# SAMD21 ARM Cortex-M0+ Microcontroller & Harmony v3

## SAM2002ADV v1.01


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


**CAE Taiwan Team**
**Microchip Technology Inc.**

October 2025

# SAM series course history and brief

- **SAM1001 – MCU32 Peripheral Library (PLIB)**
  - (2017~2018)
    - Peripheral Library (PLIB) on APP045v2.0 (SAMD21 Arm Cortex-M0+)
    - Advance Software Framework (ASF) v3.x + GNU C compiler + Microchip Studio 7
  - (2019~2022)
    - Peripheral Library (PLIB) on APP045v2.0/v4.x (SAMD21 Arm Cortex-M0+)
    - MPLAB Harmony Framework v3.x + XC32 Compiler + MPLAB X IDE
  - (2023~2024)
    - Peripheral Library (PLIB) on APP045v4.x/v5.x (SAMD21 Arm Cortex-M0+)
    - MCC Harmony + XC32 Compiler + MPLAB X IDE
- **SAM2001ADV – MCU32 Advanced Peripheral Library (PLIB)**
  - (2021~2022)
    - Peripheral Library (PLIB) Advanced modules on APP045v4.x (SAMD21 Arm Cortex-M0+)
    - MPLAB Harmony Framework v3.x + XC32 Compiler + MPLAB X IDE
  - (2023~2024)
    - Peripheral Library (PLIB) Advanced modules on APP045v4.x/v5.x (SAMD21 Arm Cortex-M0+)
    - MCC Harmony + XC32 Compiler + MPLAB X IDE
- **SAM2002 – MCU32 System Service and Driver**
  - (2019~2022)
    - System Service and Driver on APP045v4.x (SAMD21 Arm Cortex-M0+)
    - MPLAB Harmony Framework v3.x + XC32 Compiler + MPLAB X IDE
  - (2023~2024)
    - System Service and Driver on APP045v4.x/v5.x (SAMD21 Arm Cortex-M0+)
    - MCC Harmony + XC32 Compiler + MPLAB X IDE
- **SAM2002ADV – MCU32 Touch and USB Device**
  - (2021~2022)
    - QTouch Library and USB Device Driver on APP045v4.x (SAMD21 Arm Cortex-M0+)
    - MPLAB Harmony Framework v3.x + XC32 Compiler + MPLAB X IDE
  - (2023~2024)
    - QTouch Library and USB Device Driver on APP045v4.x (SAMD21 Arm Cortex-M0+)
    - MCC Harmony + XC32 Compiler + MPLAB X IDE

# Background Knowledge and Preparation

- **SAM2002ADV is for advanced users, then we will not introduce :**
  - MPALB X IDE and Harmony Configuration. (Please study from SAM2001 course)
  - How to download(prepare) latest Harmony Framework. (Please study from SAM2001 course)
  - How to create a new project. (Please study from SAM2001 course)
  - PLIB (Peripheral Library) implementation. (Please study from SAM2001 and SAM2001ADV course)
  - System Service and Driver implementation. (Please study from SAM2002 course)

- **SAM2002ADV will use below tool versions for Labs.**
  - MPLAB® X IDE v6.15 https://www.microchip.com/mplab/mplab-x-ide
  - MPLAB® XC32 v4.35 https://www.microchip.com/mplab/compilers
  - MPLAB® Code Configurator v5.4.1 (Install in MPLAB X IDE Plug-in)
  - SAMD21 DFP v3.6.144 (Device Family Pack download from X IDE \Tools\Packs)
  - CMSIS v5.8.0 (Common Microcontroller Software Interface Standard)
  - MCC Core v5.6.1 (Install with MPLAB X IDE v6.15)
  - MPLAB® MCC Harmony Framework (From X IDE MCC Harmony Content Manager)
    - Required Content (Must install)
      - csp 3.18.4
      - harmony-services 1.3.2
      - CMSIS_5 5.9.0
      - quick_docs 1.6.0
    - Optional Content (Manual select in Content Manager)
      - touch v3.15.0
      - usb v3.12.0
      - dev_packs v3.18.1
      - core v3.13.3

# Advance Course

- Introduction to QTouch® Peripheral Touch Controller (PTC)
- Harmony Touch Configurator
- APP045 EVB QTouch® Design and Pattern
  - Lab1 Touch Buttons
  - Lab2 Touch Slider
  - Lab3 Data Visualizer for Touch
- USB Fundamentals
- USB Device Library (USB Device Architecture)
- Harmony USB Device - Device Layer Configurator
  - Lab4 USB Device - Device Layer Initialize
- USB Device CDC Class
  - Lab5 USB Device CDC Class - Basic TX and RX
- USB Device HID Class
  - Lab6 USB Device HID Class - Basic TX and RX

# Course Coverage

## Course will not include :

- The principle of Capacitive Touch.
- Pattern design for Capacitive Touch.
- The principle of our PTC/CVD.
- PTC tuning parameters.

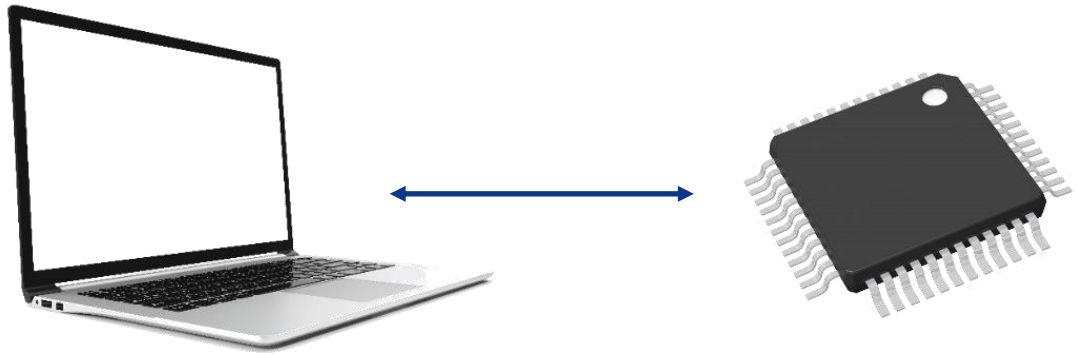
## Course will include :

- Usage of MCC Harmony Touch library.
- Introduction to the MCC Harmony Touch Configurator.
- Touch visualization with MPLAB Data Visualizer.

# Bootloader Fundamentals

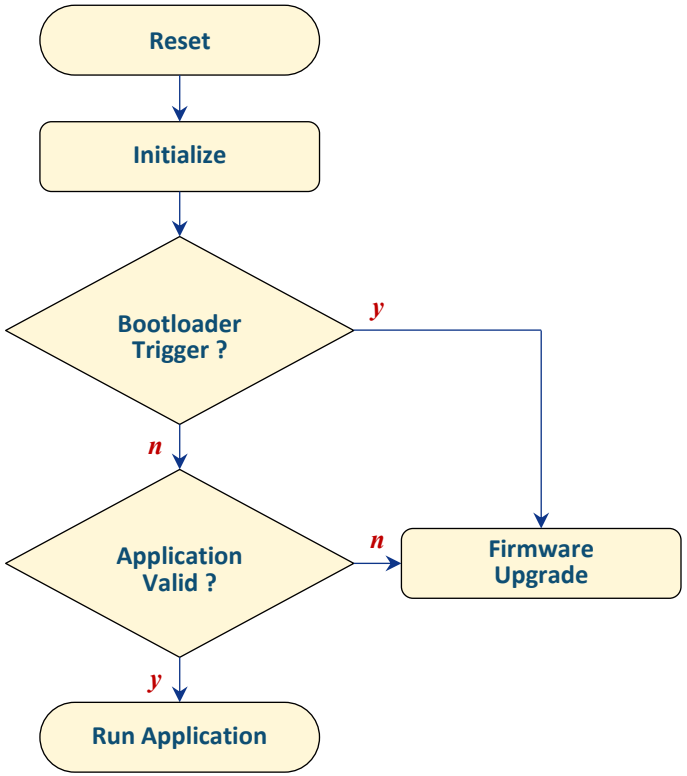
# What’s a Bootloader ?

- **Bootloader is a small application that starts the operation of the device, that can be used to upgrade firmware on a target device without the need for an external programmer/debugger.**
- **Why firmware update ?**
  - Add/remove functionality
  - Update interface
  - Parameter update
  - Any upgradable function in firmware



# Control Flow at Reset

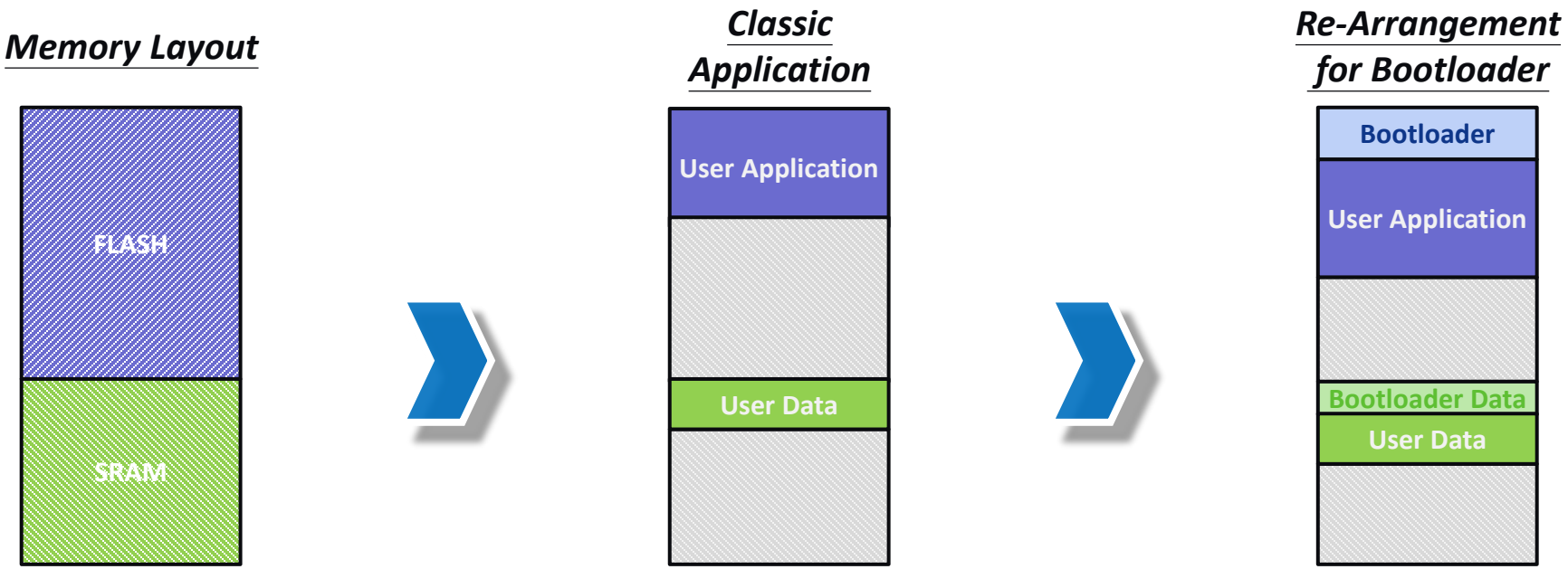
- The flowchart below outlines the startup handoff between the Bootloader and the Application.
- After reset, the Bootloader takes control first and evaluates predefined trigger conditions to decide whether to enter firmware-update mode or transfer control to the Application.
- The Bootloader and Application occupy separate Flash and SRAM regions and do not interfere with each other. Each can maintain an independent VT (Vector Table)
- The device Configuration bits/Fuses are the only shared resource.



# Memory Reallocation

# Memory Reallocation for Bootloader

- In a typical system without a Bootloader, the Application owns the entire memory space. When a Bootloader is present, portions of Flash and SRAM must be reserved for both the Bootloader and the Application.
- Use two independent linker scripts(*.*ld*) to map non-overlapping memory regions and prevent conflicts.



# Linker Script Design

- **The example below uses two independent linker scripts (*.*ld*),**
  **one for the Bootloader and one for the Application to define their memory allocations.**
- **In the linker scripts,**
  **you can see the Flash(*rom (LRX)*) and SRAM(*ram (WX!R)*)**
  **reserved separately for the Bootloader and the Application.**

***Bootloader***

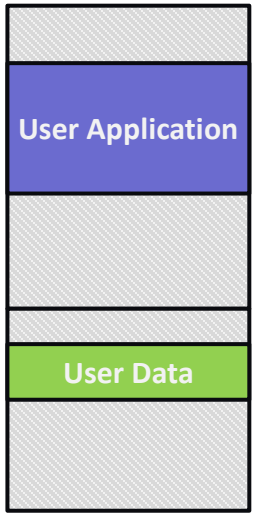

***Linker Script for Bootloader***

```
MEMORY
{
  rom (LRX) : ORIGIN = 0, LENGTH = ROM_LENGTH_BOOT
  ram (WX!R) : ORIGIN = 0, LENGTH = RAM_LENGTH_BOOT
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

***Linker Script for Application***

```
MEMORY
{
  rom (LRX) : ORIGIN = ROM_ORIGIN_APP, LENGTH = ROM_LENGTH_APP
  ram (WX!R) : ORIGIN = RAM_ORIGIN_APP, LENGTH = RAM_LENGTH_APP
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

***Application***

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# Bootloader Trigger

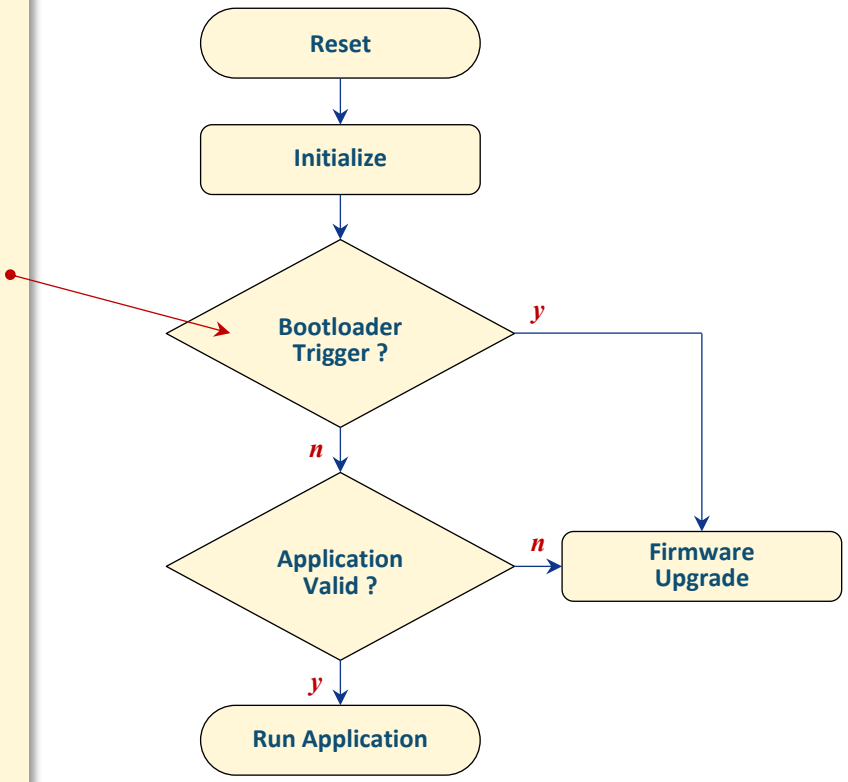
# Bootloader Trigger Mechanisms

- Bootloader should be triggered through specific mechanisms, e.g.,
  - Hardware I/O
    Check a button or GPIO state at startup to decide whether to enter the bootloader.
  - Firmware State
    Validate firmware version or markers; if they mismatch or
    the Application looks invalid, Application Reset vector is $0xFFFFFFFF$.
  - Application-invoked
    The application writes a magic value to a reserved SRAM location,
    then issues a software reset.
    *In MCC Harmony Bootloader, use "Number of Bytes to Reserve from Start of RAM"*
    *(and optional offset) to reserve this area in the linker script.*
  - Others
    Host handshake within a timeout,
    double-tap reset, debug probe detected, pin-strap/DIP switch, etc.

# Hardware I/O and Magic Number Trigger

- **The example below**
  **that triggers the bootloader via a magic number or a button status.**

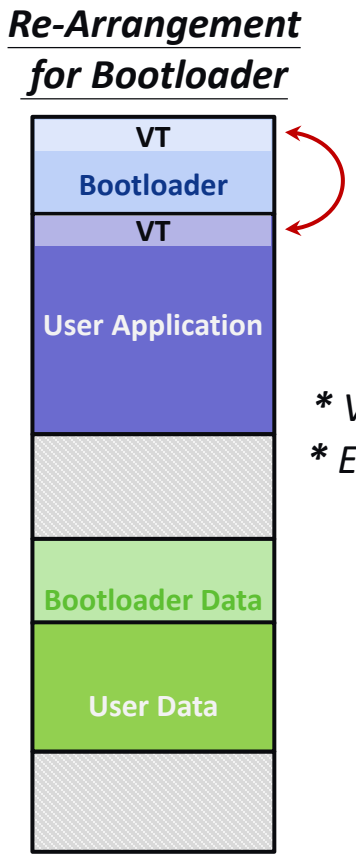
```
#define BTL_TRIGGER_PATTERN (0x5048434DUL)
static uint32_t *ramStart = (uint32_t *)BTL_TRIGGER_RAM_START;

bool bootloader_Trigger(void)
{
    uint32_t i;

    // Cheap delay. This should give at leat 1 ms delay.
    for (i = 0; i < 2000; i++)
         asm("nop");

    /* Check for Magic Number */
    if (BTL_TRIGGER_PATTERN == ramStart[0] &&
        BTL_TRIGGER_PATTERN == ramStart[1] &&
        BTL_TRIGGER_PATTERN == ramStart[2] &&
        BTL_TRIGGER_PATTERN == ramStart[3])
    {
        ramStart[0] = 0;
        DCACHE_CLEAN_BY_ADDR(ramStart, 4);
        return true;
    }

    /* Check for Button */
    if (!BT1_Get())
        return true;

    return false;
}
```



# Handoff Control

# VTs Allocation

- **Beyond Flash and SRAM placement, planning how to allocate and remap the VT (Vector Table) is critical.**
- **Decide how to allocate separate VTs for the Bootloader and the Application, and how to switch between them during handoff.**
- **At handoff to the Application, Reallocate the VT to the Application's vector table; when returning to the Bootloader, Reallocate it to the Bootloader's vector table.**
  ***(Cortex-M: VTOR; PIC32/MIPS: EBASE).***




***VT Reallocated When Switching Bootloader and Application***

** Vector Table Offset Register (Cortex M)*

** Exception Base Address Register (MIPS)*

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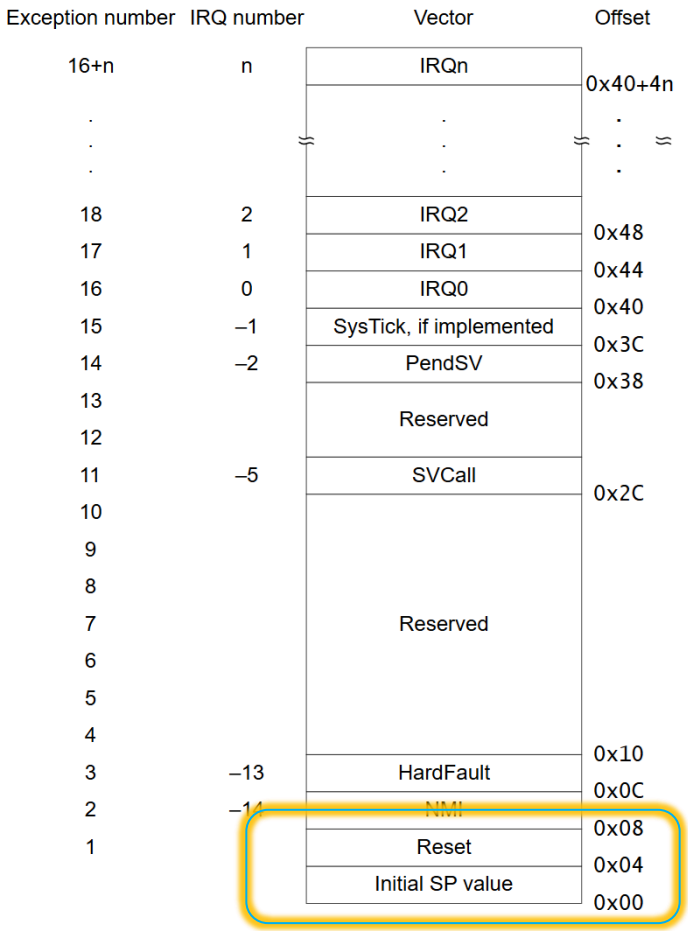
# Handoff Control to Application *(Cortex M as example)*

- **The figure shows the order of the vectors in the vector table.**
  **It contains the reset value of the stack pointer and the start addresses,**
  **also called exception vectors, for all exception handlers.**
- **Required settings for a handoff,**
  - **Stack Pointer**
    Load Application's SP Value to MSP Register.
  - **VTOR** ***(Optional)***
    Set SCB->VTOR to the application's vector table base.
  - **Reset Vector**
    Branch to the address in the application's Reset vector (*Reset_Handler*).




*https://developer.arm.com/documentation/dui0662/b/The-Cortex-M0--Processor/Exception-model/Vector-table*

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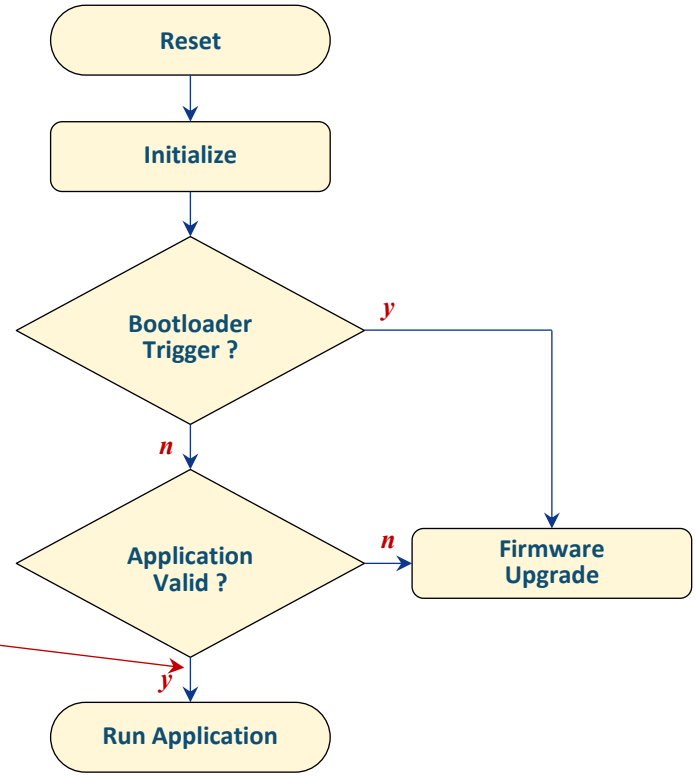
# Handoff Control to Application *cont.* *(Cortex M as example)*

- **The following code example shows the mechanism used in the bootloader to transfer control to the user application.**
- **Sets the Main Stack Pointer (MSP) to the top of the user application's stack, and finally jumps to the user Application's reset handler to begin execution.**

***In MCC Harmony Bootloader,***
***use "Application Start Address (Hex)" to set start address.***

```
void run_Application(uint32_t address)
{
    uint32_t msp = *(uint32_t *)(address); // Application Start
    uint32_t reset_vector = *(uint32_t *)(address + 4U);

    if (msp == 0xffffffffU)
        return;

    SYS_DeInitialize(NULL);

    __set_MSP(msp); // Re-initial Stack Pointer (Point to Application Stack)
    asm("bx %0"::"r" (reset_vector)); // Jumper to Application
}
```



# Robust Handoff Control to Application *(Cortex M as example)*

- **VTOR setting is optional,**
  **the Application's startup code typically setting SCB->VTOR to its own vector table anyway.**

  ** startup_xc32.c*

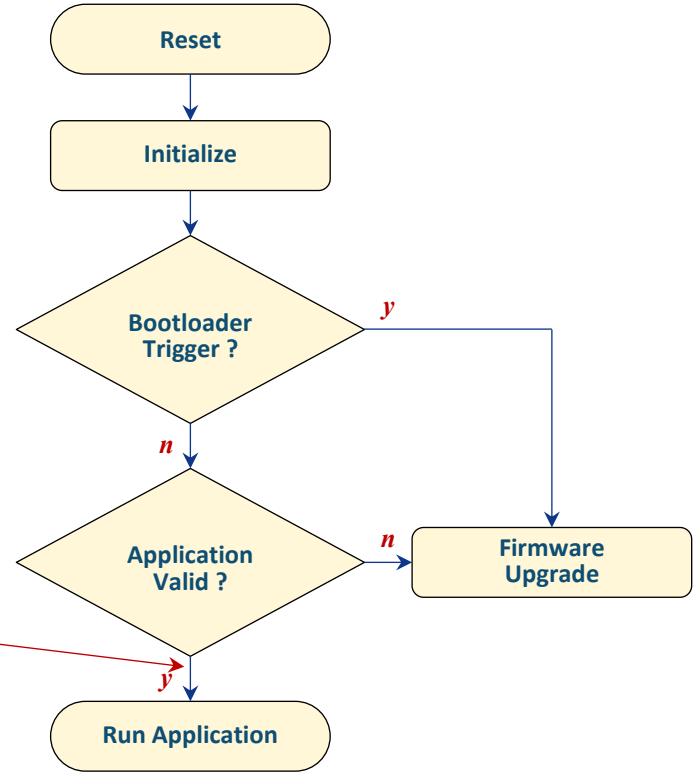
```
#  ifdef SCB_VTOR_TBLOFF_Msk
   /*  Set the vector-table base address in FLASH */
   pSrc = (uint32_t *) & __svectors;
   SCB->VTOR = ((uint32_t) pSrc & SCB_VTOR_TBLOFF_Msk);
#  endif /* SCB_VTOR_TBLOFF_Msk */
```

- **For a more robust handoff,**
  **set VTOR in advance, disable interrupts,**
  **clear any interrupt pending flags, and stop SysTick**
  **before branching to Application reset vector.**

# Robust Handoff Procedure

- **The following code example shows the mechanism used in the bootloader to transfer control to the user application with robust handoff procedure.**

```
void run_Application(uint32_t address)
{
    uint32_t msp = *(uint32_t *)(address); // Application Start
    uint32_t reset_vector = *(uint32_t *)(address + 4U);

    if (msp == 0xffffffffU)
        return;

    SYS_DeInitialize(NULL);

    SysTick->CTRL = 0;

    __disable_irq();
    NVIC->ICER[0] = 0xffffffff;
    NVIC->ICPR[0] = 0xffffffff;

    SCB->VTOR = address;
    __DSB();
    __ISB();

    __set_MSP(msp); // Re-initial Stack Pointer (Point to Application Stack)
    asm("bx %0"::"r" (reset_vector)); // Jumper to Application
}
```



# Configuration Bits & Fuses

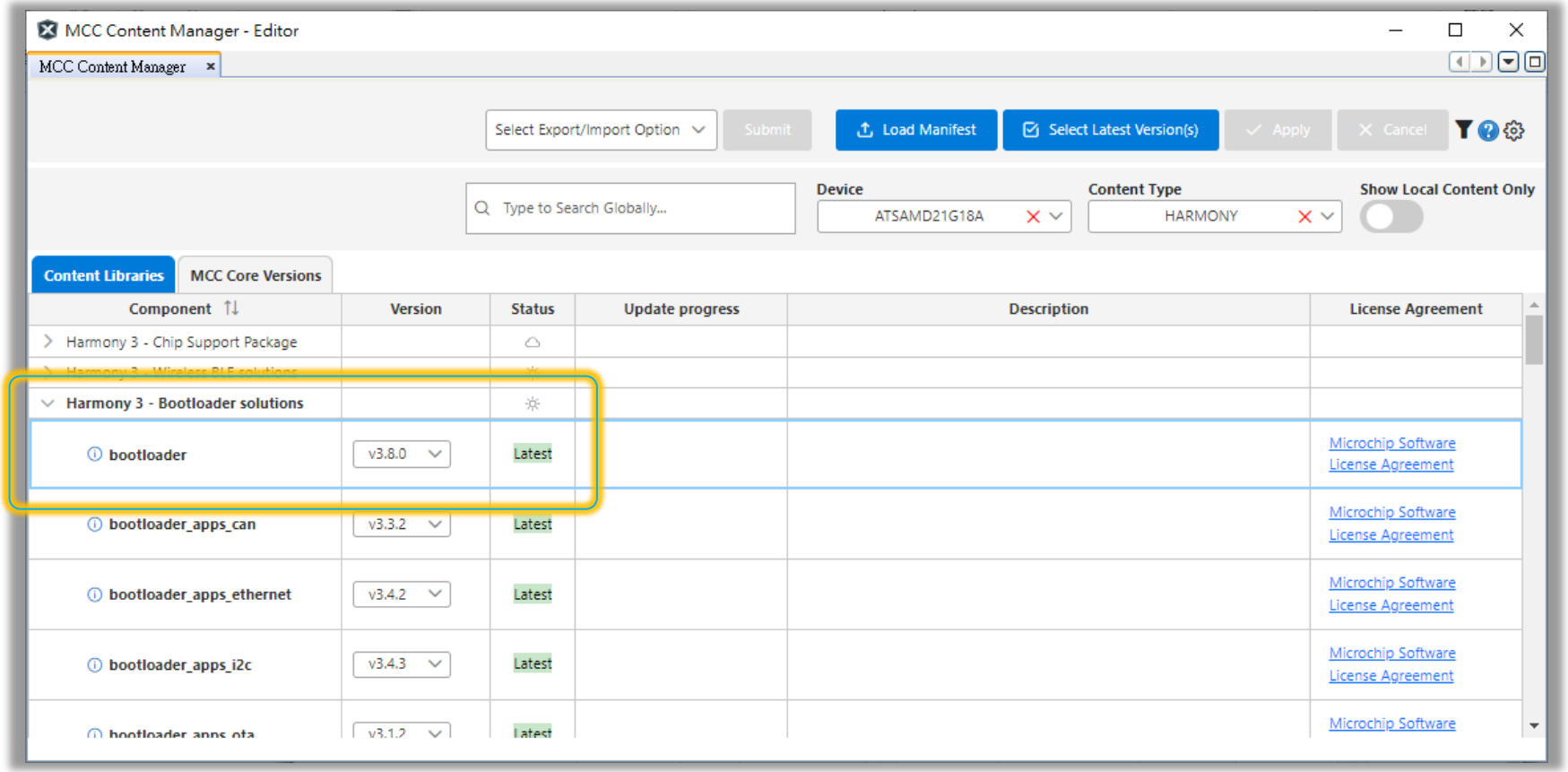
# Configuration Bits & Fuses Definition

- In A Bootloader-based design,
  the device Configuration Bits/Fuses are shared.
- The setting needs applied to both the Bootloader and the Application,
  choose a suitable setting that work for both is very important.
- In the current design, the device Configuration Bits/Fuses are defined and programmed by the Bootloader.
  The Application project bypasses these settings.
- In advanced designs, you can dynamically change (On Fly Change) the device Configuration Bits/Fuses,
  so the Bootloader and the Application can run with independent settings.
  However, this approach carries substantial risk
  (e.g., bricking the device, losing debug access, or misconfiguring clock/BOD/WDT),
  so we will not cover it in this course.”

# Bootloader Libraries Maintain at Microchip Harmony 3

# Bootloader Libraries at MH3

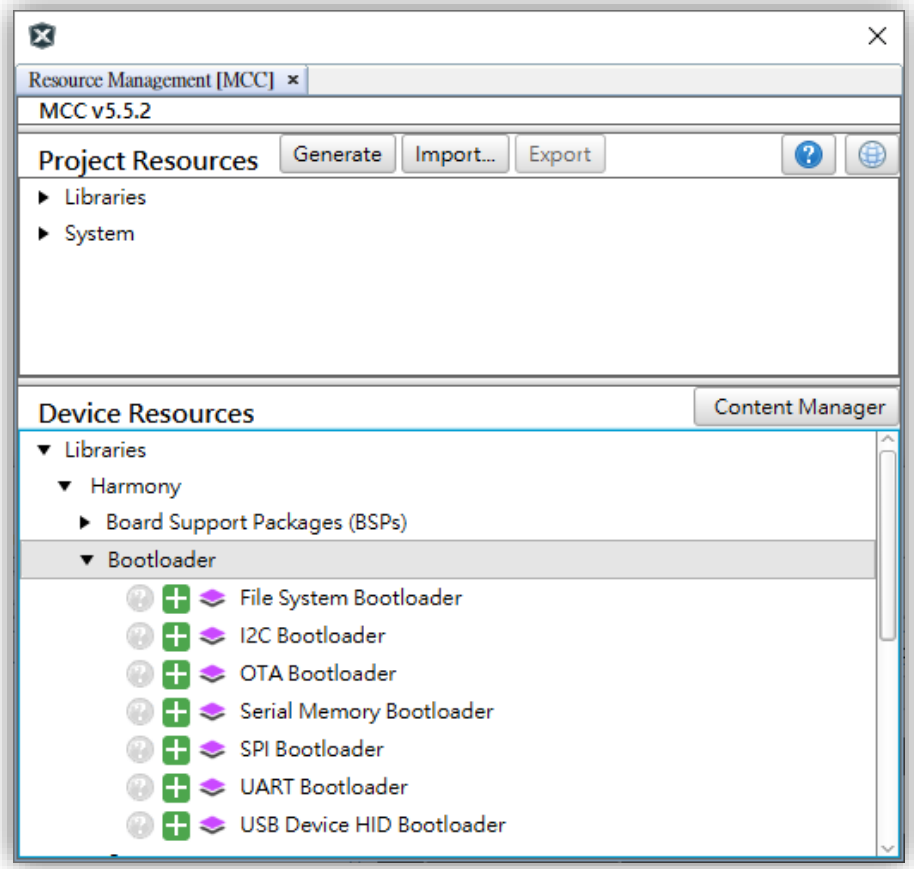
- **Bootloader Libraries must be preparation, before develop the Bootloader application.**
- **Select suitable version of “Harmony 3 - Bootloader solutions” at MCC Content Manager & Apply it.**



# Bootloader Loader Library Modes

# MCC Harmony Bootloader Loader Library

- The MCC Harmony Bootloader library provide multiple firmware updates paths mode.
  for example,
  UART, USB HID, I²C, SPI, CAN, and
  Ethernet (UDP), as well as file systems,
  serial memories,
  and over-the-air (OTA).
- The Figure shows for SAMD21G18A,
  (e.g., UART, USB HID, I²C).
- Actual support varies by device family
  and by the hardware present
  on the target board,
  such as an SD-card slot or
  an Ethernet/Wi-Fi module.

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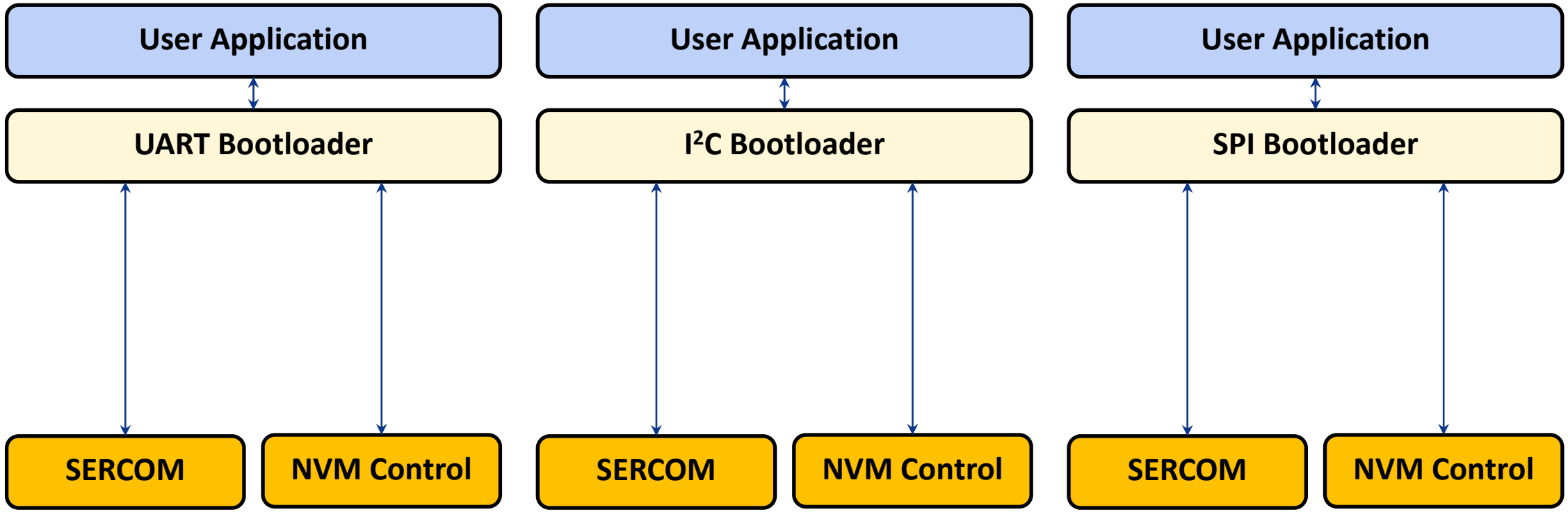
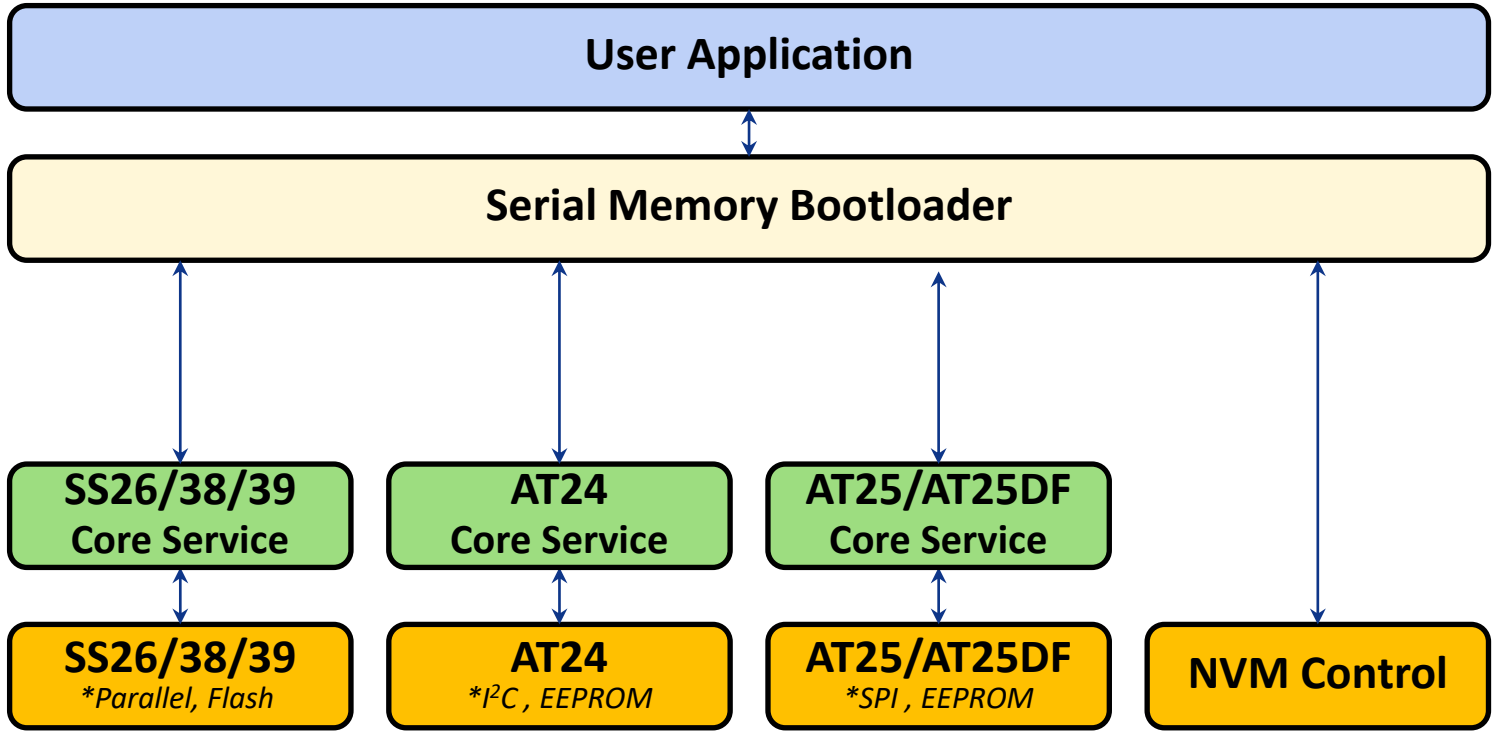
# Bootloader Loader Library

## UART, I²C & SPI Bootloader for connection and load firmware with Host



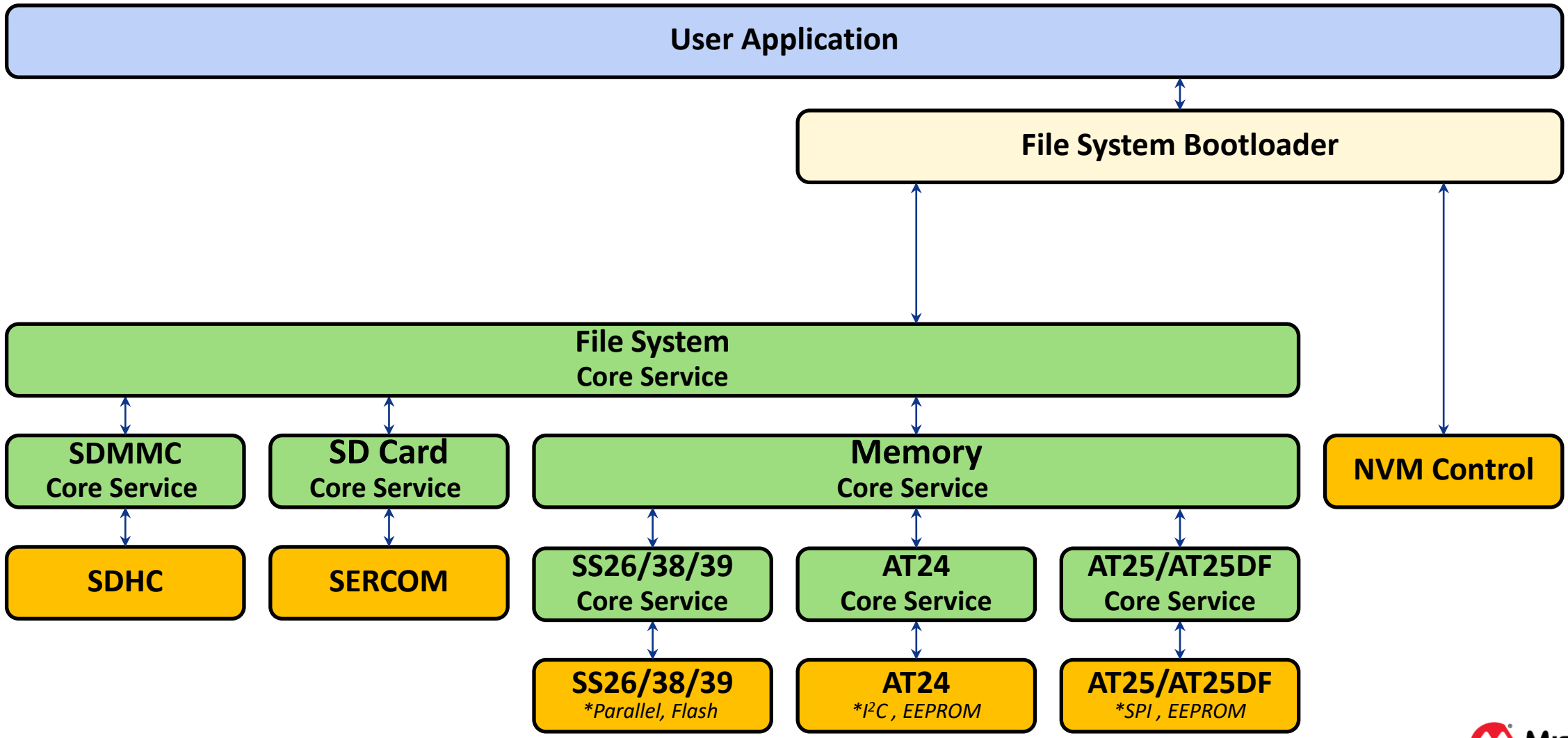
# Bootloader Loader Library

## Serial Memory Bootloader for load firmware from external memory



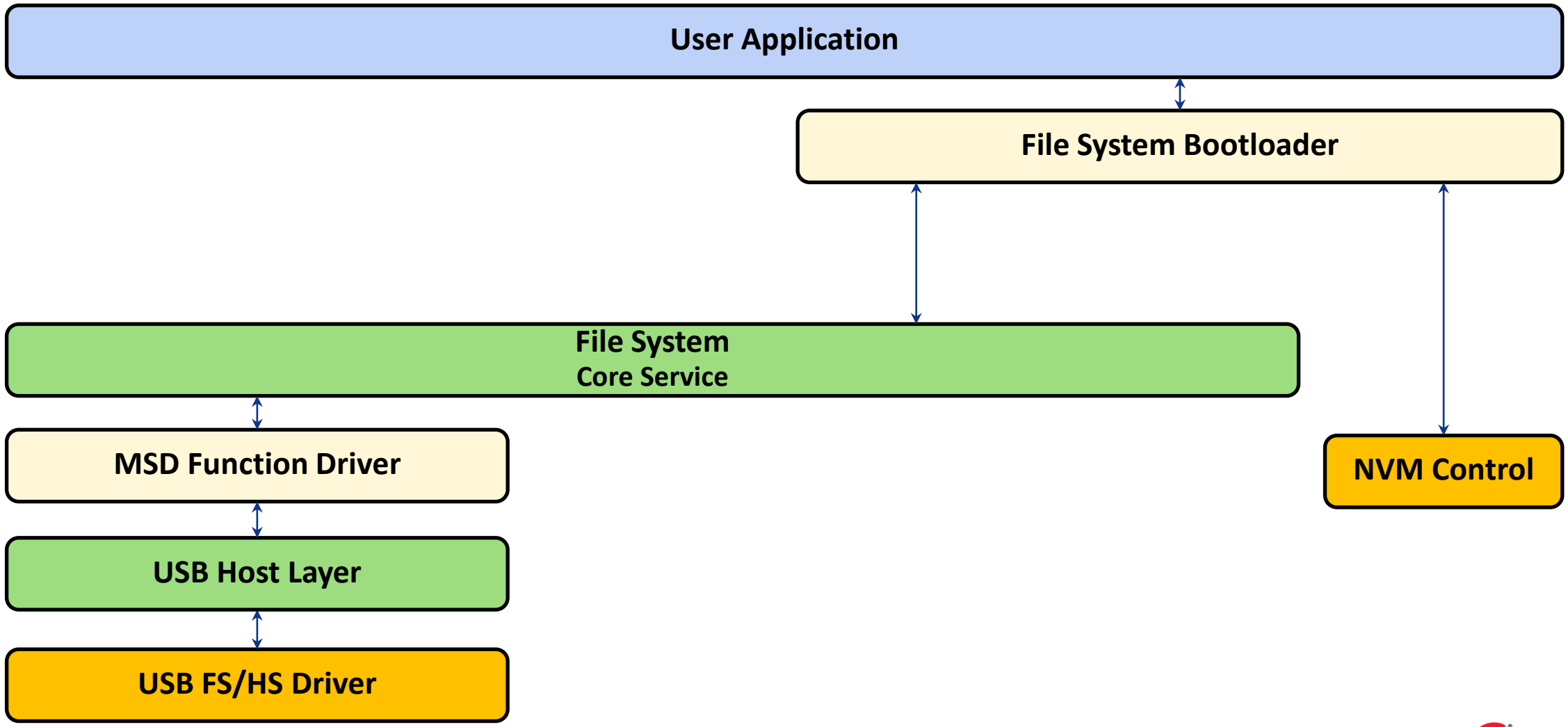
# Bootloader Loader Library

## File System Bootloader for load firmware storage



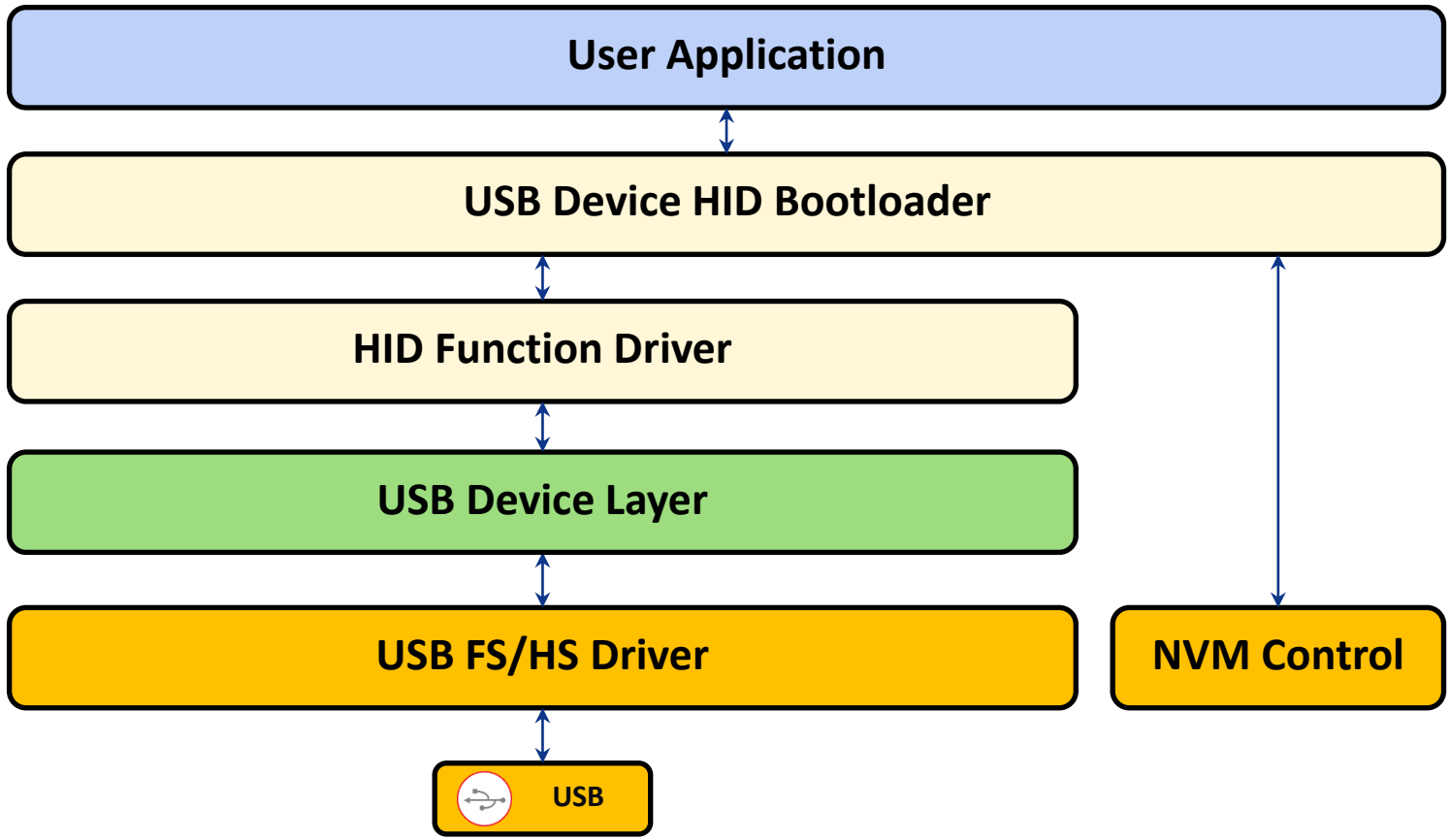
# Bootloader Loader Library

## USB Host MSD Bootloader for load firmware via USB storage



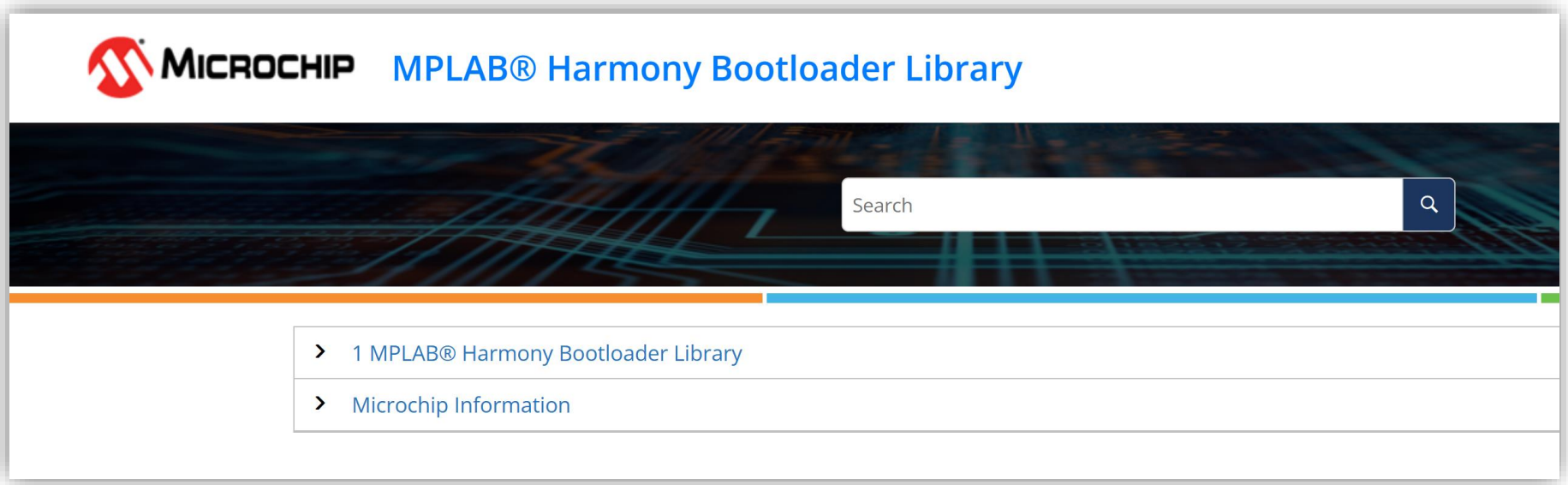
# Bootloader Loader Library

## USB Device HID Bootloader for connection and load firmware via USB Host



# Bootloader Loader Library

- **Harmony offers a wider range of bootloader modes, such as including OTA, CAN, and Ethernet (UDP), etc.**
- **For details, please refer to the example projects of MCC Harmony and documentation provided by MCC Harmony.**
  **https://microchip-mplab-harmony.github.io/bootloader/index.html**

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# UART Bootloader

# UART Bootloader

- Supported on Cortex-M based MCUs, MIPS based MCUs and MPUs
  e.g., ATSAMD21G18A (APP045 EVB), PIC32CX1025SG41128 (APP055 EVB), etc.
- MCC Harmony UART PLIB to communicate resulting in smaller bootloader size.
- Takes Binary File as input
- Uses command line host script (*btl_host.py*) to receive binary (**.BIN*) from Host PC.
- Supports Fail Safe update for the devices which have a Dual Bank flash memory.

# UART Bootloader

- **Below flowchart routine shows how to switch between the UART Bootloader and the Application at startup.**

```
#define BTL_TRIGGER_PATTERN (0x5048434DUL)
static uint32_t *ramStart = (uint32_t *)BTL_TRIGGER_RAM_START;

bool bootloader_Trigger(void)
{
    uint32_t i;

    …

    /* Check for Magic Number */
    if (BTL_TRIGGER_PATTERN == ramStart[0] &&
        BTL_TRIGGER_PATTERN == ramStart[1] &&
        BTL_TRIGGER_PATTERN == ramStart[2] &&
        BTL_TRIGGER_PATTERN == ramStart[3])
    {
        ramStart[0] = 0;
        DCACHE_CLEAN_BY_ADDR(ramStart, 4);
        return true;
    }

    /* Check for Button */
    if (!BT1_Get())
        return true;

    return false;
}
```

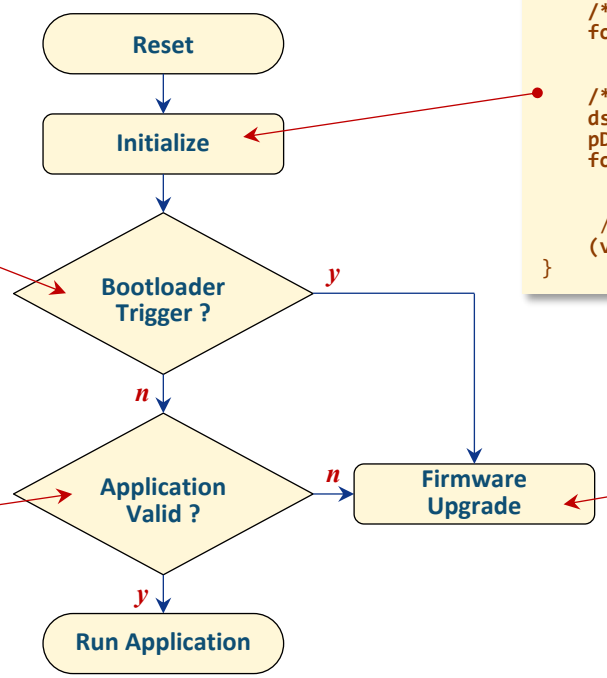
```
void __attribute__((noinline, section(".romfunc.Reset_Handler"))) Reset_Handler(void)
{
    register uint32_t count;
    uint32_t *pSrc, *pDst;
    uintptr_t src, dst;

    src = (uintptr_t)&_etext;
    pSrc = (uint32_t *)src;      /* flash functions start after .text */
    dst = (uintptr_t)&_sdata;
    pDst = (uint32_t *)dst;      /* boundaries of .data area to init */

    /* Init .data */
    for (count = 0U; count < (((uint32_t)&_edata - (uint32_t)dst) / 4U); count++)
        pDst[count] = pSrc[count];

    /* Init .bss */
    dst = (uintptr_t)&_sbss;
    pDst = (uint32_t *)dst;
    for (count = 0U; count < (((uint32_t)&_ebss - (uint32_t)dst) / 4U); count++)
        pDst[count] = 0U;

     /* Branch to application's main function */
    (void)main();
}
```




```
void run_Application(uint32_t address)
{
    uint32_t msp = *(uint32_t *)(address); // Application Start
    uint32_t reset_vector = *(uint32_t *)(address + 4U);

    if (msp == 0xffffffffU)
        return;

    …

    __set_MSP(msp); // Re-initial Stack Pointer
    asm("bx %0"::"r" (reset_vector)); // Jumper to Application
}
```

```
void bootloader_UART_Tasks(void)
{
    do
    {
        input_task();

        if (flash_data_ready)
            flash_task();

        else if (packet_received)
            command_task();


    } while (uartBLActive);
}
```

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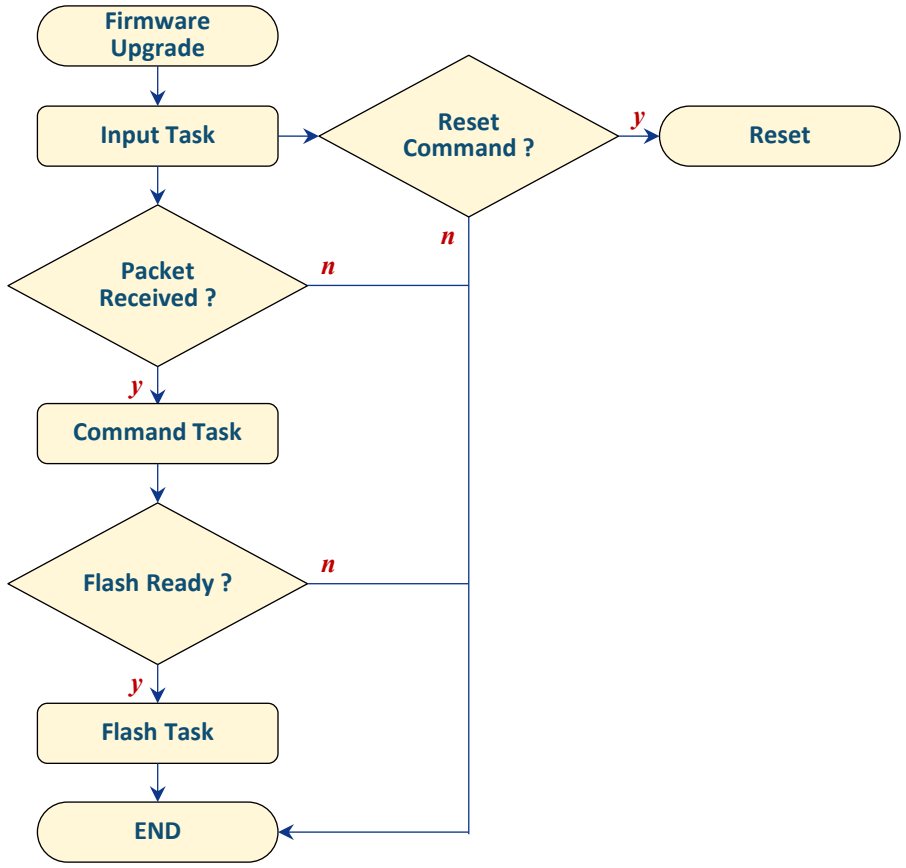
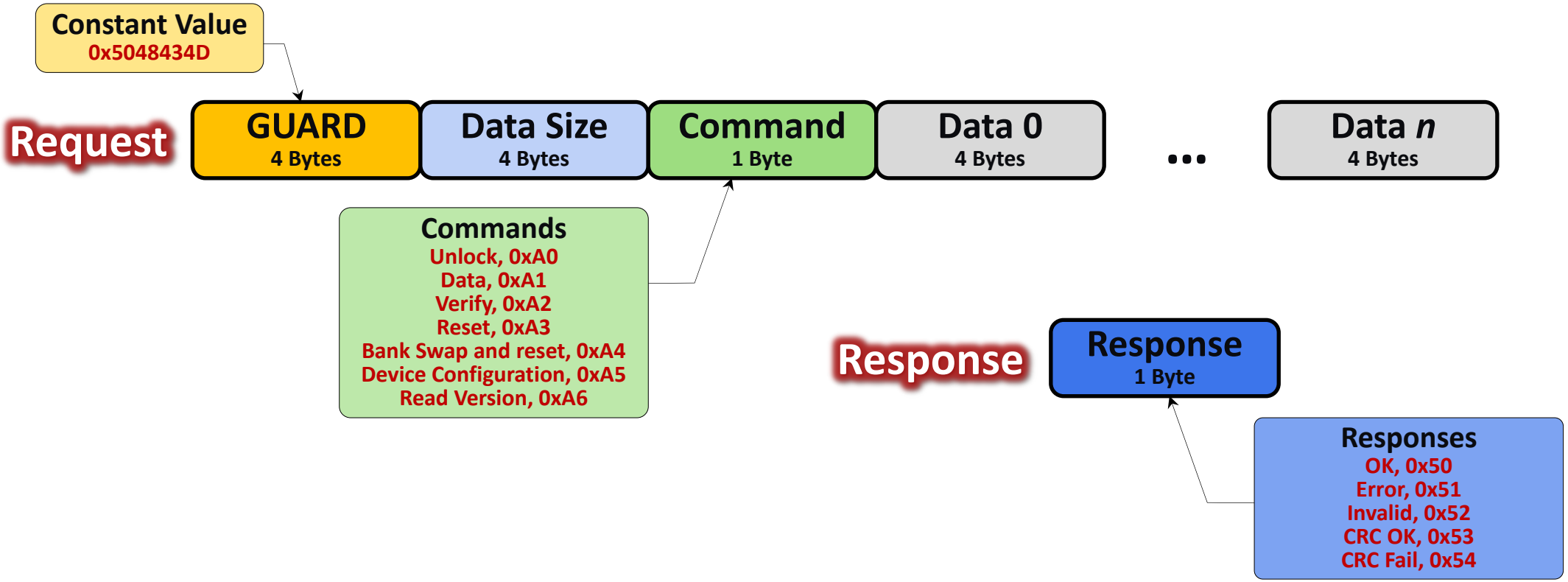
# UART Bootloader

- Below flowchart routine shows how the firmware upgrade works.
- Receives packets, parses commands, and executes them; upon receiving a reset command, the system reboots.



# UART Bootloader Protocol

- **The UART bootloader protocol as shown in below figure is common for all the supported command.**



# Binary Generation

- The UART bootloader uses a binary transfer format,
  so you must first convert the Intel HEX (.hex) file to a raw binary (.bin) image.
- xc32-objcopy,
  bundled with Microchip's XC32 toolchain, is used to convert and edit firmware images.
- It supports ELF, Intel HEX, S-record, and raw binary.
  You can select sections, shift addresses, fill gaps, and pad sizes to produce
  deterministic, bootloader-ready outputs.
- ideal for ELF -> BIN/HEX and HEX -> BIN in automated, reproducible build scripts.
- In an MPLAB X IDE project,
  you can use "Execute After Build" to run xc32-objcopy
  after compilation and automatically generate a binary (.bin) file.

```
${MP_CC_DIR}/xc32-objcopy -I ihex -O binary ${DISTDIR}/${PROJECTNAME}.${IMAGE_TYPE}.hex ${DISTDIR}/${PROJECTNAME}.${IMAGE_TYPE}.bin
```

# Bootloader Host Script

- The UART bootloader host (*btl_host.py*) is implemented as a Python script compatible with Python 3.x and later.
- It requires the "*pyserial*" package to communicate with the device over UART. Install it with:

```
pip3 install pyserial
```

- Run *btl_host.py* from the command line to perform a firmware update. e.g.

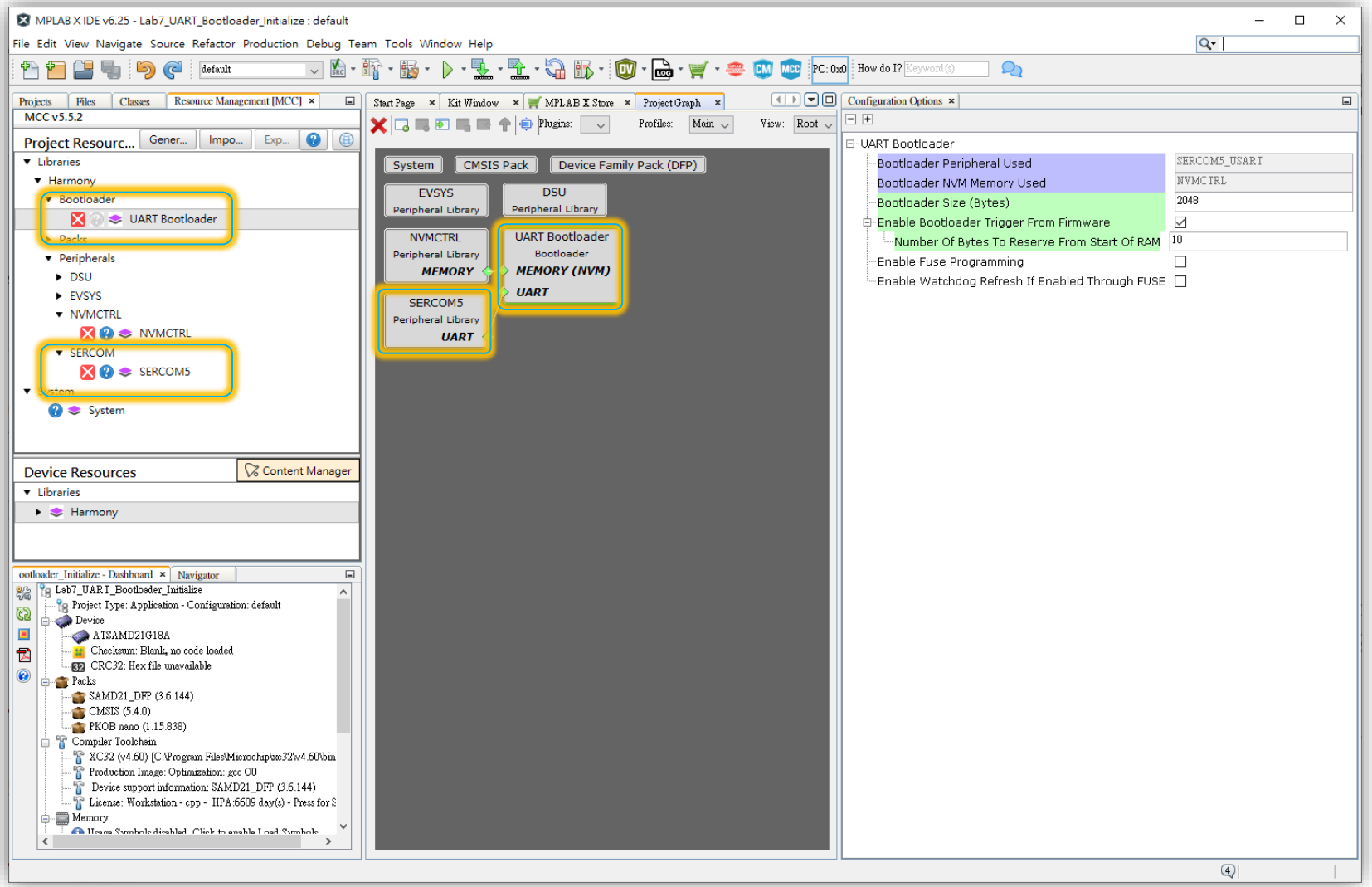
```
btl_host.py -v -i COM10 -d samd2x -a 0x800 -f .\Application.bin
```

- Below is the syntax to show help menu for the script

```
btl_host.py --help
```

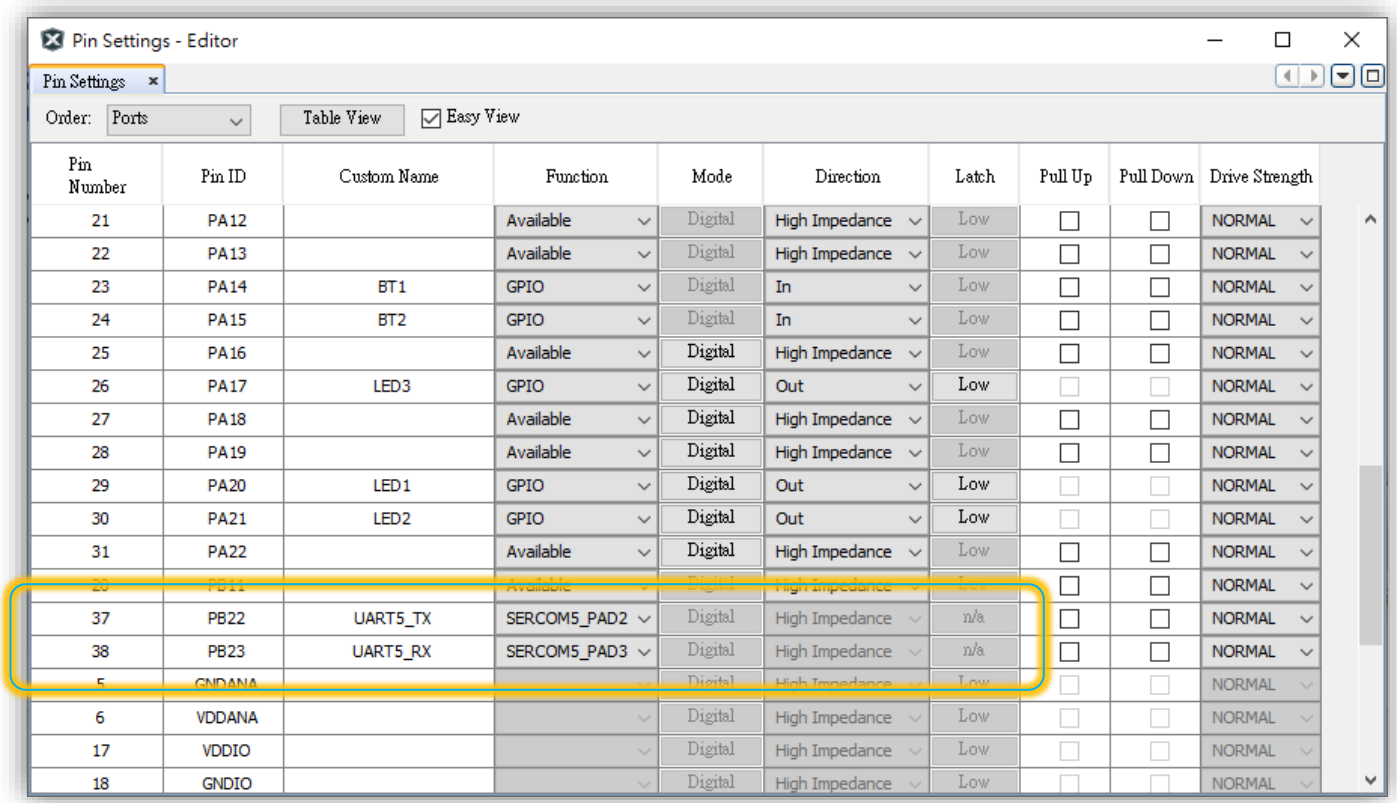
# Harmony Bootloader - UART Bootloader Configurator

## Add UART Bootloader and SERCOM in MHC



# Harmony Bootloader - UART Bootloader Configurator

## Configure SERCOM PADs at Pin Table



# UART Bootloader API

**API functions in bootloader_common.c**

| | |
|---|---|
| **bootloader_Tasks( )** | **Starts bootloader execution.** |
| **bootloader_Trigger( )** | **Checks if Bootloader has to be executed at startup.** |
| **bootloader_GetVersion( )** | **Returns the current bootloader version.** |
| **run_Application( )** | **Runs the programmed application at startup.** |
| **bootloader_ProgramFlashBankSelect( )** | **Selects Appropriate Program Flash Bank after reset.** |

# 🛠 Lab7 UART Bootloader Initialize

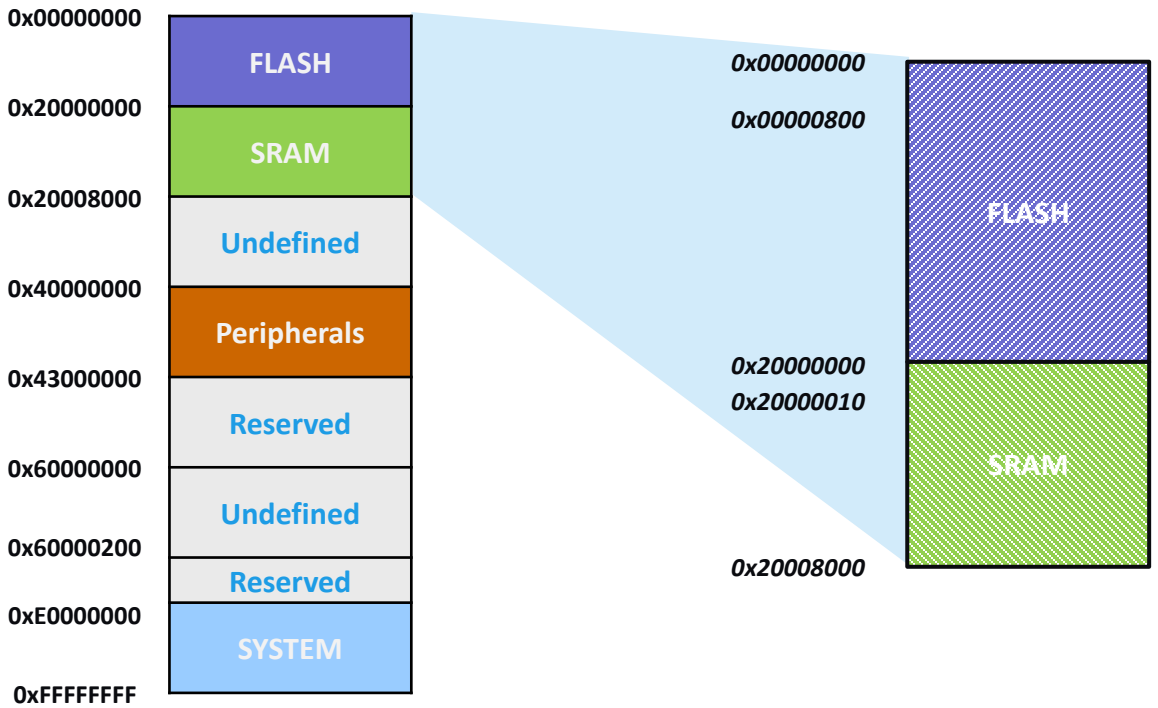
# 🛠 Lab7 UART Bootloader Initialize

- At this lab, we try to getting started with UART Bootloader.
- Add UART Bootloader in MHC and assign parameters and application start address.
- Implement suitable bootloader trigger method use to trigger Bootloader.
- Implement an LEDs status to indicate Bootloader enter or not.
- Try to use python script to upload “DemoApplication” firmware to APP045 EVB via UART based on UART Bootloader.

- **Let’s go !**

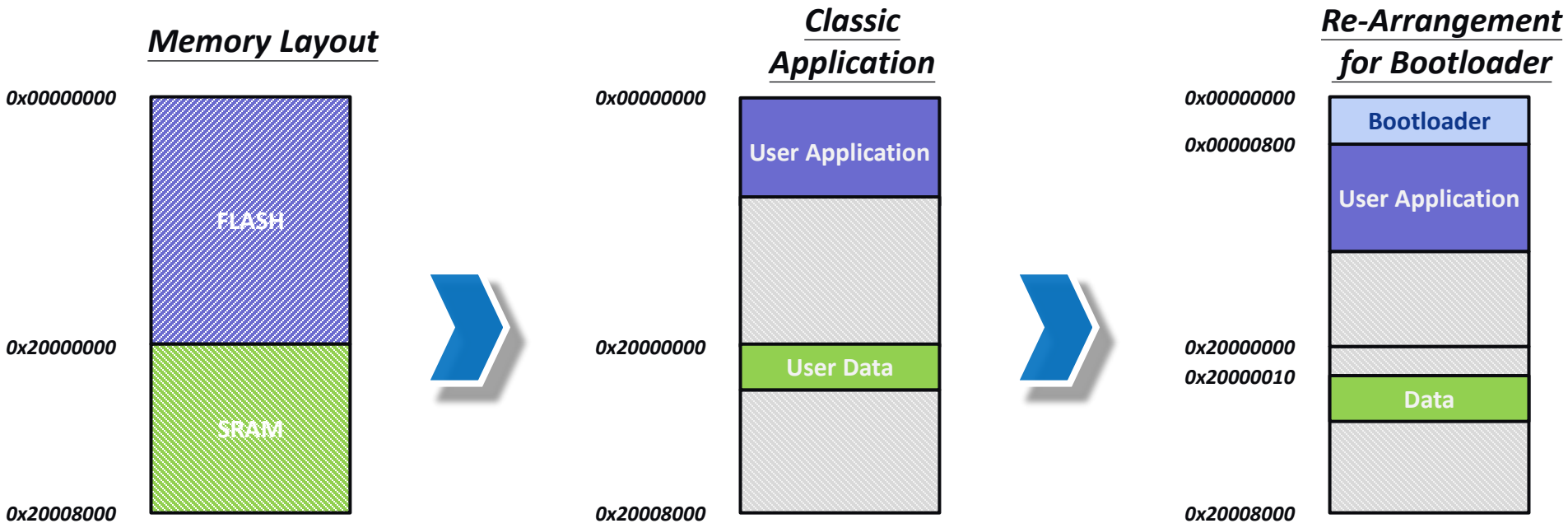
# Memory Layout for ATSAMD21

- **This figure shows the memory layout of the ATSAMD21x18A, which features 256 KB of Flash and 32 KB of SRAM within a 4 GB addressable space.**
  *Flash, 0x00000000 - 0x0003FFFF, 256KB*
  *SRAM, 0x20000000 - 0x20007FFFF, 32KB*



# Memory Re-Arrangement for Bootloader *ATSAMD21 as an Example*

- In a typical application, the entire memory space is dedicated to the application itself.
- When a bootloader is present, part of the Flash and SRAM needs to be allocated for the bootloader.
- In UART Bootloader Application, Bootloader occupies the first 0x800 bytes of flash and reserve the first 16 Bytes of SRAM for bootloader trigger by Application.

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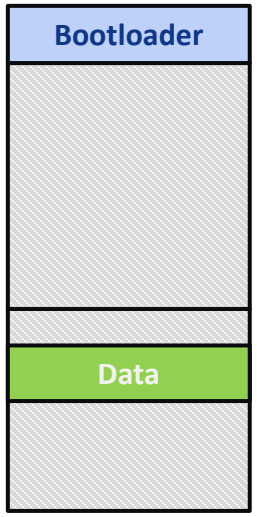
# Memory Re-Arrangement for Bootloader *cont.* *ATSAMD21 as an Example*

- **Set two independent linker scripts (**.ld*),**
  **one for the Bootloader and one for the Application to define their memory allocations.**
- **In the linker scripts,**
  **reserved separately for the Bootloader and the Application.**

***Bootloader***



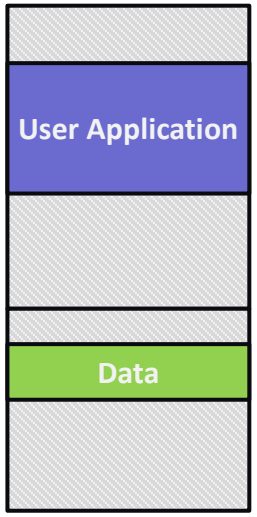

***Linker Script for Bootloader***

```
MEMORY
{
  rom (LRX) : ORIGIN = 0x00, LENGTH = 0x800
  ram (WX!R) : ORIGIN = 0x20000010, LENGTH = 0x7FF0
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

***Linker Script for Application***

```
MEMORY
{
  rom (LRX) : ORIGIN = 0x800, LENGTH = 0x3F800
  ram (WX!R) : ORIGIN = 0x20000010, LENGTH = 0x7FF0
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

***Application***

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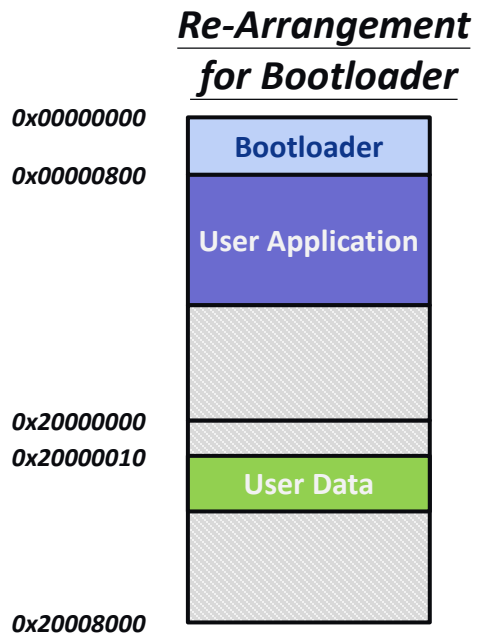
# Link Script for ATSAMD21x18A

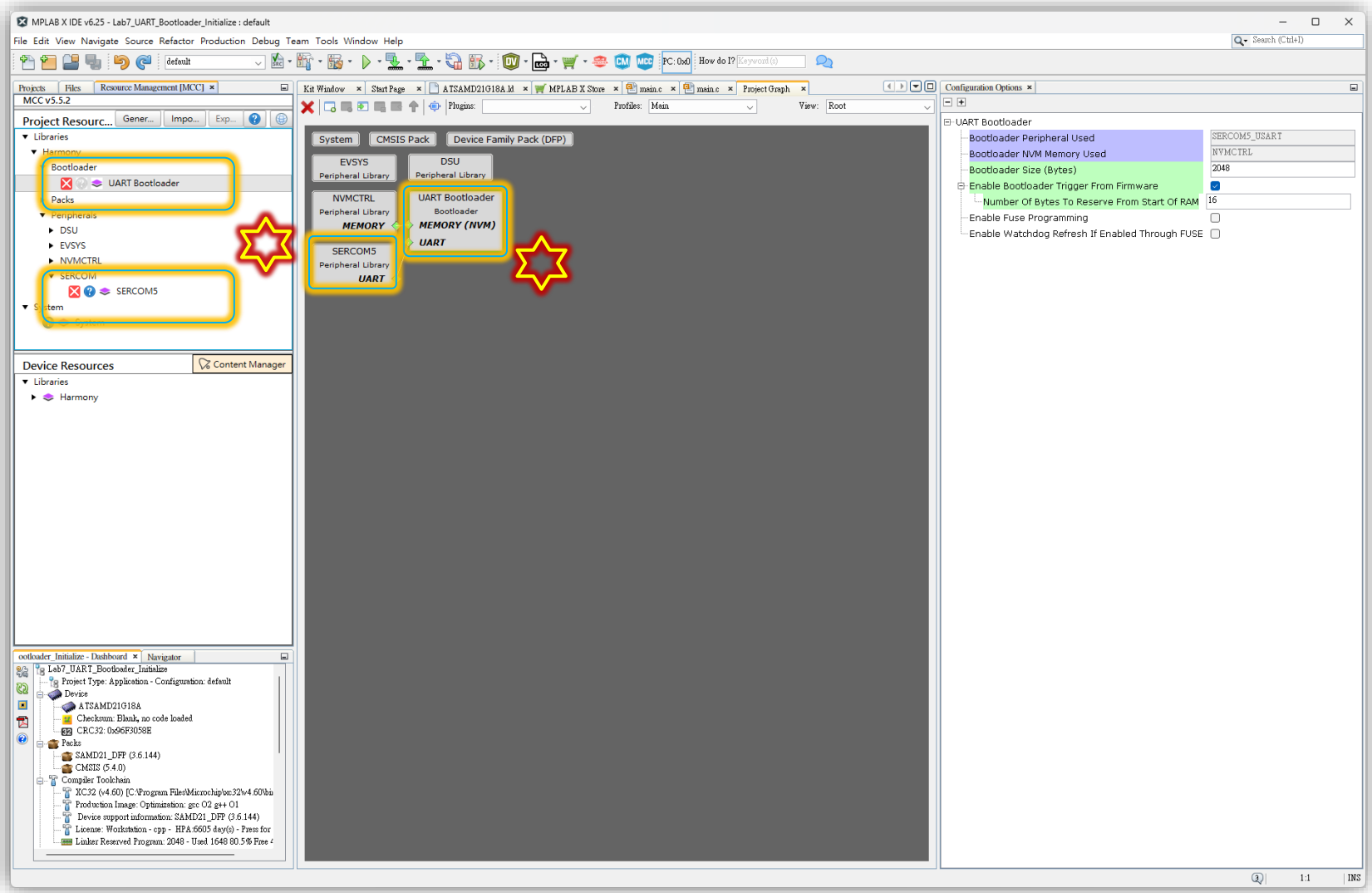
- **In MCC Harmony project, apply preprocessor definition to dynamic management linker script.**
  **The corresponding file will be generated**
  **after press “generate” button at MHC depend on your setting.**
  - **For Bootloader *(Optional)*,**
    **-DROM_ORIGIN = *0x00000000*, -DROM_LEHGTH = *0x800***
    **-DRAM_ORIGIN = *0x20000010*, -DRAM_LEHGTH = *0x7FF0***
  - **For User Application,**
    **-DROM_ORIGIN = *0x00000800*, -DROM_LEHGTH = *0x3F800***
    **-DRAM_ORIGIN = *0x20000010*, -DRAM_LEHGTH = *0x7FF0***




- **These definitions are applied in the linker script,**
  **and during the linking process,**
  **they ensure that the program code and data are in the designated memory areas.**

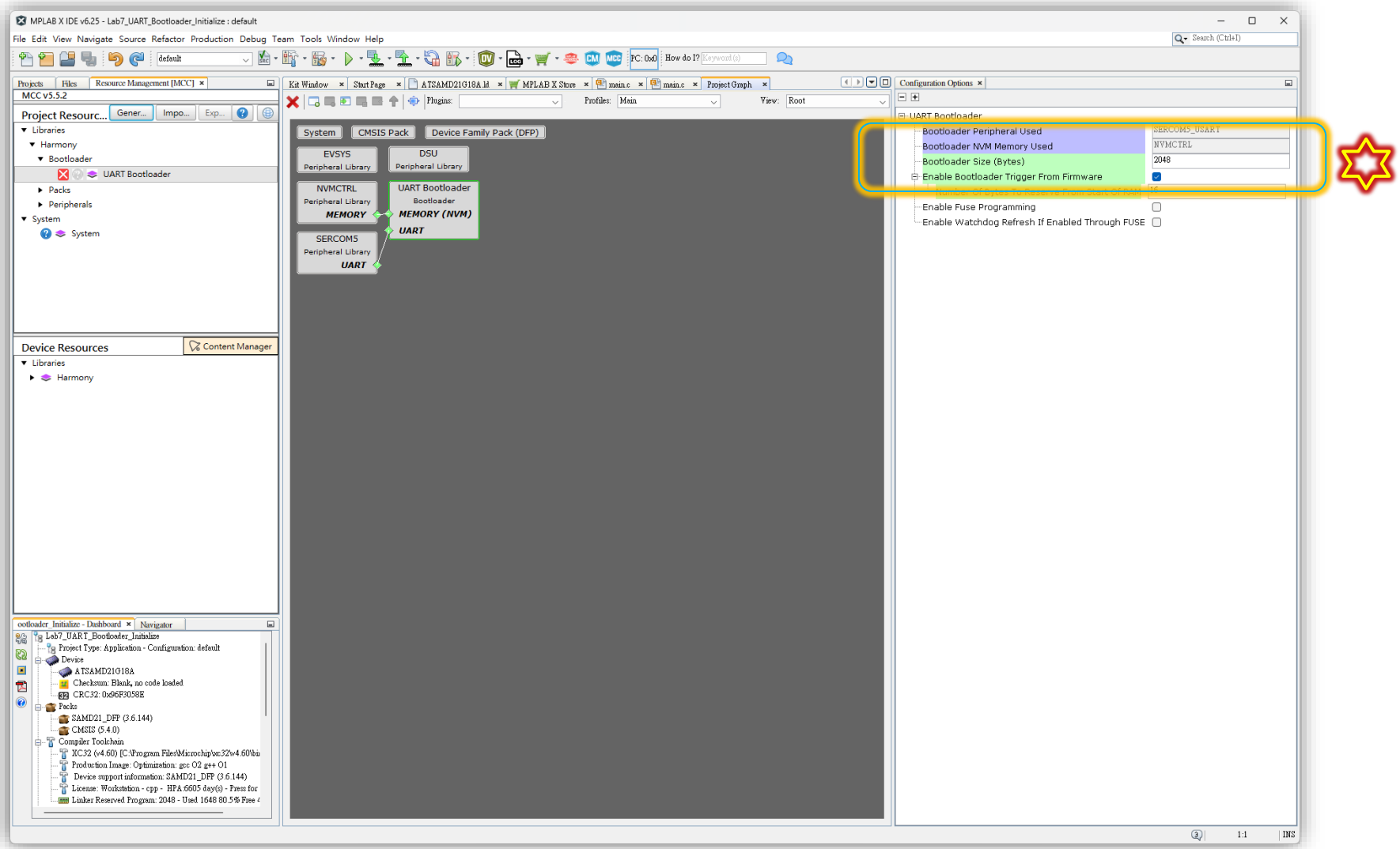
# 🛠 Lab7 UART Bootloader Initialize

- **Create a new project and add UART Bootloader and SERCOM5 in MHC.**



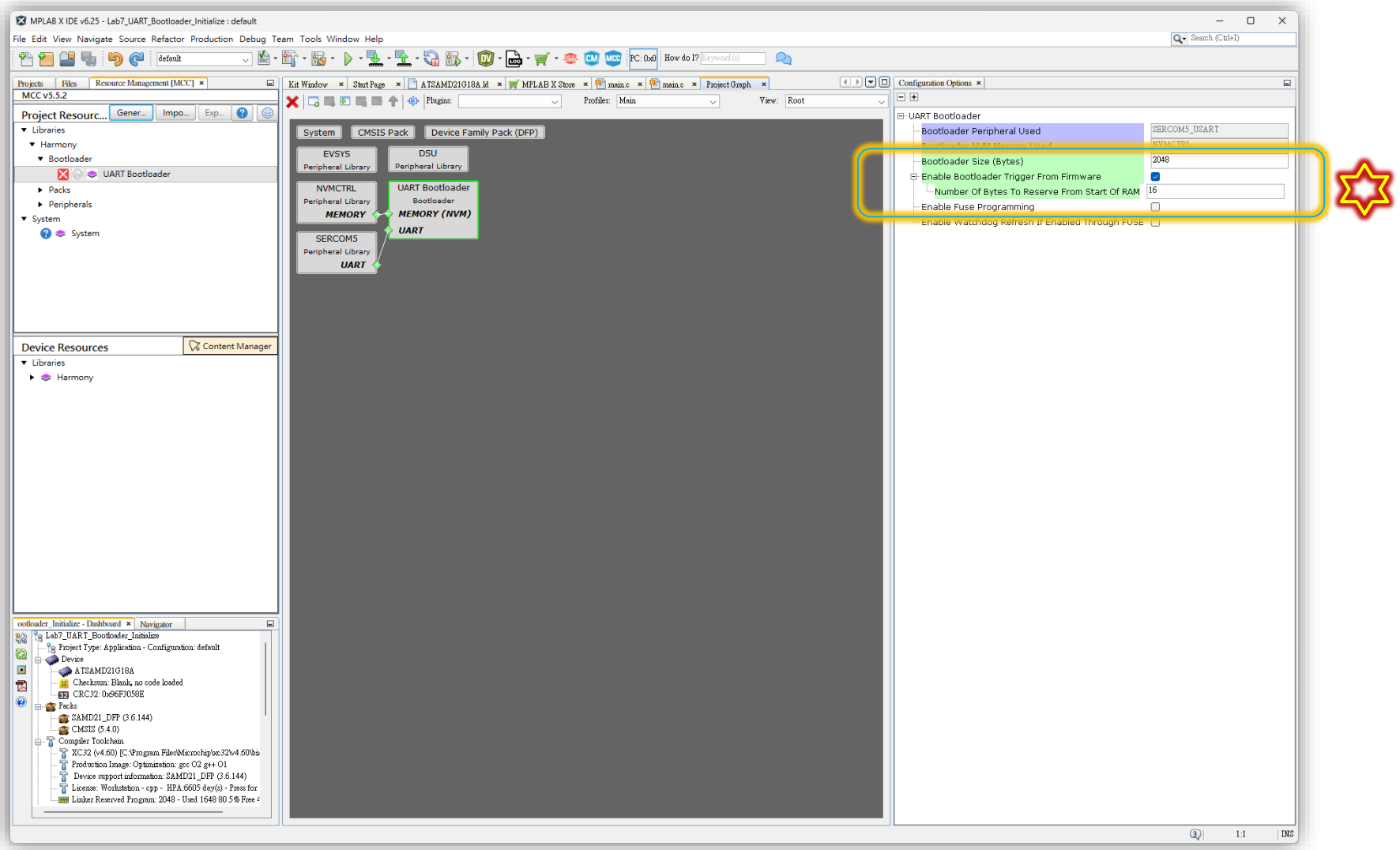
# 🛠 Lab7 UART Bootloader Initialize

- **Set “Bootloader Size (Bytes)” to 2048.**



# 🛠 Lab7 UART Bootloader Initialize

- **Check “Enable Bootloader Trigger From Firmware” and Reserve 16 bytes RAM.**

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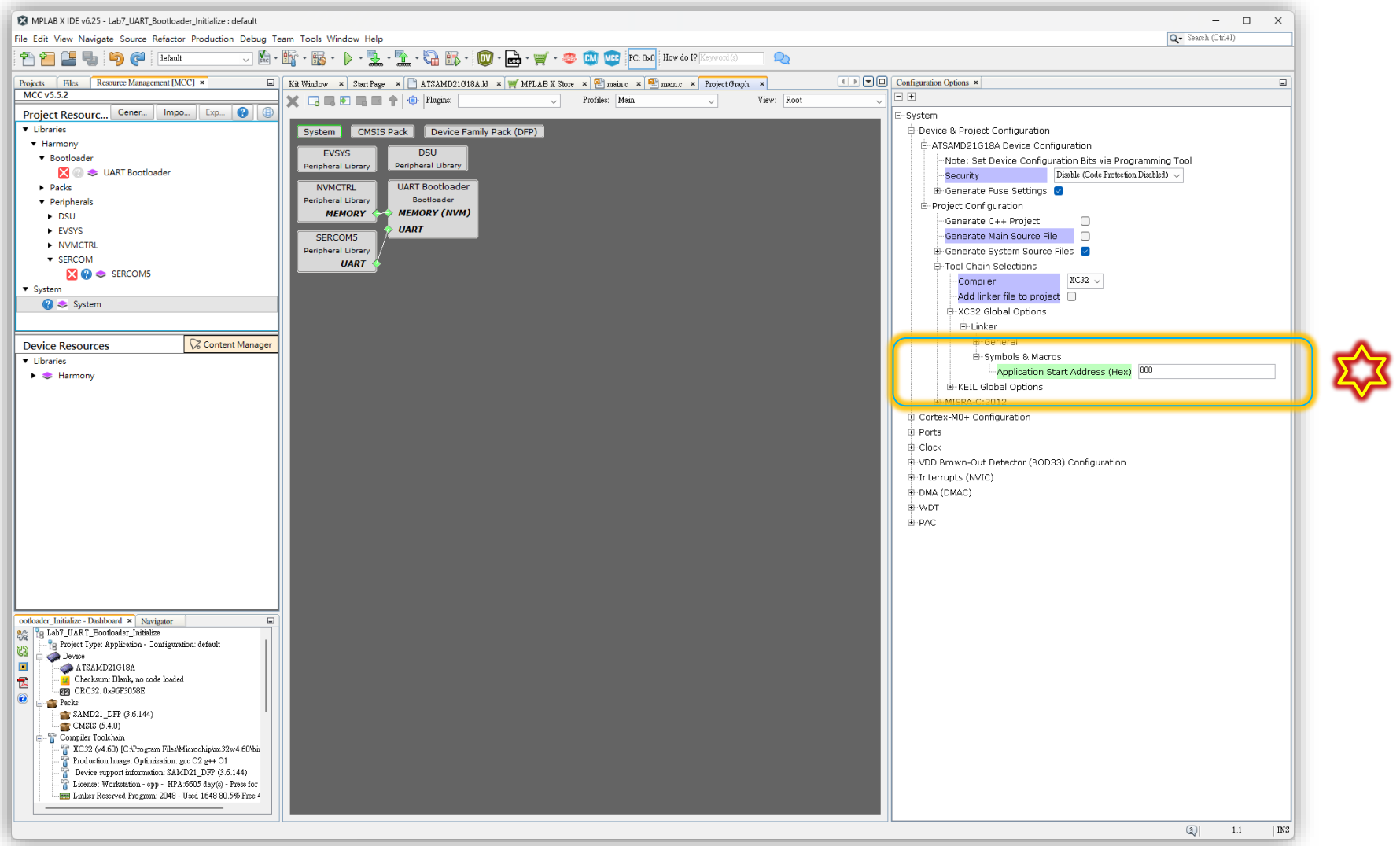
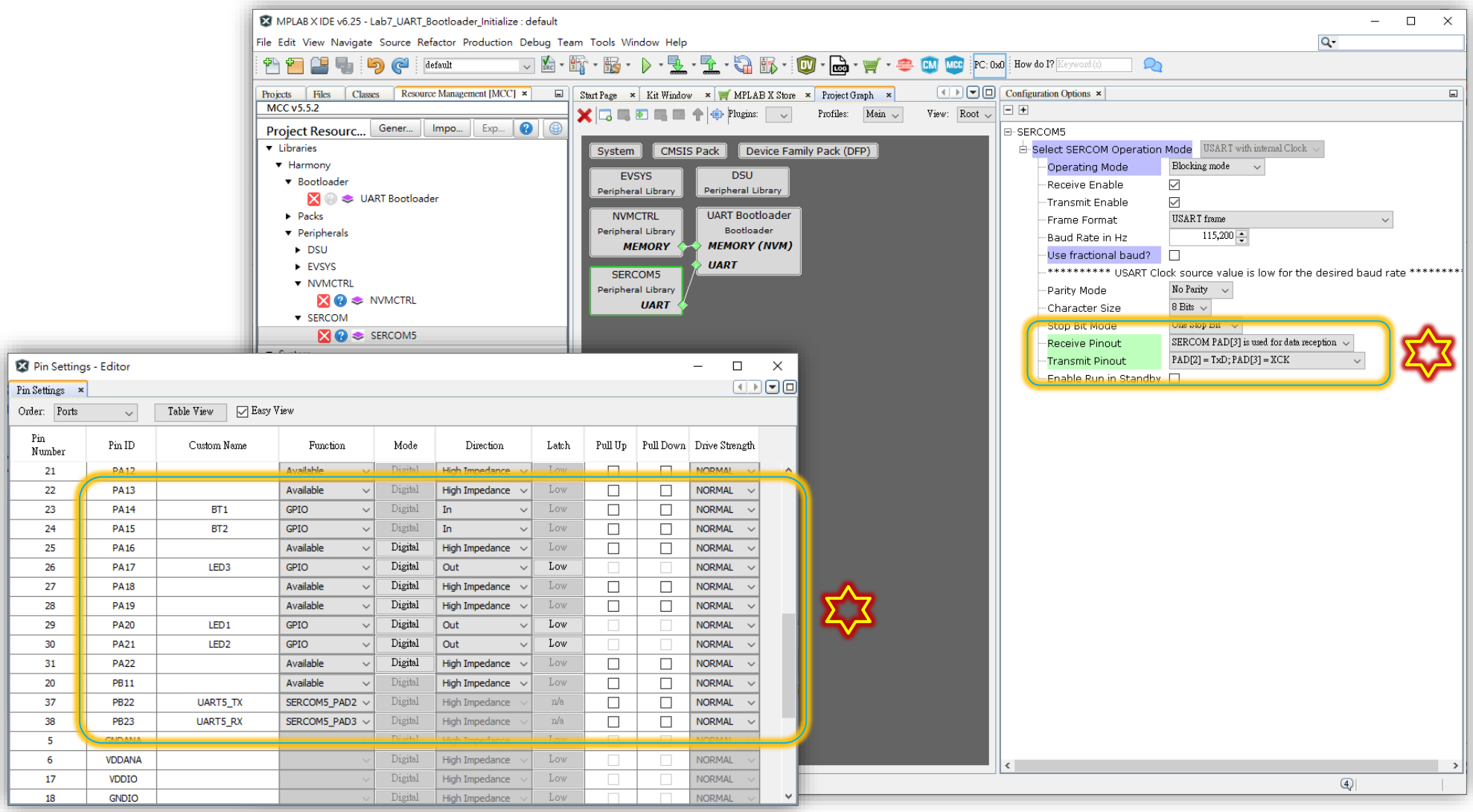
# 🛠 Lab7 UART Bootloader Initialize

- **Set Application Start Address (Hex) is 800.**



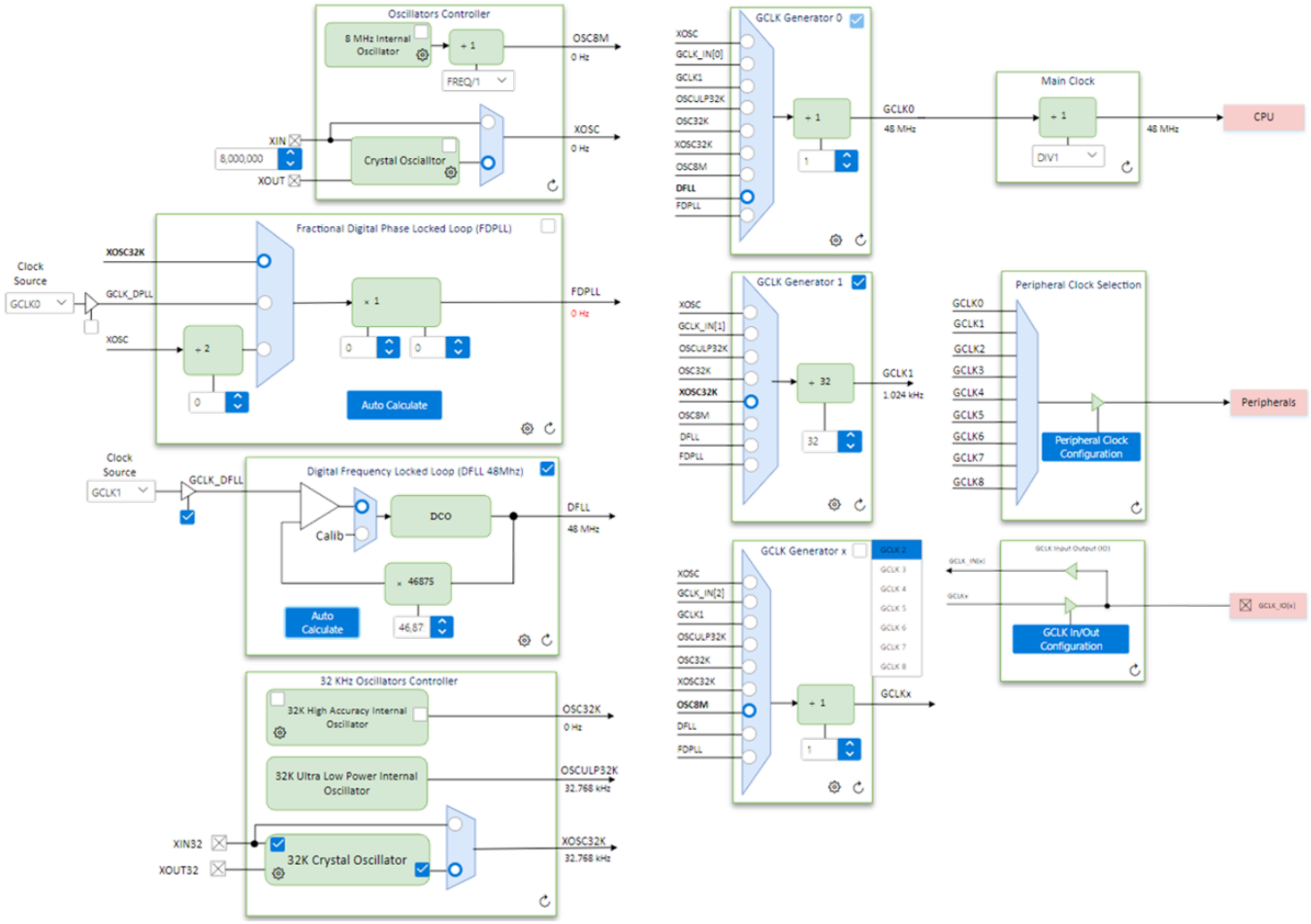
# 🛠 Lab7 UART Bootloader Initialize

- **Connect SERCOM5 with UART Bootloader and Set IO mapping.**

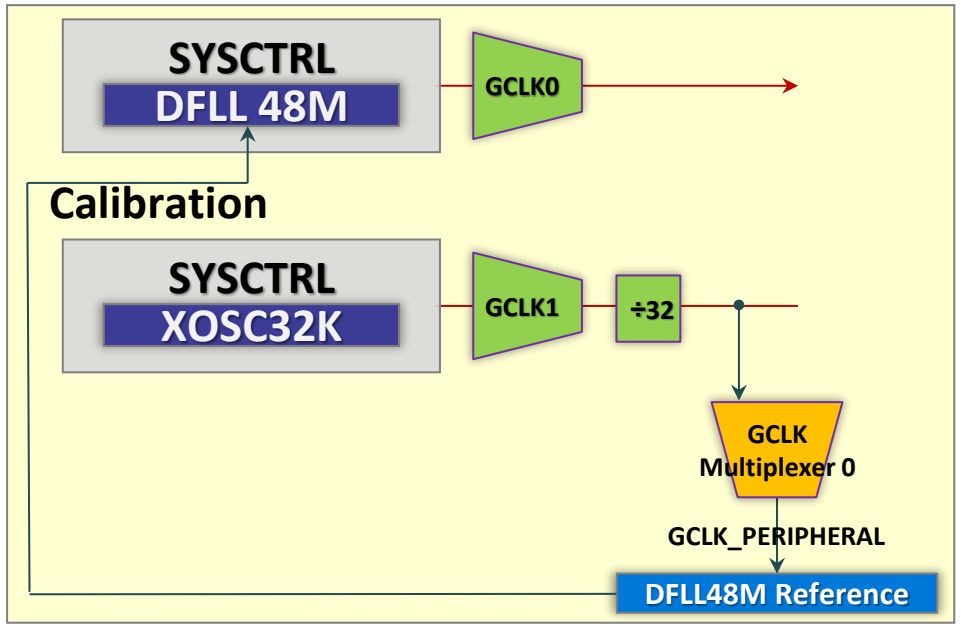


# 🛠 Lab7 UART Bootloader Initialize

- **Configure DFLL48M as Close loop as source of main clock**




## Close Loop

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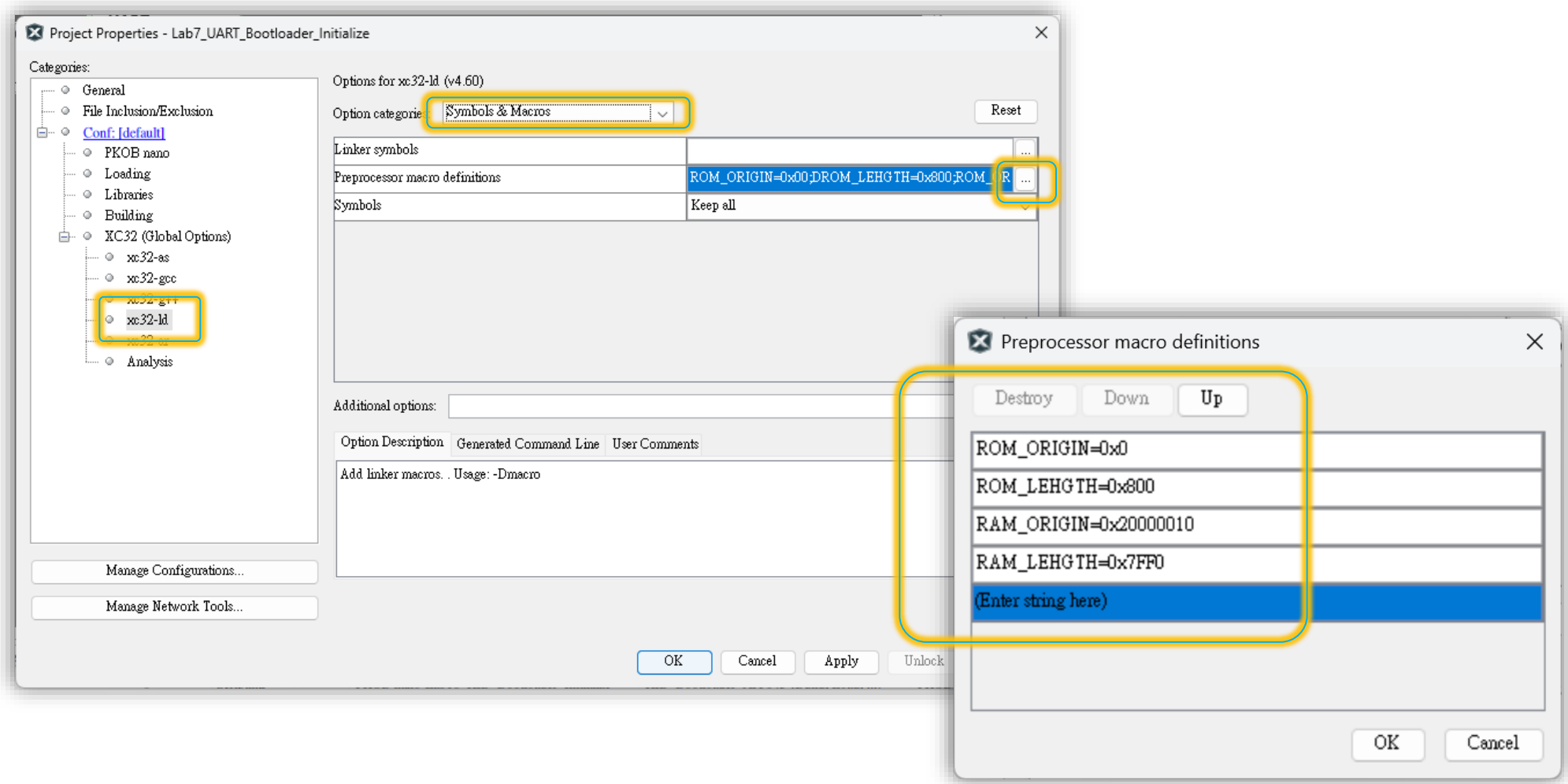
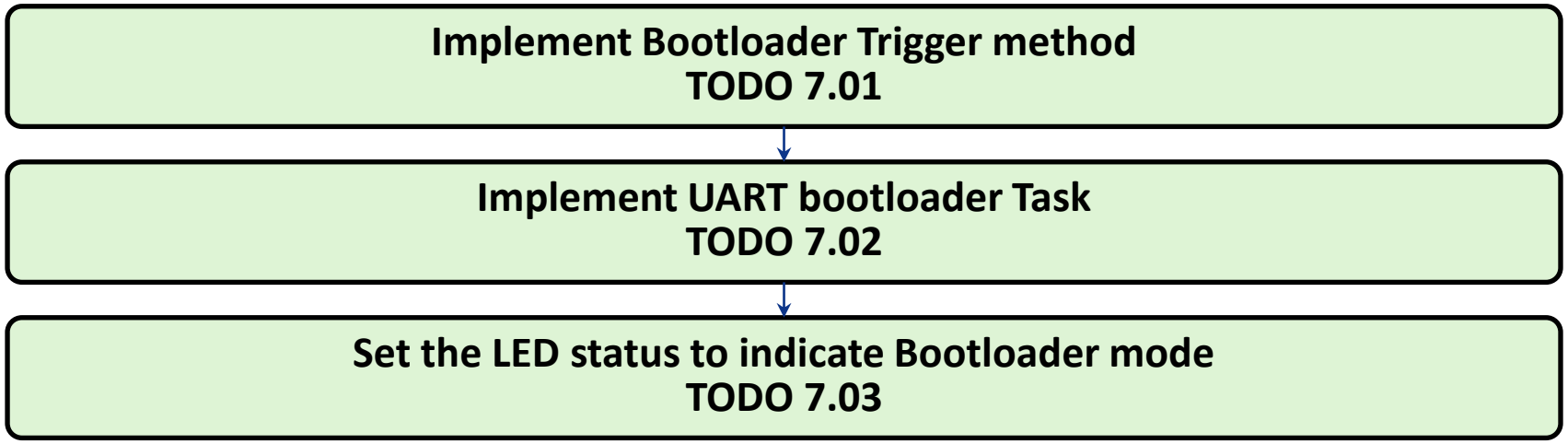
# Lab7 UART Bootloader Initialize

- **Confirm Preprocessor Definition**



# 🛠 Lab7 UART Bootloader Initialize

- **Code Implementation state**



# 🛠 Lab7 UART Bootloader Initialize

- **Implement below function at main.c**

```
// TODO 7.01
#define BTL_TRIGGER_PATTERN (0x5048434DUL)
static uint32_t *ramStart = (uint32_t *)BTL_TRIGGER_RAM_START;

bool bootloader_Trigger(void)
{
    uint32_t i;

    for (i = 0; i < 2000; i++)
        asm("nop");

    if (BT1_Get() == 0)
        return true;

    if (BTL_TRIGGER_PATTERN == ramStart[0] && BTL_TRIGGER_PATTERN == ramStart[1] &&
        BTL_TRIGGER_PATTERN == ramStart[2] && BTL_TRIGGER_PATTERN == ramStart[3])
    {
        ramStart[0] = 0;
        ramStart[1] = 0;
        ramStart[2] = 0;
        ramStart[3] = 0;
        return true;
    }

    return false;
}
```

# 🛠 Lab7 UART Bootloader Initialize

- **Implement below function at main.c**

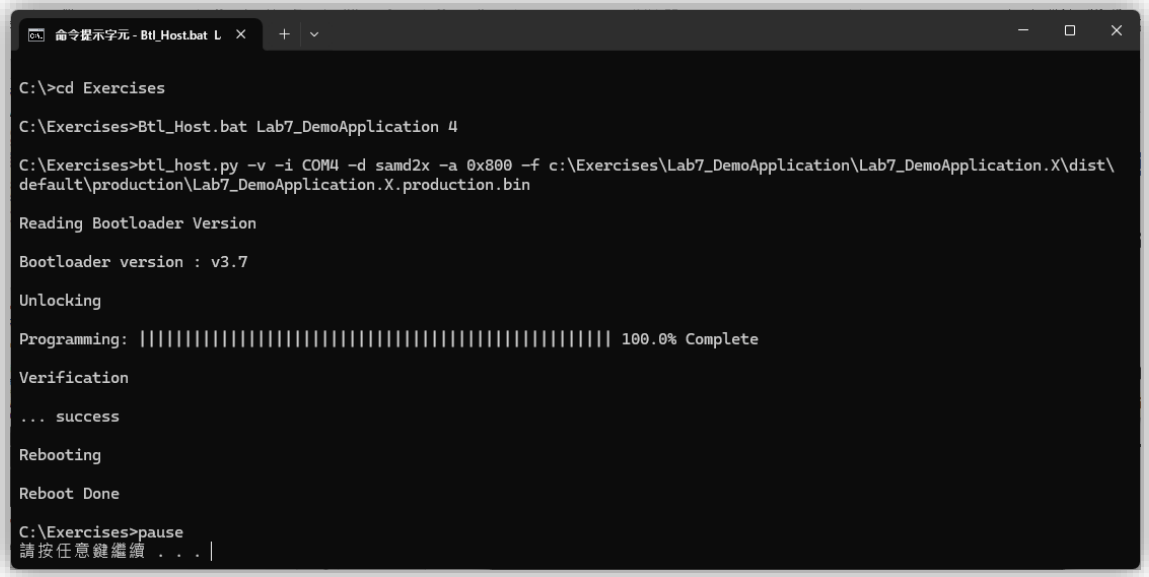
```
int main ( void )
{
    /* Initialize all modules */
    SYS_Initialize ( NULL );

    // TODO 7.03
    LED1_Set();
    LED2_Set();
    LED3_Set();

    while ( true )
    {
        /* Maintain state machines of all polled MPLAB Harmony modules. */
        SYS_Tasks ( );

        // TODO 7.02
        bootloader_UART_Tasks();
    }

    /* Execution should not come here during normal operation */

    return ( EXIT_FAILURE );
}
```

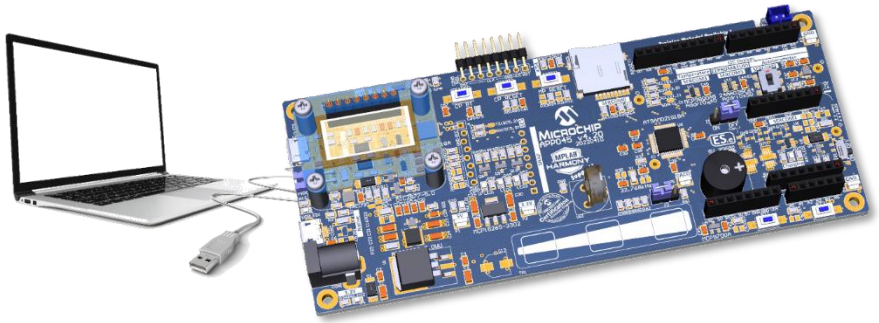
# 🛠 Lab7 UART Bootloader Initialize

- **Enter Bootloader mode automatically, because application invalid, after programming firmware.**
- **LED1 to 3 keep light to indicate Bootloader mode currently.**
- **Run *btl_host.bat* from the command line to perform a firmware update.**

```
Btl_Host.bat Lab7_DemoApplication 4
```

***Lab7_DemoApplication.bin*** **is the firmware built for use with the Bootloader, relocated to 0x800.**

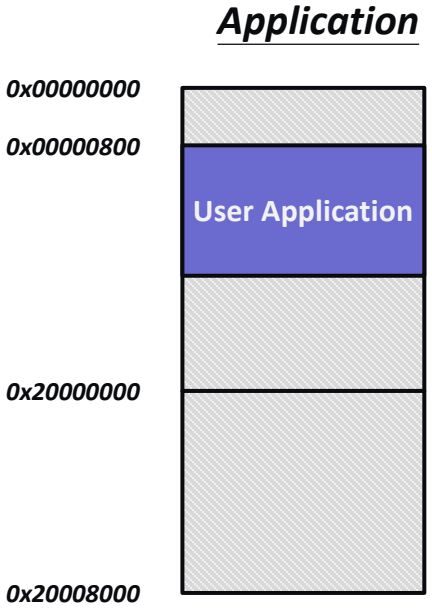


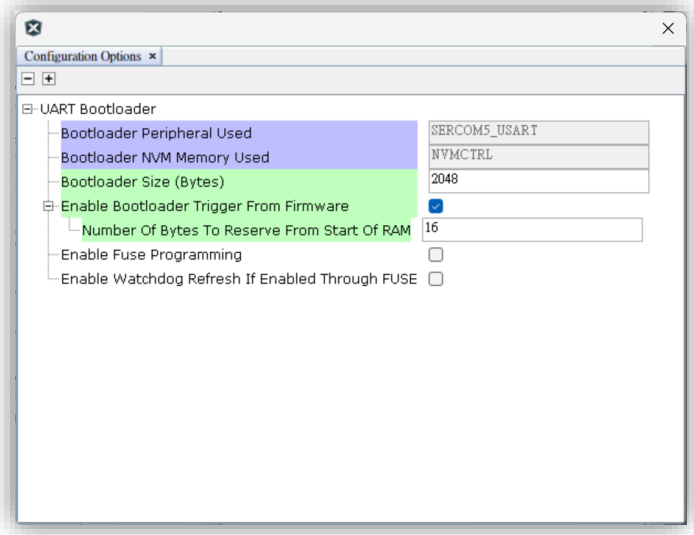



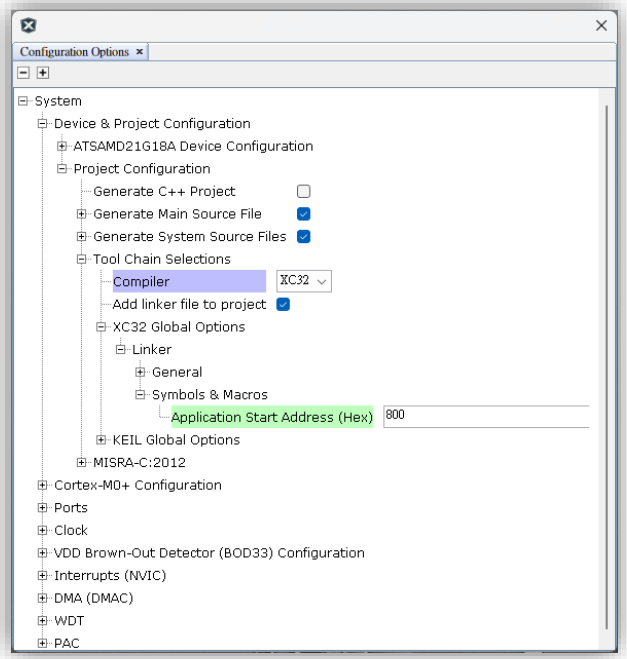
# Application Re-Arrangement

# Flash Re-Arrangement

- The UART bootloader occupies the first 0x800 bytes of flash; to preserve this region, the application must start at 0x800.
- For the Application start, you must set “Application Start Address (Hex)” under SYSTEM module in MHC let Bootloader know that how to handoff control to Application.

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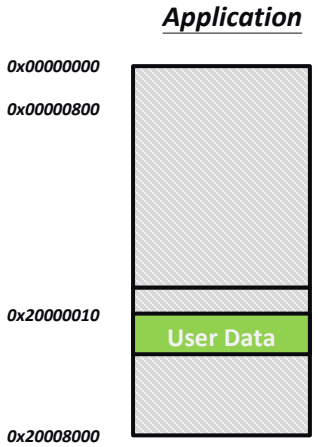
# SRAM Re-Arrangement

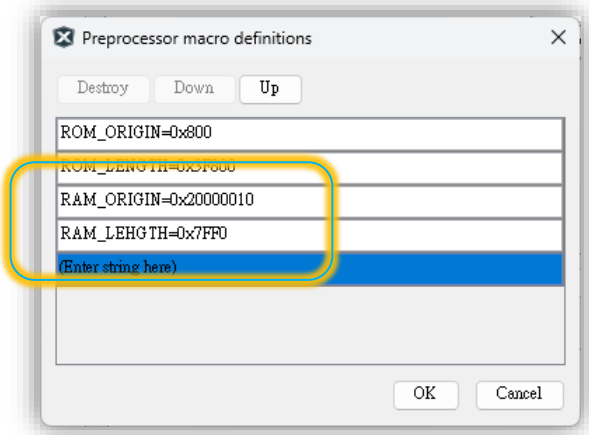
- For SRAM reserved, need manually define. Two method to do it.
  - At Linker symbols,

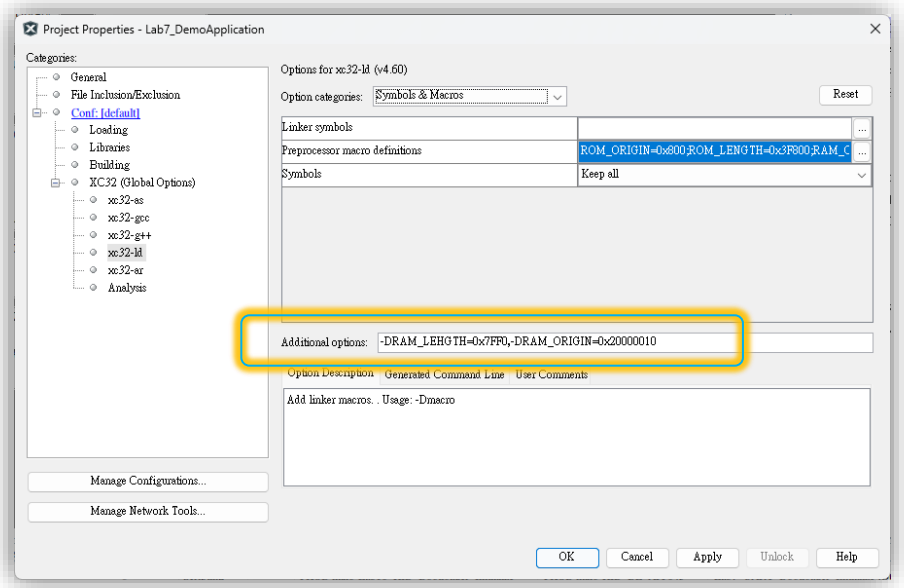
```
ROM_ORIGIN=0x800
ROM_LEHGTH=0x3F800
RAM_ORIGIN=0x20000010
RAM_LEHGTH=0x7FF0
```

  - At Additional optional,

```
-DRAM_ORIGIN=0x20000010,-DRAM_LEHGTH=0x7FF0
```

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# 🛠 Lab8 Demo Application Relocation

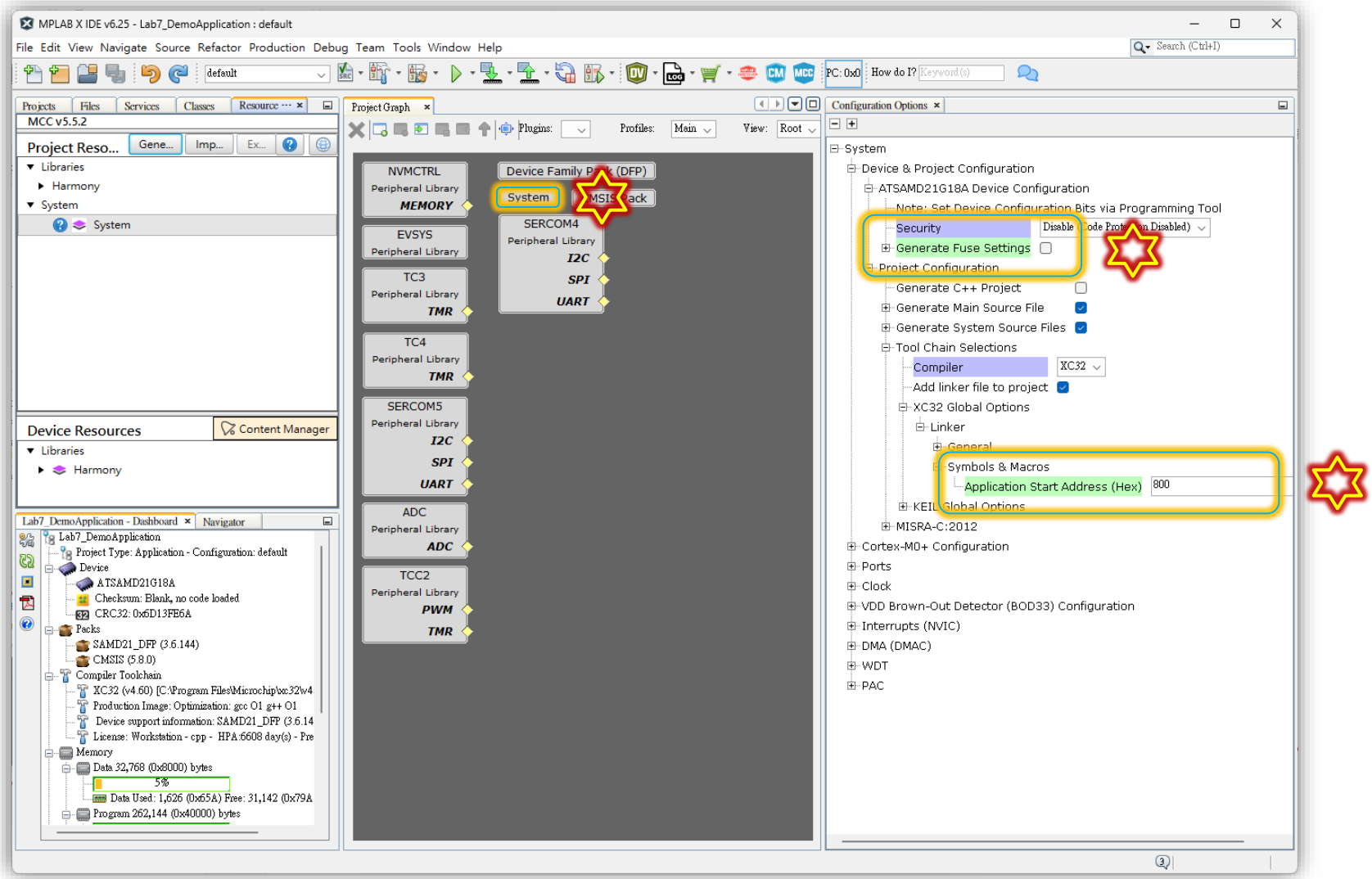
# 🛠 Lab8 Demo Application Relocation

- At this lab, we try to relocation and setting suitable parameter to fit UART Bootloader needs.
- Bypass Fuse via SYSTEM module in MHC.
- To set flash offset and  a reserved SRAM location.
- Set command line at “Execute After Build” generate a binary (.bin) file automatically after compilation.

- **Let’s go !**

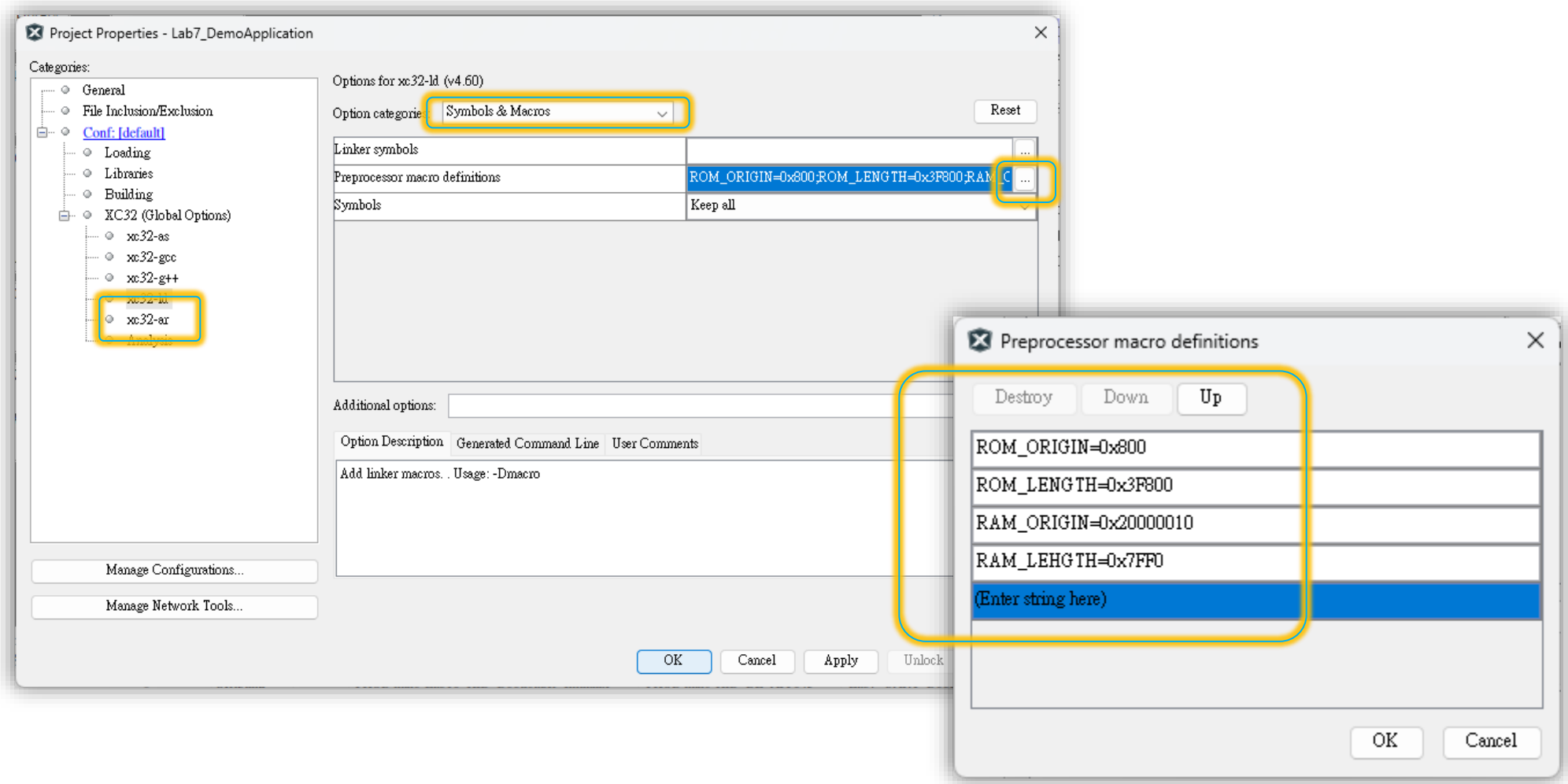
# 🛠 Lab8 Demo Application Relocation

- **Uncheck “Generate Fuse Settings” to bypass & set “Application Start Address”**



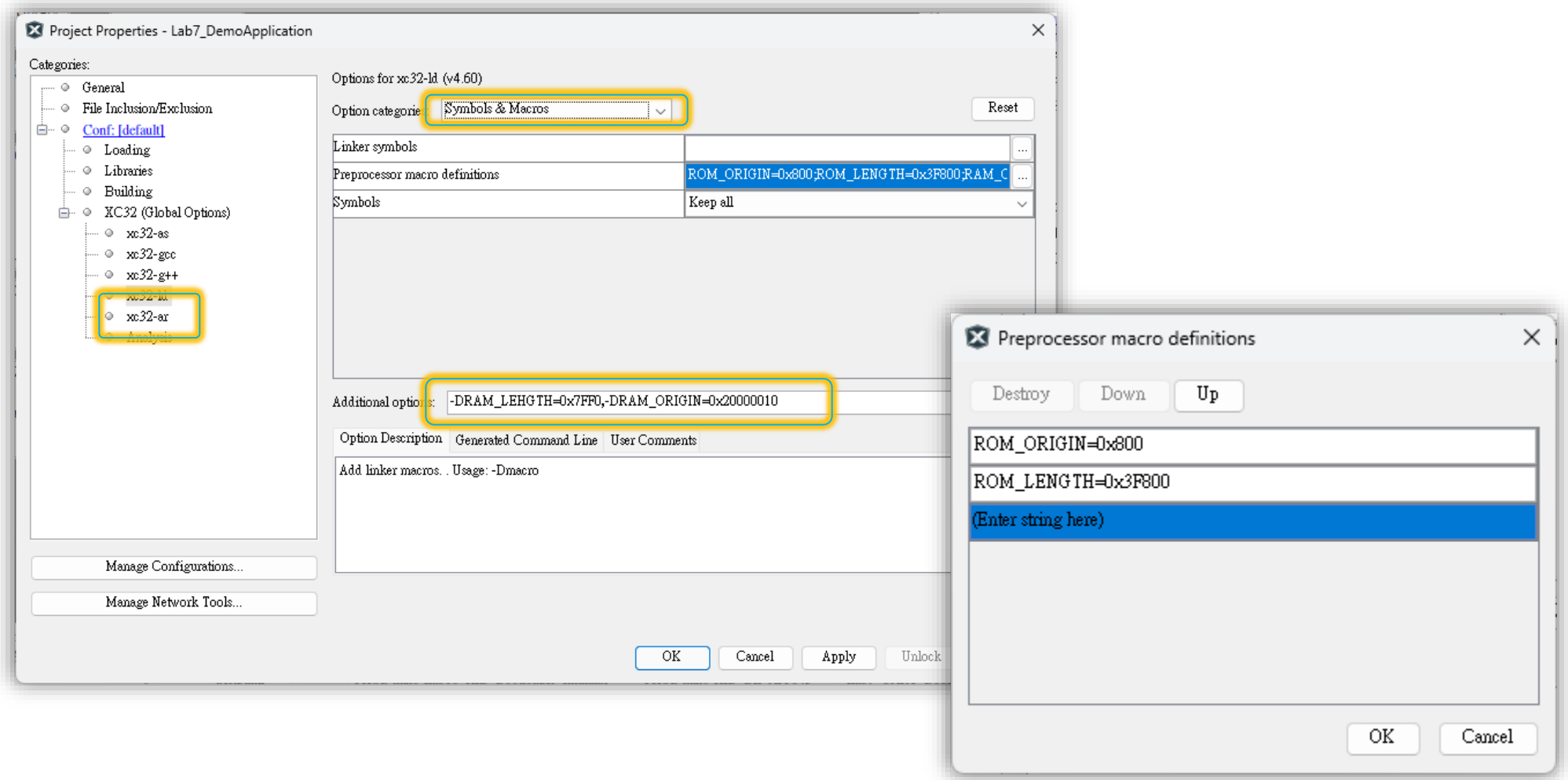
# 🛠 Lab8 Demo Application Relocation

- **Reserved SRAM location & Confirm Preprocessor Definition**



# 🛠 Lab8 Demo Application Relocation *Alternative*

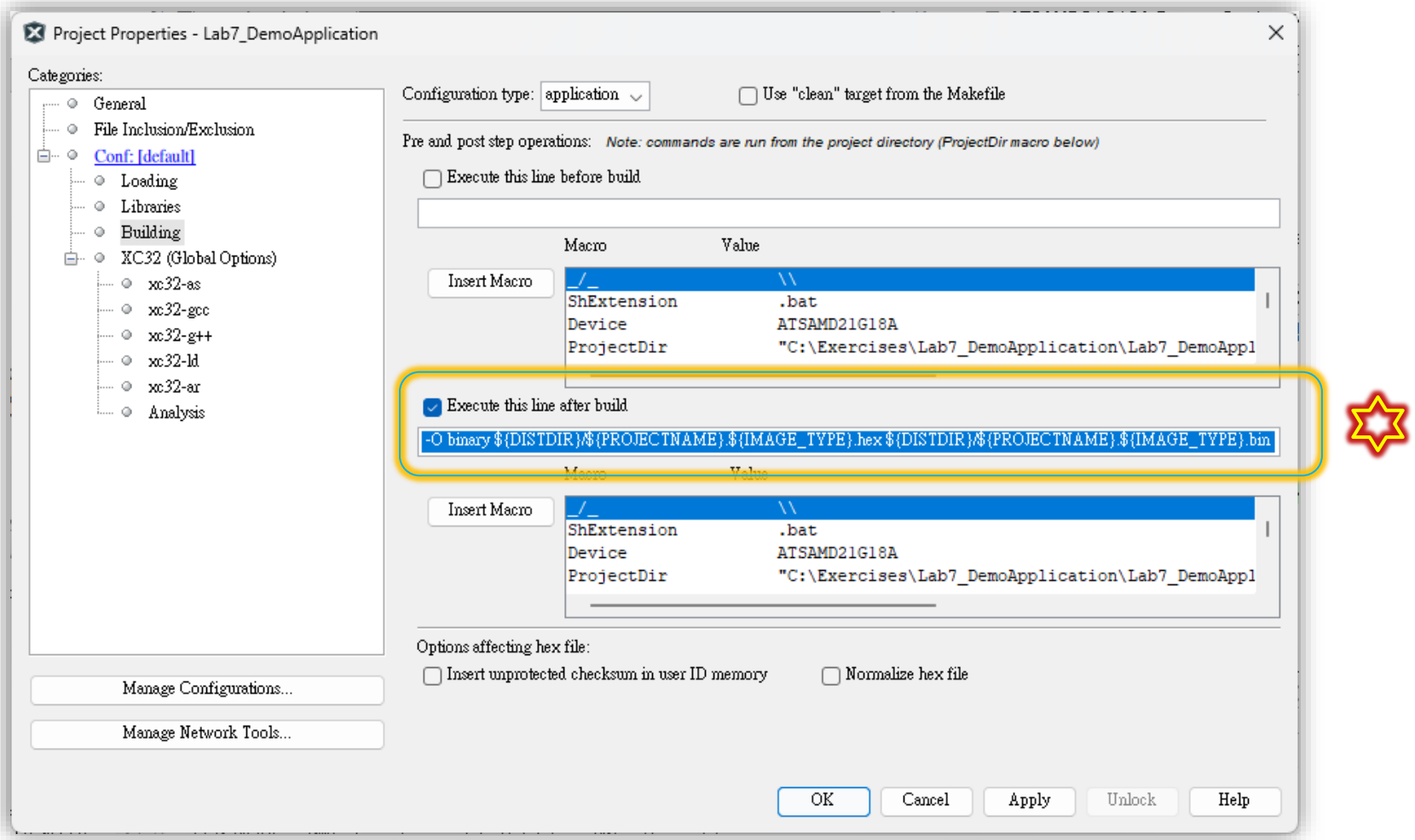
- **Reserved SRAM location & Confirm Preprocessor Definition**



# 🛠 Lab8 Demo Application Relocation

- **Check “Execute After Build” ” & set command line**

```
${MP_CC_DIR}/xc32-objcopy -I ihex -O binary ${DISTDIR}/${PROJECTNAME}.${IMAGE_TYPE}.hex ${DISTDIR}/${PROJECTNAME}.${IMAGE_TYPE}.bin
```



# 🛠 Lab8 Demo Application Relocation

- **Code Implementation state**

**Implement Bootloader Trigger method**
**TODO 8.01 - 8.02**

# 🛠 Lab8 Demo Application Relocation

- **Implement below function at main.c**

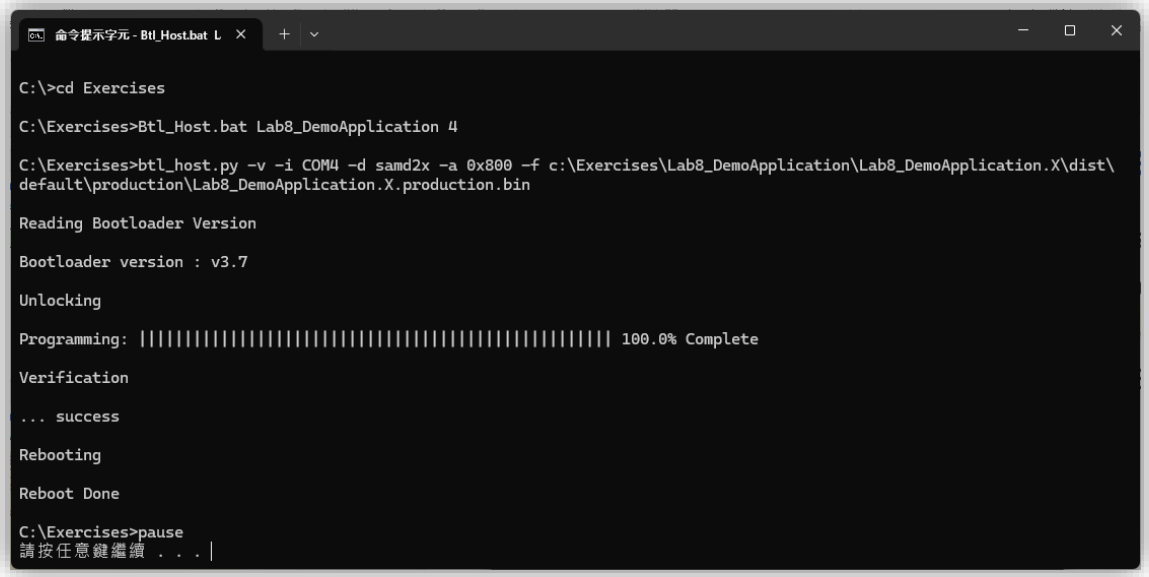
```
// TODO 8.01
#define BL_REQUEST              (0x5048434DU)
#define BL_REQUEST_LEN          (16)
#define BTL_TRIGGER_RAM_START   0x20000000U
static uint32_t *ramStart = (uint32_t *) BTL_TRIGGER_RAM_START;

int main(void)
{
    /* Initialize all modules */
    SYS_Initialize(NULL);

    while (true)
    {
        …
        // TODO 8.02
        if (!BT2_Get())
        {
            OLED_nCS_Clear();
            OLED_RS_Clear();
            memset(LCM_Blank, 0, 1024);
            LCM_DrawBitmap(0, 0, LCM_WIDTH, LCM_HEIGHT, LCM_Blank);
            sprintf((char *) USARTRTxBuffer, "Bootloader Trigger");
            LCM_DrawString(0, 0, (char *) USARTRTxBuffer);

            ramStart[0] = BL_REQUEST;
            ramStart[1] = BL_REQUEST;
            ramStart[2] = BL_REQUEST;
            ramStart[3] = BL_REQUEST;

            NVIC_SystemReset();
        }
    }
}
```

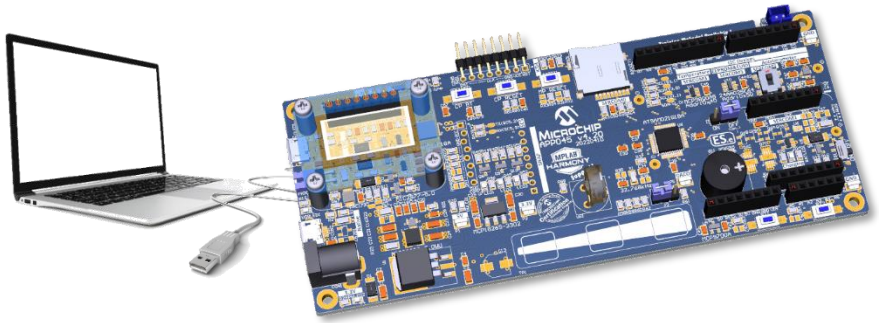
# 🛠 Lab8 Demo Application Relocation

- **Enter Bootloader mode via hold the BT1 & pressed Reset.**
- **Run *btl_host.bat* from the command line to perform a firmware update.**

```
Btl_Host.bat Lab7_DemoApplication 4
```

- **You could trigger bootloader mode via pressed BT2, after new firmware updated.**



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# Firmware Combine

# 🛠 Lab9 Bootloader Application Combine

- At this lab, we try to combine two firmware at a one. It more useful for factory firmware programming.
- The new one contains both firmware Bootloader and Application.
- Open Bootloader project firstly
  and load Application project via “loading” setting in Project Properties.

- **Let’s go !**

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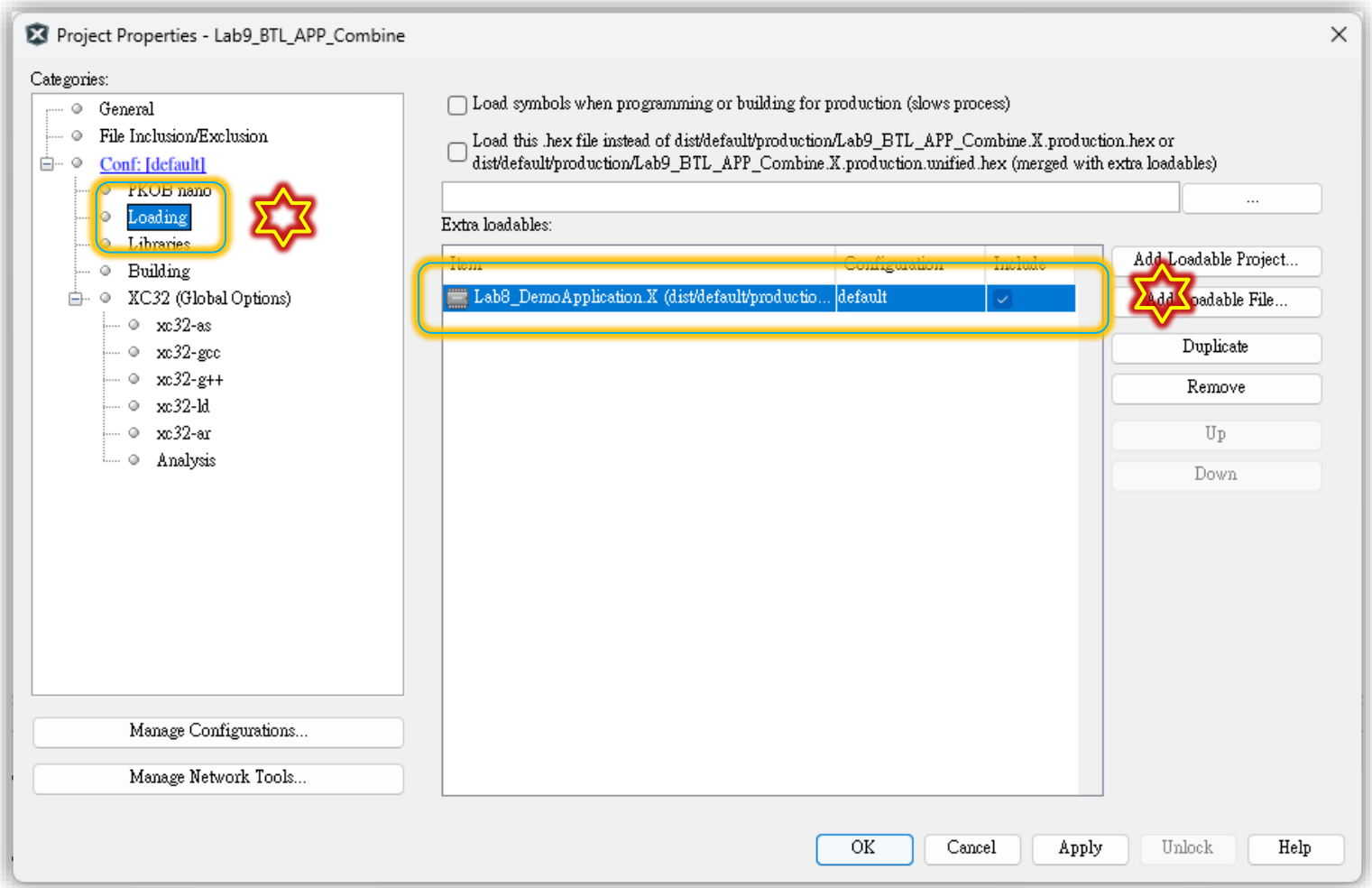
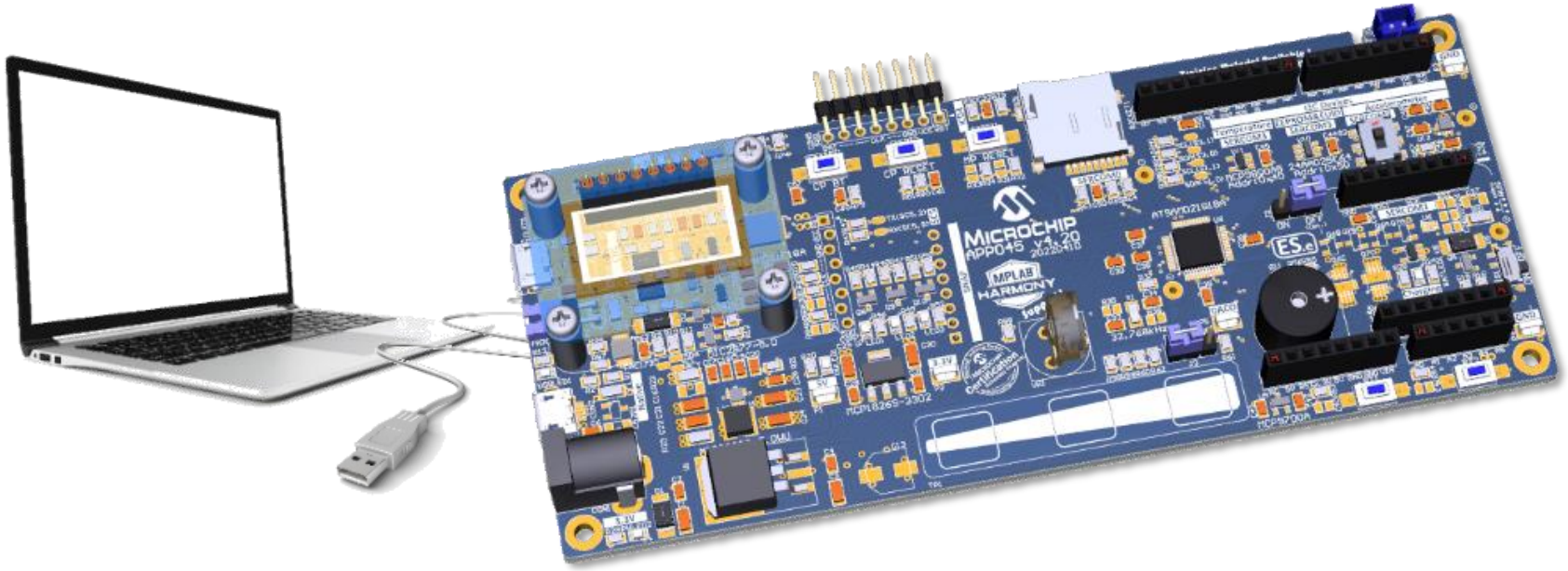
# 🛠 Lab9 Bootloader Application Combine

- load Application project via “loading” setting in Project Properties



# 🛠 Lab9 Bootloader Application Combine

- **The result same as lab8.**
- **But,**
  **Bootloader and Application programming together**
  **without via bootloader host (*btl_host.py*)**

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# USB Device HID Bootloader

# USB Device HID Bootloader

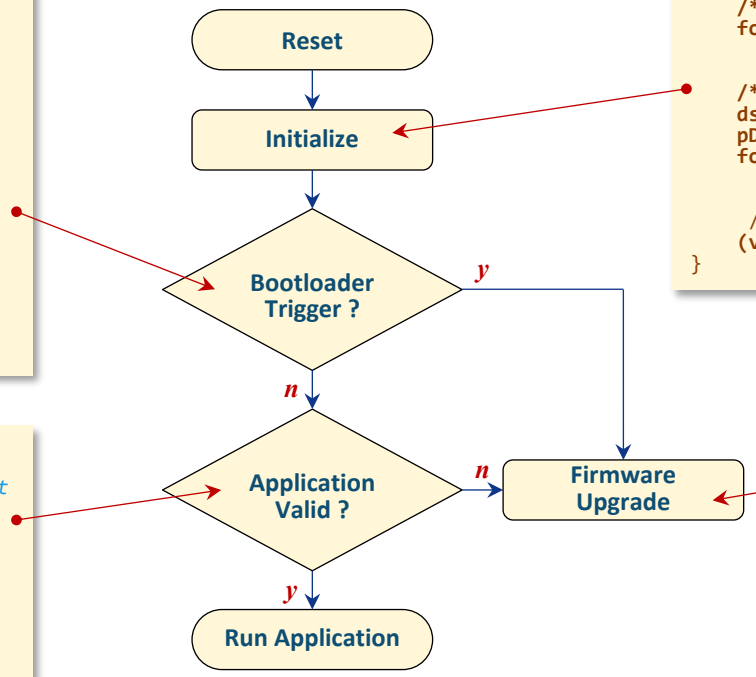
- Supported on Cortex-M based MCUs, MIPS based MCUs and MPUs
  e.g., ATSAMD21G18A (APP045 EVB), PIC32CX1025SG41128 (APP055 EVB), etc.
- Based on MCC Harmony USB Device HID driver to communicate.
- Takes Normalized Hex File as input
- Uses UBHA (Unified Bootloader Host Application)
  to receive the hex (*HEX) file from Host PC.
- Supports Live update.

# USB Device HID Bootloader

- **Below flowchart routine shows how to switch between the USB Device HID Bootloader and the Application at startup.**

```
#define BTL_TRIGGER_PATTERN (0x5048434DUL)
static uint32_t *ramStart = (uint32_t *)BTL_TRIGGER_RAM_START;

bool bootloader_Trigger(void)
{
    uint32_t i;

    …

    /* Check for Magic Number */
    if (BTL_TRIGGER_PATTERN == ramStart[0] &&
        BTL_TRIGGER_PATTERN == ramStart[1] &&
        BTL_TRIGGER_PATTERN == ramStart[2] &&
        BTL_TRIGGER_PATTERN == ramStart[3])
    {
        ramStart[0] = 0;
        DCACHE_CLEAN_BY_ADDR(ramStart, 4);
        return true;
    }

    /* Check for Button */
    if (!BT1_Get())
        return true;

    return false;
}
```

```
void run_Application(uint32_t address)
{
    uint32_t msp = *(uint32_t *)(address); // Application Start
    uint32_t reset_vector = *(uint32_t *)(address + 4U);

    if (msp == 0xffffffffU)
        return;

    …

    __set_MSP(msp); // Re-initial Stack Pointer
    asm("bx %0"::"r" (reset_vector)); // Jumper to Application
}
```




```
void __attribute__((noinline, section(".romfunc.Reset_Handler"))) Reset_Handler(void)
{
    register uint32_t count;
    uint32_t *pSrc, *pDst;
    uintptr_t src, dst;

    src = (uintptr_t)&_etext;
    pSrc = (uint32_t *)src;      /* flash functions start after .text */
    dst = (uintptr_t)&_sdata;
    pDst = (uint32_t *)dst;      /* boundaries of .data area to init */

    /* Init .data */
    for (count = 0U; count < (((uint32_t)&_edata - (uint32_t)dst) / 4U); count++)
        pDst[count] = pSrc[count];

    /* Init .bss */
    dst = (uintptr_t)&_sbss;
    pDst = (uint32_t *)dst;
    for (count = 0U; count < (((uint32_t)&_ebss - (uint32_t)dst) / 4U); count++)
        pDst[count] = 0U;

     /* Branch to application's main function */
    (void)main();
}
```

```
void bootloader_USB_DEVICE_HID_Tasks( void )
{
    switch ( )
    {
        case BOOTLOADER_OPEN_DATASTREAM: Break;
        case BOOTLOADER_GET_COMMAND: Break;
        case BOOTLOADER_PROCESS_COMMAND: Break;
        case BOOTLOADER_SEND_RESPONSE: Break;
        case BOOTLOADER_WAIT_FOR_DONE: Break;
        case BOOTLOADER_CLOSE_DATASTREAM: Break;
        case BOOTLOADER_ENTER_APPLICATION:
            bootloader_TriggerReset(); Break;
        case BOOTLOADER_ERROR: Break;
    }
    DATASTREAM_Tasks();
}
```

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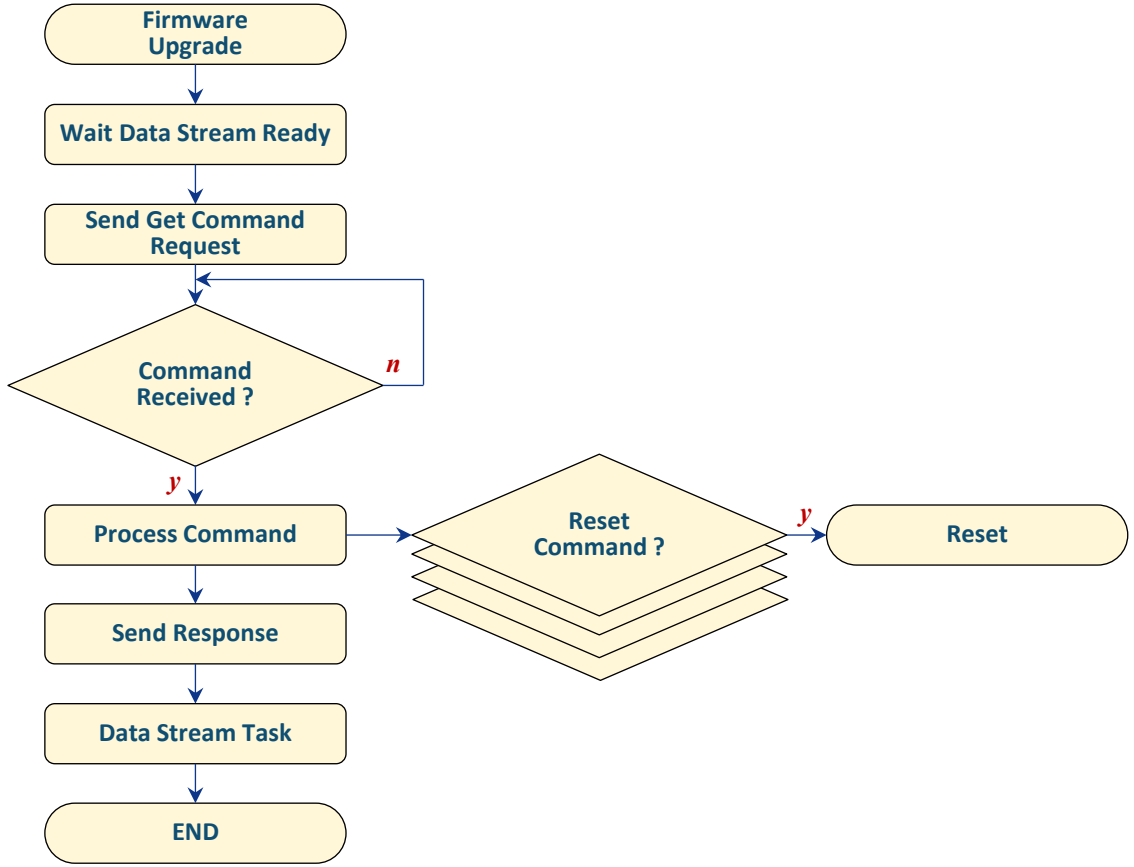
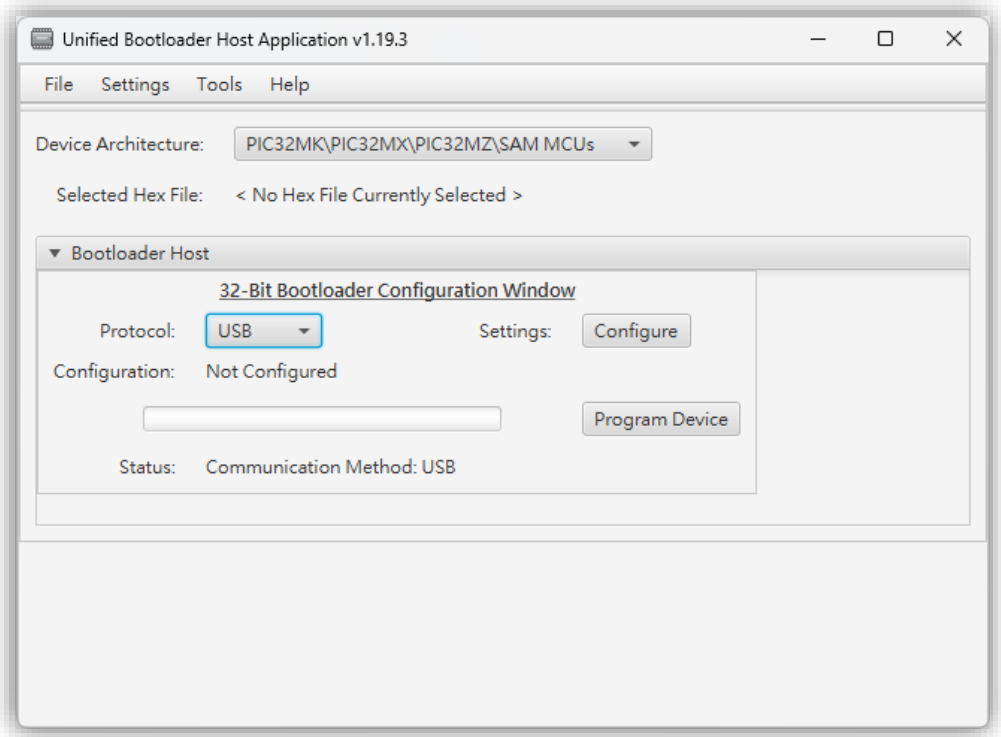
# USB Device HID Bootloader

- Below flowchart routine shows how the firmware upgrade works.
- Send command request and waiting command, parses commands, and executes them; upon receiving a reset command, the system reboots.



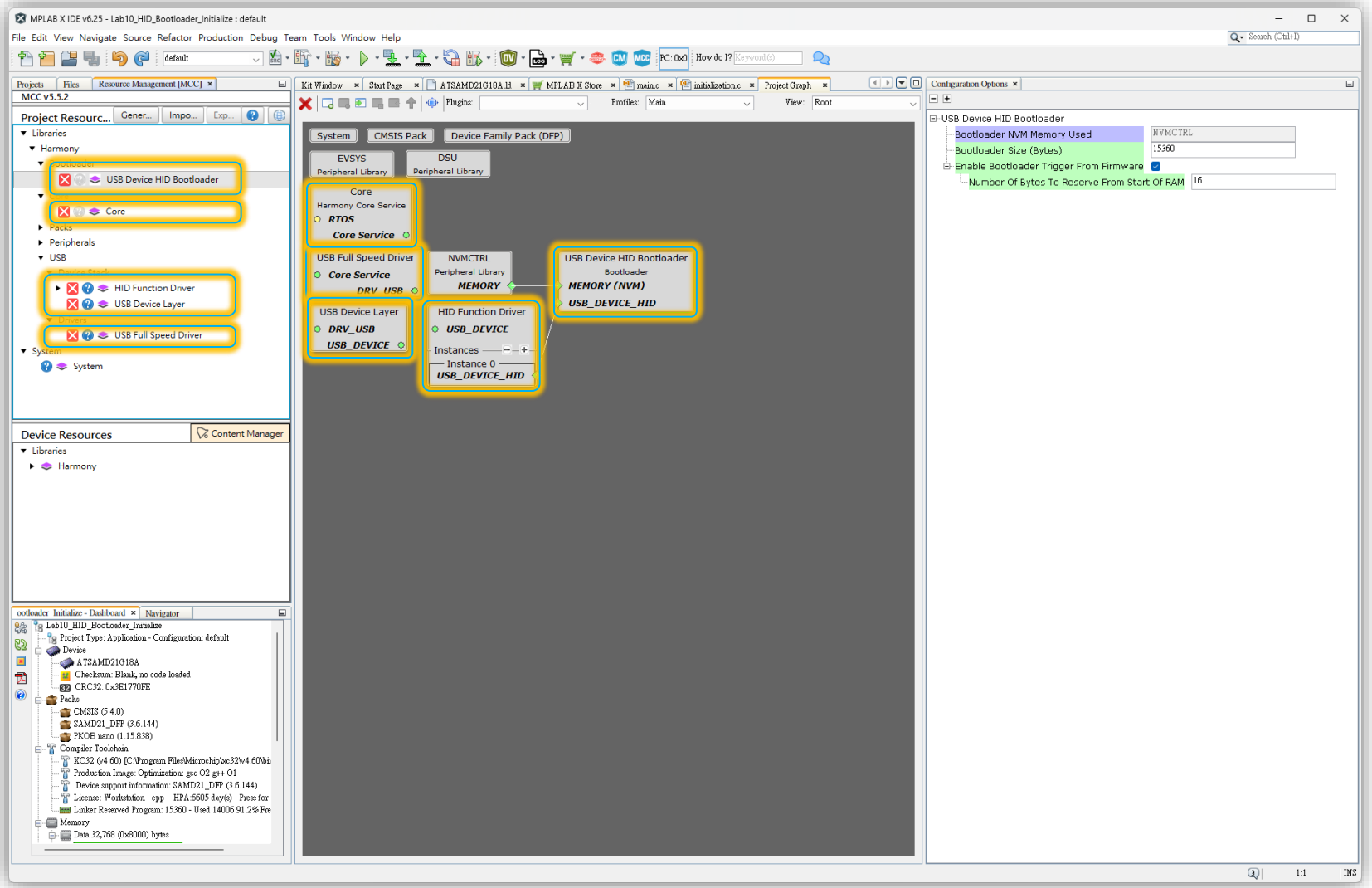
# Unified Bootloader Host Application

- **UBHA (Unified Bootloader Host Application) used to communicate with the USB Device HID Bootloader running on the device**
- **It implements the Unified bootloader protocol required to communicate from host PC**
- **It sends the Normalized Hex File of the application to be bootloader.**
- ***Important! UART Protocol is not supported in MCC Harmony using this tool.***



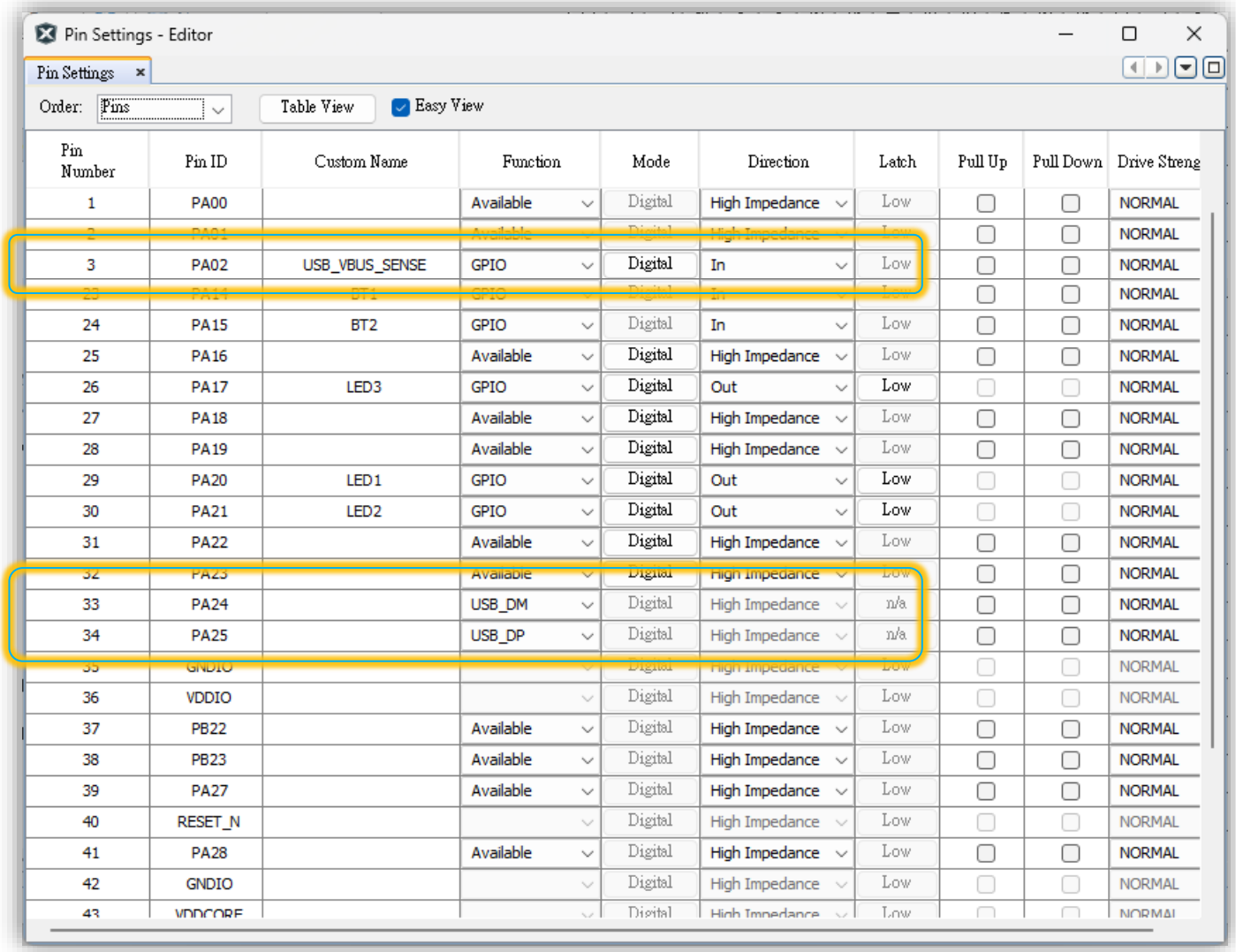
# Harmony Bootloader - USB Device HID Bootloader Configurator

## Add USB Device HID Bootloader and USB Device related in MHC



# Harmony Bootloader - USB Device HID Bootloader Configurator

## Configure USB related pins at Pin Table



# 🛠 Lab10 USB Device HID Bootloader Initialize

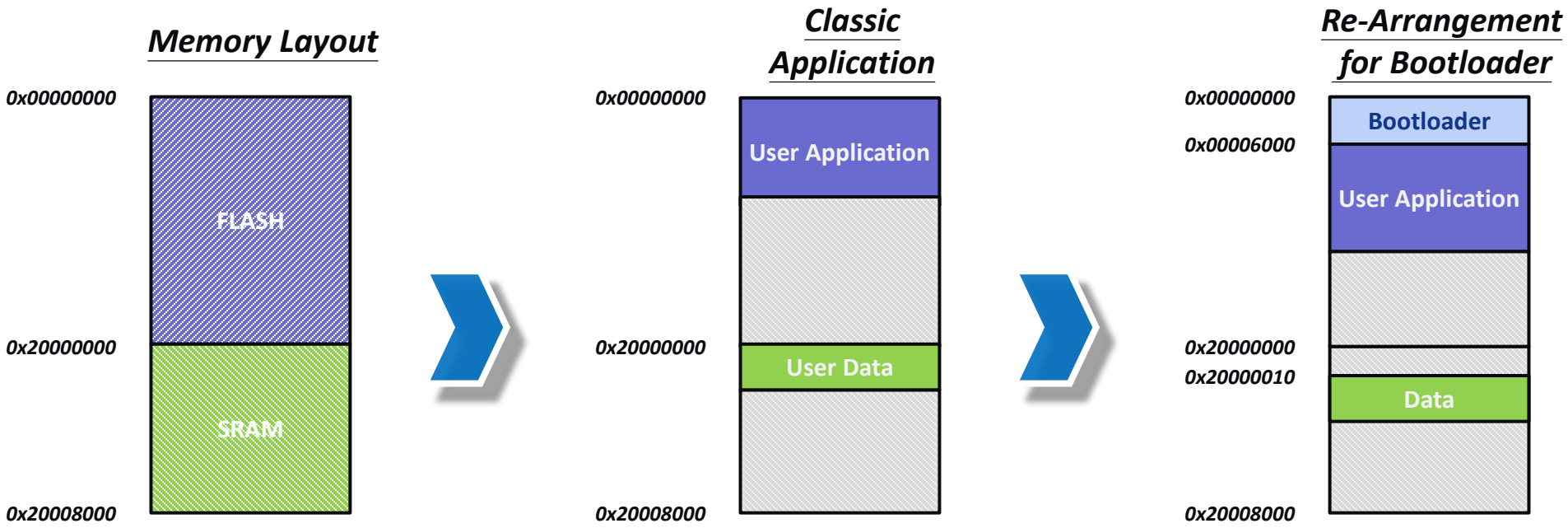
# 🛠 Lab10 USB Device HID Bootloader Initialize

- At this lab, we try to getting started with USB Device HID Bootloader.
- Add UART USB Device HID and USB Device related in MHC and assign parameters and application start address.
- Implement suitable bootloader trigger method use to trigger Bootloader.
- Implement an LEDs status to indicate Bootloader enter or not.
- Try to use UBHA to upload “DemoApplicationUSB” firmware to APP045 EVB via USB Device HID based on USB Device HID Bootloader.

- **Let’s go !**

# Memory Re-Arrangement for Bootloader *ATSAMD21 as an Example*

- **In USB Device HID Bootloader application,**
  **Bootloader occupies the first 0x6000 bytes of flash and the first 16 Bytes of SRAM.**

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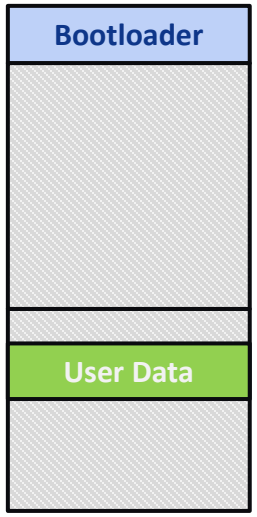
# Memory Re-Arrangement for Bootloader *cont.* *ATSAMD21 as an Example*

- **Set two independent linker scripts (**.ld*),**
  **one for the Bootloader and one for the Application to define their memory allocations.**
- **In the linker scripts,**
  **reserved separately for the Bootloader and the Application.**

***Bootloader***



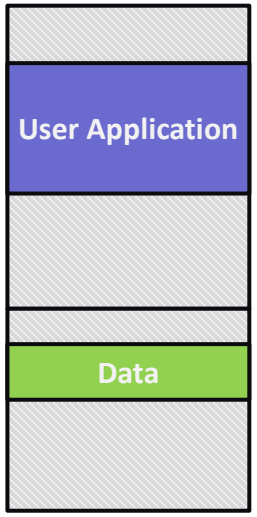

***Linker Script for Bootloader***

```
MEMORY
{
  rom (LRX) : ORIGIN = 0x0, LENGTH = 0x6000
  ram (WX!R) : ORIGIN = 0x20000010, LENGTH = 0x7FF0
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

***Linker Script for Application***

```
MEMORY
{
  rom (LRX) : ORIGIN = 0x6000, LENGTH = 0x3A000
  ram (WX!R) : ORIGIN = 0x20000010, LENGTH = 0x7FF0
  config_00804000 : ORIGIN = 0x00804000, LENGTH = 0x4
  config_00804004 : ORIGIN = 0x00804004, LENGTH = 0x4
}
```

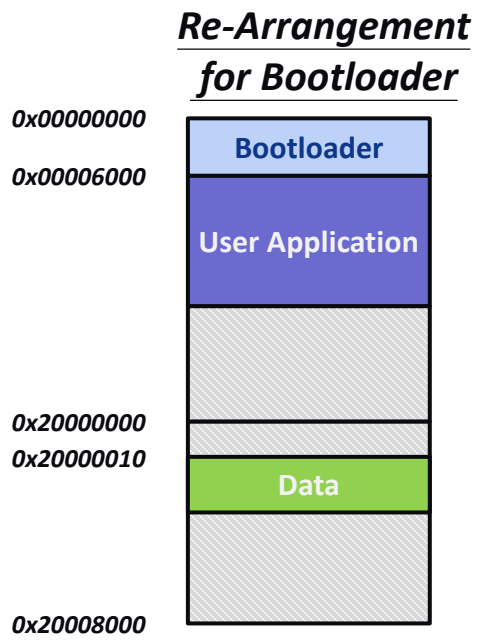
***Application***



# Link Script for ATSAMD21x18A

- In MCC Harmony project, apply preprocessor definition to dynamic management linker script.
  The corresponding file will be generated
  after press “generate” button at MHC depend on your setting.
  - For Bootloader *(Optional)*,
    -DROM_ORIGIN = *0x00000000*, -DROM_LEHGTH = *0x6000*
    -DRAM_ORIGIN = *0x20000010*, -DRAM_LEHGTH = *0x7FF0*

  For User Application,
    -DROM_ORIGIN = *0x00006000*, -DROM_LEHGTH = *0x3A000*
    -DRAM_ORIGIN = *0x20000010*, -DRAM_LEHGTH = *0x7FF0*




- These definitions are applied in the linker script,
  and during the linking process,
  they ensure that the program code and data are in the designated memory areas.

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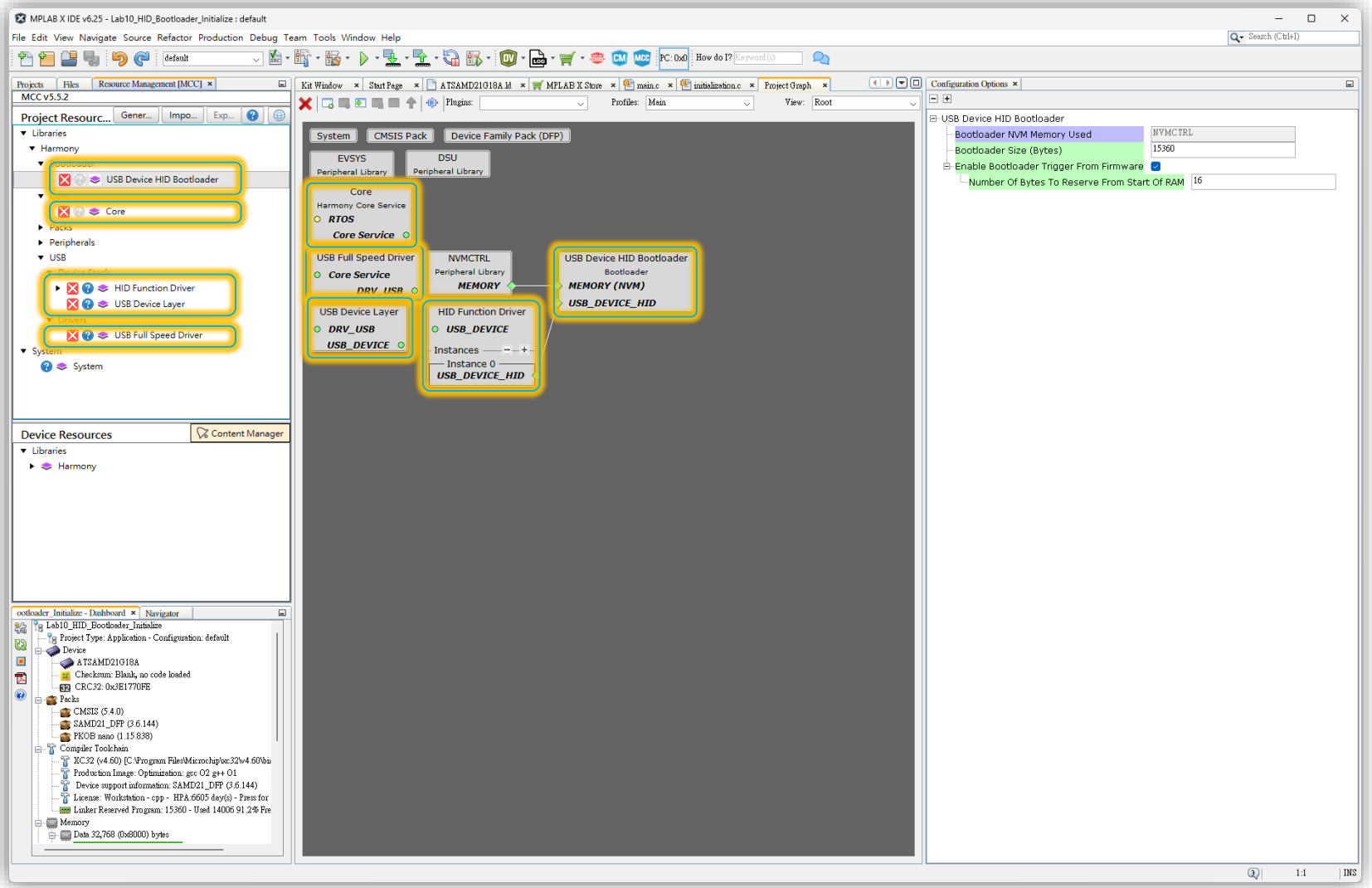
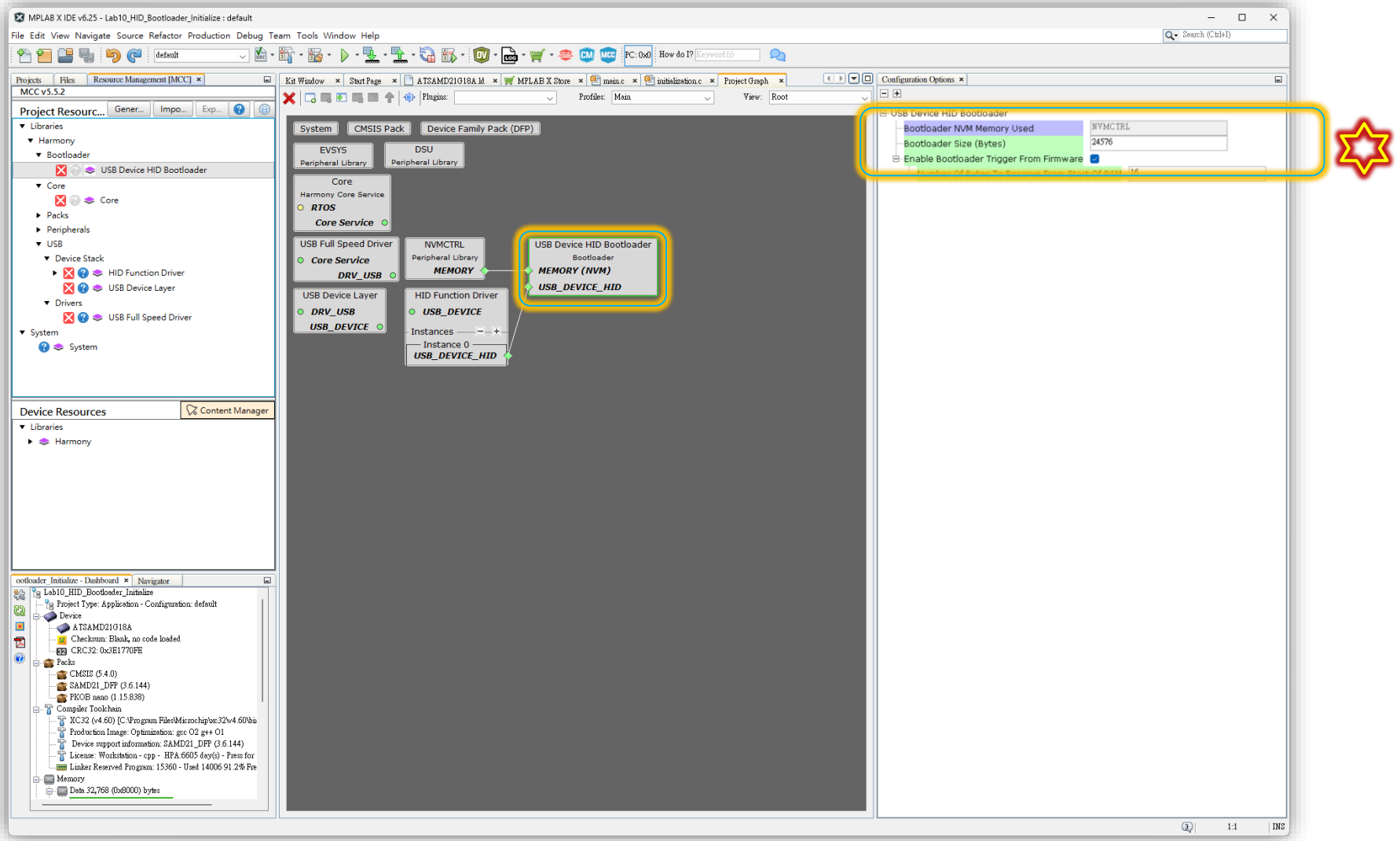
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Create a new project and USB Device HID Bootloader and USB Device related in MHC.**



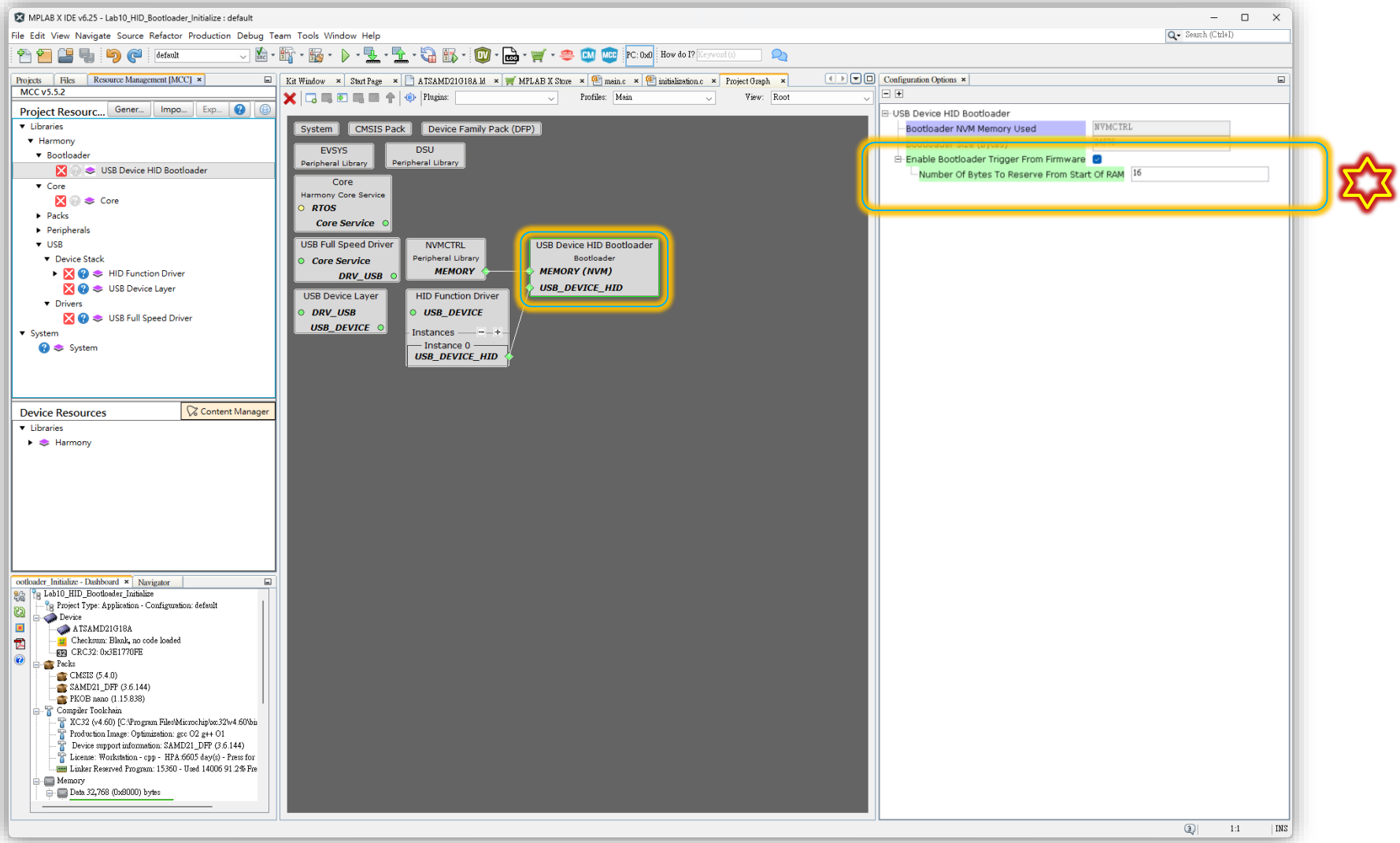
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Set “Bootloader Size (Bytes)” to 24576.**



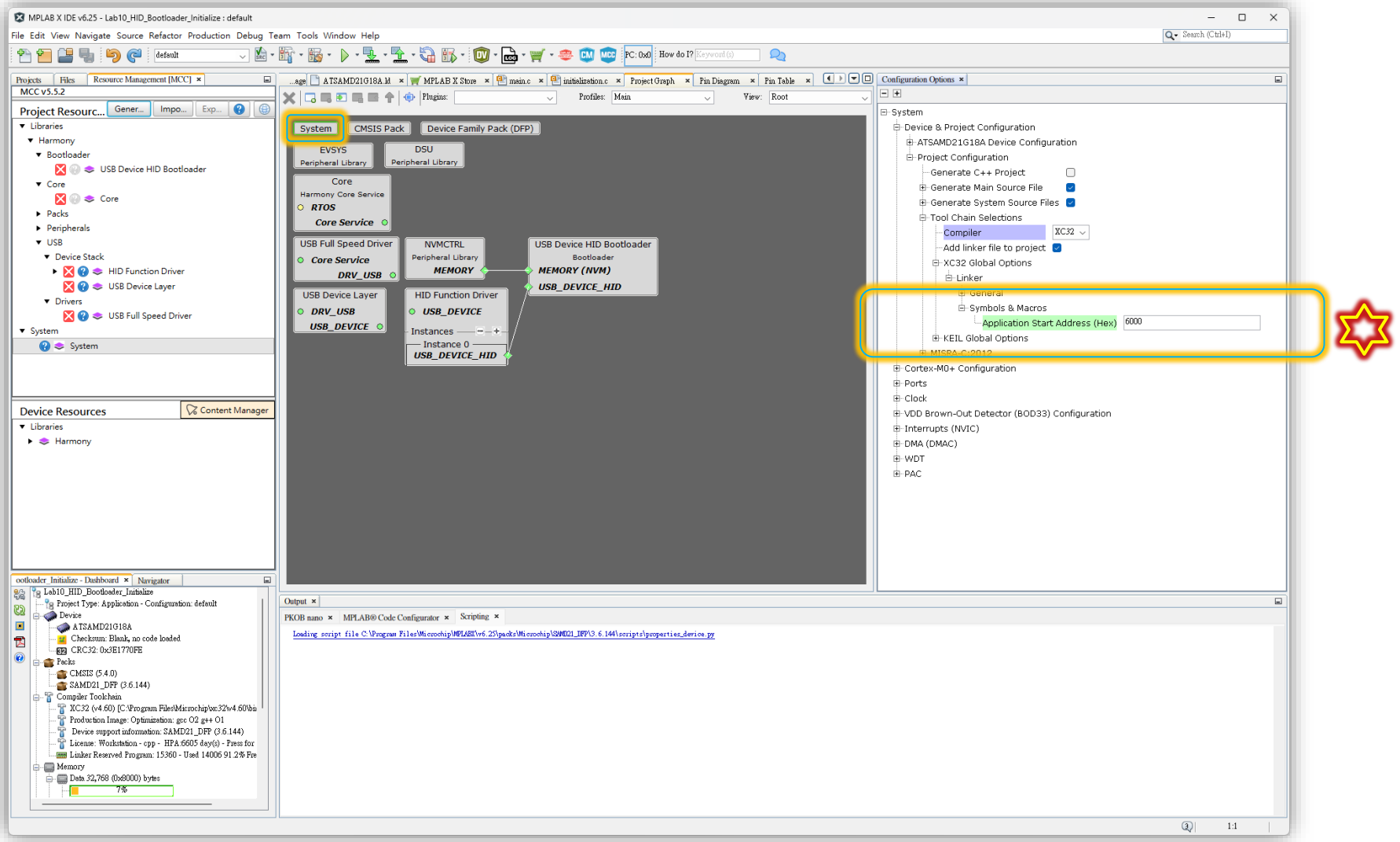
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Check “Enable Bootloader Trigger From Firmware” and Reserve 16 bytes RAM.**



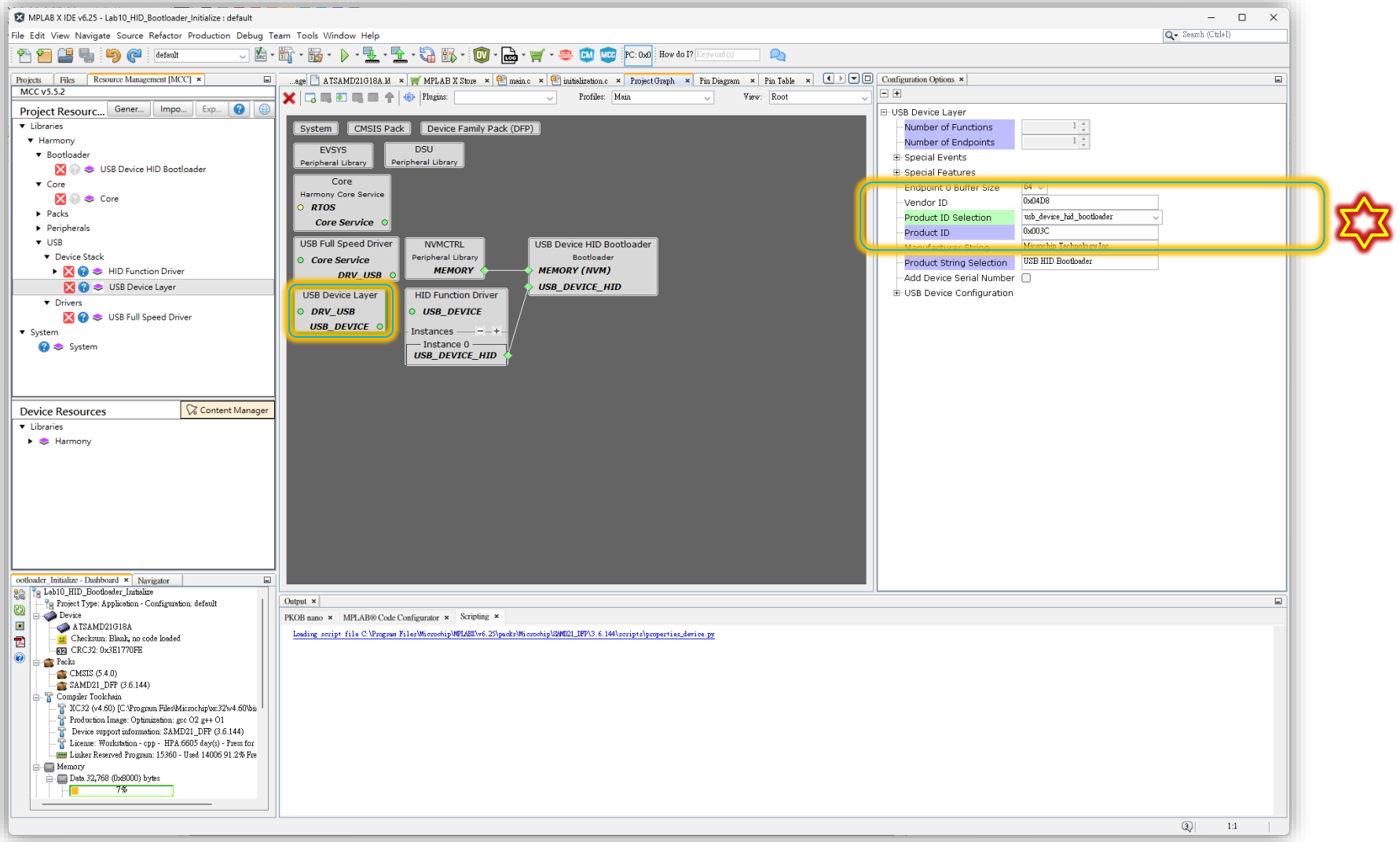
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Check Application Start Address (Hex) is 6000.**



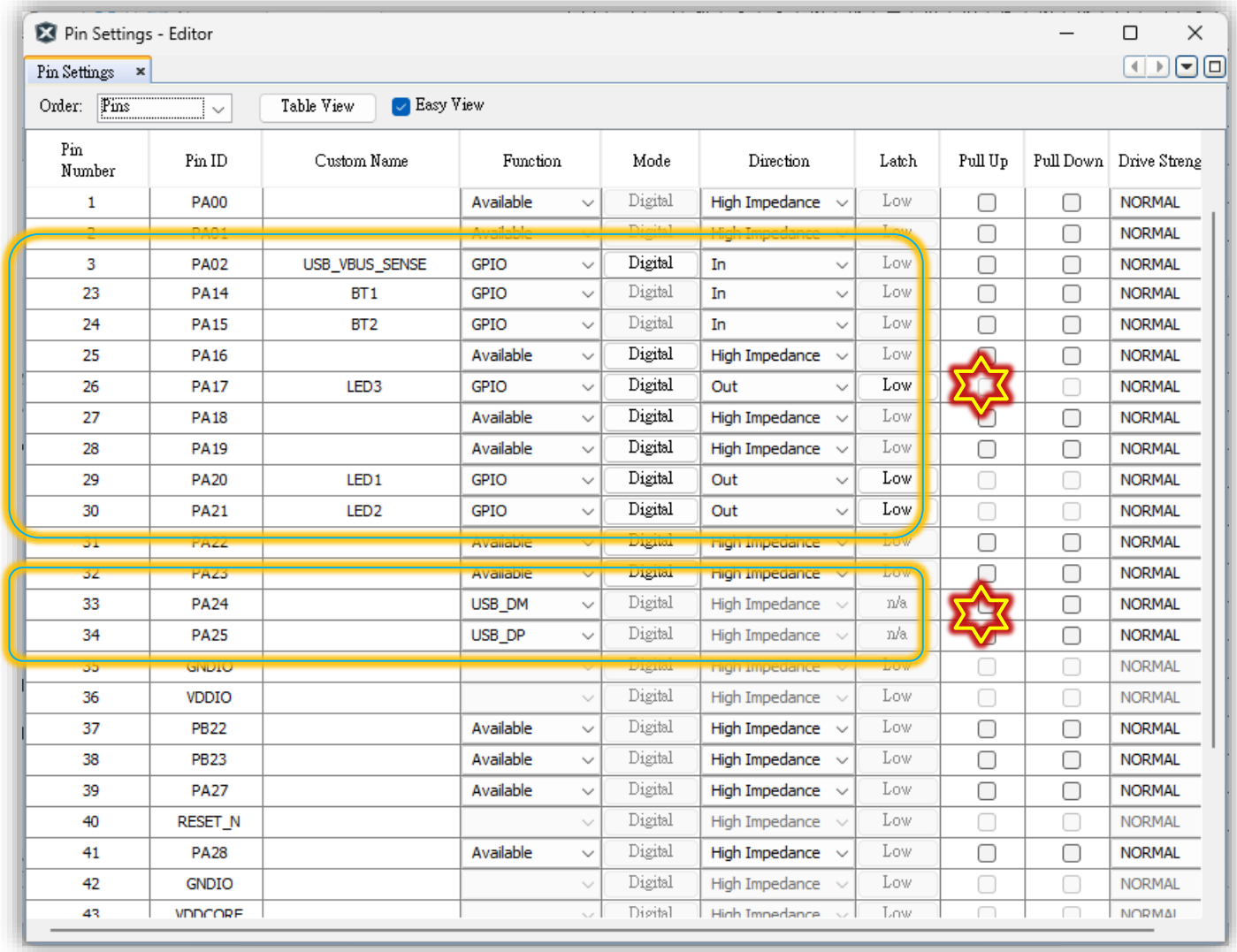
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Set VID/PID to 0x04D8, 003C (usb_device_hid_bootloader).**



# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Configure USB related and Application pins at Pin Table**




| Pin Number | Pin ID | Custom Name | Function | Mode | Direction | Latch | Pull Up | Pull Down | Drive Streng |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PA00 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 3 | PA02 | USB_VBUS_SENSE | GPIO | Digital | In | Low | ☐ | ☐ | NORMAL |
| 23 | PA14 | BT1 | GPIO | Digital | In | Low | ☐ | ☐ | NORMAL |
| 24 | PA15 | BT2 | GPIO | Digital | In | Low | ☐ | ☐ | NORMAL |
| 25 | PA16 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 26 | PA17 | LED3 | GPIO | Digital | Out | Low | ☐ | ☐ | NORMAL |
| 27 | PA18 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 28 | PA19 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 29 | PA20 | LED1 | GPIO | Digital | Out | Low | ☐ | ☐ | NORMAL |
| 30 | PA21 | LED2 | GPIO | Digital | Out | Low | ☐ | ☐ | NORMAL |
| 33 | PA24 | | USB_DM | Digital | High Impedance | n/a | ☐ | ☐ | NORMAL |
| 34 | PA25 | | USB_DP | Digital | High Impedance | n/a | ☐ | ☐ | NORMAL |
| 36 | VDDIO | | | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 37 | PB22 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 38 | PB23 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 39 | PA27 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 40 | RESET_N | | | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 41 | PA28 | | Available | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |
| 42 | GNDIO | | | Digital | High Impedance | Low | ☐ | ☐ | NORMAL |

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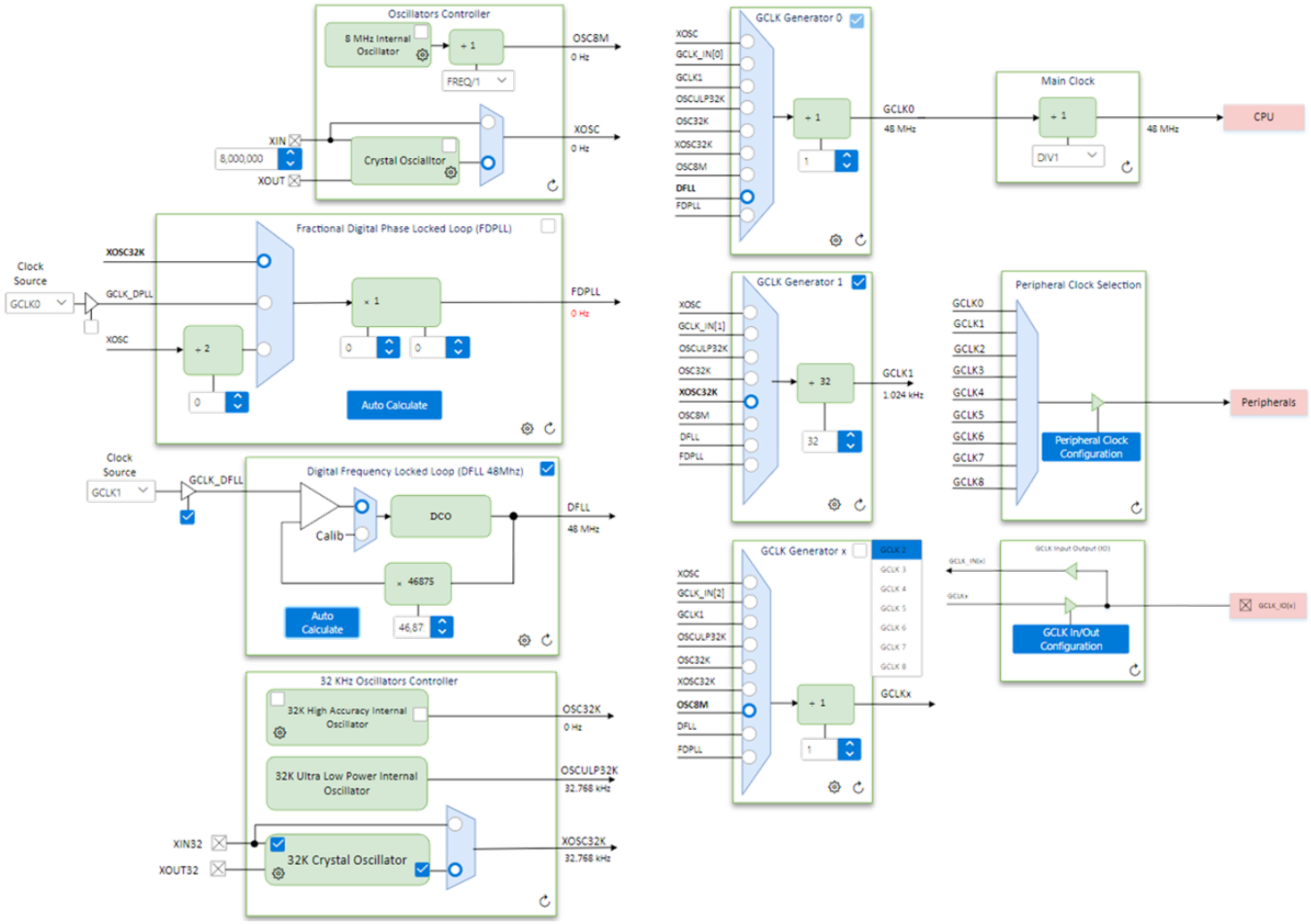
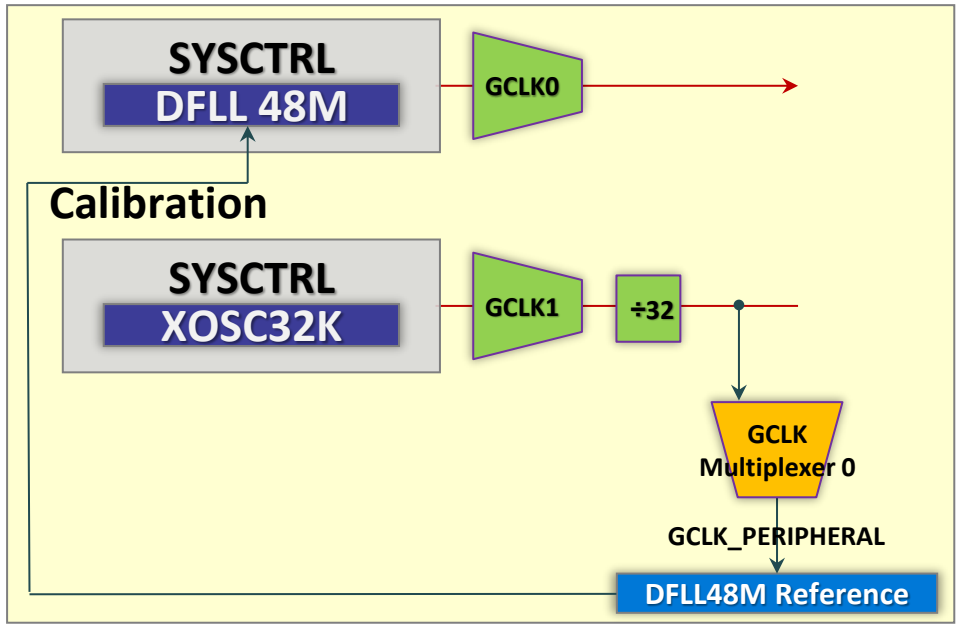
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Configure DFLL48M as Close loop as source of main clock**




## Close Loop

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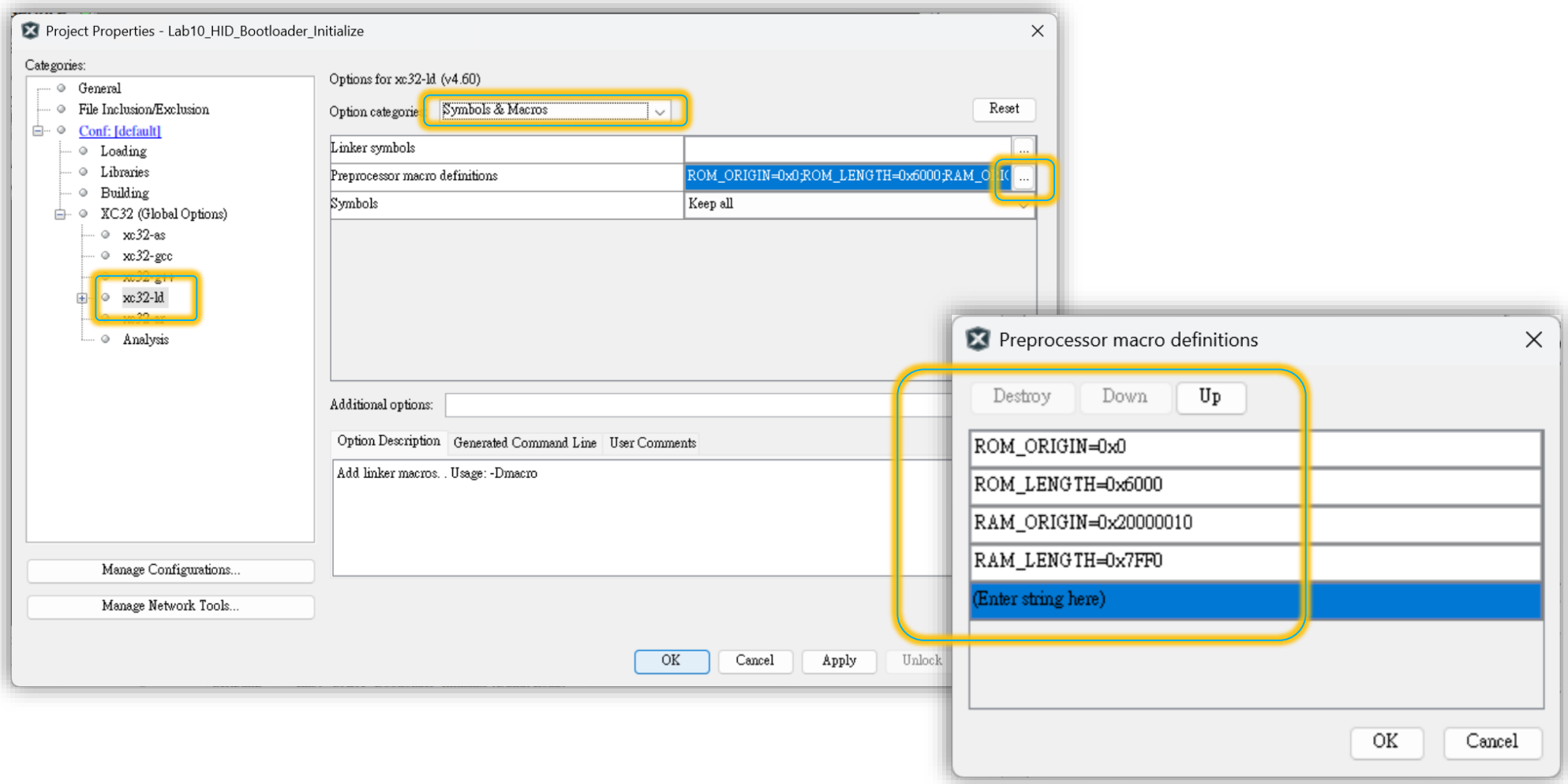
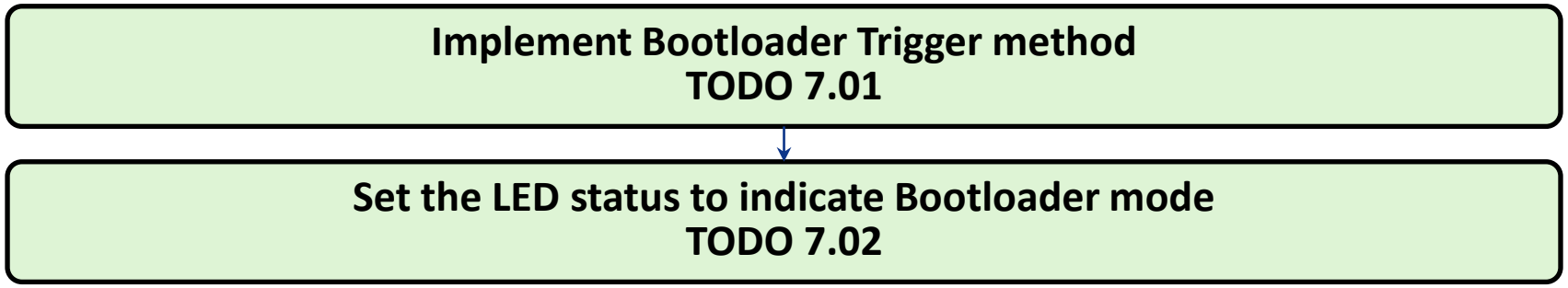
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Confirm Preprocessor Definition**



# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Code Implementation state**



# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Implement below function at main.c**

```
// TODO 10.01
#define BTL_TRIGGER_PATTERN (0x5048434DUL)
static uint32_t *ramStart = (uint32_t *)BTL_TRIGGER_RAM_START;

bool bootloader_Trigger(void)
{
    uint32_t i;

    for (i = 0; i < 2000; i++)
        asm("nop");

    if (BT1_Get() == 0)
        return true;

    if (BTL_TRIGGER_PATTERN == ramStart[0] && BTL_TRIGGER_PATTERN == ramStart[1] &&
        BTL_TRIGGER_PATTERN == ramStart[2] && BTL_TRIGGER_PATTERN == ramStart[3])
    {
        ramStart[0] = 0;
        ramStart[1] = 0;
        ramStart[2] = 0;
        ramStart[3] = 0;
        return true;
    }

    return false;
}
```

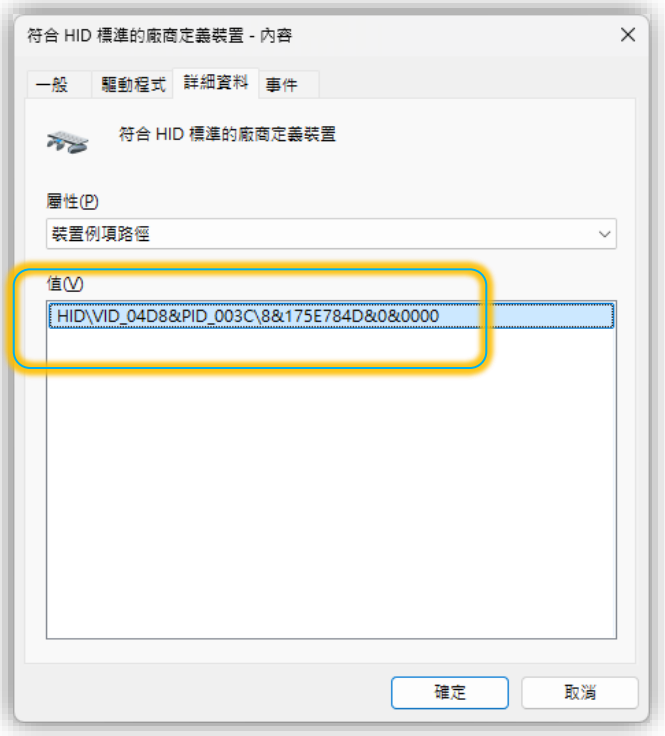
# 🛠 Lab10 USB Device HID Bootloader Initialize

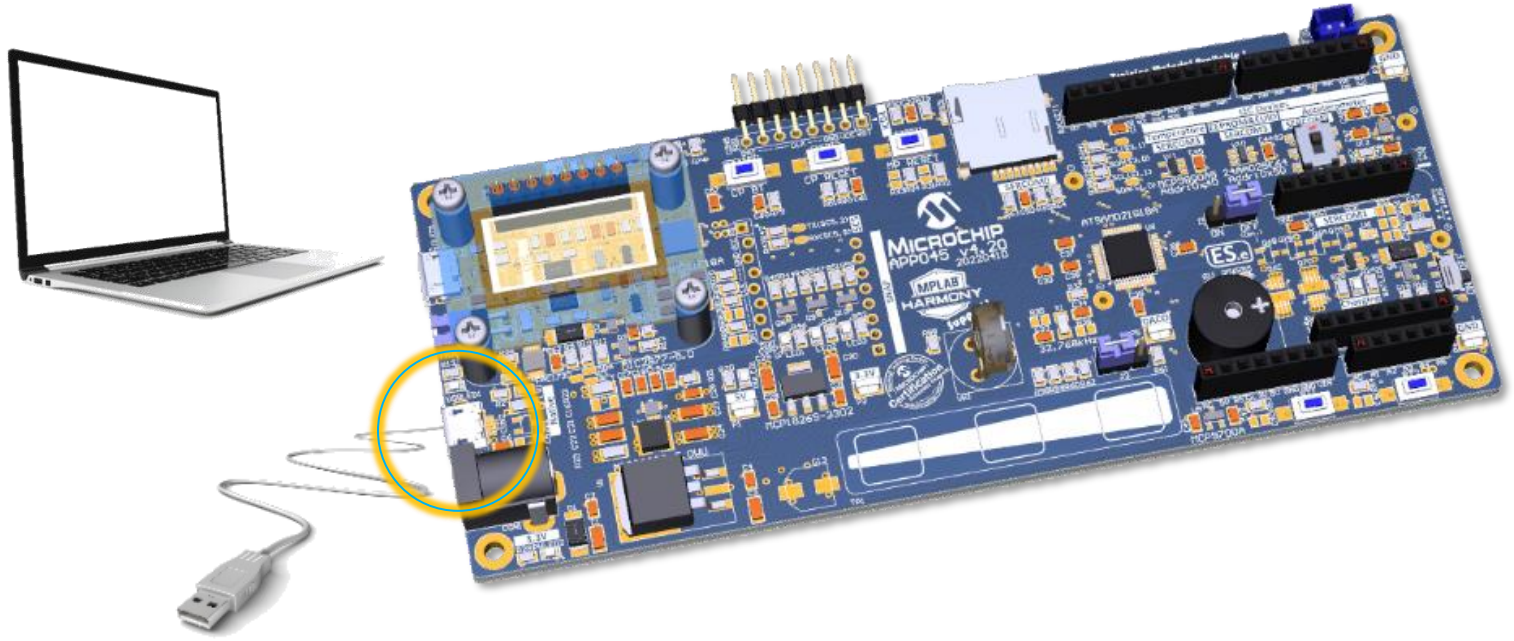
- **Implement below function at main.c**

```
int main ( void )
{
    /* Initialize all modules */
    SYS_Initialize ( NULL );

    // TODO 10.02
    LED1_Set();
    LED2_Set();
    LED3_Set();

    while ( true )
    {
        /* Maintain state machines of all polled MPLAB Harmony modules. */
        SYS_Tasks ( );

    }

    /* Execution should not come here during normal operation */

    return ( EXIT_FAILURE );
}
```

# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Re-connect USB cable to CON2 after programming USB Device HID Bootloader.**
- **Check HID Bootloader is work, you will see the device at device manager.**

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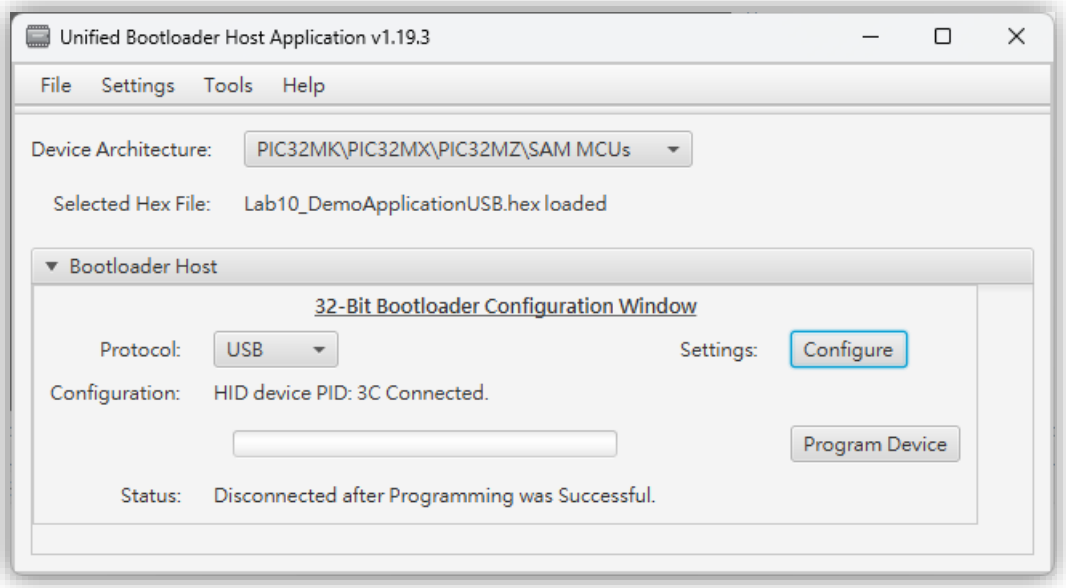
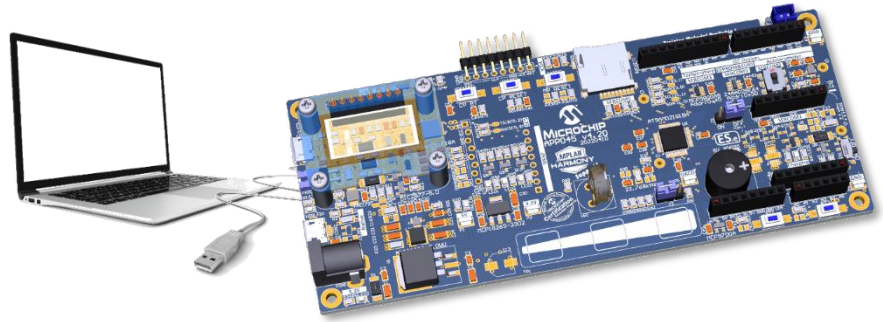
# 🛠 Lab10 USB Device HID Bootloader Initialize

- **Enter Bootloader mode automatically, because application invalid, after programming firmware.**
- **LED1 to 3 keep light to indicate Bootloader mode currently.**
- **Run *UBHA Host* and set protocol is USB, Setting PID is 0x3C, perform a firmware update after load application firmware (*Lab10_DemoApplicationUSB.hex*) *Lab10_DemoApplicationUSB.hex* is the firmware built for use with the Bootloader, relocated to 0x6000.**



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