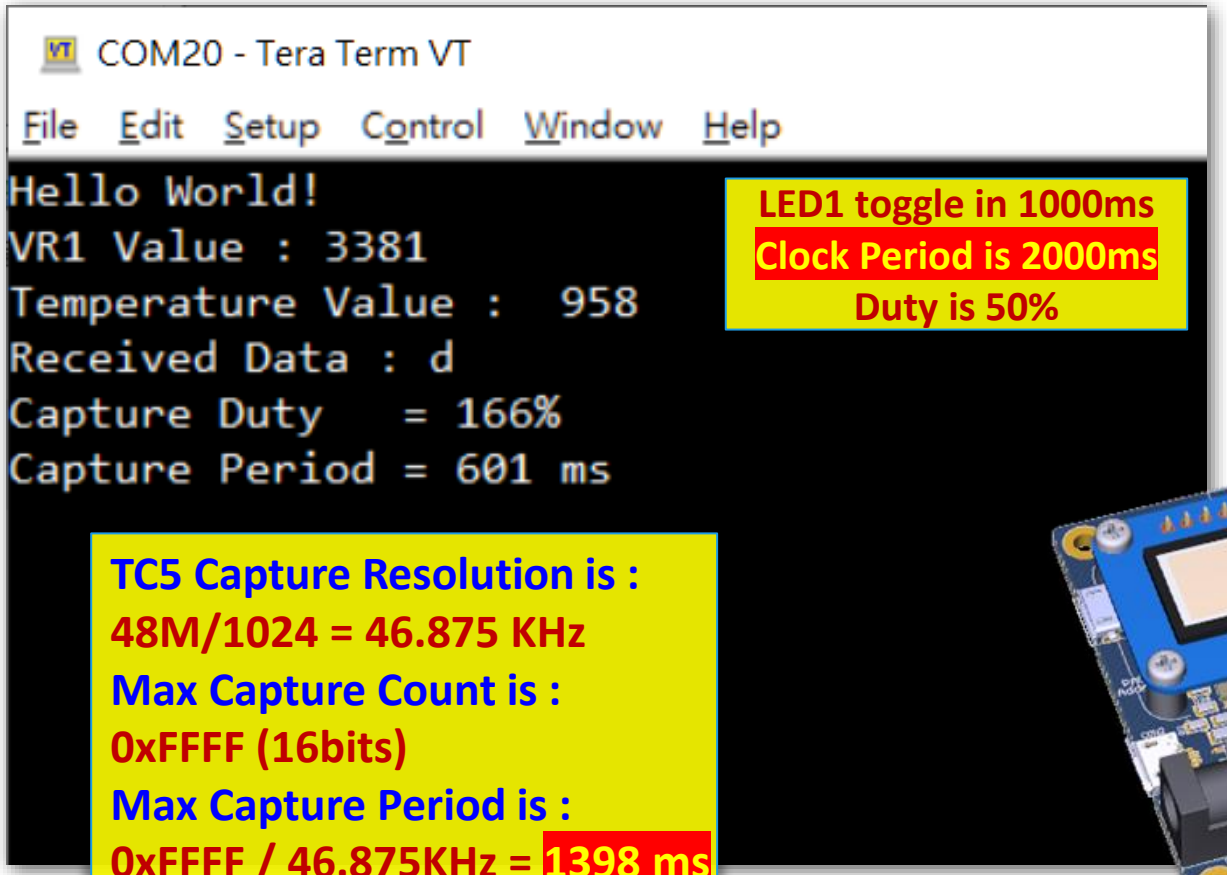




Lab16-4 TC Waveform Capture

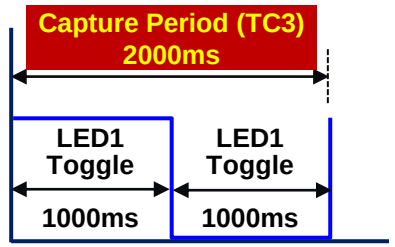
Discuss

- Wire from PA20(LED1) to PA15(EIC_EXTINT_15) and try to measure the LED1 toggle frequency that control by TC3 Timer, what's happen and why?



LED1 toggle in 1000ms
Clock Period is 2000ms
Duty is 50%

TC5 Capture Resolution is :
48M/1024 = 46.875 KHz
Max Capture Count is :
0xFFFF (16bits)
Max Capture Period is :
0xFFFF / 46.875KHz = 1398 ms

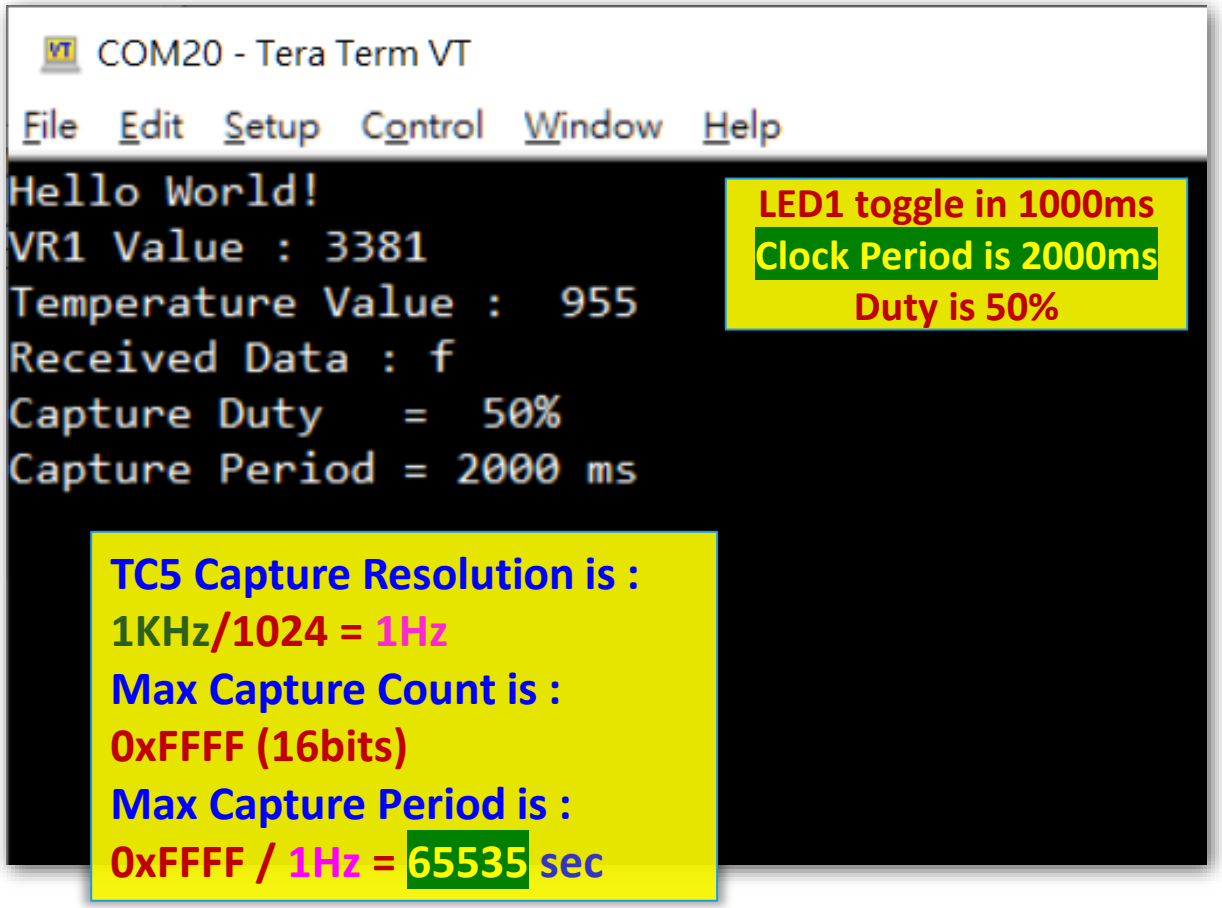


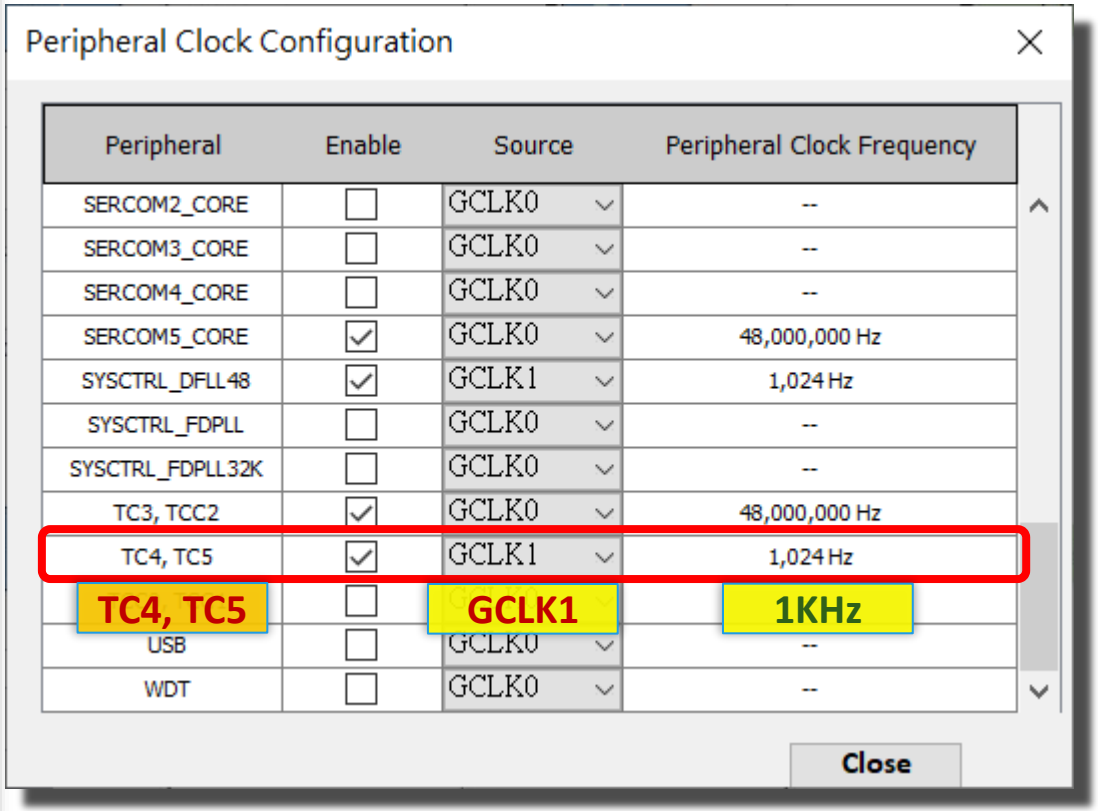
MICROCHIP

Lab16-4 TC Waveform Capture

Discuss

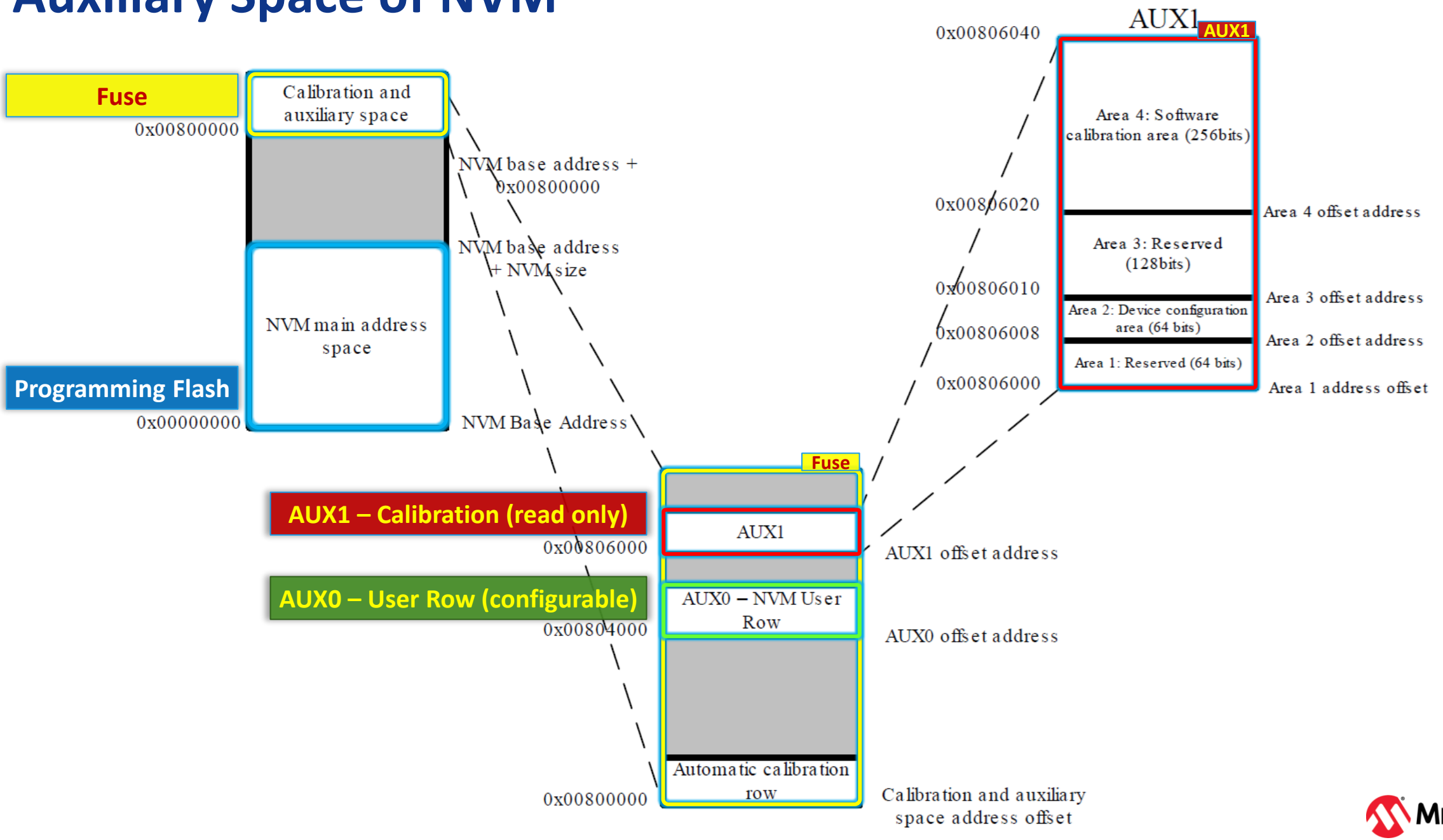
- To change the clock source of TC5 from GCLK0(48MHz) to GCLK1(1KHz) then try measure the LED1 frequency again, what's happen ? How about the LED2 frequency?



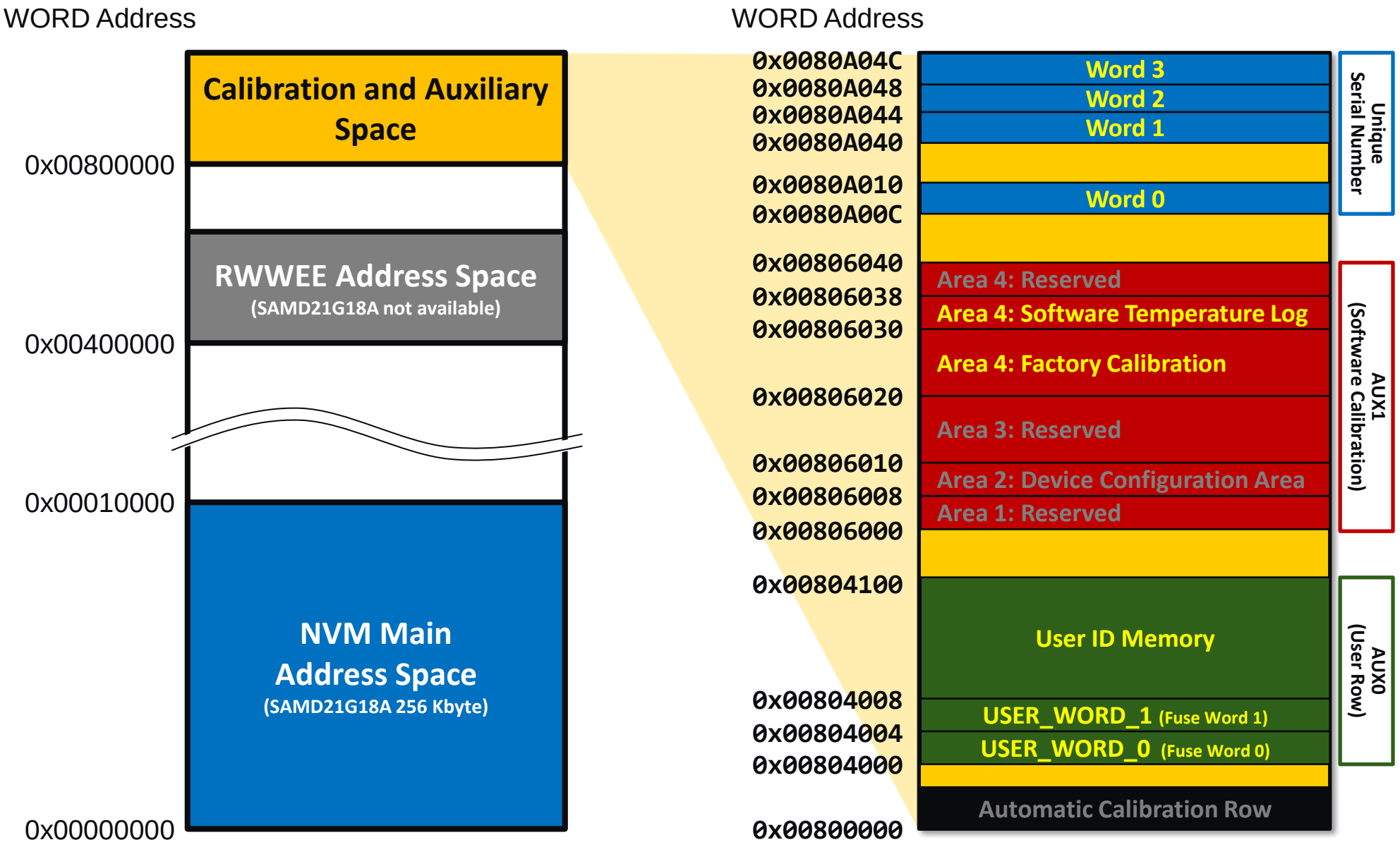


Auxiliary Space of NVM and Fuse Maintains

Auxiliary Space of NVM

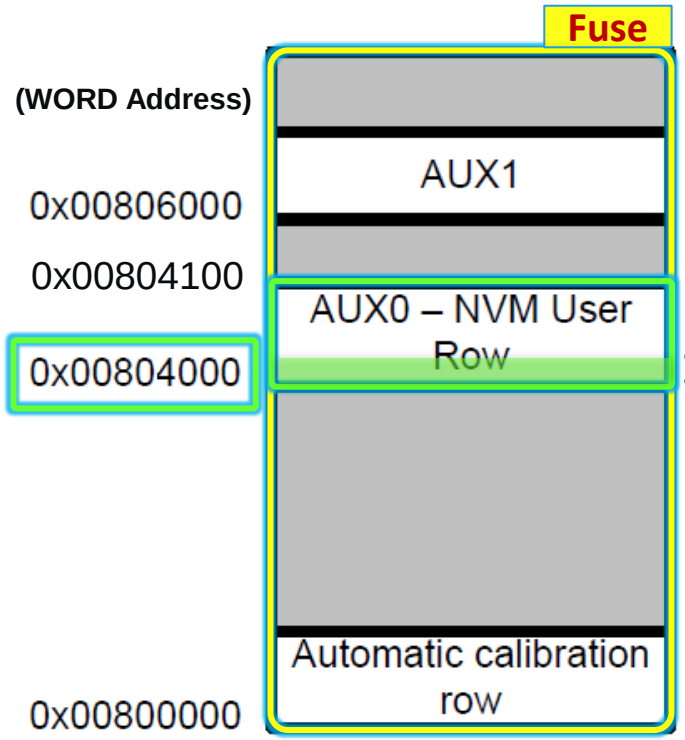


NVM Flash Memory Map



AUX0 (User Row)

User configurable Fuse settings



Bit Position	Name	Usage	
2:0	BOOTPROT	Used to select one of eight different bootloader sizes. Refer to "NVMCTRL – Non-Volatile Memory Controller". Default value = 7 except for WLCSP (Default value = 3).	Boot Protect
3	Reserved		
6:4	EEPROM	Used to select one of eight different EEPROM Emulation sizes. Refer to "NVMCTRL – Non-Volatile Memory Controller". Default value = 7.	EEPROM Emulation
7	Reserved		
13:8	BOD33 Level	BOD33 Threshold Level at power on. Refer to the SYSCTRL BOD33 register. Default value = 0x7 (non-AECQ100) Default value = 0x22 (AECQ100)	Brown Out Detect
14	BOD33 Enable	BOD33 enable at power on. Refer to the SYSCTRL BOD33 register. Default value = 1.	
16:15	BOD33 Action	BOD33 Action at power on. Refer to the SYSCTRL BOD33 register. Default value = 1.	
24:17	Reserved	Voltage Regulator Internal BOD (BOD12) configuration. These bits are written in production and must not be changed. Default value = 0x70.	
25	WDT Enable	WDT Enable at power on. Refer to the WDT CTRL register. Default value = 0.	Watch Dog Timer
26	WDT Always-On	WDT Always-On at power on. Refer to the WDT CTRL register. Default value = 0.	
30:27	WDT Period	WDT Period at power on. Refer to the WDT CONFIG register. Default value = 0x0B.	
34:31	WDT Window	WDT Window mode time-out at power on. Refer to the WDT CONFIG register. Default value = 0x05.	
38:35	WDT EWOFFSET	WDT Early Warning Interrupt Time Offset at power on. Refer to the WDT EWCTRL register. Default value = 0x0B.	
39	WDT WEN	WDT Timer Window Mode Enable at power on. Refer to the WDT CTRL register. Default value = 0.	
40	BOD33 Hysteresis	BOD33 Hysteresis configuration at power on. Refer to the SYSCTRL BOD33 register. Default value = 0.	
41	Reserved	Voltage Regulator Internal BOD(BOD12) configuration. This bit is written in production and must not be changed. Default value = 0.	
47:42	Reserved		
63:48	LOCK	NVM Region Lock Bits. Refer to "NVMCTRL – Non-Volatile Memory Controller". Default value = 0xFFFF.	NVM Region Lock

MICROCHIP

AUX1 (Software Calibration - Factory Calibration)

Factory Calibration Value – read only

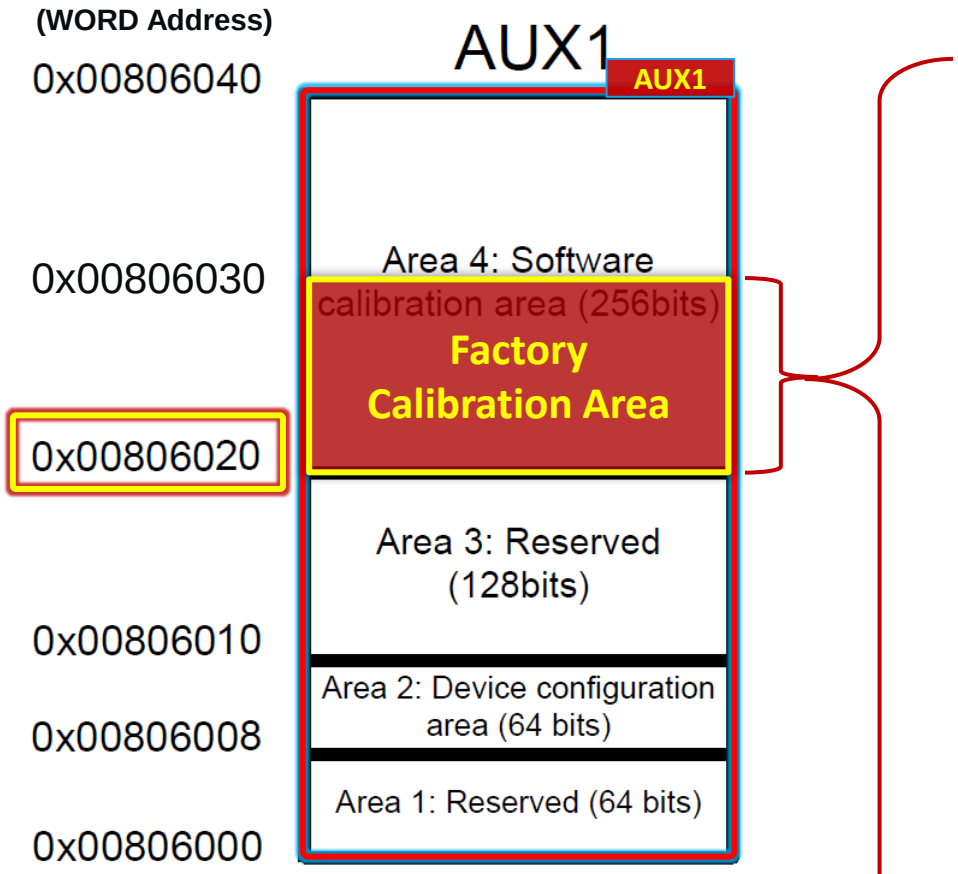


Table 10-5. NVM Software Calibration Area Mapping

Bit Position	Name	Description
2:0	Reserved	
14:3	Reserved	
26:15	Reserved	
34:27	ADC LINEARITY	ADC Linearity Calibration. Should be written to ADC CALIB register.
37:35	ADC BIASCAL	ADC Bias Calibration. Should be written to ADC CALIB register.
44:38	OSC32K CAL	OSC32KCalibration. Should be written to SYSCTRL OSC32K register.
49:45	USB TRANSN	USB TRANSN calibration value. Should be written to USB PADCAL register.
54:50	USB TRANSP	USB TRANSP calibration value. Should be written to USB PADCAL register.
57:55	USB TRIM	USB TRIM calibration value. Should be written to the USB PADCAL register.
63:58	DFLL48M CAL (COARSE and FINE)	DFLL48M Coarse calibration value. Should be written to SYSCTRL DFLLVAL register.
73:64		
127:74	Reserved	

AUX1 (Software Calibration - Factory Calibration)

Factory Calibration Value – read only

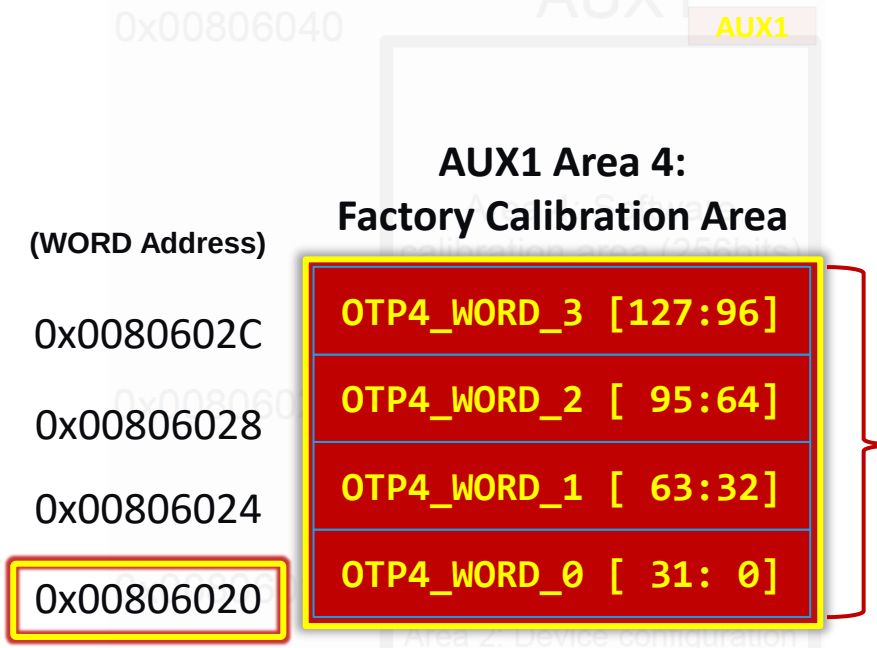


Table 10-5. NVM Software Calibration Area Mapping

Bit Position	Name	Description
2:0	Reserved	
14:3	Reserved	
26:15	Reserved	
34:27	ADC LINEARITY	ADC Linearity Calibration. Should be written to ADC CALIB register.
37:35	ADC BIASCAL	ADC Bias Calibration. Should be written to ADC CALIB register.
44:38	OSC32K CAL	OSC32KCalibration. Should be written to SYSCTRL OSC32K register.
49:45	USB TRANSN	USB TRANSN calibration value. Should be written to USB PADCAL register.
54:50	USB TRANSP	USB TRANSP calibration value. Should be written to USB PADCAL register.
57:55	USB TRIM	USB TRIM calibration value. Should be written to the USB PADCAL register.
63:58	DFLL48M CAL (COARSE and FINE)	DFLL48M Coarse calibration value. Should be written to SYSCTRL DFLLVAL register.
73:64		
127:74	Reserved	

[44:38]
[63:58]
[73:64]

AUX1 (Software Calibration - Factory Calibration)

Read and applicate DFLL48M Factory Calibration Value

- OSC Factory calibration value in **AUX1** will read and applicate in **DFLL_Initialize()** function of **plib_clock.c**

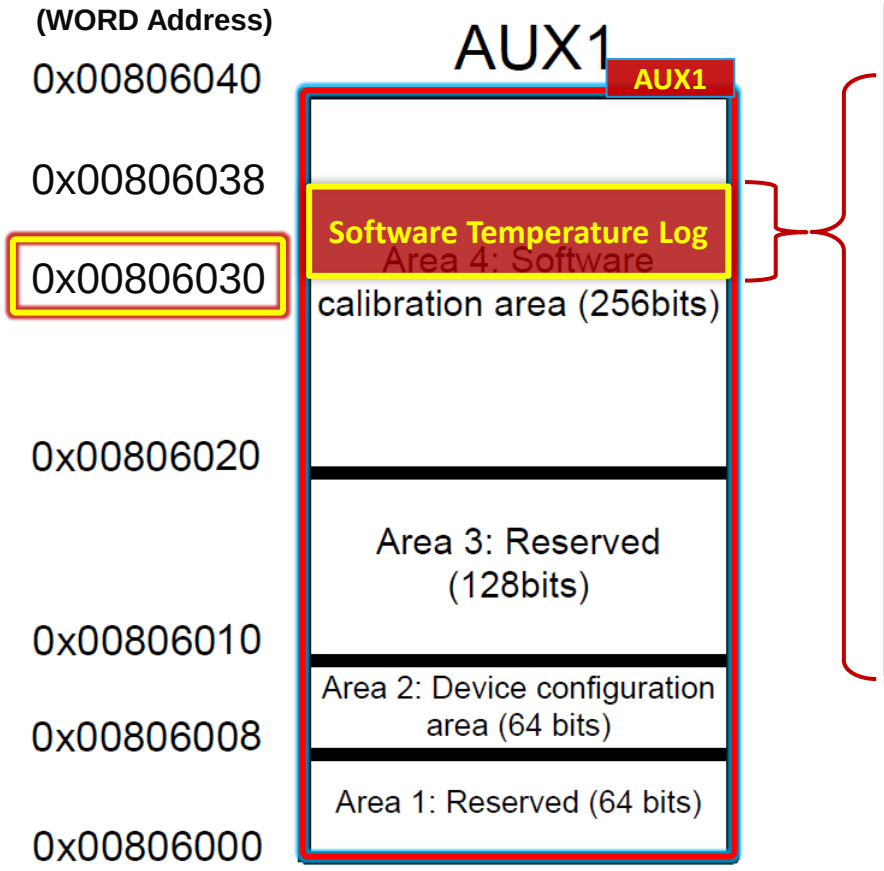
```
static void DFLL_Initialize(void)
{
    /************ DFLL Initialization  ***************/
    ...

    /*Load DFLL48M CAL (COARSE) */      OTP4_WORD_1 Address >> (58-32)      [63:58] 6-bits
    uint32_t calibCoarse = (((*(uint32_t*)0x806020U + 1U) >> 26U ) & 0x3FU);
    calibCoarse = (((calibCoarse) == 0x3FU) ? 0x1FU : (calibCoarse));

    SYSCTRL_REGS->SYSCTRL_DFLLVAL =
                SYSCTRL_DFLLVAL_COARSE(calibCoarse) |
                SYSCTRL_DFLLVAL_FINE(512U);

    GCLK_REGS->GCLK_CLKCTRL = GCLK_CLKCTRL_GEN(0x1U) |
                              GCLK_CLKCTRL_CLKEN_Msk |
                              GCLK_CLKCTRL_ID(0U);
    while((SYSCTRL_REGS->SYSCTRL_PCLKSR &
                         SYSCTRL_PCLKSR_DFLLRDY_Msk) != SYSCTRL_PCLKSR_DFLLRDY_Msk)
    { ... }
}
```

Bit Position	Name
2:0	Reserved
14:3	Reserved
26:15	Reserved
34:27	ADC LINEARITY
37:35	ADC BIASCAL
44:38	OSC32K CAL
49:45	USB TRANSN
54:50	USB TRANSP
57:55	USB TRIM
63:58	DFLL48M CAL (COARSE and FINE)
73:64	
127:74	Reserved

MICROCHIP

AUX1 (Software Calibration - Software Temperature Log)

Software Temperature Log – Read Only



Temperature Log Row Content

Bit position	Name	Description
7:0	ROOM_TEMP_VAL_INT	Integer part of room temperature in °C
11:8	ROOM_TEMP_VAL_DEC	Decimal part of room temperature
19:12	HOT_TEMP_VAL_INT	Integer part of hot temperature in °C
23:20	HOT_TEMP_VAL_DEC	Decimal part of hot temperature
31:24	ROOM_INT1V_VAL	2's complement of the internal 1V reference drift at room temperature (versus a 1.0 centered value)
39:32	HOT_INT1V_VAL	2's complement of the internal 1V reference drift at hot temperature (versus a 1.0 centered value)
51:40	ROOM_ADC_VAL	12-bit ADC conversion at room temperature
63:52	HOT_ADC_VAL	12-bit ADC conversion at hot temperature

Calibration condition :

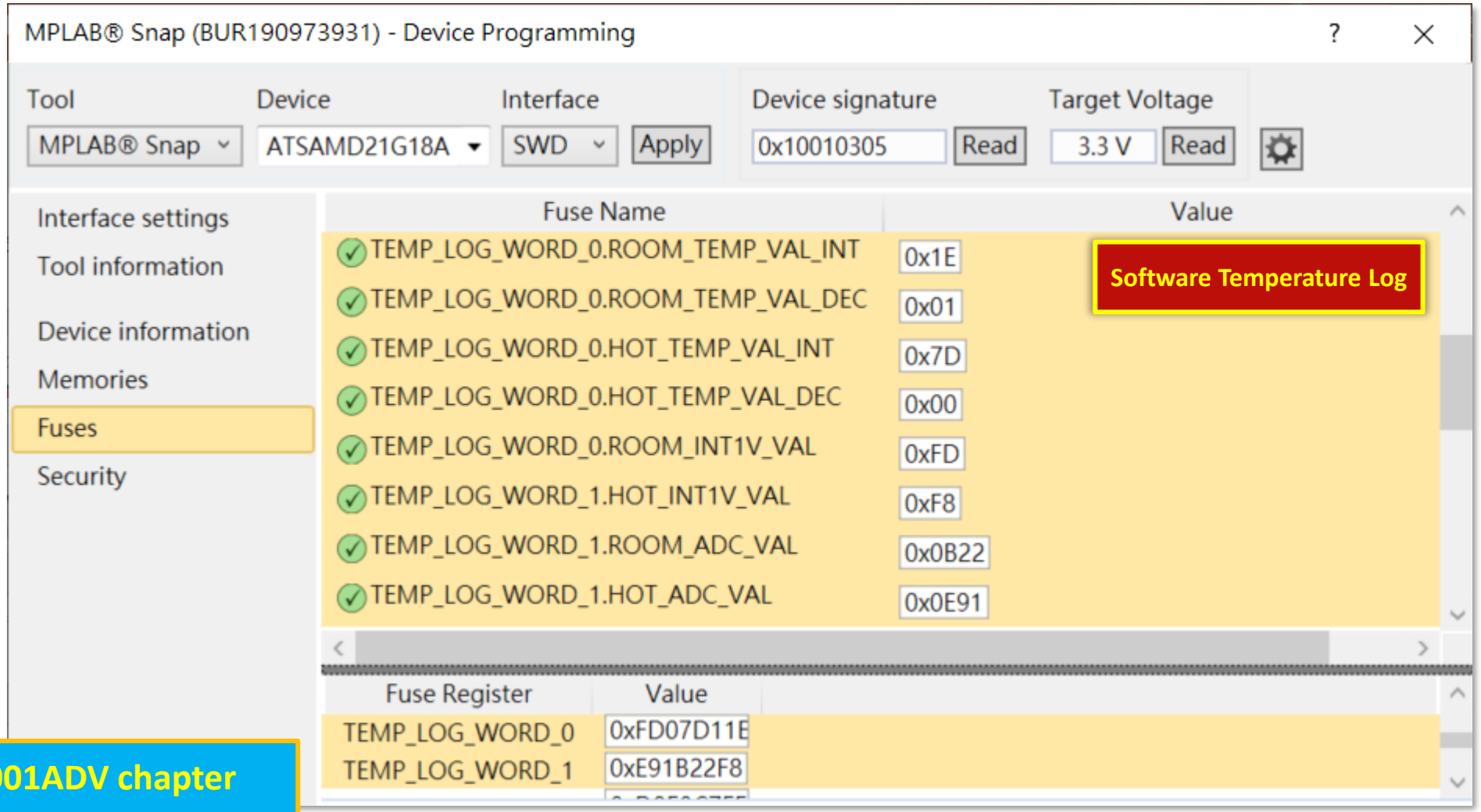
- $V_{DDIN} = V_{DDIO} = V_{DDANA} = 3.3V$
- ADC Clock speed = 1MHz (Free running mode)
- ADC averaging mode with 4 averaged samples
- ADC voltage reference = 1.0V (Internal reference INT1V)
- ADC input = Temperature sensor
- Room Temperature 25.2°C, • Hot temperature 83.3°C

Learn this detail in SAM2001ADV chapter Internal Temperature Sensor

MICROCHIP

AUX1 (Software Calibration - Software Temperature Log)

Temperature Log could be read and check in Microchip Studio



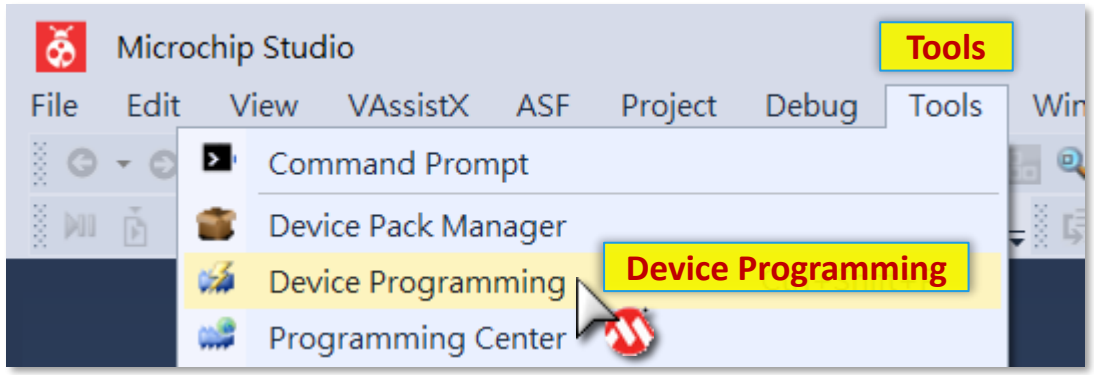
Learn this detail in SAM2001ADV chapter Internal Temperature Sensor

Fuse (Configuration Bits) setting in Microchip Studio

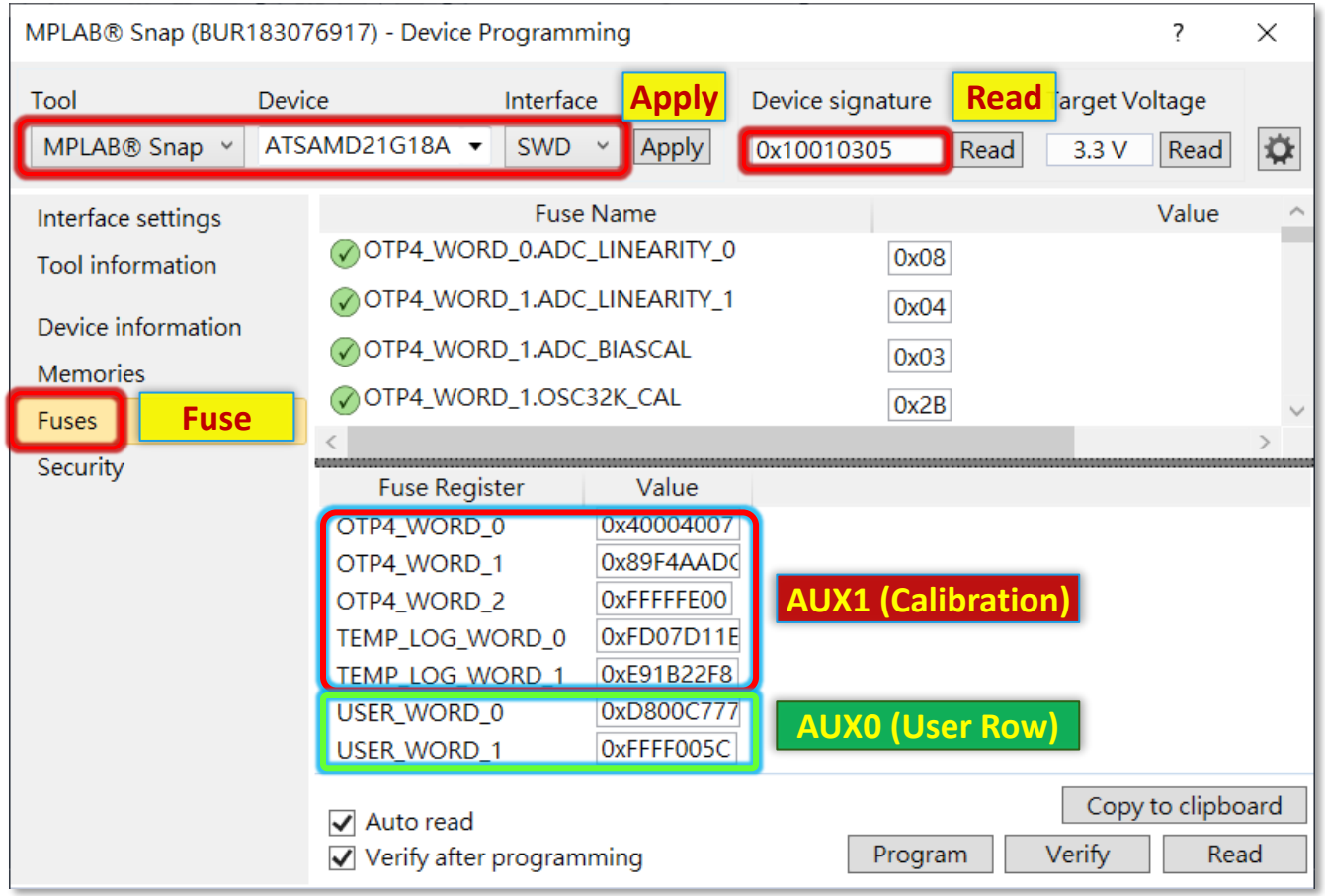
Predecessor is Atmel Studio 7

MICROCHIP

Fuse (Configuration Bits) setting in Microchip Studio



Microchip Studio Fuses setting could see both AUX0 and AUX1.



Open Tools

- ► **Device Programming**
  - Tool : MPLAB Snap
  - Device : ATSAMD21G18A
  - Interface : SWD
- ► **[Apply]** — SNAP will Auto switch to AVR mode
- ► **[Read]**
  - Device signature
- ► **[Fuse]**

MICROCHIP STUDIO FOR AVR® AND SAM DEVICES

MICROCHIP

Fuse (Configuration Bits) setting in Microchip Studio

Programming through Microchip Studio atprogram command line

- **Microchip Studio** has a standalone command line program **atprogram.exe** could programming HEX and Fuse settings. Please enter below directory (need Studio 7 pre-installed)

C:\Program Files (x86)\Atmel\Studio\7.0\atbackend

atprogram now could support Microchip Classic programmer
snap , pickit4

Ex1. Erase whole chip through EDBG's SWD interface.

```
atprogram -t snap -i swd -d atsamd21g18a erase
```

Ex2. Program HEX to MCU through EDBG's SWD interface.

```
atprogram -t snap -i swd -d atsamd21g18a program -f "Filename.hex"
```

Ex3. Program 0xD800C777 to USER_WORD_0 and 0xFFFF005C to USER_WORD_1 of AUX0(Fuse).

```
atprogram -t snap -i swd -d atsamd21g18a write -fs -o 0x804000 --values 77C700D85C00FFFF
```

Mind the data byte order !!

Fuse Register	Value
OTP4_WORD_2	0xFFFFFE00
TEMP_LOG_WORD_0	0xFC25561F
TEMP_LOG_WORD_1	0xD35B2CFA
USER_WORD_0	0xD800C777
USER_WORD_1	0xFFFF005C

0xD800C777
0xFFFF005C

AUX0 (User Row)

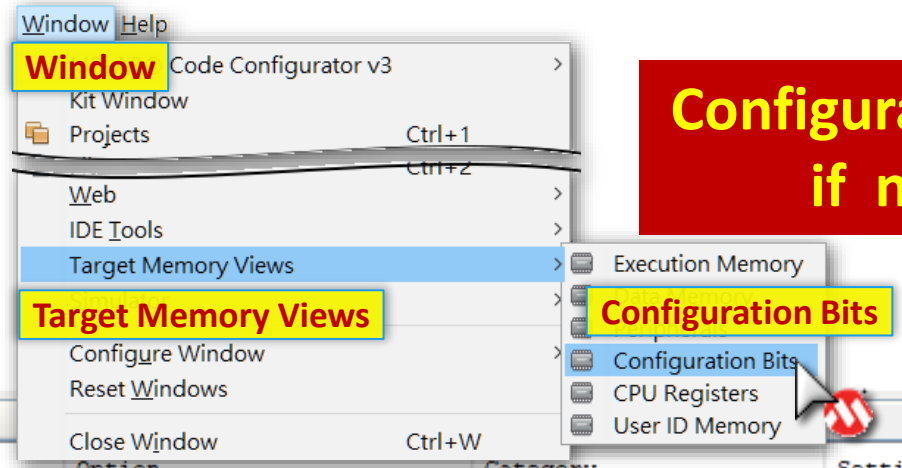
MICROCHIP

Configuration Bits (Fuse) setting in MPLAB X IDE

Configuration Bits (Fuse) setting in MPLAB X IDE

MPLAB Configuration Bits GUI

- Open Window
  - ► Target Memory Views
  - ► Configuration Bits



Configuration Bits will show Red if not to read it firstly

Output | Configuration Bits × | Search Results | Notifications

Read from chip

	Value	Field	Option	Category	Setting
0080_4000 USER_WORD_0	D8E0C7FF	-	-	-	-
	7	NVMCTRL_BOOTPROT	SIZE_0BYTES	Bootloader Size	0 Bytes
	7	NVMCTRL_EEPROM_SIZE	SIZE_0BYTES	EEPROM Size	0 Bytes
	7	BOD33USERLEVEL	User range: 0x0 - 0x3F	BOD33 User Level	Enter Hexadecimal value
	1	BOD33_EN	ENABLED	BOD33 Enable	BOD33 is enabled
	1	BOD33_ACTION	RESET	BOD33 Action	The BOD33 generates a reset
	0	WDT_ENABLE	DISABLED	WDT Enable	WDT is disabled
	0	WDT_ALWAYSON	DISABLED	WDT Always On	WDT is enabled and disabled through ENABLE bit
	B	WDT_PER	CYC16384	WDT Period	16384 clock cycles
	1	WDT_WINDOW_0	SET	WDT Window bit 0	SET
0080_4004 USER_WORD_1	FFFFFC5C	-	-	-	-
	4	WDT_WINDOW_1	User range: 0x0 - 0x7	WDT Window bits 3:1	Enter Hexadecimal value
	B	WDT_EWOFFSET	CYC16384	WDT Early Warning Offset	16384 clock cycles
	0	WDT_WEN	DISABLED	WDT Window Mode Enable	WDT is disabled
	0	BOD33_HYST	DISABLED	BOD33 Hysteresis	No Hysteresis
	FFFF	NVMCTRL_REGION_LOCKS	User range: 0x0 - 0xFFFF	NVM Region Locks	Enter Hexadecimal value

(Lab11-4_NVM_Fuse_ReadSN) - ARM Configuration Bits require a Read Device Memory step.

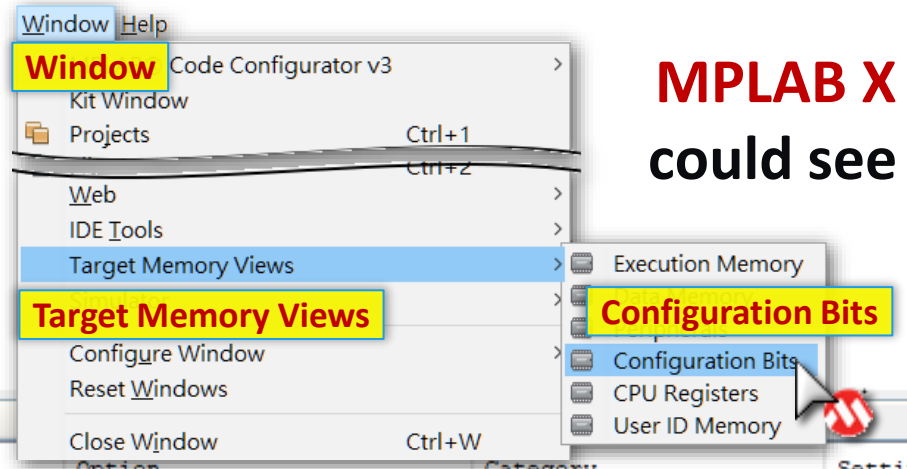
Must Read firstly before to configure

It is recommended that you read Configuration Bit settings on the ARM device before editing values. Note: Edit access is always enabled when the Simulator tool is selected.

Configuration Bits (Fuse) setting in MPLAB X IDE

MPLAB Configuration Bits GUI

- Open **Window**
  - ► **Target Memory Views**
  - ► **Configuration Bits**



MPLAB X IDE Configuration Bits could see only **AUX0 (User Row)**

Output | Configuration Bits × | Search Results | Notifications

Program to chip

AUX0 (User Row)

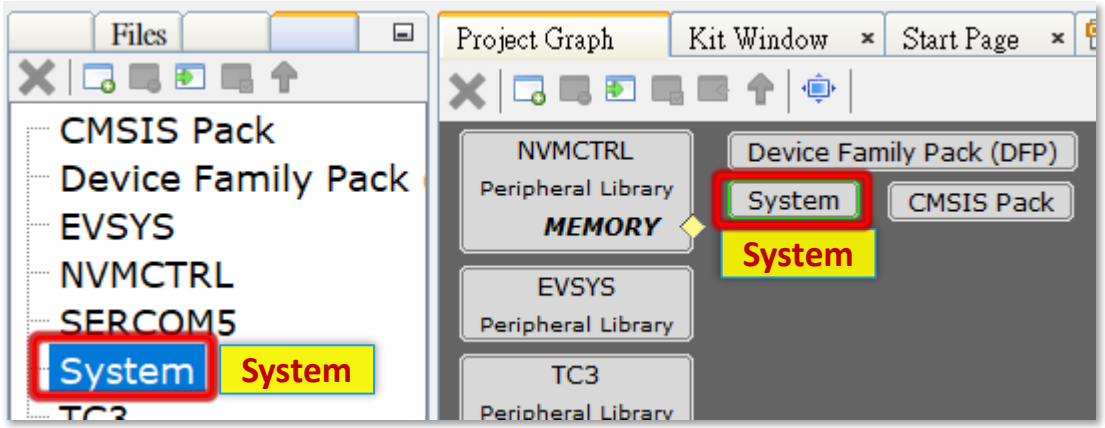
Address	Name	Value	Field	Option	Category	Setting
0080_4000	USER_WORD_0	D800C777	-	-	-	-
		7	NVMCTRL_BOOTPROT	SIZE_0BYTES	Bootloader Size	0 Bytes
		7	NVMCTRL_EEPROM_SIZE	SIZE_0BYTES	EEPROM Size	0 Bytes
		7	BOD33USERLEVEL	User range: 0x0 - 0x3F	BOD33 User Level	Enter Hexadecimal value
		1	BOD33_EN	ENABLED	BOD33 Enable	BOD33 is enabled
		1	BOD33_ACTION	RESET	BOD33 Action	The BOD33 generates a reset
		0	WDT_ENABLE	DISABLED	WDT Enable	WDT is disabled
		0	WDT_ALWAYSON	DISABLED	WDT Always On	WDT is enabled and disabled through ENABLE bit
		B	WDT_PER	ENABLED	WDT Period	16384 clock cycles
		1	WDT_WINDOW_0	SET	WDT Window bit 0	SET
0080_4004	USER_WORD_1	FFFF005C	-	-	-	-
		4	WDT_WINDOW_1	User range: 0x0 - 0x7	WDT Window bits 3:1	Enter Hexadecimal value
		B	WDT_EWOFFSET	CYC16384	WDT Early Warning Offset	16384 clock cycles
		0	WDT_WEN	DISABLED	WDT Window Mode Enable	WDT is disabled
		0	BOD33_HYST	DISABLED	BOD33 Hysteresis	No Hysteresis
		FFFF	NVMCTRL_REGION_LOCKS	User range: 0x0 - 0xFFFF	NVM Region Locks	Enter Hexadecimal value

Configure Fuse

Configuration Bits will show Black if success to read it before configure

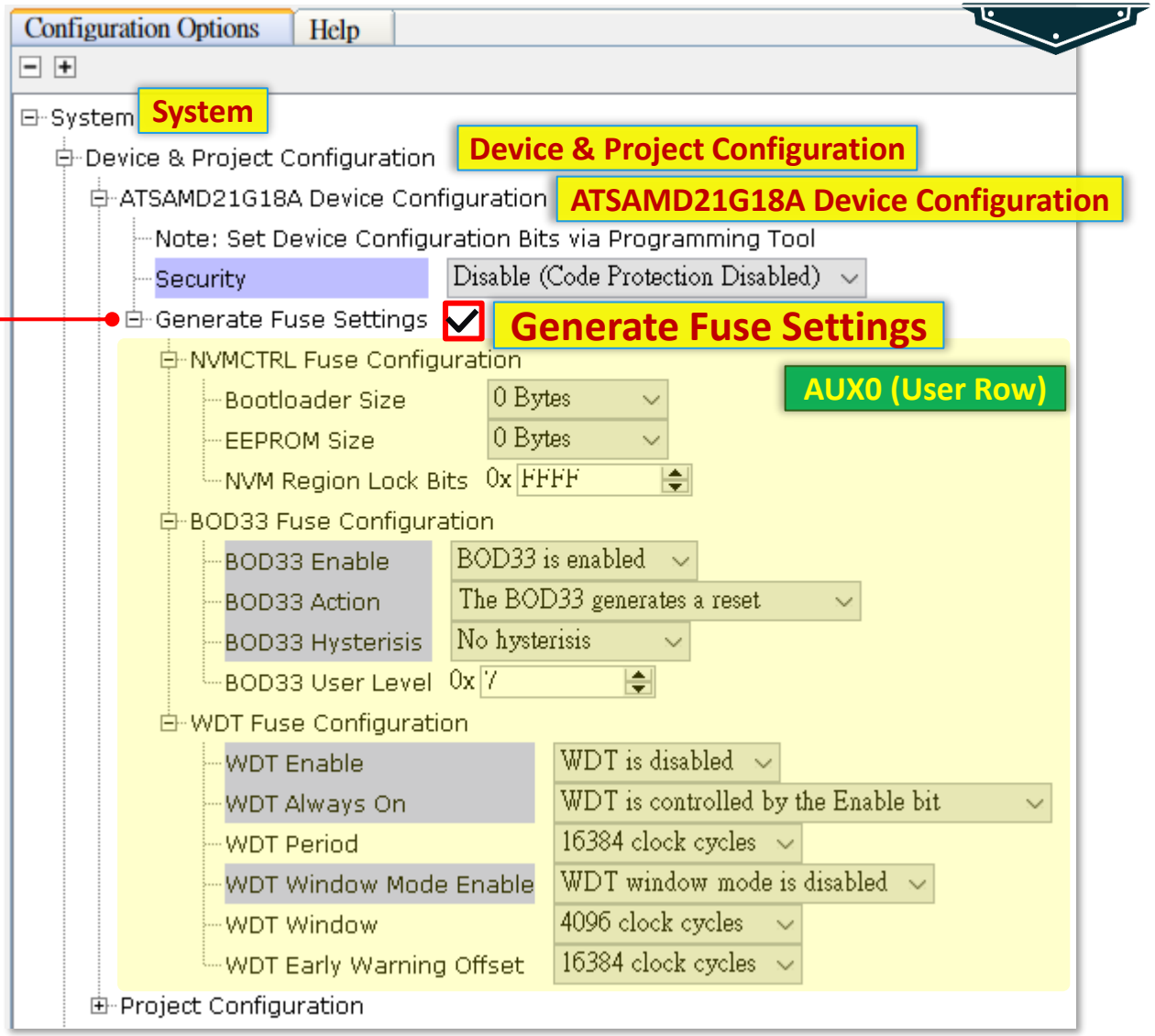
Configuration Bits (Fuse) setting in MPLAB X IDE

Generate Fuse Settings in Harmony



- Open System
  - ► Device & Project Configuration
  - ► ATSAMD21G18A Device Configuration
  - ► Generate Fuse Settings ☑

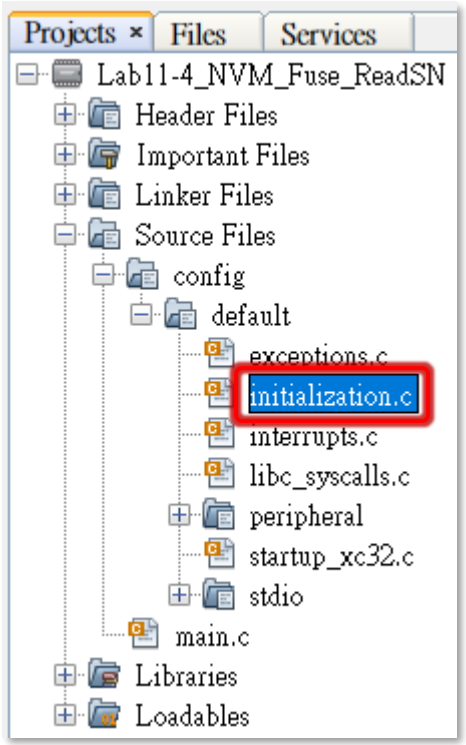
Check this to include Fuse settings in HEX image
MPLAB X IDE and IPE supports support program the Fuse setting with HEX image



Configuration Bits (Fuse) setting in MPLAB X IDE

Generate Fuse Settings in Harmony

- **Fuse setting will be generated as pre-define #pragma in initialization.c**



AUX0 (User Row)

```
// *****************************************************************************
// Section: Configuration Bits
// *****************************************************************************
#pragma config NVMCTRL_BOOTPROT = SIZE_0BYTES
#pragma config NVMCTRL_EEPROM_SIZE = SIZE_0BYTES
#pragma config BOD33USERLEVEL = 0x7 // Enter Hexadecimal value
#pragma config BOD33_EN = ENABLED
#pragma config BOD33_ACTION = RESET

#pragma config BOD33_HYST = DISABLED
#pragma config NVMCTRL_REGION_LOCKS = 0xffff // Enter Hexadecimal value

#pragma config WDT_ENABLE = DISABLED
#pragma config WDT_ALWAYSON = DISABLED
#pragma config WDT_PER = CYC16384

#pragma config WDT_WINDOW_0 = SET
#pragma config WDT_WINDOW_1 = 0x4 // Enter Hexadecimal value
#pragma config WDT_EWOFFSET = CYC16384
#pragma config WDT_WEN = DISABLED
```

Configuration Bits (Fuse) setting in MPLAB X IDE

Generate Fuse Settings in Harmony

- **Fuse settings will be appended in tail of project's HEX image if using XC32 compiler.**

Project.hex

```
...
:020000040000fa
:020ad800704765
:020000040000fa
:020ada00fee735
:020000040000fa
:020adc00fee733
:020000040000fa
:020ade00fee731
:00000001FF
```

Project.hex

```
...
:020000040000fa
:020ad800704765
:020000040000fa
:020ada00fee735
:020000040000fa
:020adc00fee733
:020000040000fa
:020ade00fee731
:020000040000fa
:0200000400807a
:0440000077c700d8a6
:020000040000fa
:0200000400807a
:044004005c00ffff5e
:00000001FF
```

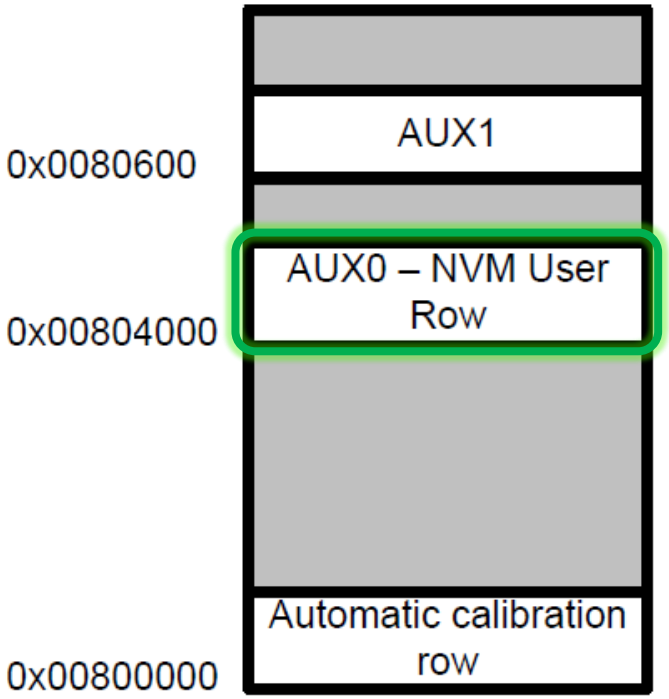
AUX0 (User Row) WORD 1

AUX0 (User Row) WORD 2

Configuration Bits (Fuse) setting in MPLAB X IDE

Bit format analysis of Fuse settings in HEX image

```
04400000 77c700d8 a6
04          : Four bytes
4000        : Starting address
00          : Record type
77c700d8    : Data payload
a6          : Checksum
```



Configuration Bits (Fuse) setting in MPLAB X IDE

Bit format analysis of Fuse settings in HEX image

Bit Position	Name
2:0	BOOTPROT
3	Reserved
6:4	EEPROM
7	Reserved
13:8	BOD33 Level
14	BOD33 Enable
16:15	BOD33 Action
24:17	Reserved
25	WDT Enable
26	WDT Always-On
30:27	WDT Period
34:31	WDT Window
38:35	WDT EWOFFSET
39	WDT WEN
40	BOD33 Hysteresis
41	Reserved
47:42	Reserved
63:48	LOCK

User Row WORD 1

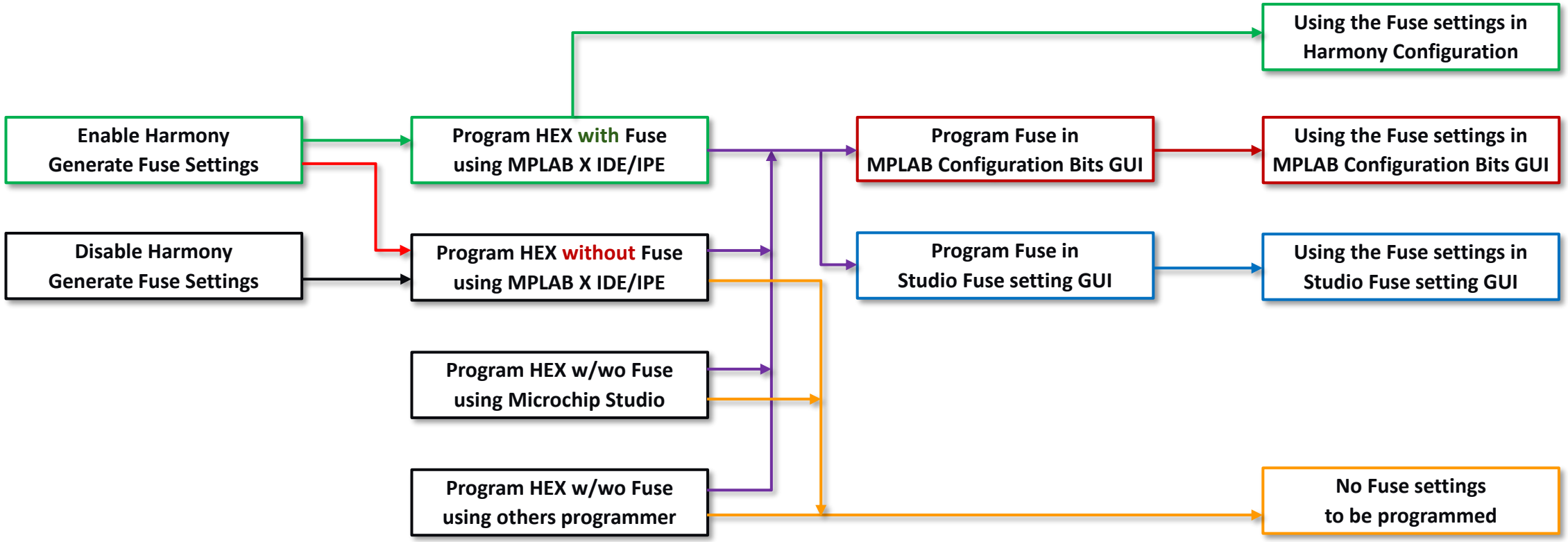
BitPos	Name	Bit Mapping of HEX Data
[2:0]	BOOTPORT	---- -XXX ---- ---- ---- ---- ---- ----
[3]	reserved	---- ---- ---- ---- ---- ---- ---- ----
[6:4]	EEPROM	-XXX ---- ---- ---- ---- ---- ---- ----
[7]	reserved	---- ---- ---- ---- ---- ---- ---- ----
[13:8]	BOD33.UserLevel	---- ---- --XX XXXX ---- ---- ---- ----
[14]	BOD33.Enable	---- ---- -X-- ---- ---- ---- ---- ----
[16:15]	BOD33.Action	---- ---- X--- ---- ---- ---- ---- ----
[24:17]	reserved	---- ---- ---- ---- ---- ---- ---- ----
[25]	WDT.Enable	---- ---- ---- ---- ---- ---- ---- --X-
[26]	WDT.AlwaysOn	---- ---- ---- ---- ---- ---- ---- -X--
[30:27]	WDT.Period	---- ---- ---- ---- ---- ---- -XXX X---
[31]	WDT.Window	---- ---- ---- ---- ---- ---- X--- ----

User Row WORD 2

BitPos	Name	Bit Mapping of HEX Data
[34:32]	WDT.Window	---- -XXX ---- ---- ---- ---- ---- ----
[38:35]	WDT.EWOFFSET	-XXX X--- ---- ---- ---- ---- ---- ----
[39]	WDT.WindowEnable	X--- ---- ---- ---- ---- ---- ---- ----
[40]	BOD33.Hysteresis	---- ---- ---- ---X ---- ---- ---- ----
[41]	reserved	---- ---- ---- ---- ---- ---- ---- ----
[47:42]	reserved	---- ---- ---- ---- ---- ---- ---- ----
[63:48]	LOCK	---- ---- ---- ---- XXXX XXXX XXXX XXXX

Configuration Bits (Fuse) setting in MPLAB X IDE

Configuration Bits GUI and Harmony Generated Fuse setting in HEX



🛠 Lab11-4 Read Unique Serial Number

- Please continue from SAM2001 Lab11 (SERCOM - UART TxRx Interrupt Callback with myprintf)
- In SAM D20 / SAM D21 / SAM R21 devices, each device has a unique 128-bit serial number which is a concatenation of four 32-bit words contained at the following addresses:
  Word 0: 0x0080A00C
  Word 1: 0x0080A040
  Word 2: 0x0080A044
  Word 3: 0x0080A048
- Try to read the unique serial number from your SAMD21 MCU and output as below
  “Unique serial number : (4 Words)”
  “0x0080A00C : 0x55574129”
  ”0x0080A010 : 0x514E5357”
  ”0x0080A014 : 0x4C202020”
  ”0x0080A018 : 0xFF130E33”
  ”- done”

The unique serial number will vary depending on the device

- **Let’s go !**

MICROCHIP

🛠 Lab11-4 Read Unique Serial Number

Step1

```
// TODO 11-4.01
uint32_t NVM_UQSN_Word[4];

void USART5_Transmit( uintptr_t context )
...

// TODO 11-4.02
void NVM_Read_UQSN( uint32_t *Word )
{
    volatile uint32_t *pWord, i;

    while( NVMCTRL_IsBusy() ) {}
    pWord = (volatile uint32_t *)0x0080A00C;
    myprintf( "Unique serial number : (4 Words)\r\n" );
    for( i=0 ; i<4 ; i++ )
    {
        Word[i] = *pWord;
        myprintf( "0x%08X : 0x%08X\r\n", 0x0080A00C+(i*4), Word[i] );
        if( i==0 ) pWord = (volatile uint32_t *)0x0080A040;
        else       pWord++;
    }
    myprintf( "- done\r\n\r\n" );
}

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

🛠 Lab11-4 Read Unique Serial Number

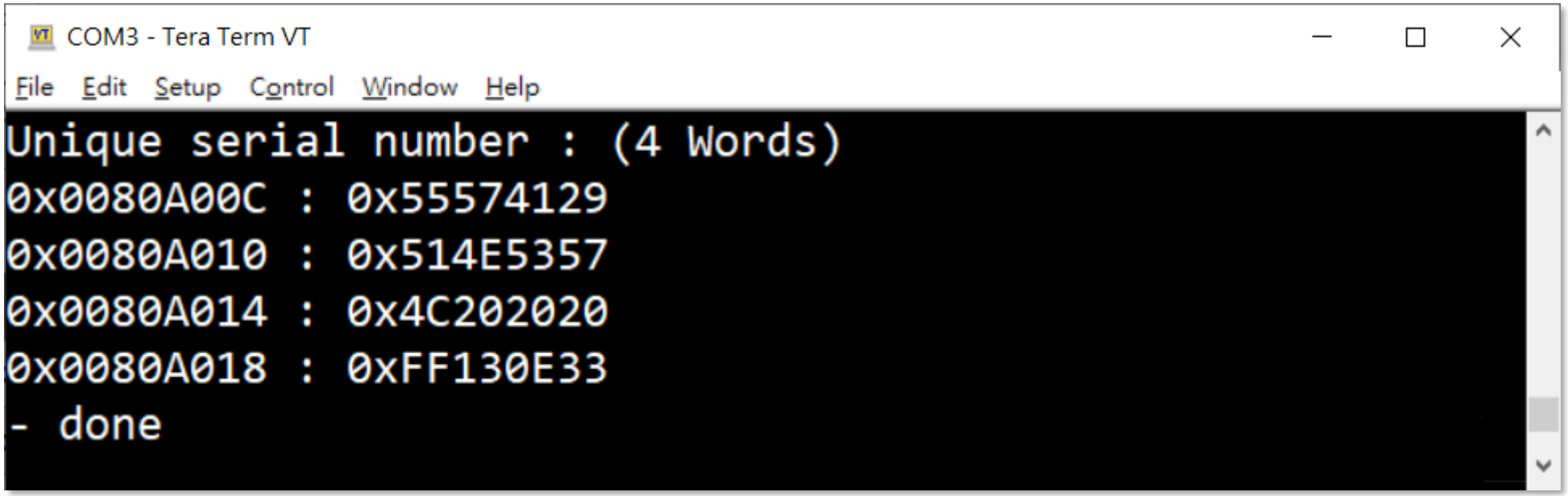
Step2

```
...
void myprintf(const char *format, ...) { ... };

// TODO 11-4.02
void NVM_Read_UQSN( uint32_t *Word )
{ ... }

int main ( void )
{
    ...
    SERCOM5_USART_Read( USART5_ReceiveData, 1 );

    // TODO 11-4.03
    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );

    while ( true )
    { ...
        if (TC3_HasExpired)
        { ...
            // TODO 11-4.04
            // myprintf( "Hello World!\r\n" );
        }
    }
```

MICROCHIP

🛠 Lab11-4 Read Unique Serial Number

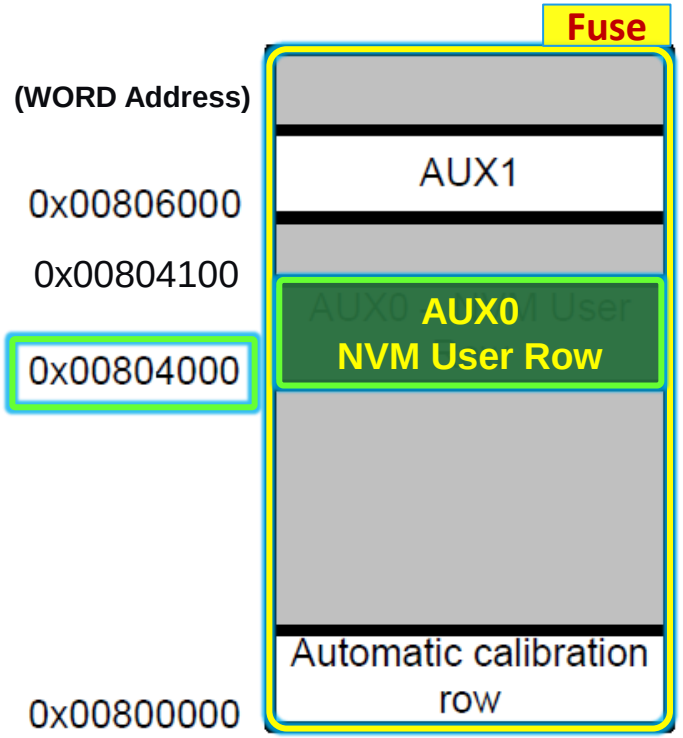
Result



🛠 Lab11-5 Read NVM AUX0 (User Row)

- Please continue from SAM2001 Lab11-4 Read Unique Serial Number
- Try to read the AUX0 (User Row) from NVM Fuse(Configuration Bit) which locate at address 0x00804000 and has total 64 WORDs (256 Bytes).
- The Fuse Settings should be the first two WORDs of AUX0.
- Please output as below format :

  “NVM-AUX0 User Row : (64 Words)”
  “- Word 0 and Word 1 ”
  “0x00804000 : 0xD800C777 ”
  “0x00804004 : 0xFFFF005C ”
  “- User ID Memory ”
  “0x00804008 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF ”
  “0x00804018 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF ”
  “0x00804028 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF ”
  “ ……..”
  “0x008040F8 : 0xFFFFFFFF 0xFFFFFFFF ”
  “- done”



- **Let’s go !**

MICROCHIP

🛠 Lab11-5 Read NVM AUX0 (User Row)

Step1

```
uint32_t NVM_UQSN_Word[4];
// TODO 11-5.01
uint32_t NVM_AUX0_Word[64];
...
void NVM_Read_UQSN( uint32_t *Word )
// TODO 11-5.02
void NVM_Read_AUX0( uint32_t *Word )
{
    volatile uint32_t *pWord, i;

    while( NVMCTRL_IsBusy() ) {}
    pWord = (volatile uint32_t *)USER_PAGE_ADDR;
    myprintf( "NVM-AUX0 User Row : (64 Words)\r\n" );
    for( i=0 ; i<64 ; i++ )
    {
        Word[i] = *pWord;
        if( i==0 ) myprintf( "- Word 0 and Word 1\r\n" );
        if( i==2 ) myprintf( "- User ID Memory\r\n" );
        if( i<2 || (i-2+4)%4==0 ) myprintf( "0x%08X :", USER_PAGE_ADDR+(i*4) );
        myprintf( " 0x%08X", Word[i] );
        if( i<2 || (i-1)%4==0 )  myprintf( "\r\n" );
        pWord++;
    }
    myprintf( "\r\n- done\r\n\r\n" );
}
```

MICROCHIP

🛠 Lab11-5 Read NVM AUX0 (User Row)

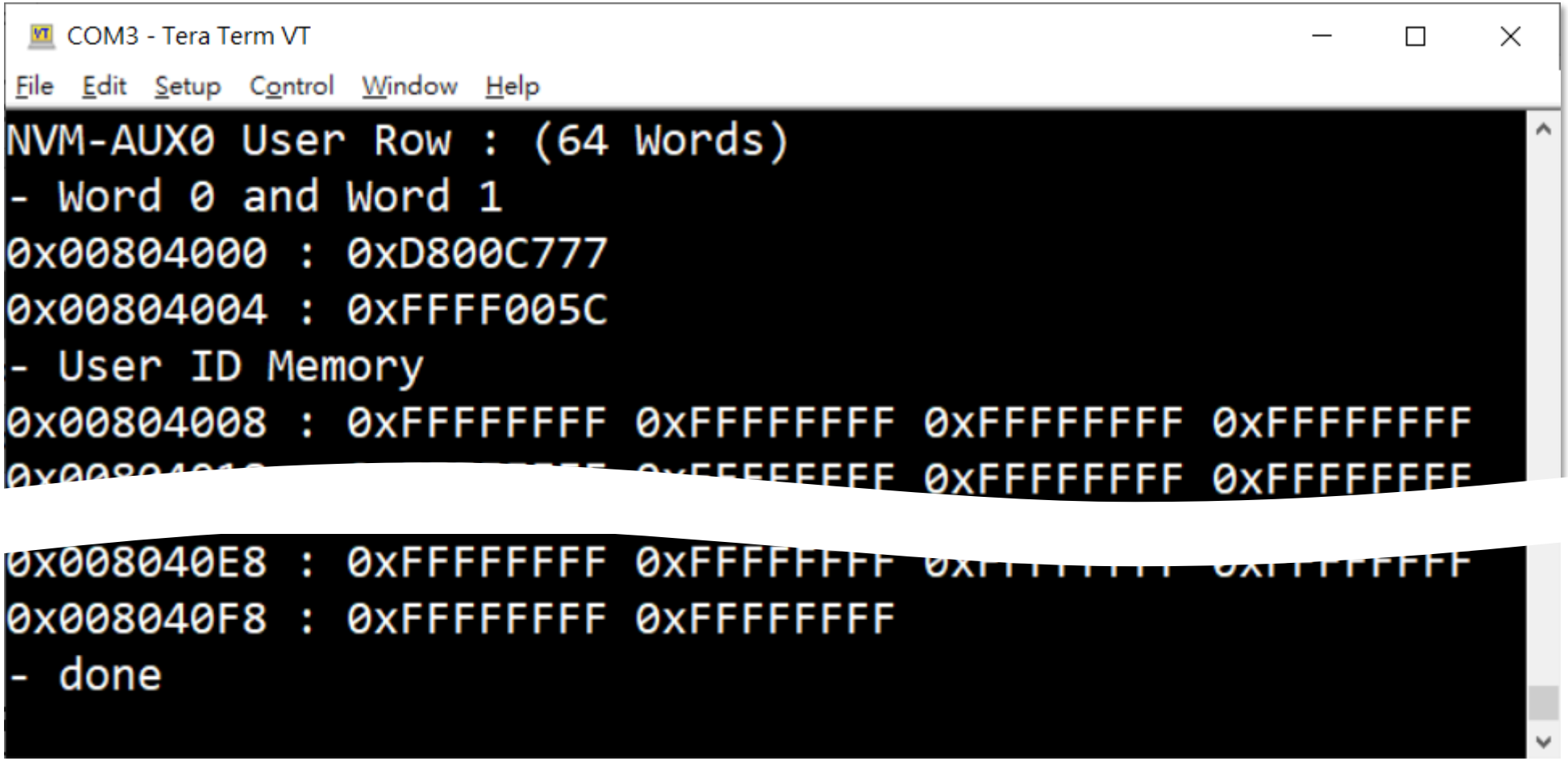
Step2

```
uint32_t NVM_UQSN_Word[4];
// TODO 11-5.01
uint32_t NVM_AUX0_Word[64];
...
void NVM_Read_UQSN( uint32_t *Word )
// TODO 11-5.02
void NVM_Read_AUX0( uint32_t *Word )
{ ... }

int main ( void )
{
    ...
    SERCOM5_USART_Read( USART5_ReceiveData, 1 );

    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );
    // TODO 11-5.03
    NVM_Read_AUX0( NVM_AUX0_Word );

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

MICROCHIP

Lab11-5 Read NVM AUX0 (User Row)

Result

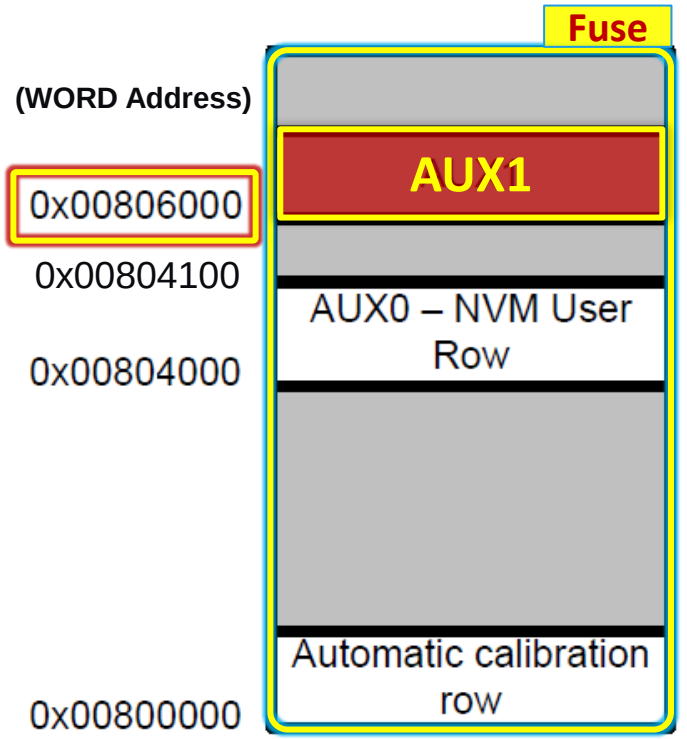


🛠 Lab11-6 Read NVM AUX1 (Software Calibration)

- Please continue from SAM2001 Lab11-5 Read NVM AUX0 (User Row)
- Try to read the AUX1 (Software Calibration) from NVM Fuse(Configuration Bit) which locate at address 0x00806000 and has total 16 WORDs (64 Bytes).
- The Factory Calibration should in OTP Area 4 and Software Temperature Log of AUX1.
- Please output as below format :

  “NVM-AUX1 : (16 Words) ”
  “- OTP Area 1 (Reserved) ”
  “- OTP Area 2 (Device Configuration Area) ”
  “- OTP Area 3 (Reserved) ”
  “- OTP Area 4 (Software Calibration Area) ”
  “0x00806020 : 0x40004007”
  “……”
  “ > Software Temperature Log row”
  “0x00806030 : 0xFD07D11E”
  “……”
  “ > Reserved”
  “- done”

- **Let’s go !**



MICROCHIP

🛠 Lab11-6 Read NVM AUX1 (Software Calibration)

Step1

```
...
uint32_t NVM_UQSN_Word[4];
uint32_t NVM_AUX0_Word[64];
// TODO 11-6.01
uint32_t NVM_AUX1_Word[16];
...
void NVM_Read_UQSN( uint32_t *Word )
{
    ...
}

void NVM_Read_AUX0( uint32_t *Word )
{
    ...
}

int main ( void )
{
    ...
    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );
    ...
}
```

MICROCHIP

🛠 Lab11-6 Read NVM AUX1 (Software Calibration)

Step1

```
// TODO 11-6.01
uint32_t NVM_AUX1_Word[16];
...
// TODO 11-6.02
void NVM_Read_AUX1( uint32_t *Word )
{
    volatile uint32_t *pWord, i;

    while( NVMCTRL_IsBusy() ) {}
    pWord = (volatile uint32_t *)OTP1_ADDR;
    myprintf( "NVM-AUX1 : (16 Words)\r\n" );
    for( i=0 ; i<16 ; i++ )
    {
        Word[i] = *pWord;
        if( i== 0 ) myprintf( "- OTP Area 1 (Reserved)\r\n" );
        if( i== 2 ) myprintf( "- OTP Area 2 (Device Configuration Area)\r\n" );
        if( i== 4 ) myprintf( "- OTP Area 3 (Reserved)\r\n" );
        if( i== 8 ) myprintf( "- OTP Area 4 (Software Calibration Area)\r\n" );
        if( i==12 ) myprintf( " > Software Temperature Log row\r\n" );
        if( i==14 ) myprintf( " > Reserved\r\n" );
        myprintf( "0x%08X : 0x%08X\r\n", OTP1_ADDR+(i*4), Word[i] );
        pWord++;
    }
    myprintf( "- done\r\n\r\n" );
}
```

🛠 Lab11-6 Read NVM AUX1 (Software Calibration)

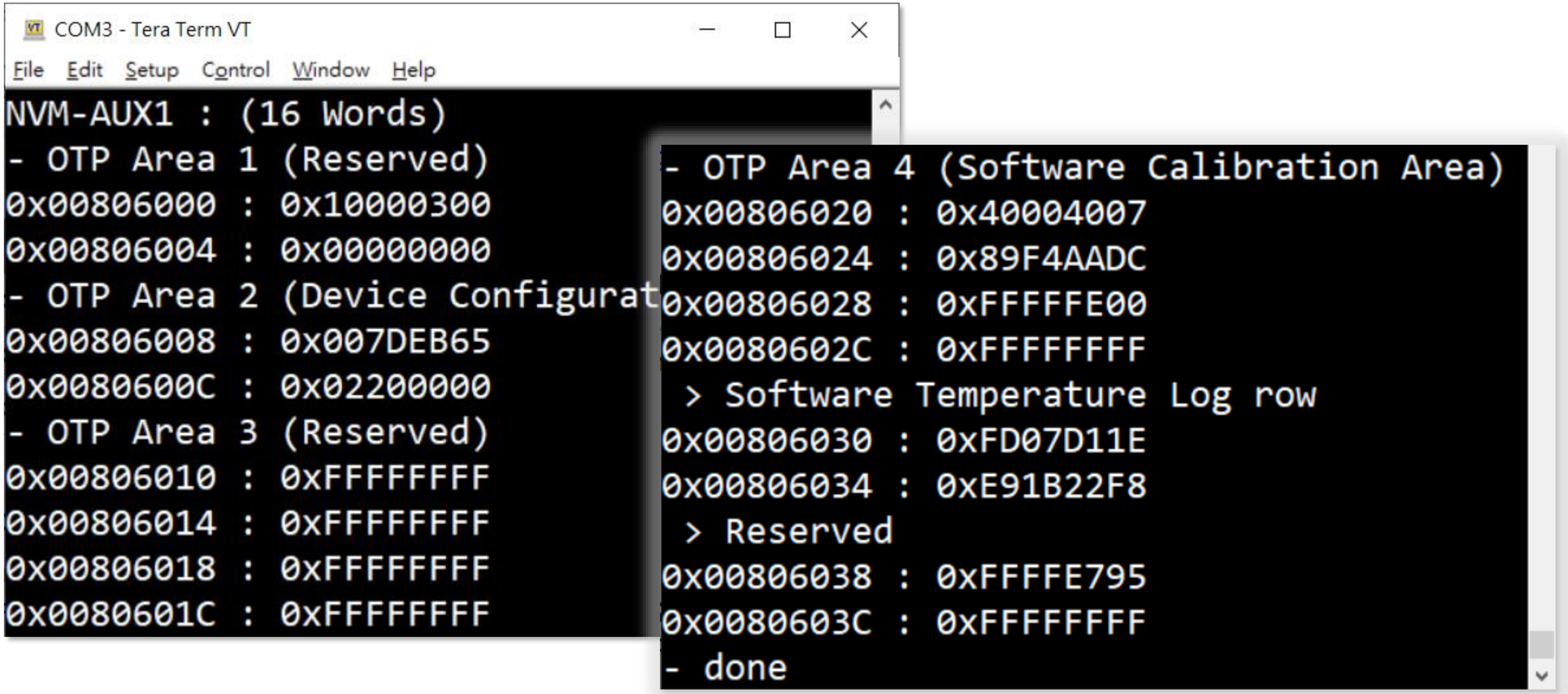
Step2

```
// TODO 11-6.01
uint32_t NVM_AUX1_Word[16];
...
// TODO 11-6.02
void NVM_Read_AUX1( uint32_t *Word )
{
    ...
}

int main ( void )
{
    ...

    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );
    // TODO 11-6.03
    NVM_Read_AUX1( NVM_AUX1_Word );

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

MICROCHIP

Lab11-6 Read NVM AUX1 (Software Calibration)

Result

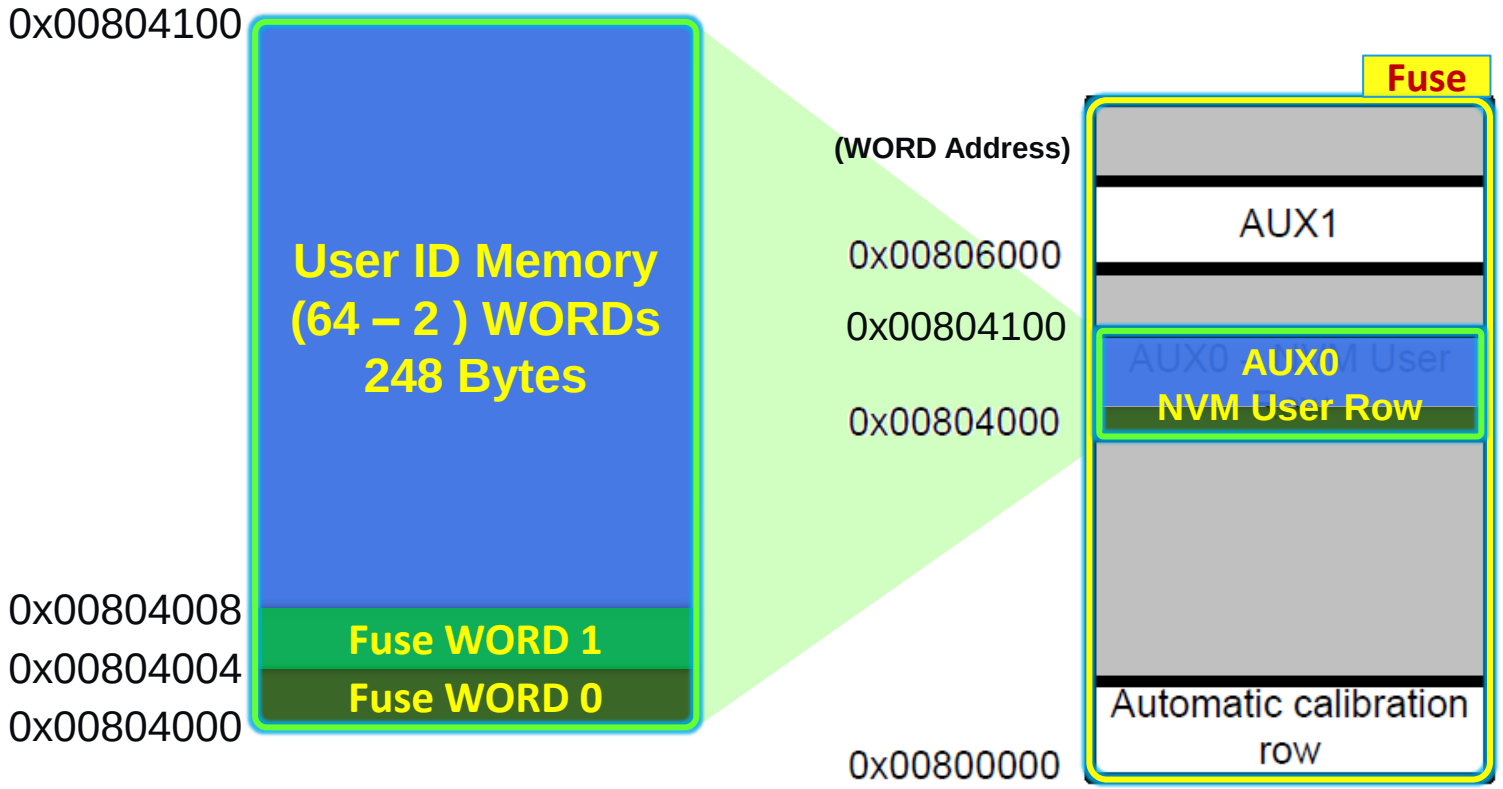


User ID Memory in NVM AUX0 (User Row)

User ID Memory in NVM AUX0 (User Row)

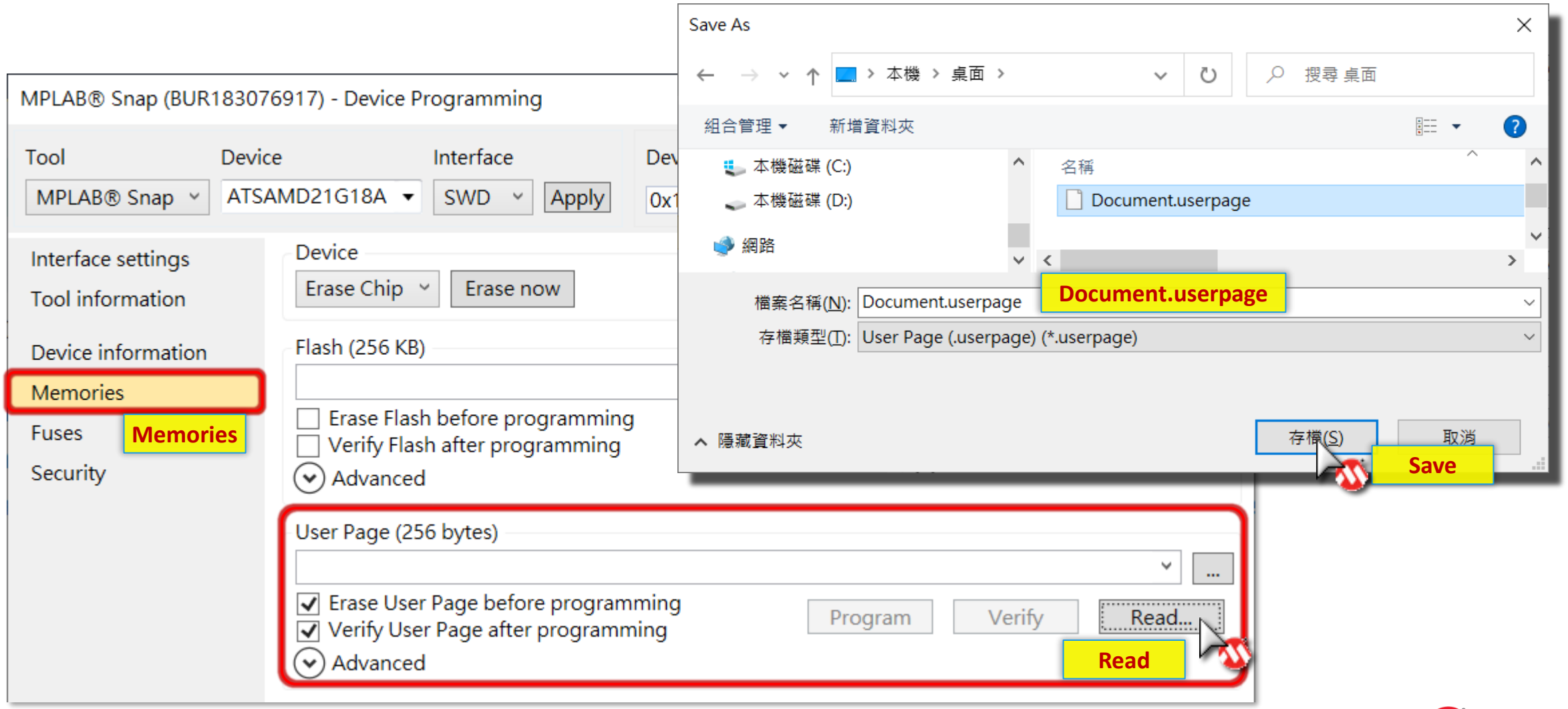
User Fuse WORD 0, WORD1 and User ID Memory

```
NVM-AUX0 User Row : (64 Words)
- Word 0 and Word 1
0x00804000 : 0xD800C777
0x00804004 : 0xFFFF005C
- User ID Memory
0x00804008 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804018 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804028 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804038 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804048 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804058 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804068 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804078 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804088 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804098 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040A8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040B8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040C8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040D8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040E8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040F8 : 0xFFFFFFFF 0xFFFFFFFF
- done
```



User ID Memory in NVM AUX0 (User Row)

User Microchip Studio to access User ID Memory



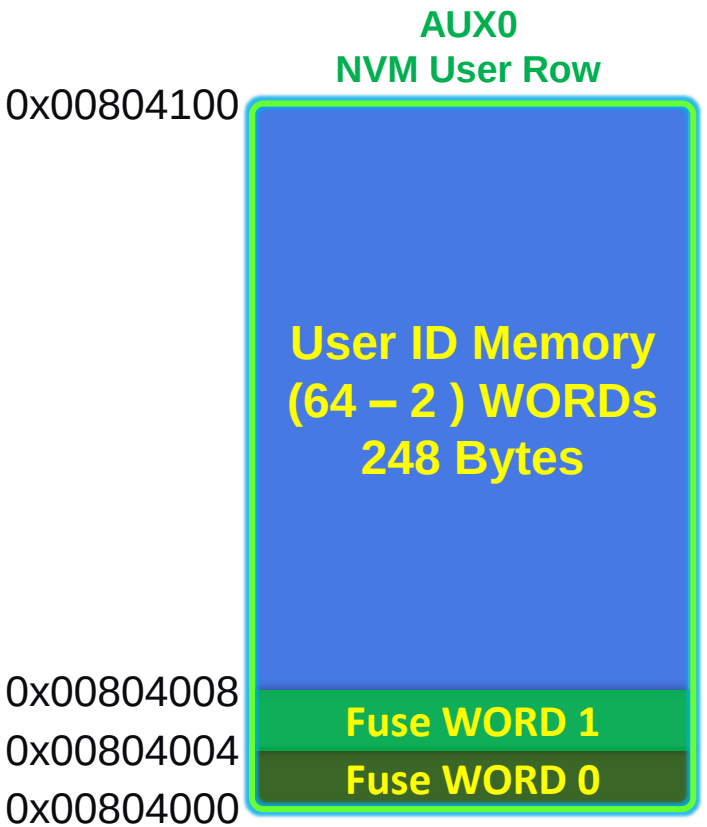
User ID Memory in NVM AUX0 (User Row)

User Microchip Studio to access User ID Memory

Document.userpage

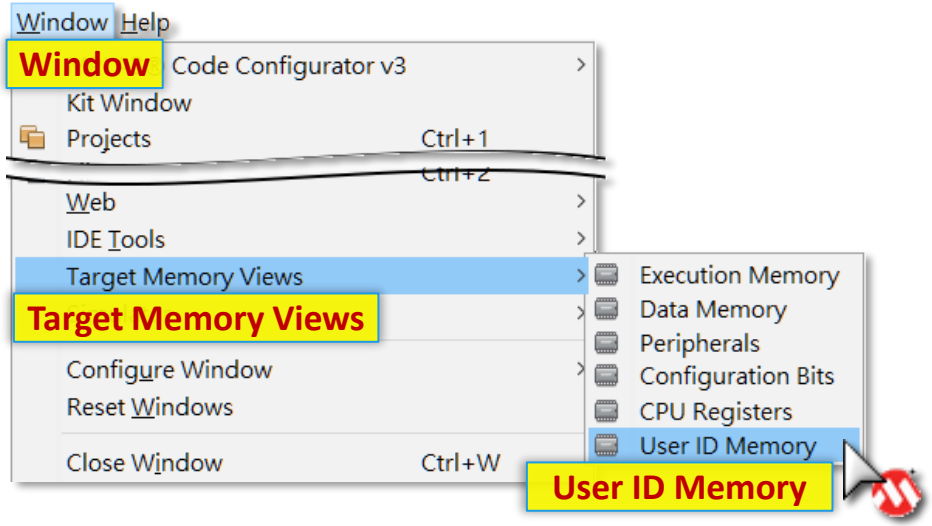
```
:020000040080 7A
:10400000 77C700D8 5C00FFFF FFFFFFFFFFFFFFFF 48
:10401000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF B0
:10402000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF A0
:10403000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 90
:10404000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 80
:10405000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 70
:10406000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 60
:10407000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 50
:10408000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 40
:10409000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 30
:1040A000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 20
:1040B000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 10
:1040C000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 00
:1040D000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF F0
:1040E000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF E0
:1040F000 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF D0
:00000001FF
```

Microchip Studio IDE to store **Fuse** and **User ID Memory** together

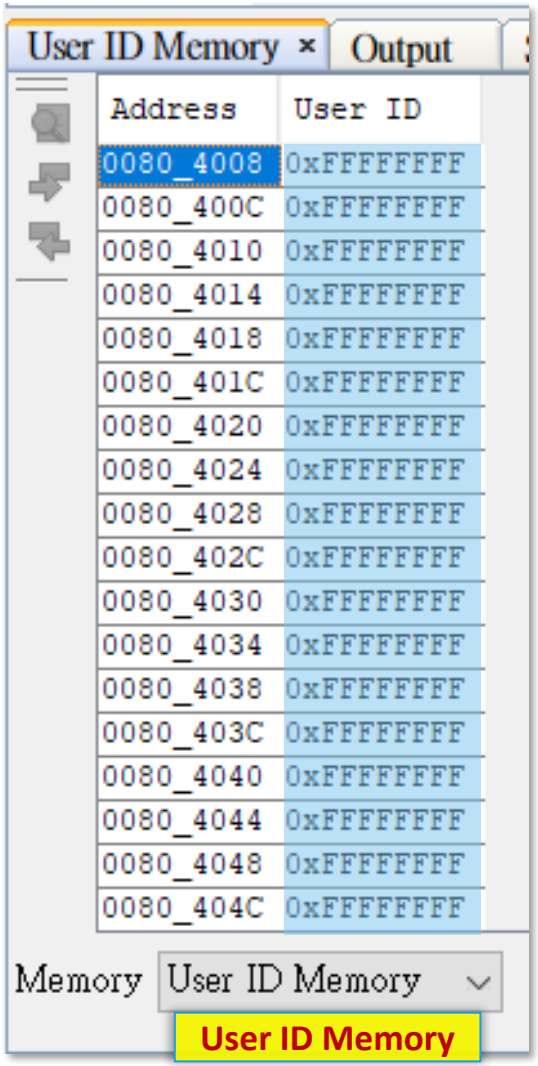


User ID Memory in NVM AUX0 (User Row)

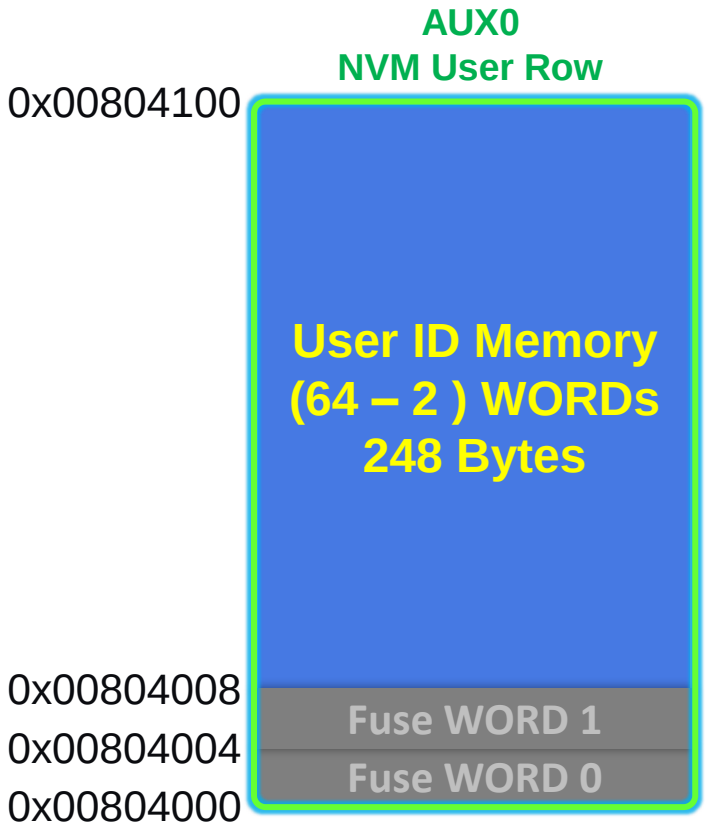
User MPLAB X IDE to access User ID Memory



We cannot manually read and write User ID Memory here

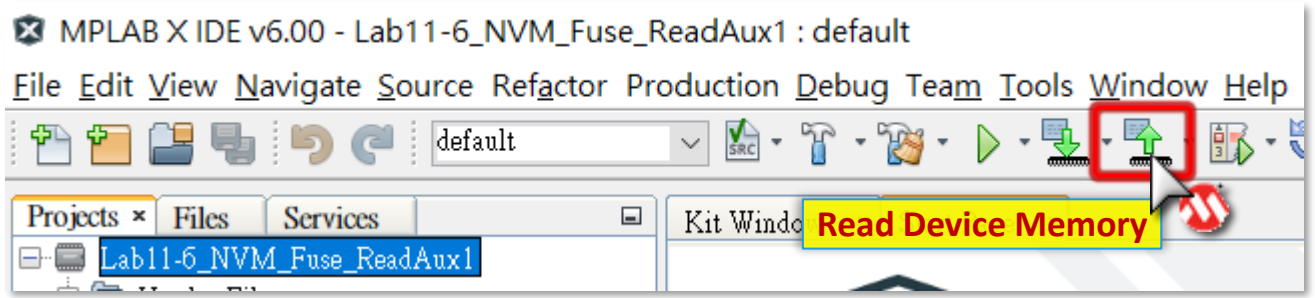


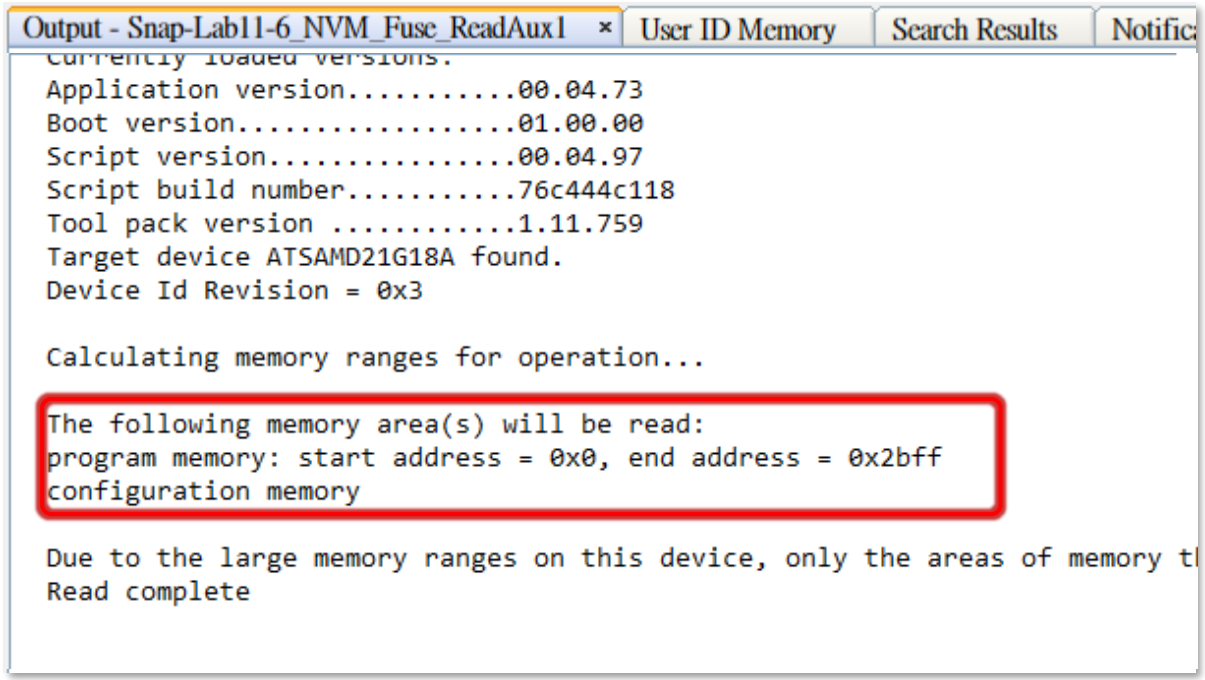
MPLAB X IDE separate to shows User ID Memory in GUI

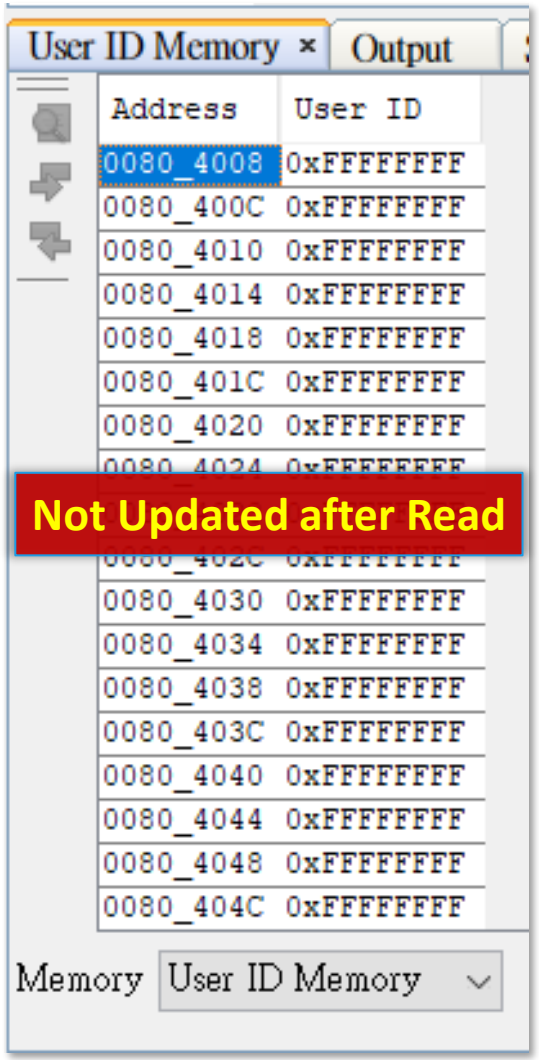


User ID Memory in NVM AUX0 (User Row)

Read User ID Memory in MPLAB X IDE

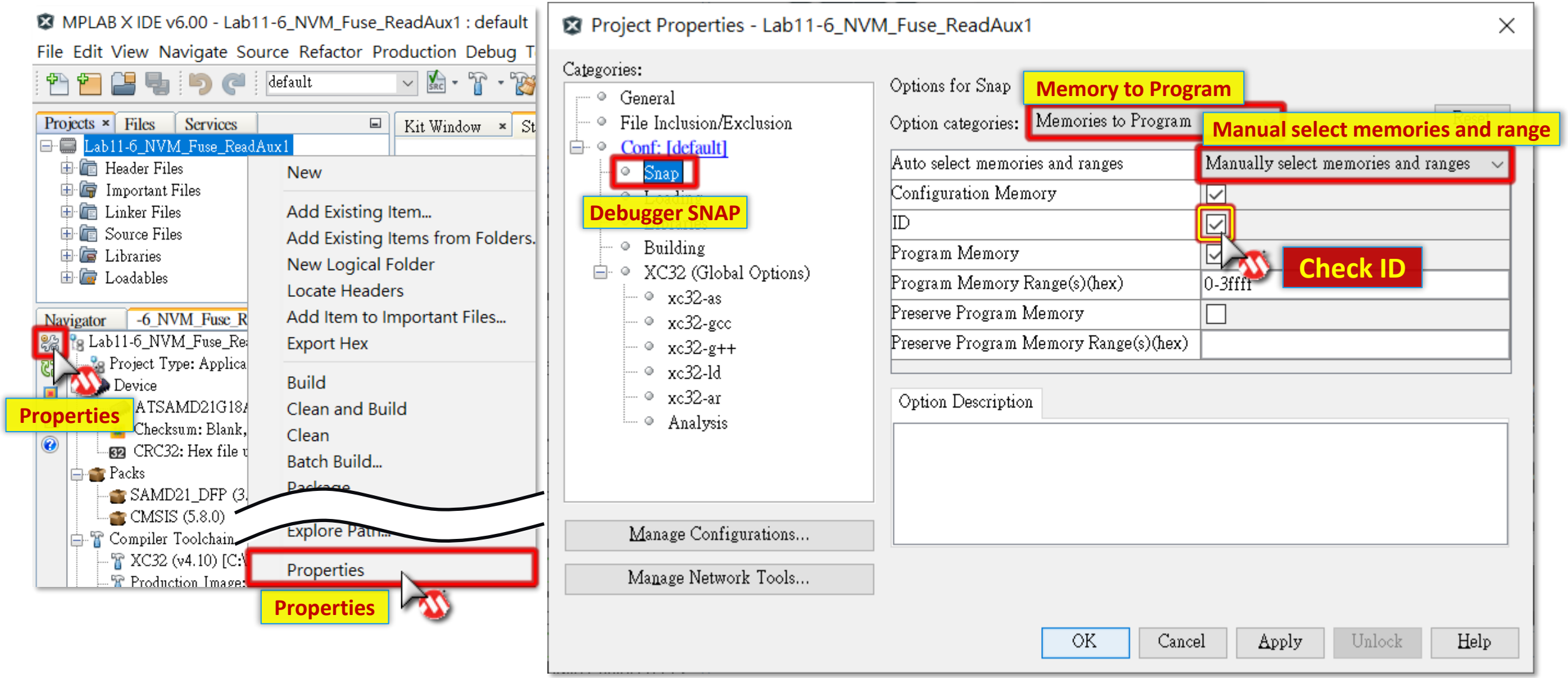






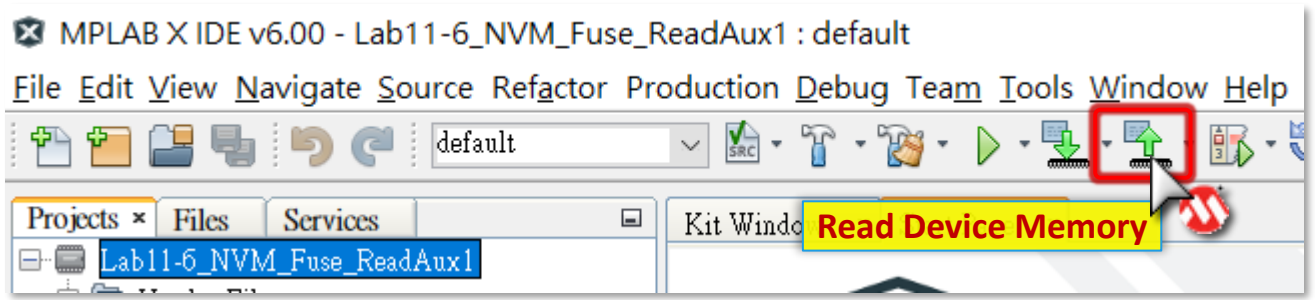
User ID Memory in NVM AUX0 (User Row)

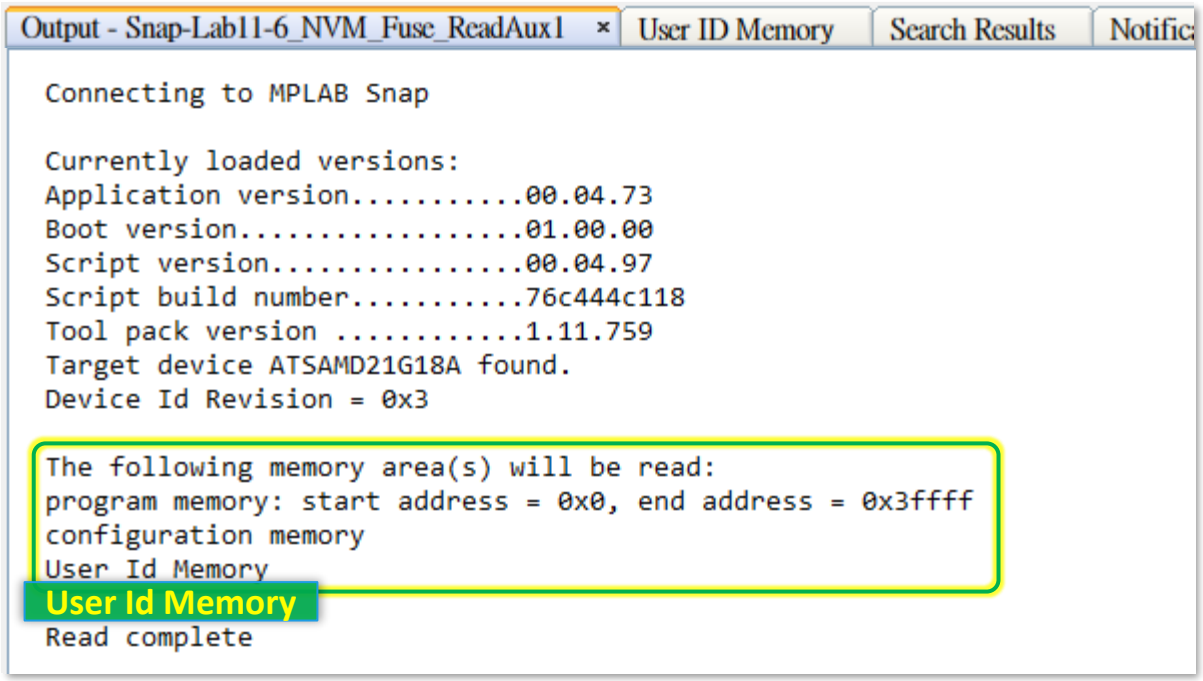
Read User ID Memory in MPLAB X IDE

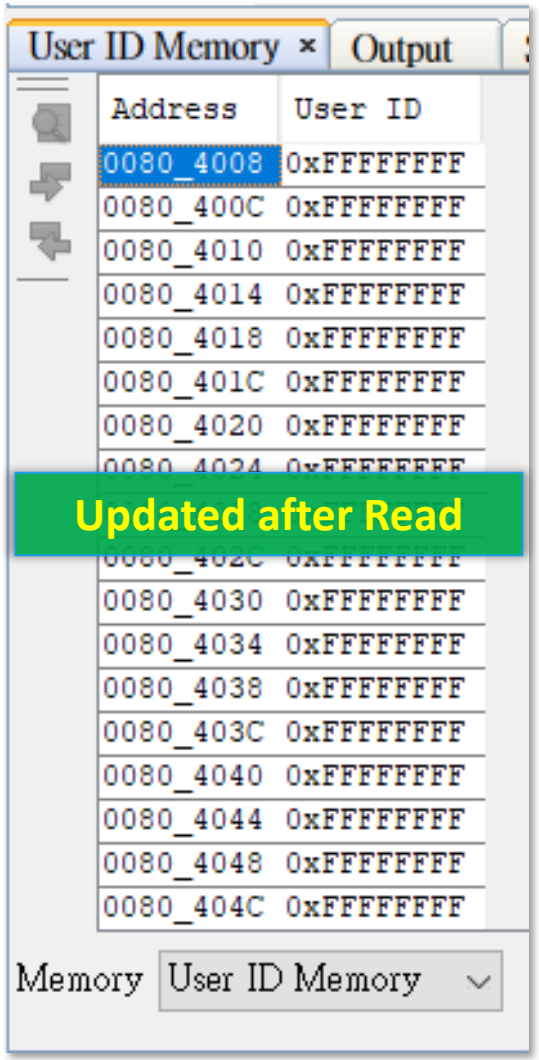


User ID Memory in NVM AUX0 (User Row)

Read User ID Memory in MPLAB X IDE

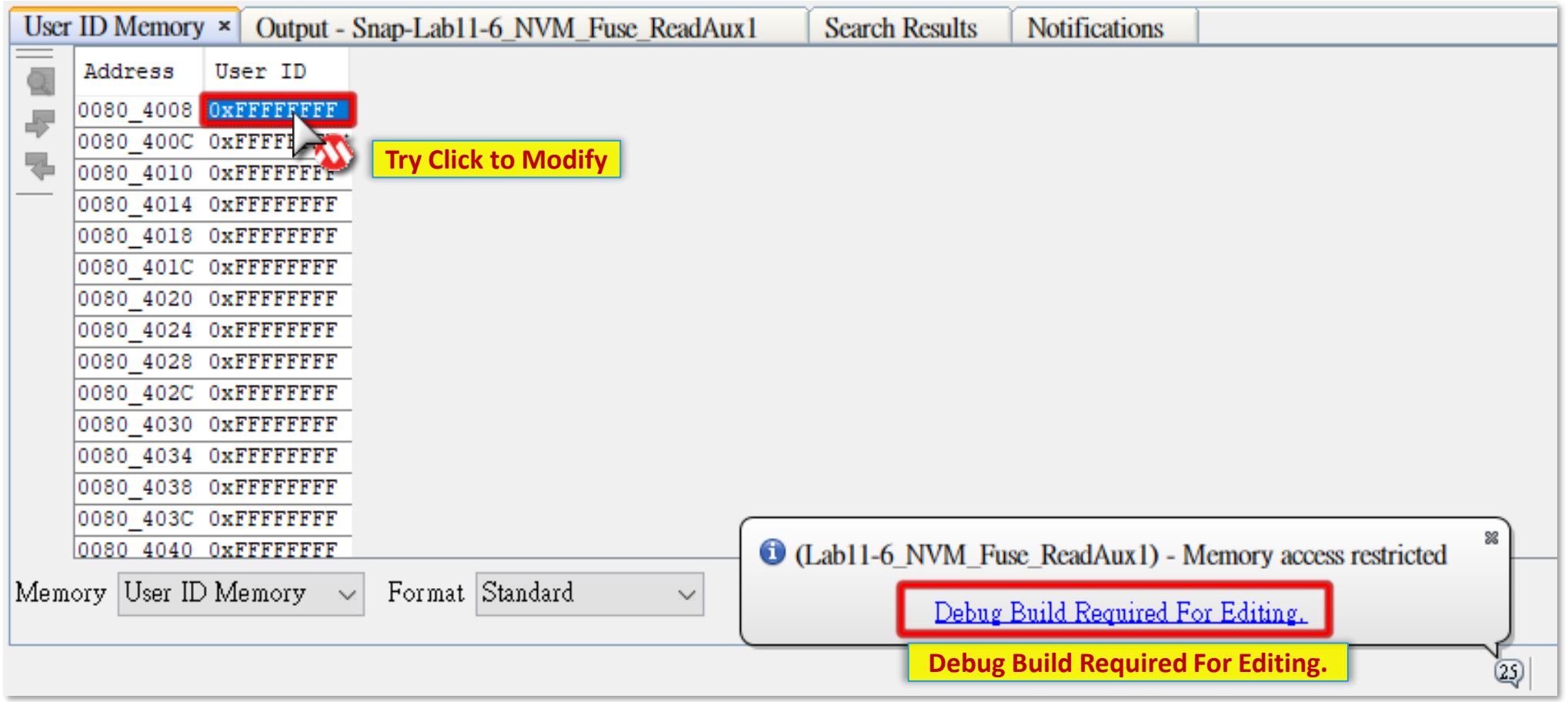






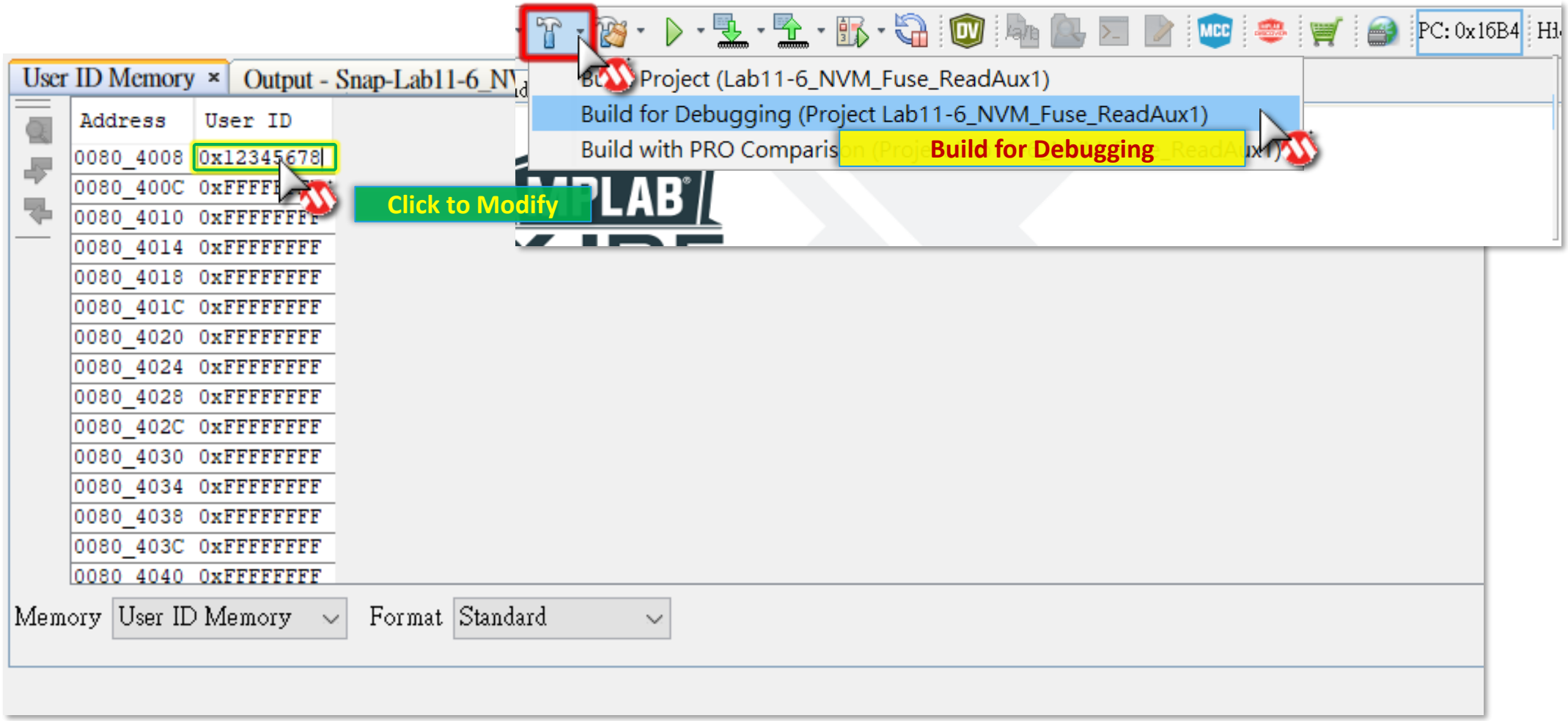
User ID Memory in NVM AUX0 (User Row)

Modify and write User ID Memory in MPLAB X IDE



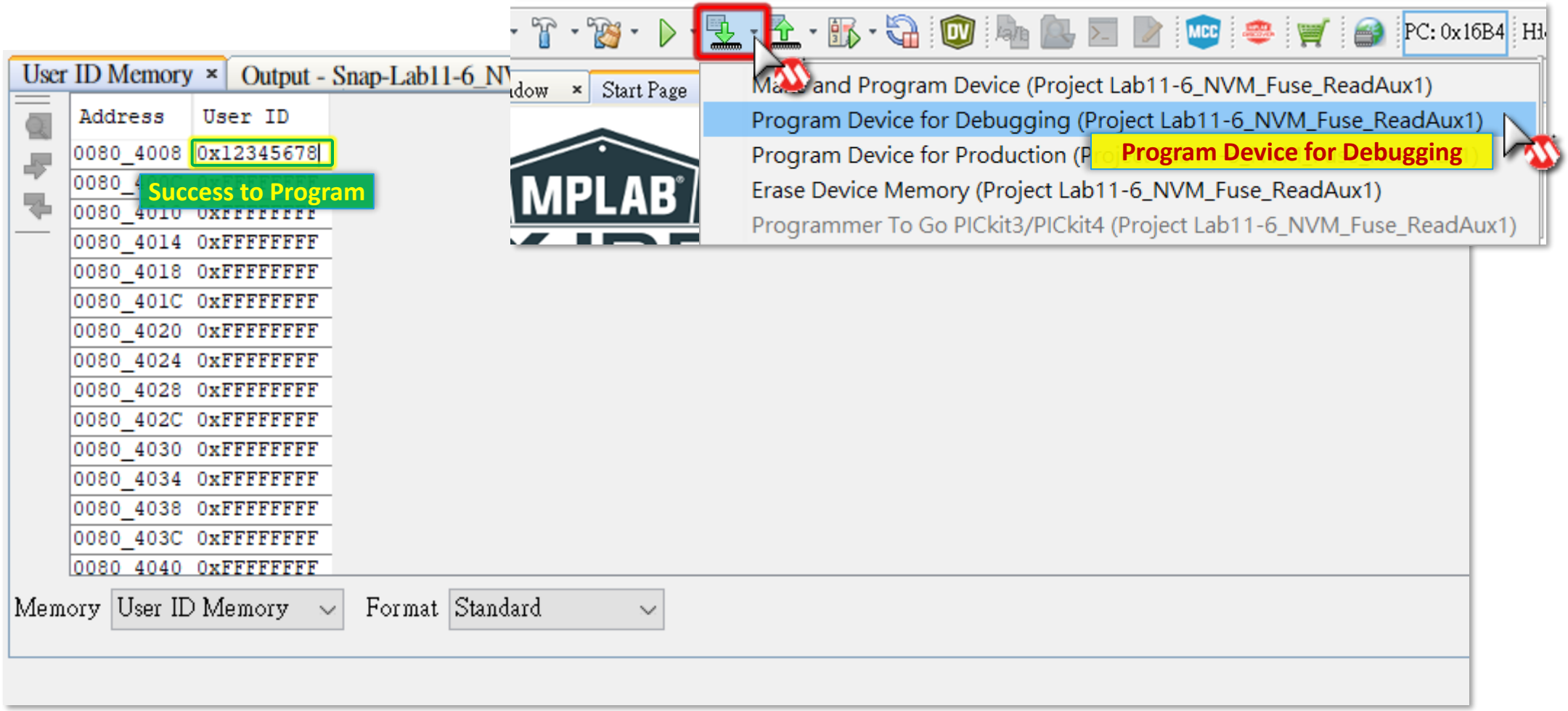
User ID Memory in NVM AUX0 (User Row)

Modify and write User ID Memory in MPLAB X IDE



User ID Memory in NVM AUX0 (User Row)

Modify and write User ID Memory in MPLAB X IDE



User ID Memory in NVM AUX0 (User Row)

NVMCTRL User Row Interface function

- **Latest Harmony Framework(PLIB) to support below User Row NVM operation.**

bool NVMCTRL_USER_ROW_RowErase(uint32_t address)
NVM AUX0(User Row) Erase Row of given address.

bool NVMCTRL_USER_ROW_PageWrite(uint32_t *data, const uint32_t address)
NVM AUX0(User Row) Page Write to given address.

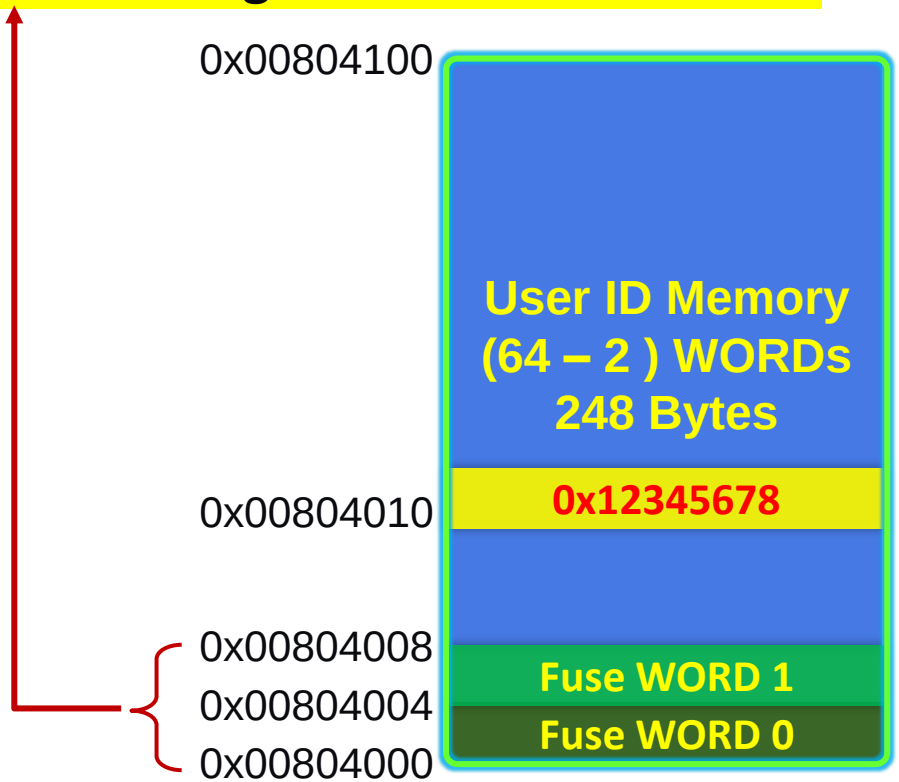
void NVMCTRL_SecurityBitSet(void)
Set the Security Bit by software.

🛠 Lab11-7 Write NVM AUX0 (User Row)

- Please continue from SAM2001 Lab11-6 Read NVM AUX1 (Software Calibration)
- Try to write one WORD user data 0x12345678 to AUX0 User ID Memory address 0x00804010, and then read it back to make sure write has successed.
- Remember always execute NVM_Read_AUX0(NVM_AUX0_Word) once, before you to execute the NVM_Write_AUX0(NVM_AUX0_Word) function for make sure to get the first two WORD of Fuse Setting and then execute erase and write it back.
- Please output AUX0 write function as below format :

  “Erase NVM-AUX0 User Row :”
  “ - success”
  “Write NVM-AUX0 User Row :”
  “ - Page 0 : success”
  “ - Page 1 : success”
  “ - Page 2 : success”
  “ - Page 3 : success”
  “done”

Let’s go !



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🛠 Lab11-7 Write NVM AUX0 (User Row)

Step1

```
...
void NVM_Read_AUX1( uint32_t *Word ) {...}

// TODO 11-7.01
bool NVMCTRL_GetSecurityBitStatus( void )
{
    if( NVMCTRL_REGS->NVMCTRL_STATUS & NVMCTRL_STATUS_SB(1UL) )
    {
        return true;
    }

    return false;
}

void NVM_Write_AUX0( uint32_t *Word )
{
    uint32_t i;

    while( NVMCTRL_IsBusy() ) {}

    if( NVMCTRL_GetSecurityBitStatus() )
    {
        myprintf( "Security Bit has been set!\r\n" );
        return;
    }
```

Check Security Bits before Write AUX0
Let's talk it later in next LAB

🛠 Lab11-7 Write NVM AUX0 (User Row)

Step2

```
...
void NVM_Read_AUX1( uint32_t *Word ) {...}

// TODO 11-7.01
bool NVMCTRL_GetSecurityBitStatus( void ) { ... }

void NVM_Write_AUX0( uint32_t *Word )
{
    ...
    myprintf( "Erase NVM-AUX0 User Row : \r\n" );
    NVMCTRL_USER_ROW_RowErase((uint32_t)USER_PAGE_ADDR);
    while( NVMCTRL_IsBusy() ) {}
    myprintf( " - success\r\n" );

    myprintf( "Write NVM-AUX0 User Row : \r\n" );
    for( i=0 ; i<4 ; i++ )
    {
        myprintf( " - Page %d : ", i );
        NVMCTRL_USER_ROW_PageWrite((uint32_t *)Word, (uint32_t)USER_PAGE_ADDR+(i*64));
        while( NVMCTRL_IsBusy() ) {}
        myprintf( "success\r\n" );
        Word+=16;
    }
    myprintf( "done\r\n\r\n" );
}
```

MICROCHIP

🛠 Lab11-7 Write NVM AUX0 (User Row)

Step3

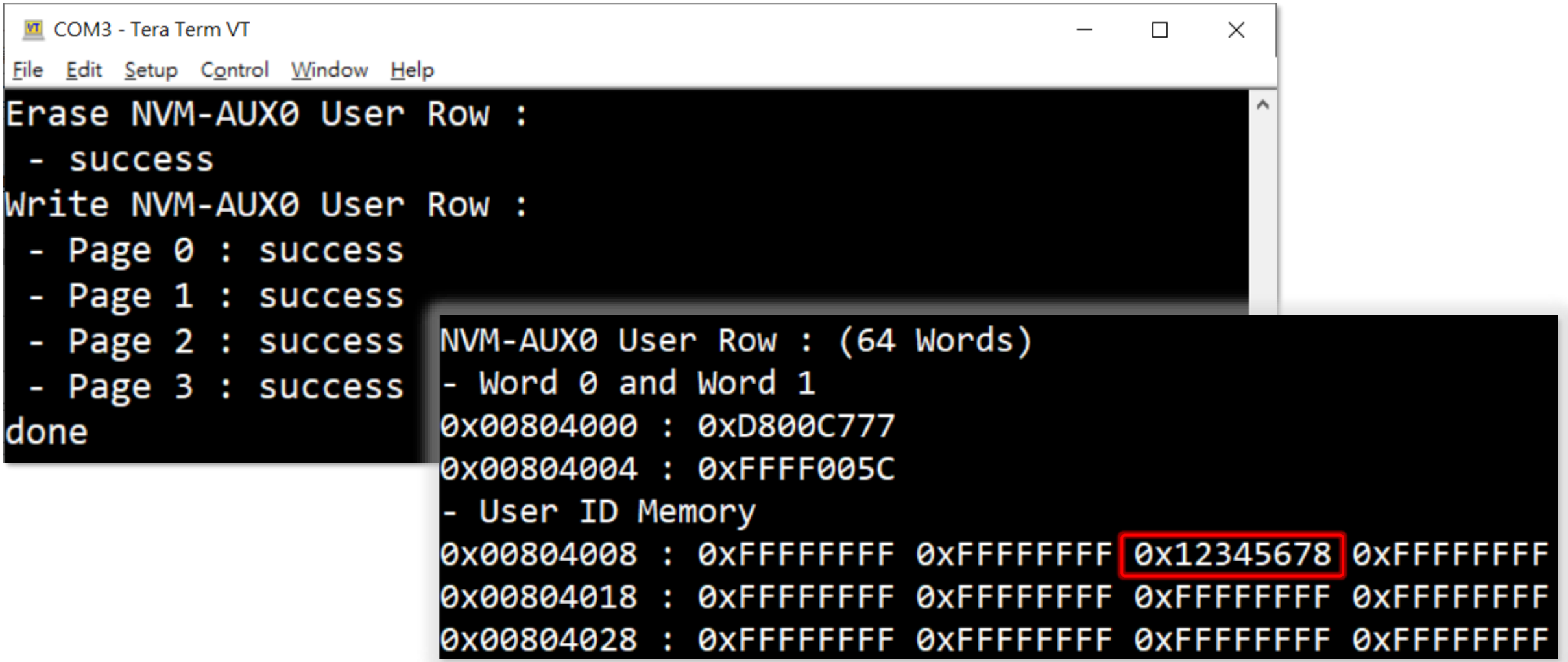
```
...
void NVM_Read_AUX1( uint32_t *Word ) {...}

// TODO 11-7.01
bool NVMCTRL_GetSecurityBitStatus( void ) { ... }

void NVM_Write_AUX0( uint32_t *Word ) { ... }

int main ( void )
{
    ...
    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );
    NVM_Read_AUX1( NVM_AUX1_Word );

    // TODO 11-7.02
    NVM_AUX0_Word[4] = 0x12345678;
    NVM_Write_AUX0( NVM_AUX0_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );

    while ( true )
    {
        ...
```

Remember always execute NVM_Read_AUX0(NVM_AUX0_Word) once, before you to execute the NVM_Write_AUX0(NVM_AUX0_Word) function for make sure to get the first two WORD of Fuse Setting

MICROCHIP

🛠 Lab11-7 Write NVM AUX0 (User Row)

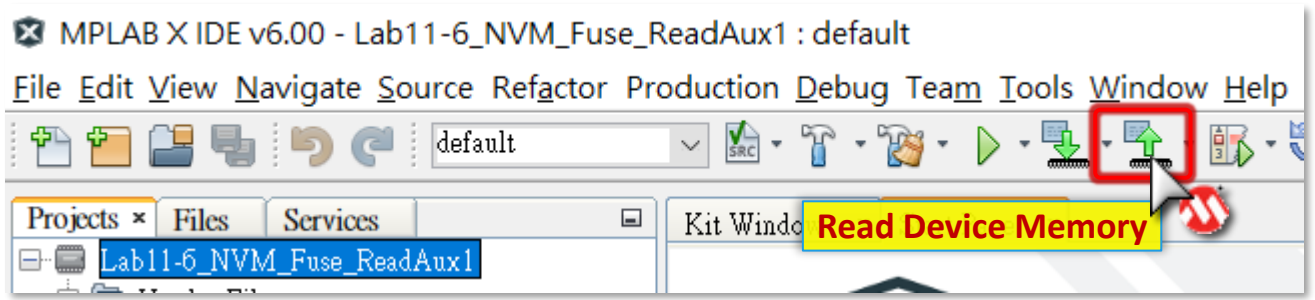
Result

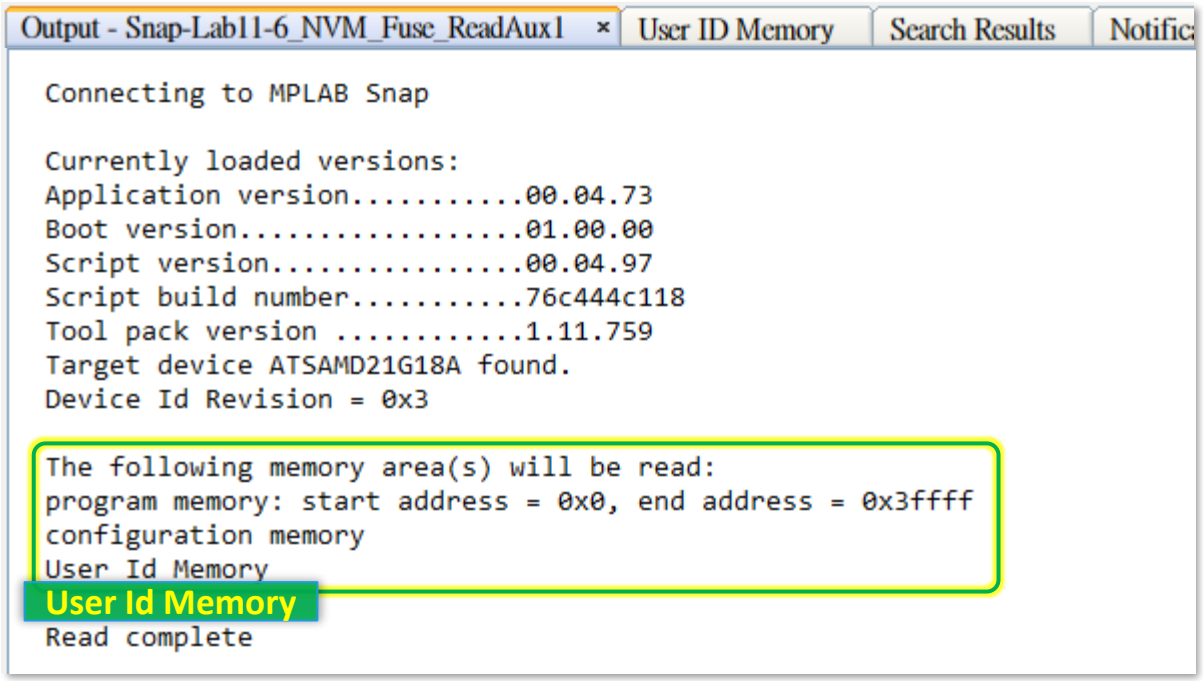


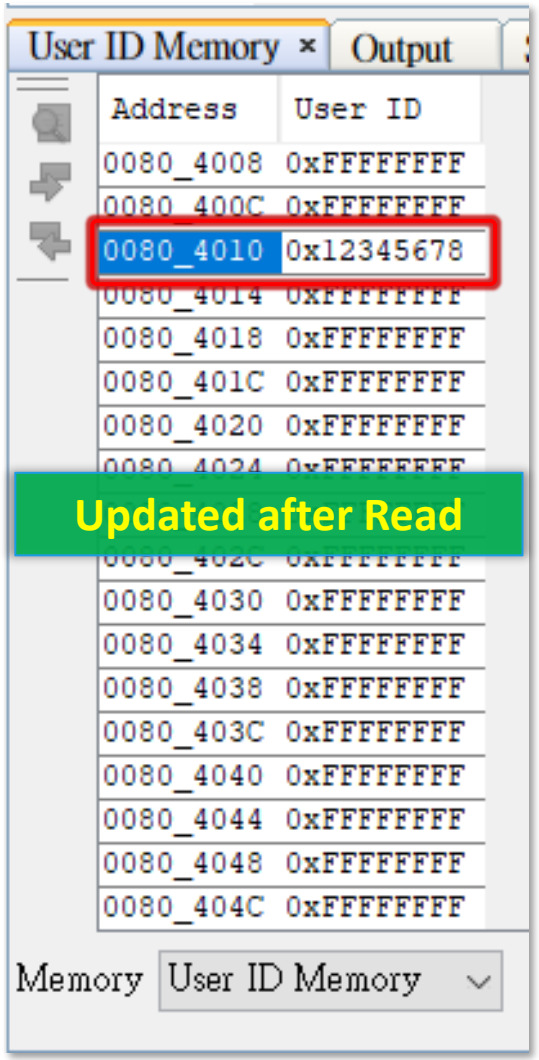
MICROCHIP

Lab11-7 Write NVM AUX0 (User Row)

Read User ID Memory in MPLAB X IDE







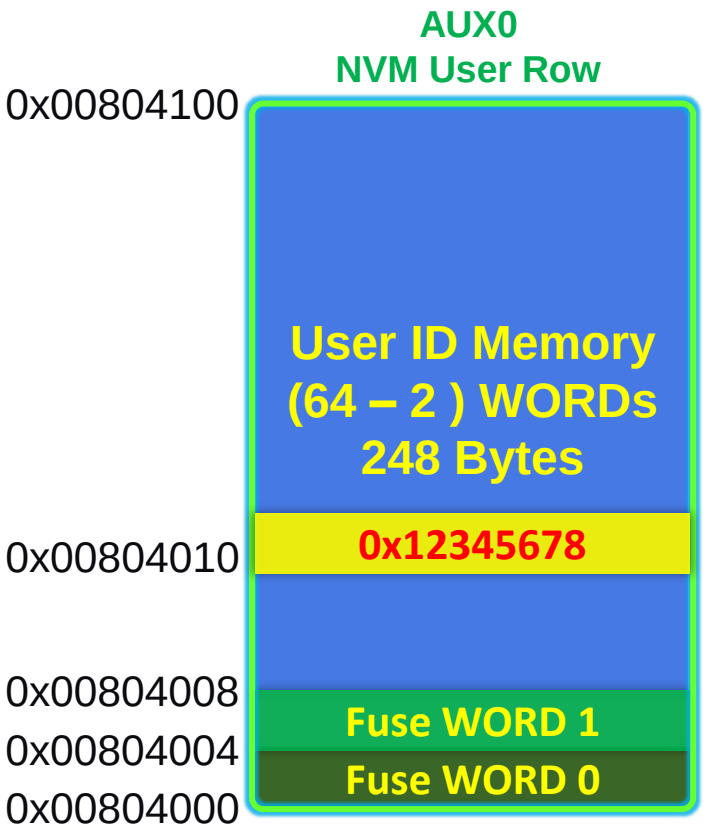
Lab11-7 Write NVM AUX0 (User Row)

Read User ID Memory in Microchip Studio

Document.userpage

```
:020000040080 7A
:10400000 77C700D8 5C00FFFF FFFFFFFFFFFFFFFF 48
:10401000 78563412 FFFFFFFFFFFFFFFFFFFFFFFF 98
:10402000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF A0
:10403000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 90
:10404000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 80
:10405000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 70
:10406000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 60
:10407000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 50
:10408000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 40
:10409000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 30
:1040A000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 20
:1040B000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 10
:1040C000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF 00
:1040D000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF F0
:1040E000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF E0
:1040F000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF D0
:00000001FF
```

Microchip Studio IDE to store **Fuse** and **User ID Memory** together



NVM Security Bit

- **Security Bit**
  - The security bit allows the entire chip to be locked from external access for code security.
  - The security bit can be written by a dedicated command, Set **Security Bit (SSB)**.
  - Once set Security Bit, the only way to **clear** the security bit is **through a debugger Chip Erase command**.
  - After issuing the SSB command, the PROGE error bit can be checked.
  - In order to increase the security level, it is recommended to enable the internal BOD33 when the security bit is set.
- **Chip Erase**
  - Chip-Erase consists of removing all sensitive information stored in the chip and **clearing the NVMCTRL security bit**.
  - **All volatile memories**, the **Flash memory** (including the EEPROM Emulation area) and the **RWWEE Emulation** section will be erased.
  - The **Flash auxiliary rows**, **including the user row**, **will not be erased**.
- **Programming**
  - Programming the Flash or RAM memories **through external programmer** is only possible when the device is **not protected by the NVMCTRL security bit**.
- **NVM Auxiliary space**
  - Auxiliary space **cannot be accessed from outside** if the security bit is set.
- **Debug Operation**
  - When an external debugger forces the CPU into debug mode, the peripheral continues normal operation.
  - **Access to the NVM block can be protected by the security bit**. In this case, the NVM block will not be accessible.

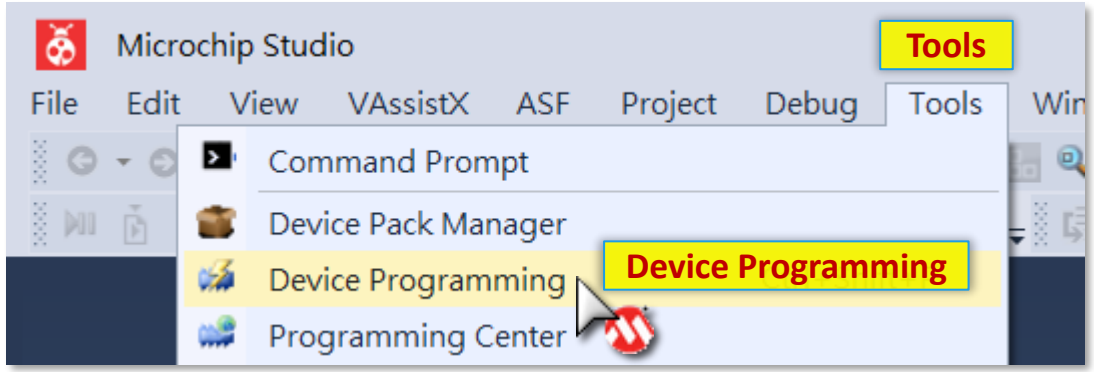
🛠 Lab11-8 Code Protect by NVM Security Bit

- Please continue from SAM2001 Lab11-7 Write NVM AUX0 (User Row)
- You will practice below exercises in this LAB.
  - Try use Microchip Studio to enable the Security Bit.
  - Try under MPLAB X IDE and use Harmony to enable the Security Bit.
  - Try read Flash memory while Security Bit has been settled.
  - Try un-seal the Security Bit by Erase Chip. In both Microchip Studio and MPLAB X IDE.
  - Make sure the “Self Flash Access” is executable while enable the Security Bit.

Let’s go !

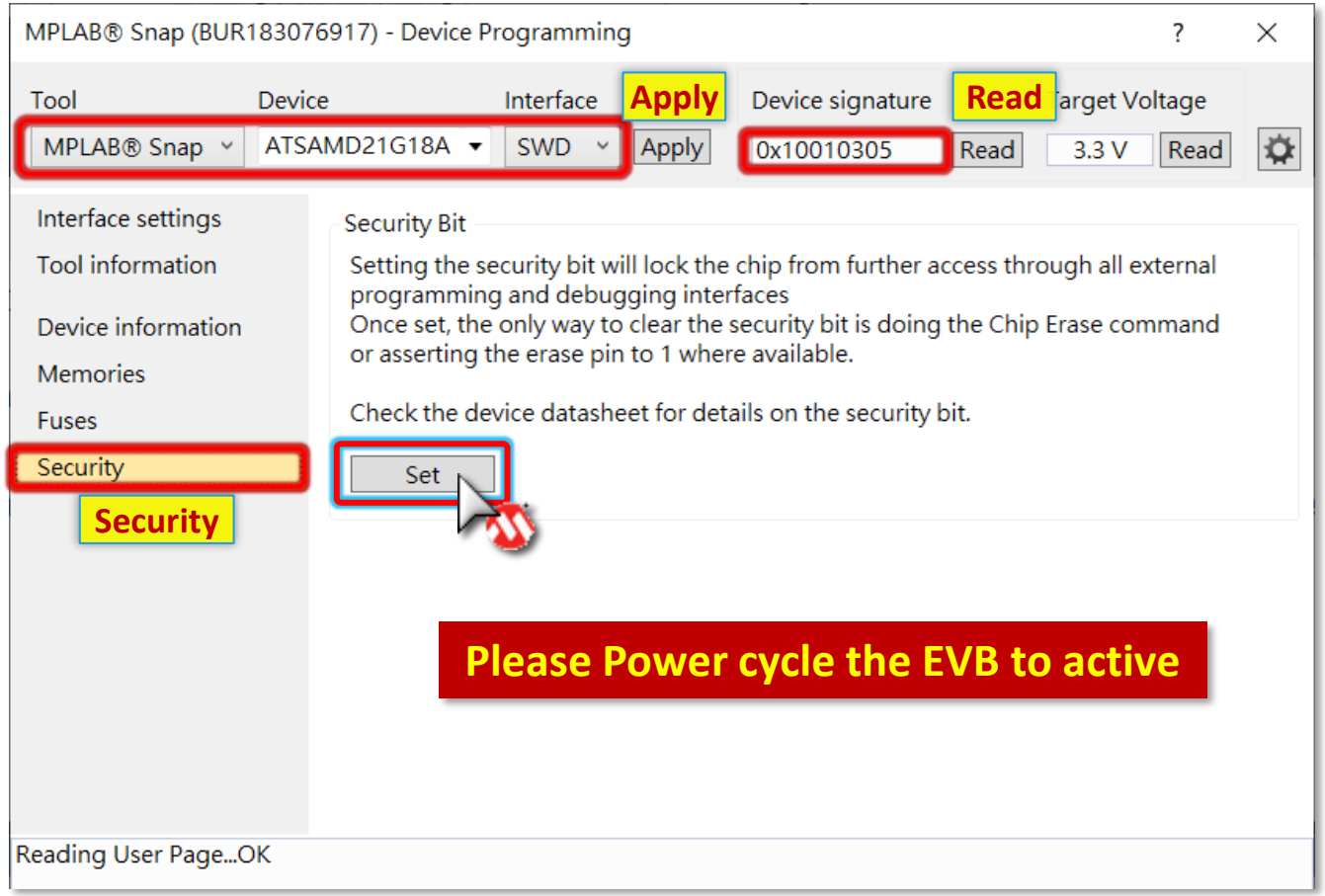
🛠 Lab11-8 Code Protect by NVM Security Bit

Use Microchip Studio to enable Security Bit



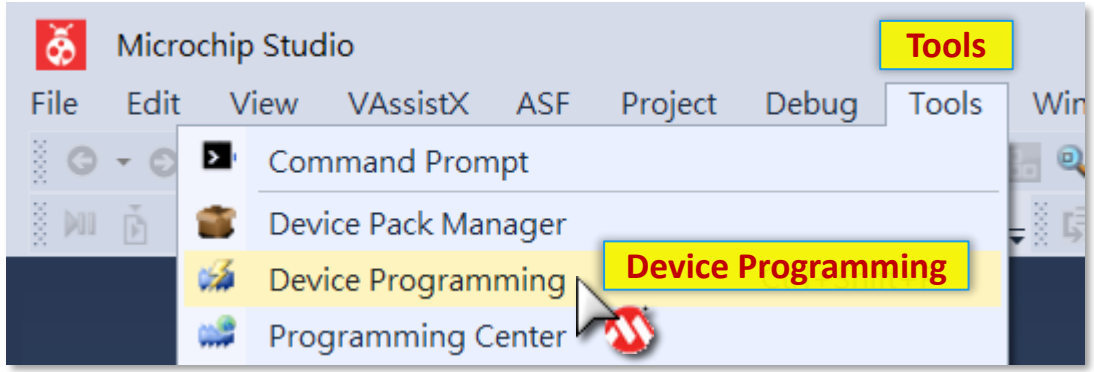
Open Tools

- ► **Device Programming**
  - Tool : MPLAB Snap
  - Device : ATSAMD21G18A
  - Interface : SWD
- ► **[Apply]**
- ► **[Read]**
  - Device signature
- ► **[Security]**



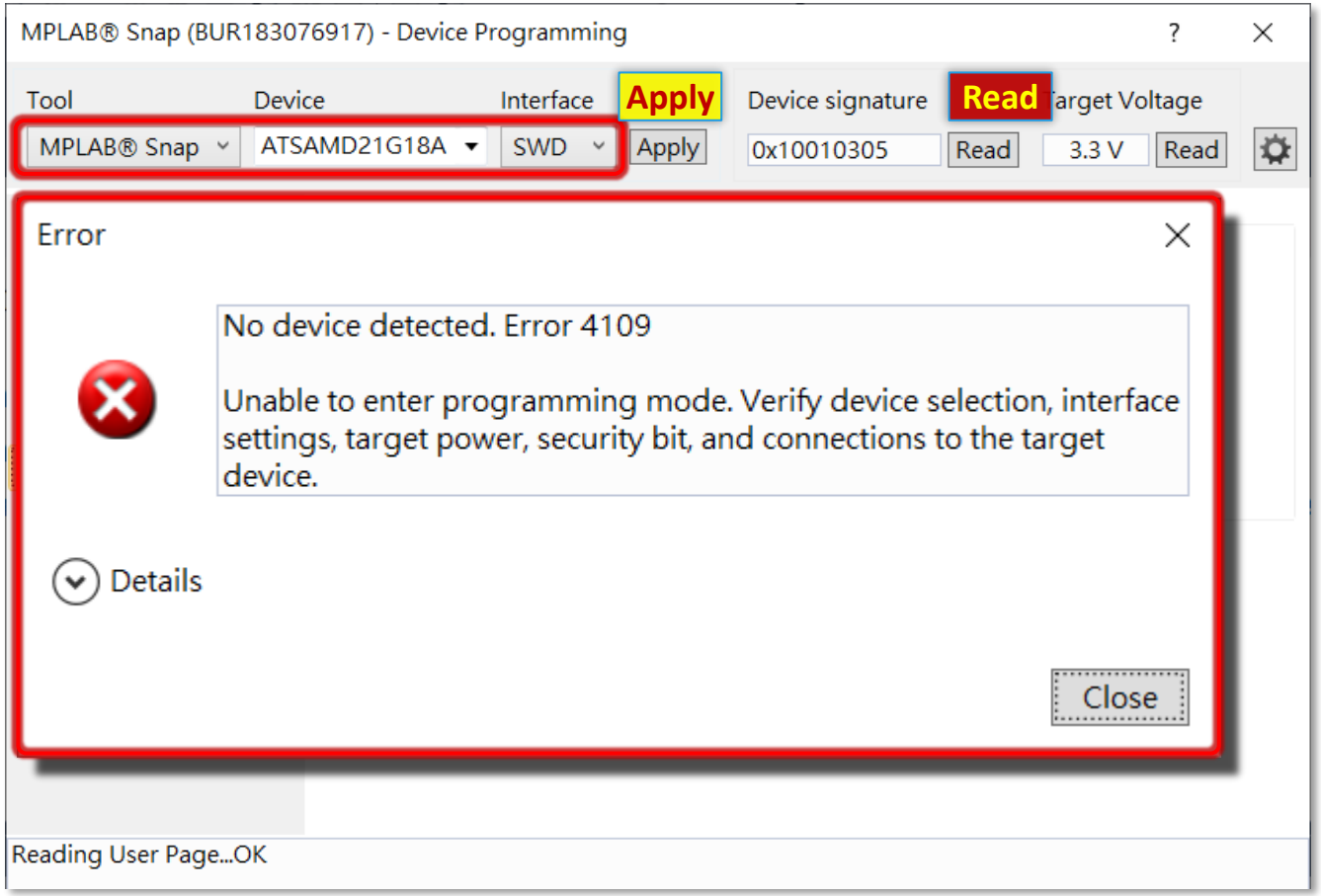
🛠 Lab11-8 Code Protect by NVM Security Bit

Use Microchip Studio to Read Device signature after enable Security Bit



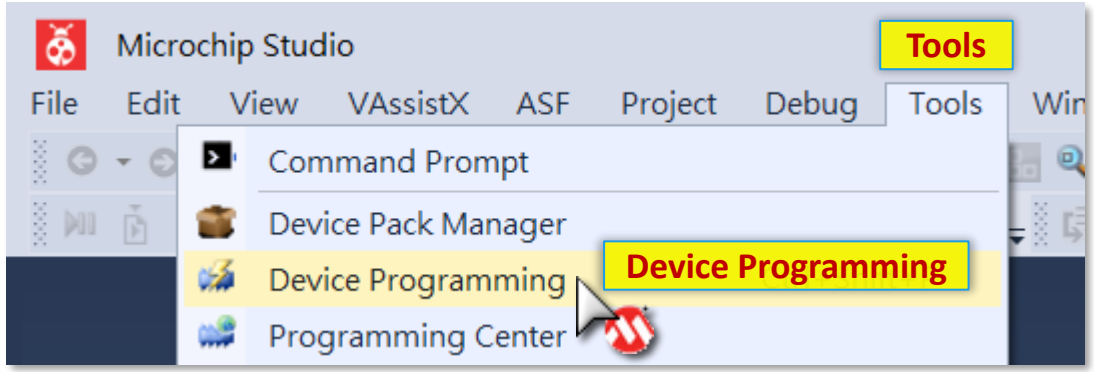
Power cycle the EVB

- ► Tools
- ► Device Programming
  - Tool : MPLAB Snap
  - Device : ATSAMD21G18A
  - Interface : SWD
- ► [Apply]
- ► [Read]



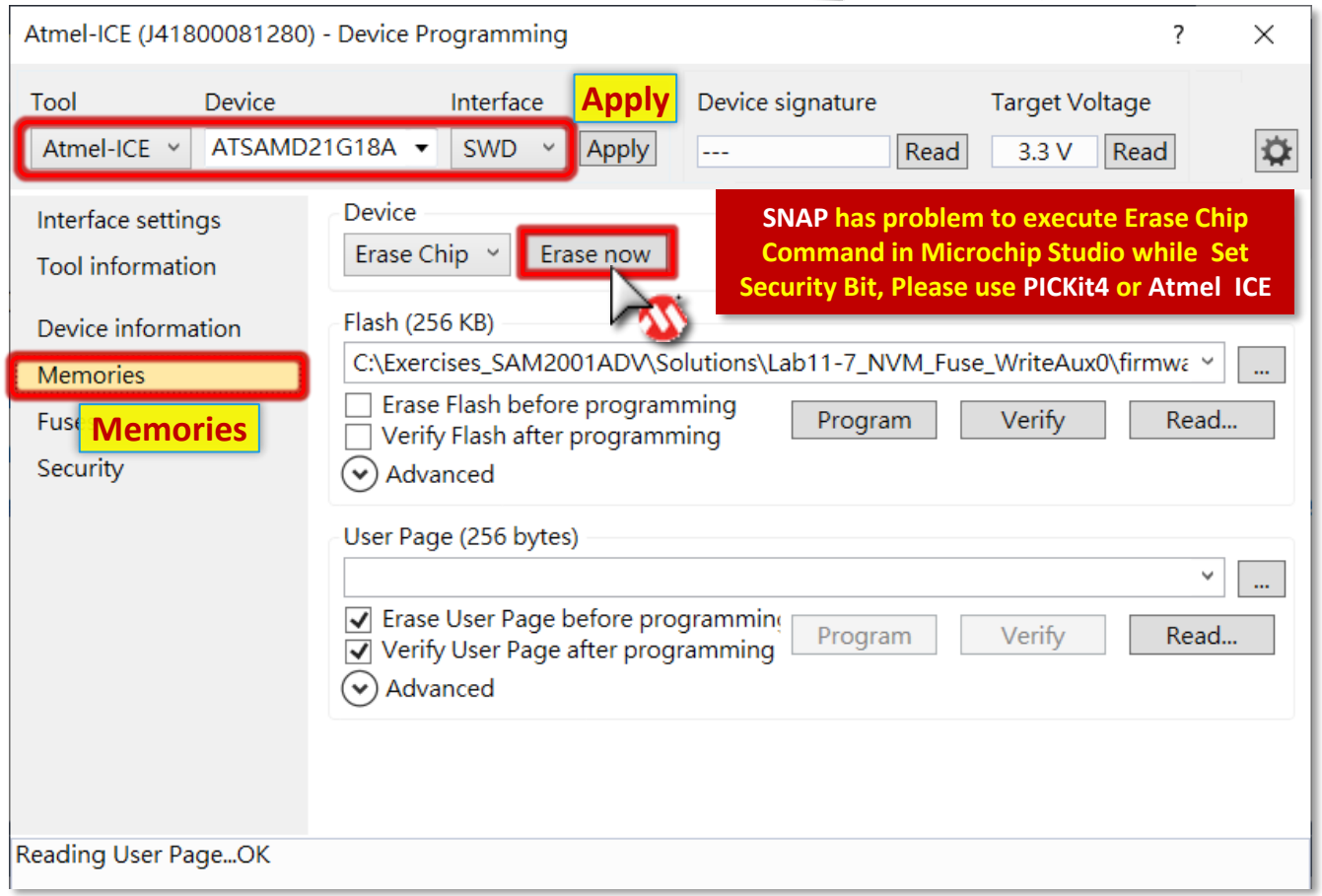
🛠 Lab11-8 Code Protect by NVM Security Bit

Use Microchip Studio to Erase Chip for un-seal the Security Bit



Power cycle the EVB

- ► Tools
- ► Device Programming
  - Tool : PICKit4 or Atmel ICE
  - Device : ATSAMD21G18A
  - Interface : SWD
- ► [Apply]
- ~~► [Read]~~
- ► [Memory]



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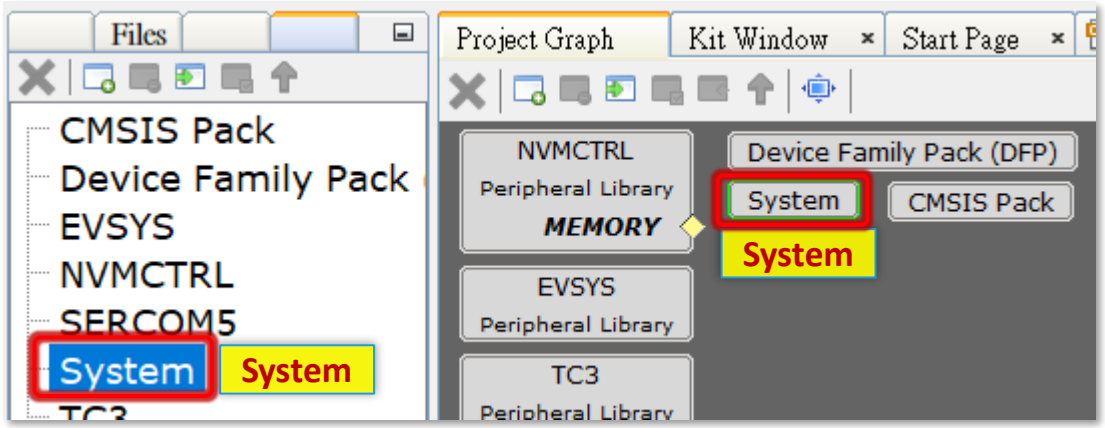
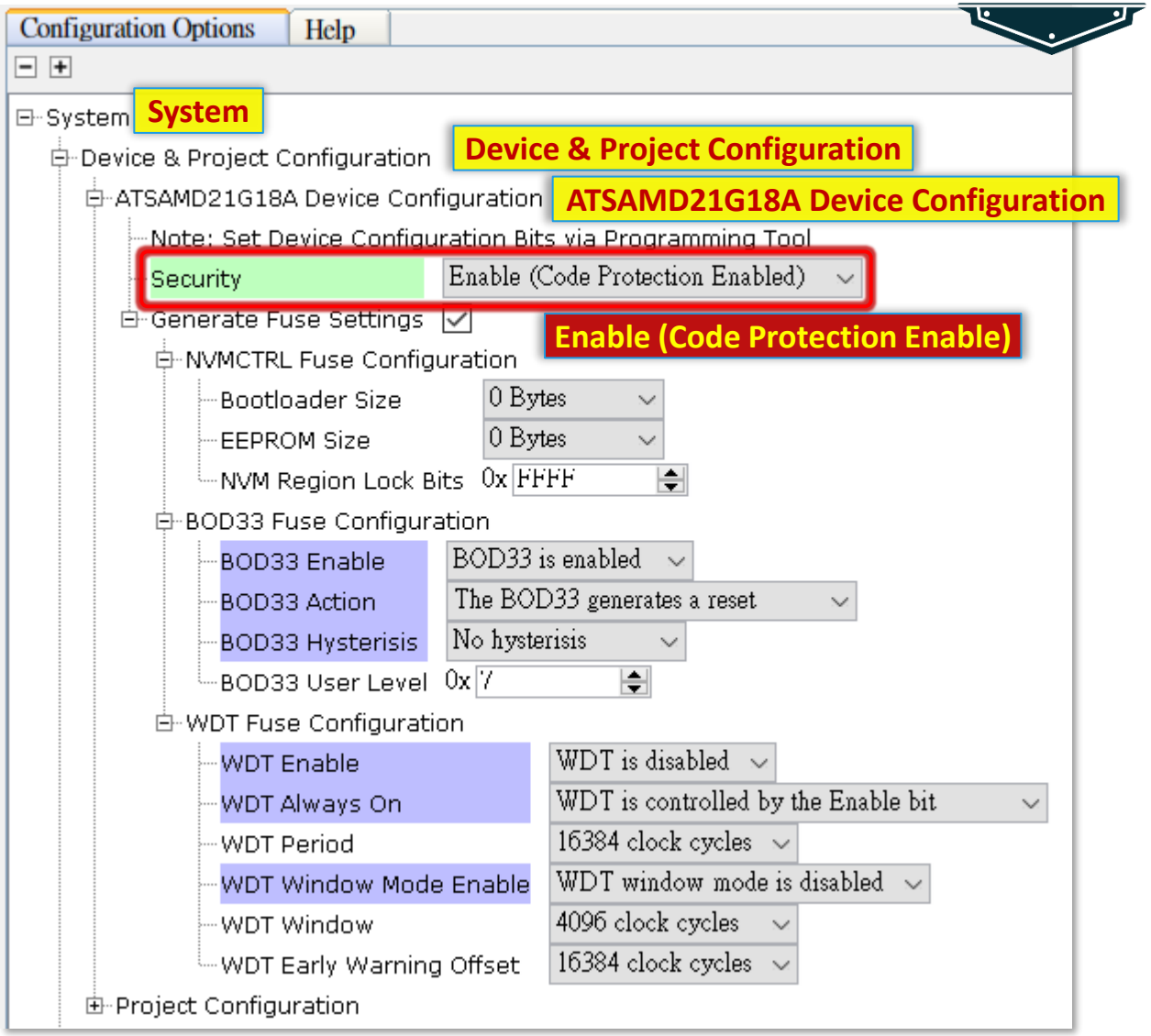
Lab11-8 Code Protect by NVM Security Bit

Enable Code Protect in MPLAB Harmony



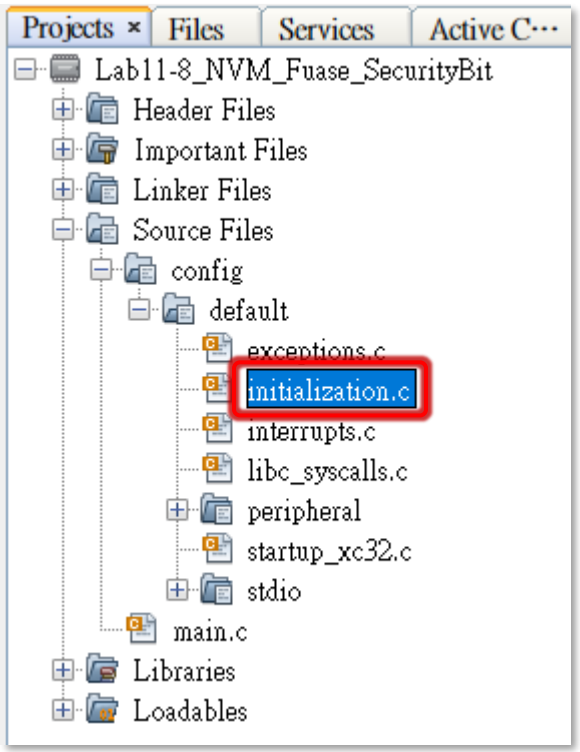
- Open System
  - ► Device & Project Configuration
  - ► ATSAMD21G18A Device Configuration
  - ► Security
  - ► Enable (Code Protection Enable)



Lab11-8 Code Protect by NVM Security Bit

Enable Code Protect in MPLAB Harmony

- **Security Bit will be configured in initialization.c**



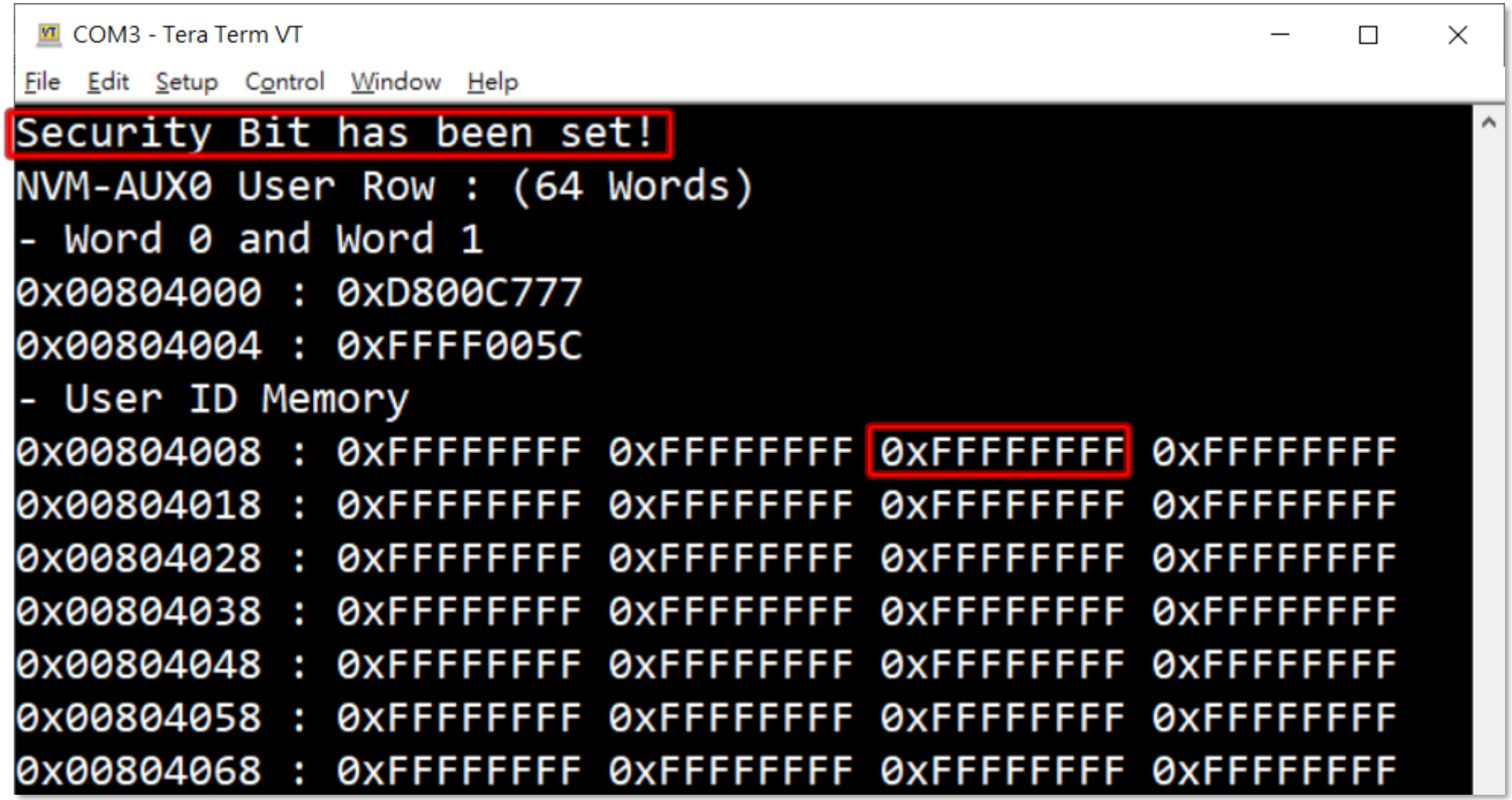

```
// *****************************************************************************
// Section: Configuration Bits
// *****************************************************************************
#pragma config NVMCTRL_BOOTPROT = SIZE_0BYTES
#pragma config NVMCTRL_EEPROM_SIZE = SIZE_0BYTES
#pragma config BOD33USERLEVEL = 0x7 // Enter Hexadecimal value
#pragma config BOD33_EN = ENABLED
#pragma config BOD33_ACTION = RESET

#pragma config BOD33_HYST = DISABLED
...

#pragma config WDT_WINDOW_0 = SET
#pragma config WDT_WINDOW_1 = 0x4 // Enter Hexadecimal value
#pragma config WDT_EWOFFSET = CYC16384
#pragma config WDT_WEN = DISABLED

#ifndef __DEBUG
const unsigned int __attribute__((space(prog), keep, address(0x41004000))) SET_SECURITY_BIT = 1;
#endif
```

HEX image has enabled Code Protect in Harmony will only active while using MPLAB X IDE/IPE to program such kind of HEX image

Security Bit

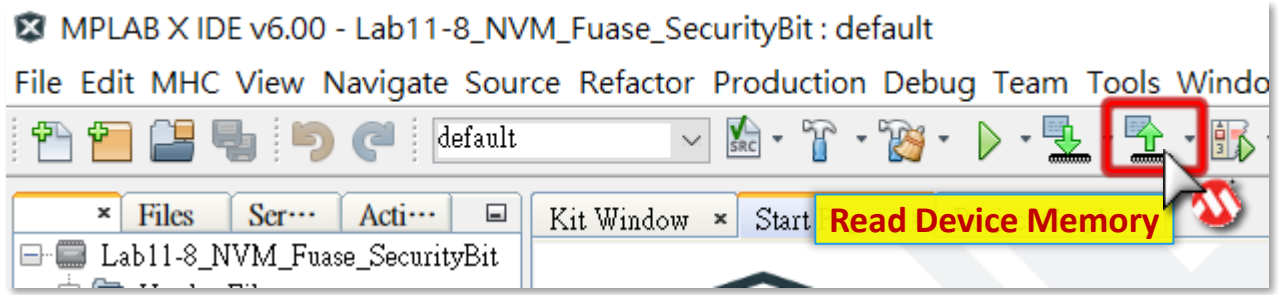
Lab11-8 Code Protect by NVM Security Bit

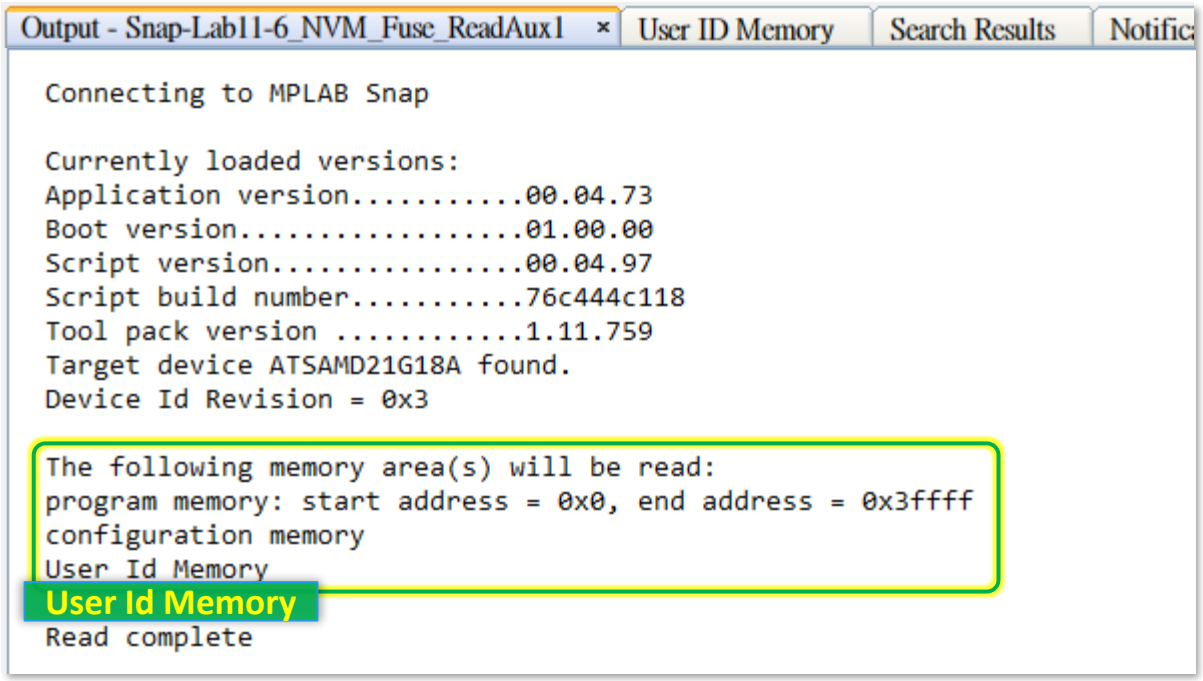
Result

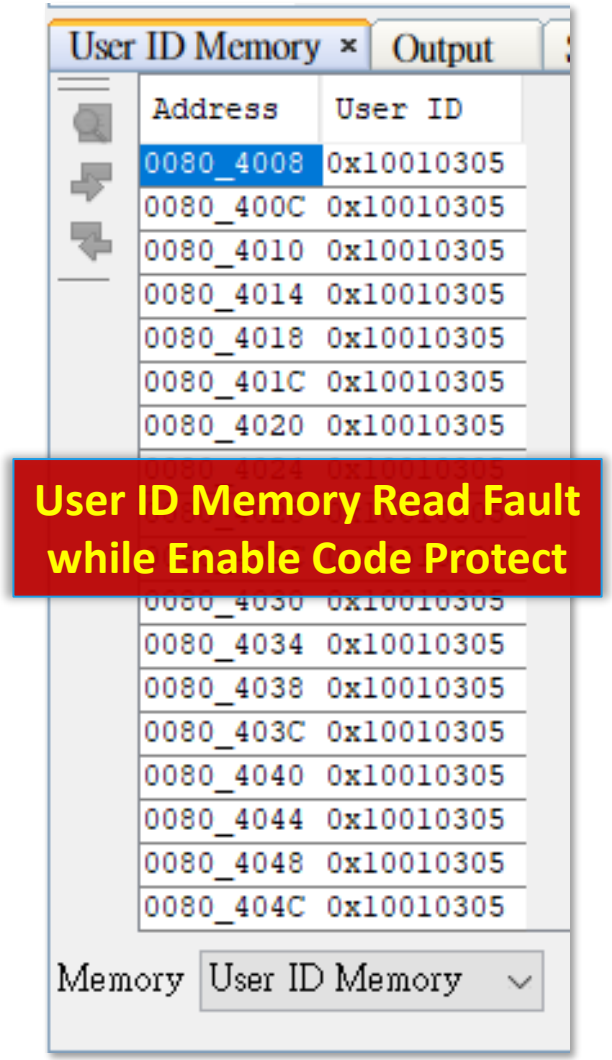


Lab11-8 Code Protect by NVM Security Bit

Read User ID Memory in MPLAB X IDE while Code Protect enabled

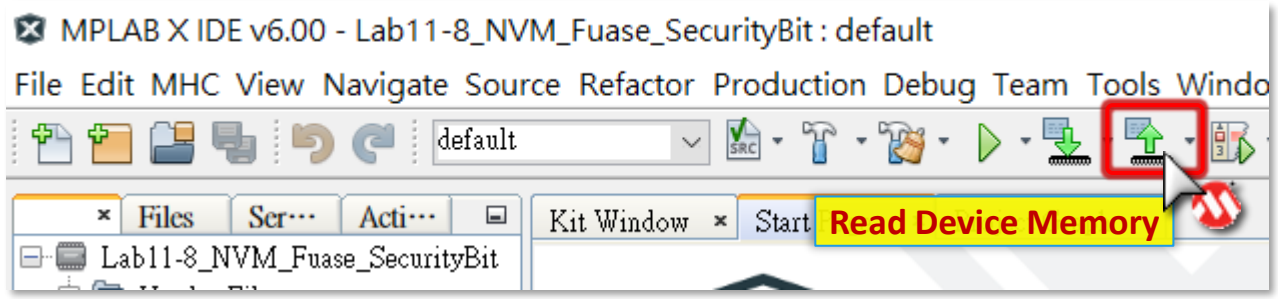


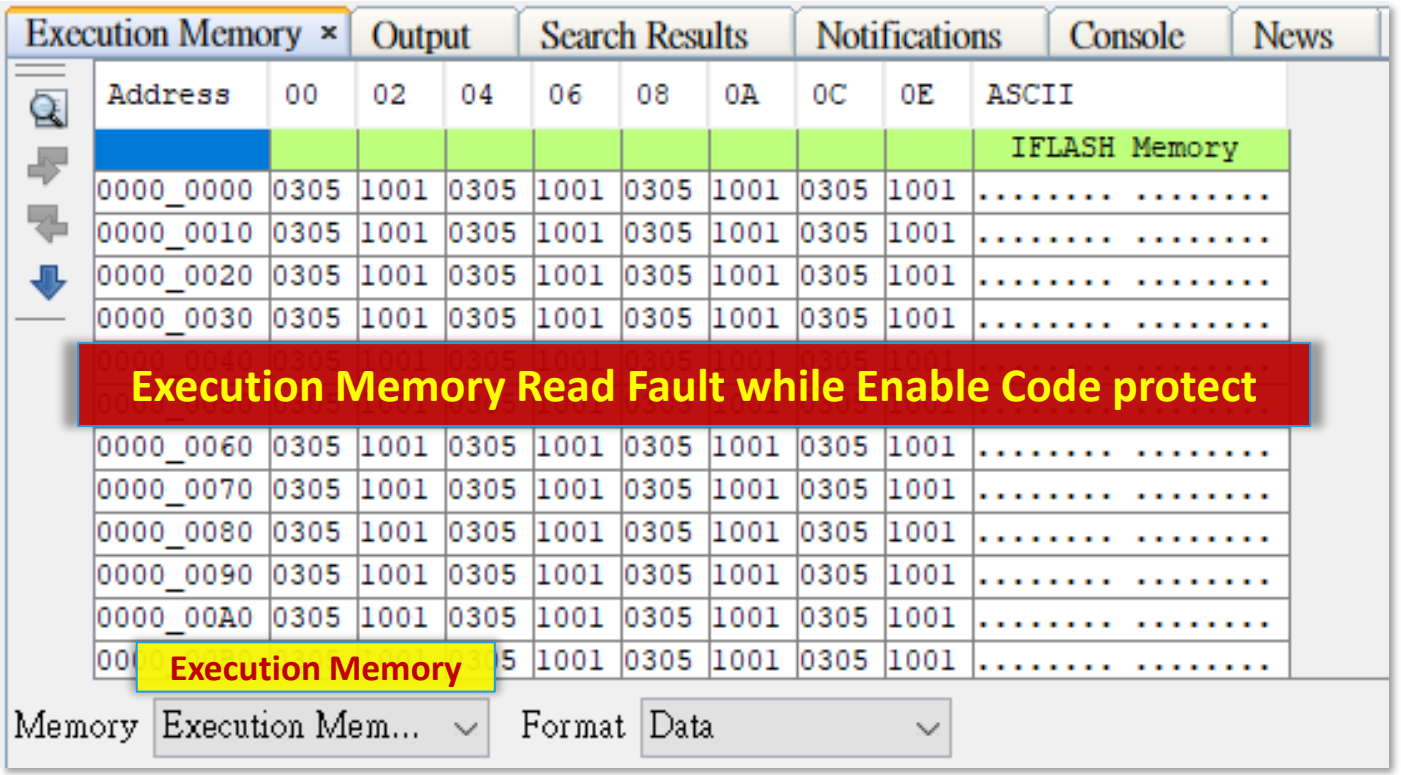




Lab11-8 Code Protect by NVM Security Bit

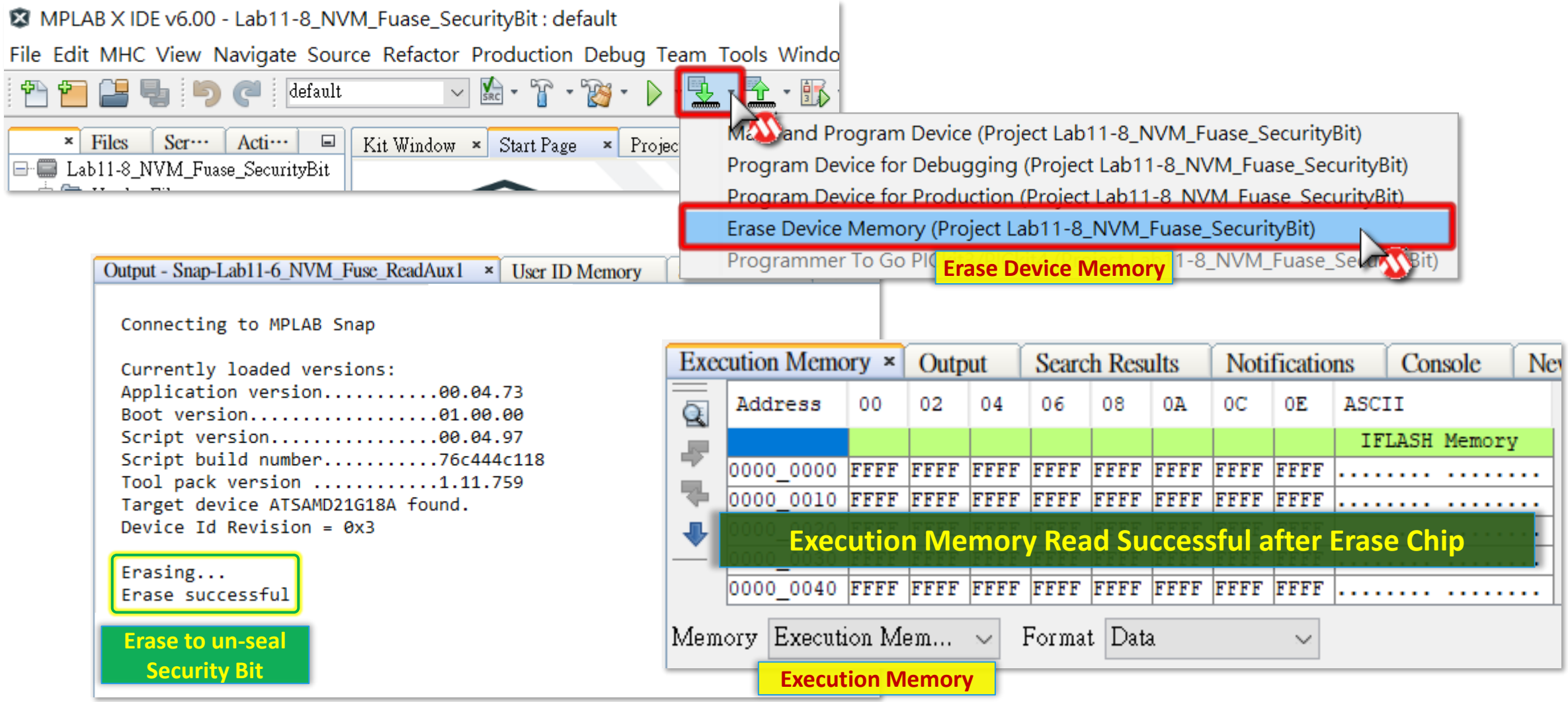
Read Execution Memory in MPLAB X IDE while Code Protect enabled





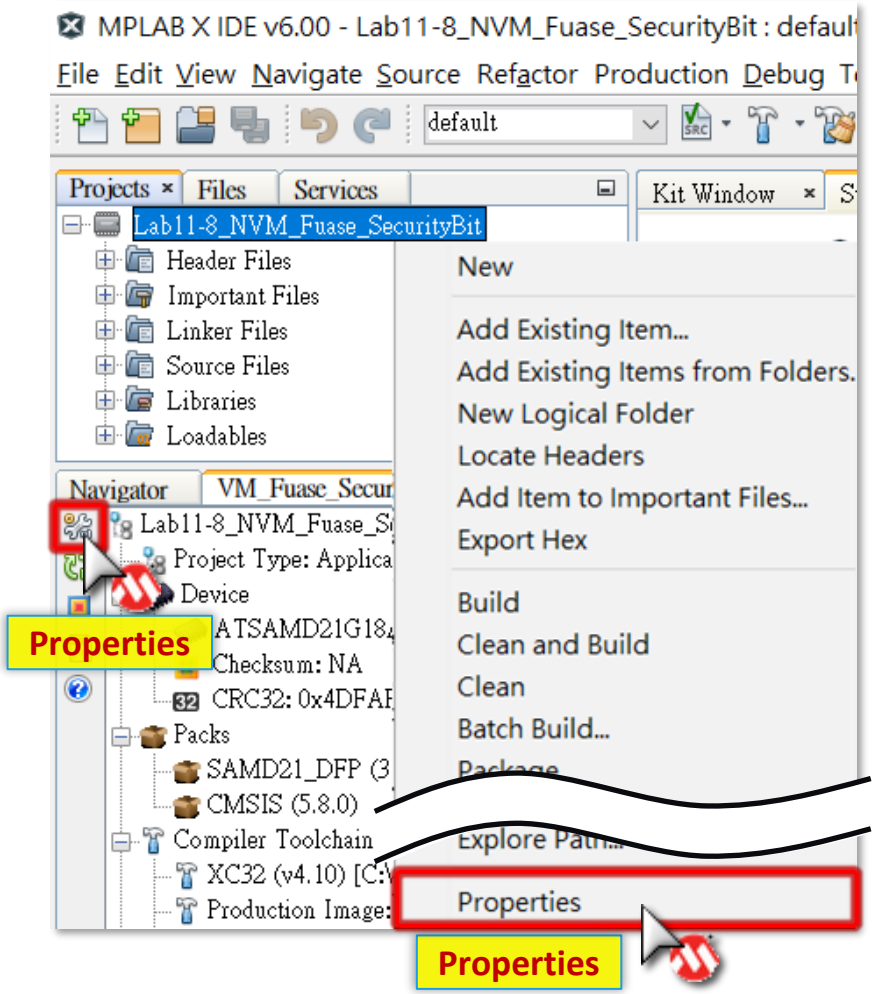
Lab11-8 Code Protect by NVM Security Bit

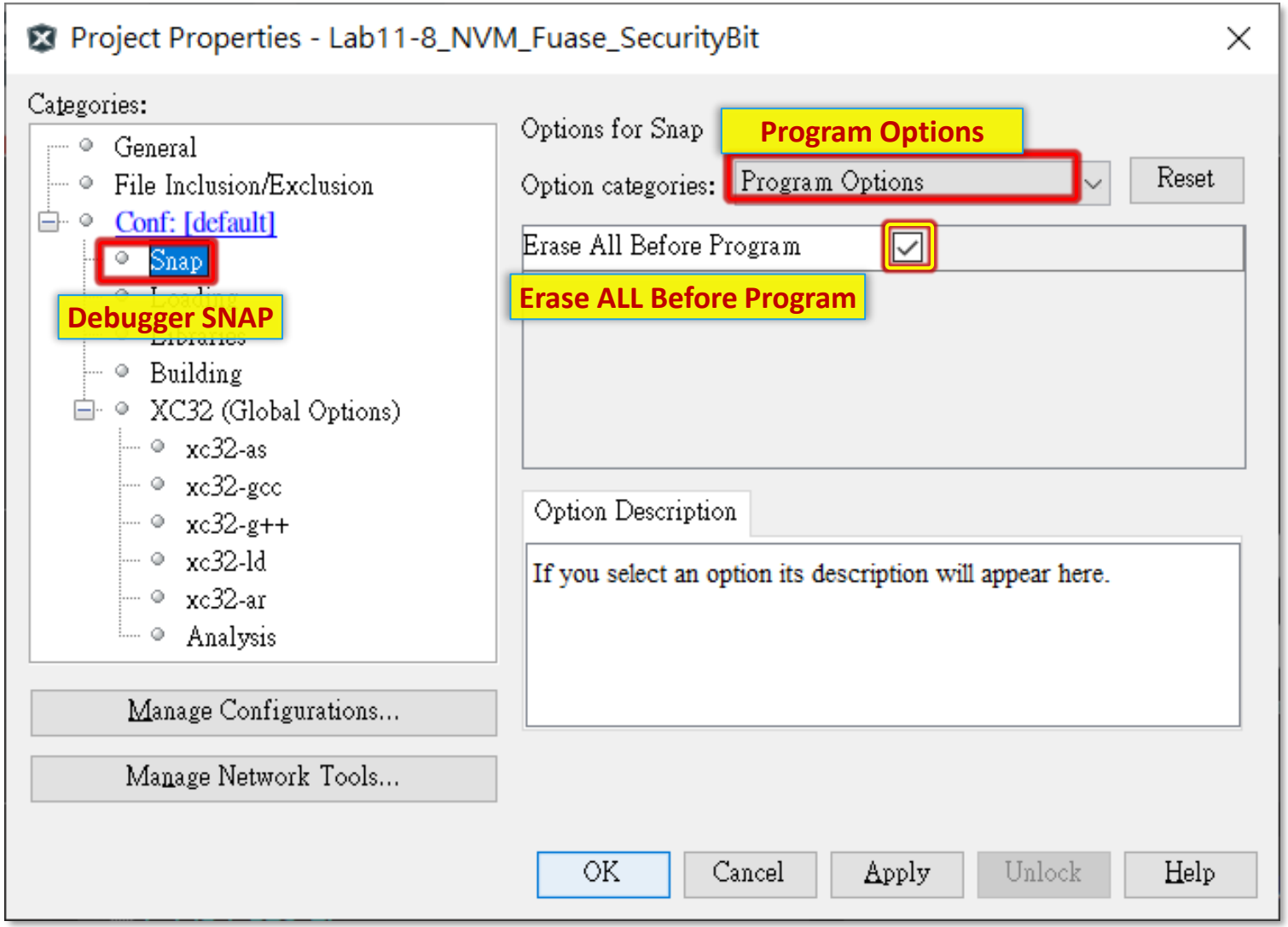
Read Execution Memory in MPLAB X IDE after execute Erase Chip



Lab11-8 Code Protect by NVM Security Bit

Harmony New project will enable Erase All Before Program option





🛠 Lab11-8 Code Protect by NVM Security Bit

Step1 : Implement a software Security Bit configure function

```
...
bool NVMCTRL_GetSecurityBitStatus( void ) {...}
void NVM_Write_AUX0( uint32_t *Word ) {...}

// TODO 11-8.01
void NVM_Code_Protect( void )
{
    while( NVMCTRL_IsBusy() ) {}

    if( NVMCTRL_GetSecurityBitStatus() )
        return;

    NVMCTRL_SecurityBitSet();

    myprintf( "Security Bit set successfully, please cycle power to active!\r\n\r\n" );
}

int main ( void )
{
    ...
    myprintf("\033[2J");
    myprintf("\033[?25l\033[1;1H");
    NVM_Read_UQSN( NVM_UQSN_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );
    ...
```

Security Bit will be enabled after execute this function whatever to using MPLAB X IDE/IPE , Microchip Studio or others programmer to program this HEX image

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🛠 Lab11-8 Code Protect by NVM Security Bit

Step2 : Implement Self NVM Flash Read and Write function

```
...
bool NVMCTRL_GetSecurityBitStatus( void ) {...}
void NVM_Write_AUX0( uint32_t *Word ) {...}

// TODO 11-8.01
void NVM_Code_Protect( void ) {...}

#define SELF_RW_ADDRESS 0x3000
void NVM_Self_ReadWrite()
{
    uint32_t ReadWord[4];
    uint32_t WritePage[16];

    while( NVMCTRL_IsBusy() ) {}

    NVMCTRL_Read( ReadWord, 16, SELF_RW_ADDRESS );

    myprintf( "Self Read (4 Words)\r\n");
    myprintf( "0x%08X : 0x%08X\r\n", SELF_RW_ADDRESS+0x0, ReadWord[0] );
    myprintf( "0x%08X : 0x%08X\r\n", SELF_RW_ADDRESS+0x4, ReadWord[1] );
    myprintf( "0x%08X : 0x%08X\r\n", SELF_RW_ADDRESS+0x8, ReadWord[2] );
    myprintf( "0x%08X : 0x%08X\r\n", SELF_RW_ADDRESS+0xC, ReadWord[3] );
    NVMCTRL_RowErase( SELF_RW_ADDRESS );
    while( NVMCTRL_IsBusy() ) {}
    myprintf( "Erase Row  at address 0x%08X\r\n", SELF_RW_ADDRESS );
```

🛠 Lab11-8 Code Protect by NVM Security Bit

Step3 : Implement Self NVM Flash Read and Write function (cont.)

```
...
bool NVMCTRL_GetSecurityBitStatus( void ) {...}
void NVM_Write_AUX0( uint32_t *Word ) {...}

// TODO 11-8.01
void NVM_Code_Protect( void ) {...}

#define SELF_RW_ADDRESS 0x3000
void NVM_Self_ReadWrite()
{
    ...
    myprintf( "Erase Row  at address 0x%08X\r\n", SELF_RW_ADDRESS );

    WritePage[0] = ReadWord[0]-0x11111111;
    WritePage[1] = ReadWord[1]-0x22222222;
    WritePage[2] = ReadWord[2]-0x33333333;
    WritePage[3] = ReadWord[3]-0x44444444;
    NVMCTRL_PageWrite( WritePage, SELF_RW_ADDRESS );
    while( NVMCTRL_IsBusy() ) {}
    myprintf( "Write Page at address 0x%08X\r\n", SELF_RW_ADDRESS );
    myprintf( "done\r\n\r\n" );
}

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

🛠 Lab11-8 Code Protect by NVM Security Bit

Step4 : Execute Self NVM Flash Read and Write function

```
...
bool NVMCTRL_GetSecurityBitStatus( void ) {...}
void NVM_Write_AUX0( uint32_t *Word ) {...}

// TODO 11-8.01
void NVM_Code_Protect( void ) {...}

#define SELF_RW_ADDRESS 0x3000
void NVM_Self_ReadWrite() {...}

int main ( void )
{
    ...
    NVM_Read_UQSN( NVM_UQSN_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );
    NVM_Read_AUX1( NVM_AUX1_Word );
    NVM_AUX0_Word[4] = 0x12345678;
    NVM_Write_AUX0( NVM_AUX0_Word );
    NVM_Read_AUX0( NVM_AUX0_Word );

    // TODO 11-8.02
    NVM_Code_Protect();
    NVM_Self_ReadWrite();

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

MICROCHIP

Lab11-8 Code Protect by NVM Security Bit

Result

COM3 - Tera Term VT

File Edit Setup Control Window Help

1st boot after program

```
Erase NVM-AUX0 User Row :
 - success
Write NVM-AUX0 User Row :
 - Page 0 : success
 - Page 1 : success
 - Page 2 : success
 - Page 3 : success
done

NVM-AUX0 User Row : (64 Words)
- Word 0 and Word 1
0x00804000 : 0xD800C777
0x00804004 : 0xFFFF005C
- User ID Memory
0x00804008 : 0xFFFFFFFF 0xFFFFFFFF 0x12345678 0xFFFFFFFF
0x00804018 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040E8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040F8 : 0xFFFFFFFF 0xFFFFFFFF
- done

Security Bit set successfully, please cycle power to active!

Self Read (4 Words)
0x00003000 : 0xFFFFFFFF
0x00003004 : 0xFFFFFFFF
0x00003008 : 0xFFFFFFFF
0x0000300C : 0xFFFFFFFF
Erase Row  at address 0x00003000
Write Page at address 0x00003000
done
```

COM3 - Tera Term VT

File Edit Setup Control Window Help

2nd boot after power cycle

```
Security Bit has been set!
NVM-AUX0 User Row : (64 Words)
- Word 0 and Word 1
0x00804000 : 0xD800C777
0x00804004 : 0xFFFF005C
- User ID Memory
0x00804008 : 0xFFFFFFFF 0xFFFFFFFF 0x12345678 0xFFFFFFFF
0x00804018 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804028 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804038 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804048 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804058 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804068 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804078 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804088 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x00804098 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040A8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040D8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040E8 : 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF 0xFFFFFFFF
0x008040F8 : 0xFFFFFFFF 0xFFFFFFFF
- done

Self Read (4 Words)
0x00003000 : 0xEEEEEEEE
0x00003004 : 0xDDDDDDDD
0x00003008 : 0xCCCCCCCC
0x0000300C : 0xBBBBBBBB
Erase Row  at address 0x00003000
Write Page at address 0x00003000
done
```

Self Flash Write successfully While Security Bit enabled

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