STM32 - Tools for development, programming and debugging

A tool-chain is a set of programs which are used to develope, compile, debug and monitor an application. Setting up a complete toolchain can help to speed up the development, as they are configured to work together, mainly in automated scripts or having shared data format.

#arm #stm32 #toolchain

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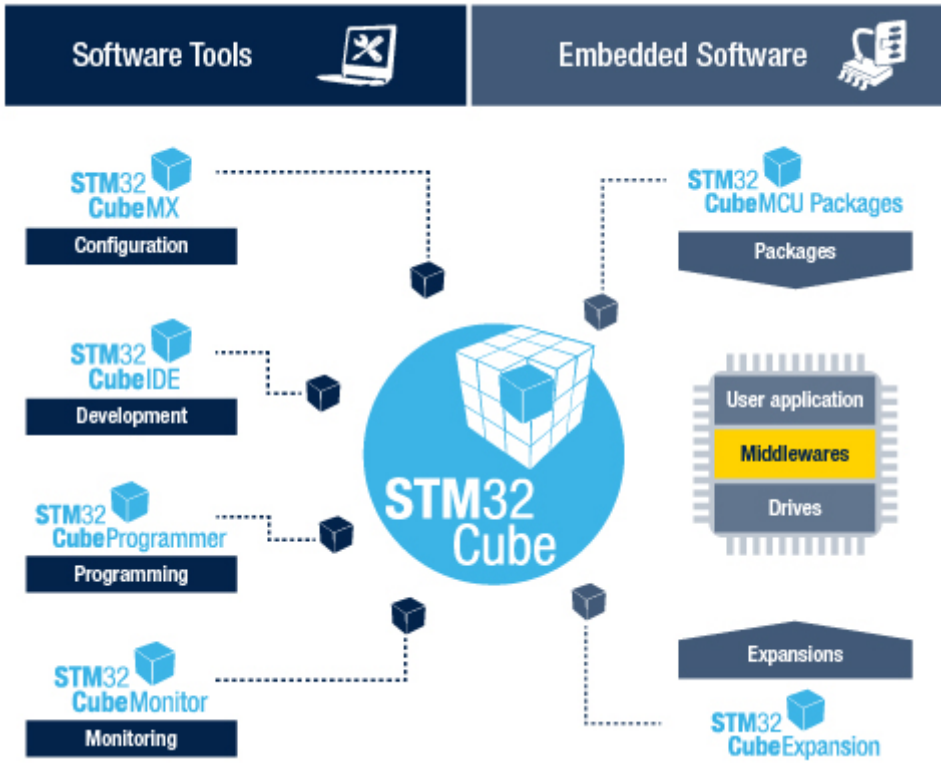
Table of Content

1. STM32 Ecosystem

A tool-chain is a set of programming tools that allow developers to:

1. Configure the settings on the target MCU
2. Write code and navigate inside source files of the project
3. Inspect the code to show additional information about variables, function definitions, etc.
4. Compile the source code to an executable application
5. Program the target MCU
6. Debug the application running on the target MCU
7. Monitor the application on the target MCU

The STM32Cube ecosystem is a complete software solution for STM32 microcontrollers and microprocessors. It has a complete toolchain and extended packages to well support developers on STM32 MCUs.



STM32 Ecosystem

STM32CubeMX, a configuration tool for any STM32 device. This easy-to-use graphical user interface generates initialization C code for Cortex-M cores and generates the Linux device tree source for Cortex-A cores.

STM32CubeIDE, an Integrated Development Environment. Based on open-source solutions like Eclipse or the GNU C/C++ toolchain, this IDE includes compilation reporting features and

advanced debug features. It also integrate additional features present in other tools from the ecosystem, such as the HW and SW initialization and code generation from STM32CubeMX. This software includes:

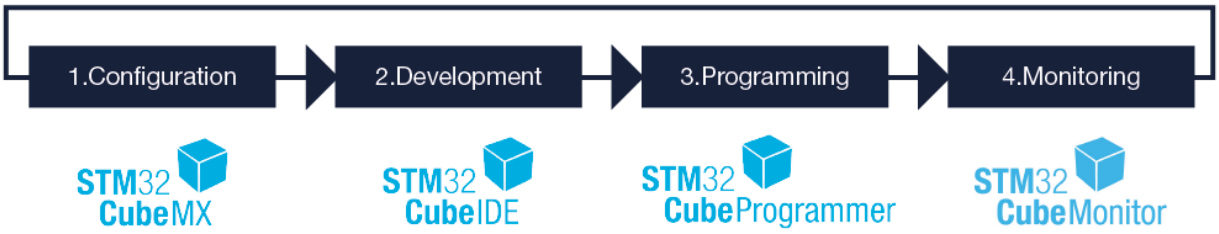
- Eclipse IDE - an open source code editor and manager which supports many plugins such as C/C++ Development Platform, GCC Cross Compiler, GDB Hardware Debugger, Make and build scripts.
- GNU ARM Cross-compiler with ST patch for STM32 MCUs - a compiler that converts code to executable and linkable file (.elf) or binary file (.bin, .hex).
- GDB for inspecting, debugging the target application.

STM32CubeProgrammer, a programming tool. It provides an easy-to-use and efficient environment for reading, writing and verifying devices and external memories via a wide variety of available communication media (JTAG, SWD, UART, USB DFU, I2C, SPI, CAN, etc.).

STM32CubeMonitor, a monitoring tool. Powerful monitoring tools that help developers fine-tune the behavior and performance of their applications in real time.

STM32Cube MCU and MPU packages, dedicated to each STM32 series. Packages offer all the required embedded software bricks to operate the available set of STM32 peripherals. They include drivers (HAL, low-layer, etc.), middleware, and lots of example code used in a wide variety of real-world use cases.

STM32Cube expansion packages, for application-oriented solutions. Complementing and expanding the STM32Cube MCU Package offer with additional embedded software bricks, STM32 expansion packages come either from ST or approved partners to create an extensive and scalable embedded software offer around the STM32.



4 steps of an interactive development process

2. STMCubeIDE

STM32CubeIDE is an advanced C/C++ development platform with peripheral configuration, code generation, code compilation, and debug features for STM32 microcontrollers and microprocessors. It is based on the Eclipse®/CDT framework and GCC toolchain for the

development, and GDB for the debugging. It allows the integration of the hundreds of existing plugins that complete the features of the Eclipse® IDE.

This tool includes the STM32CubeMX for code generation. At any time during the development, the user can return to the initialization and configuration of the peripherals or middleware and regenerate the initialization code with no impact on the user code written in the user blocks.

STM32CubeIDE includes build and stack analyzers that provide the user with useful information about project status and memory requirements.

STM32CubeIDE also includes standard and advanced debugging features including views of CPU core registers, memories, and peripheral registers, as well as live variable watch, Serial Wire Viewer interface, or fault analyzer.

> Other IDEs that support ARM Cortex:
>
> - ARM®, Atollic TrueSTUDIO®: was bought by ST, included in STM32CubeIDE
> - Keil™, MDK-ARM™: only free for STM32F0 and STM32L0 processes
> - Altium®, TASKING™ VX-toolset: paid license
> - IAR™, EWARM (IAR Embedded Workbench®): paid license

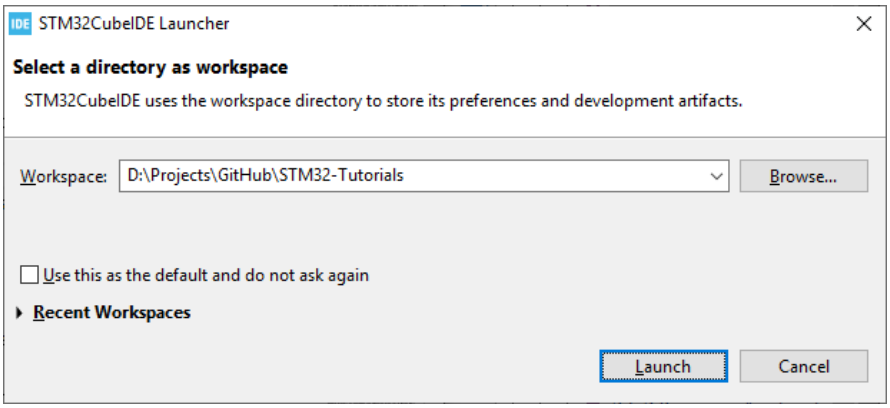
2.1. Installation

Download STM32CubeIDE | STM32CubeIDE User Manual

During the installation, please be suare to install ST-LINK and SEGGER J-Link drivers.

2.2. Create a workspace

When start the program, it will ask to select a directory as a workspace - the location to save projects. Consider to make new workspaces for different big projects.



Select a workspace

Each workspace has its own **Preferences** settings under the **Windows** menu.

Some personal settings

Due to the generated code from CubeMX is 2-space tab width, it is better to configure the Text Editor to adapt with the tab width behavior in **General → Editor → Text Editor**:

- Displayed tab width: **2**
- Insert spaces for tabs: **Checked**
  - Remove multiple spaces on backspace/delete: **Checked**

There are some options for **Code Analysis** under the **C/C++ → Build**. I recommended to enable some check for **Potential Programming Problems**:

- Assignment in condition `if(a=b)`
- No return in a function which is declared to return a value `int func(){}`
- Return without value `int func(){ return;}`
- Return the address of a local variable `int* func(){int a; return &a;}`
- Virtual method call in constructor/ destructor

Next is the formatting style under the option **C/C++ → Code Style → Formatter**:

- Create a new profile from K&R
- In the **Indentation**, change Tab Policy to Space Only; then set Indentation size and Tab size both to 2.

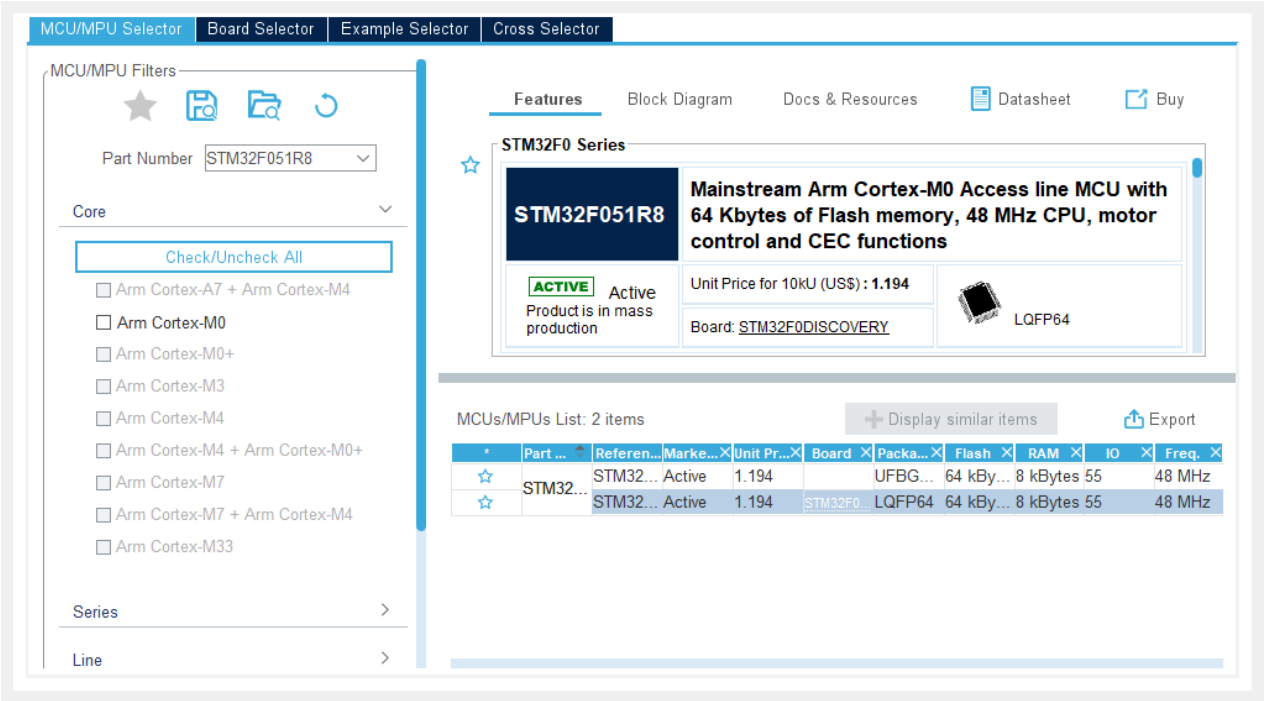
Finally, it should increase the buffer for terminals in **Terminal** option to 1000 or more.

2.3. Create a project

It is recommended to start a new project with STM32CubeIDE as it will automatically configure the project for the selected target processor. When start a new STM32 project, IDE shows up the *Device Finder* screen first. There are options to select the target MCU/MPU by name, board, example, and cross-reference.

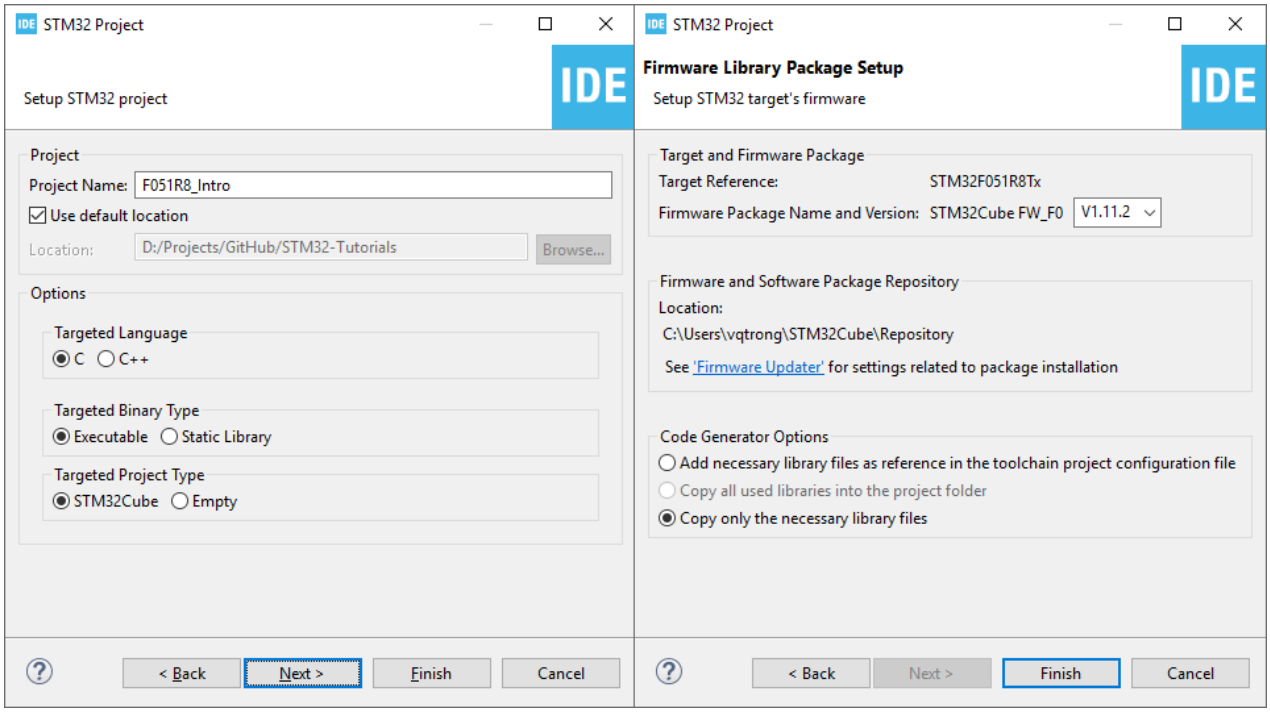
The first project

I am using a **STM32F0-Discovery board** (STM32F051R8) to make an example project for this post. This project does not require any knowledge about the target microprocessor, as it will be written like a normal C application.



Select the target MCU by name

After selecting the microprocessor, it's time to name the project, and select the *STM32Cube MCU packages* version for the selected target. In this example, it is *STM32Cube FW F0 v1.11.2*.



Set name and select firmware package for a new project

Press on Finish then IDE will run a screen named *Device Configuration Tool* from the CubeMX tool, in there, it's easy to enable any supported features in graphical mode. If the selected target

is a development board, this tool will ask to use a default system config for the target board - usually including ST-Link pins, on-board buttons, LEDs, USB connect.

2.4. STM32CubeMX

STM32CubeMX is a graphical tool that allows a very easy configuration of STM32 microcontrollers and microprocessors, as well as the generation of the corresponding initialization C code for the Arm® Cortex®-M cores.

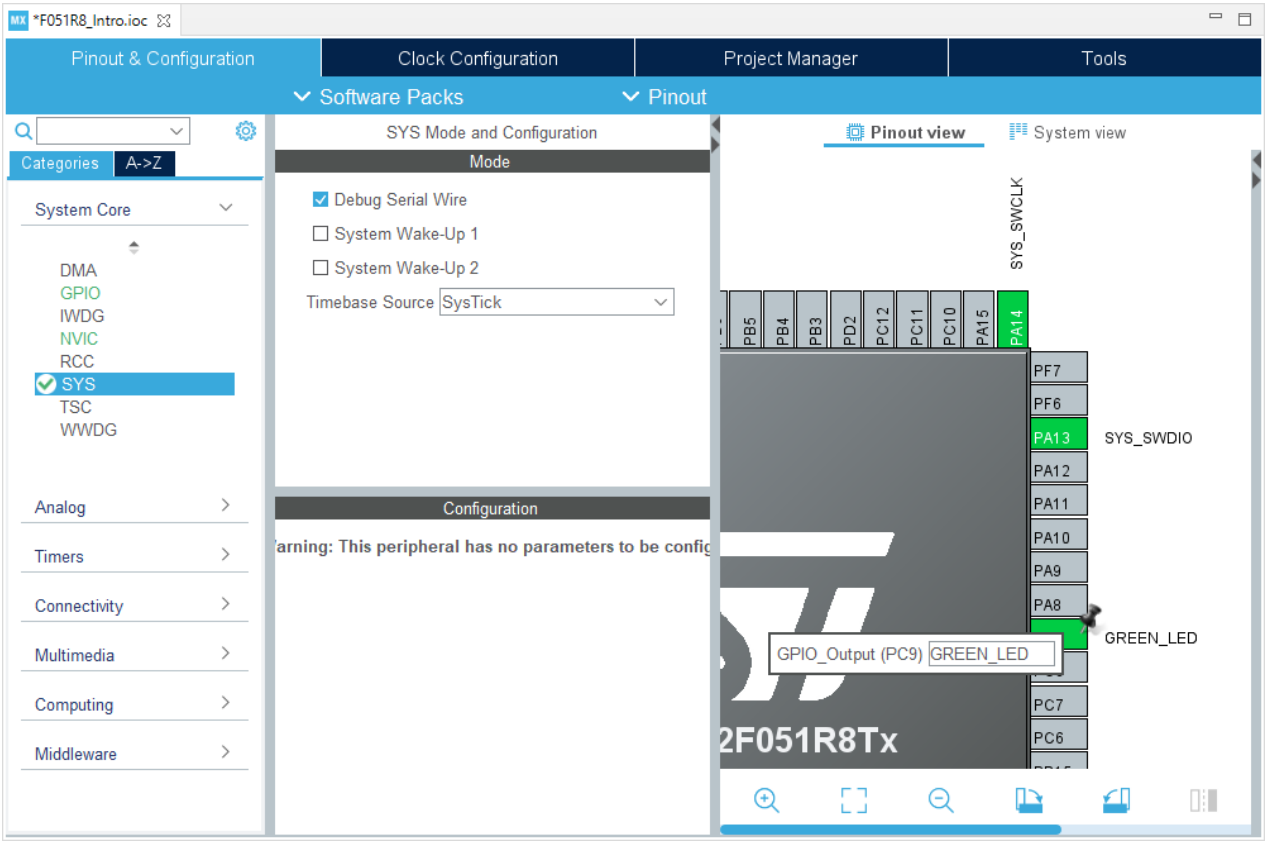
STM32CubeMX User Manual

STM32CubeMX allows the user to create, save and load previously saved projects. MCU configuration `.ioc` file is saved in the project folder, and user can open it in CubeMX for editing.

2.4.1. Pinout Configuration

This tab shows available *Components* in categories or in A-Z list. Select on a component will show its *Configuration* screen.

The large *Pinout* view show a graphic representation of the pin assignment. Left-click to select the function, and Right-click to do extra actions such as assigning a custom name.

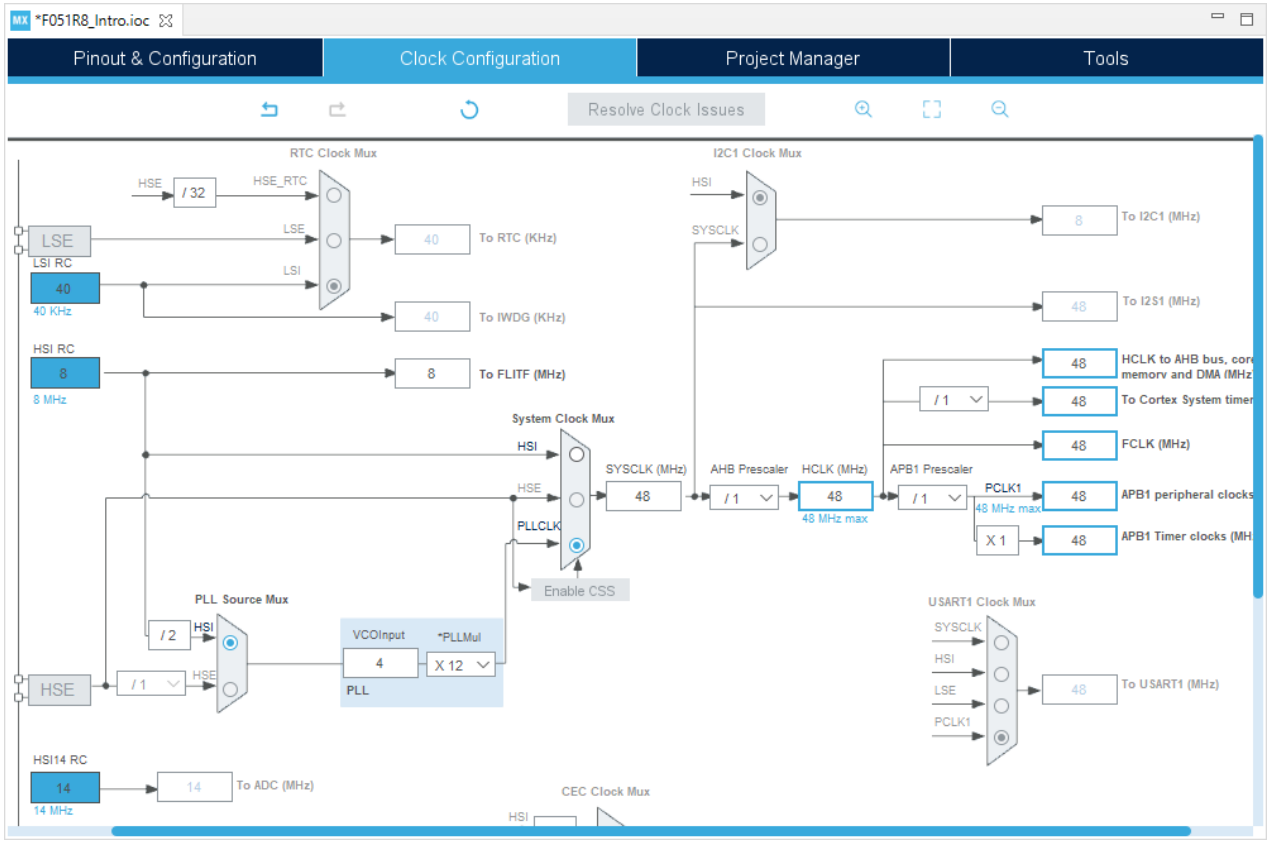


The Pinout config screen

2.4.2. Clock Configuration

This tab provides a schematic overview of the clock paths, clock sources, dividers, and multipliers. Drop-down menus and buttons can be used to modify the actual clock tree configuration, to meet the application requirements.

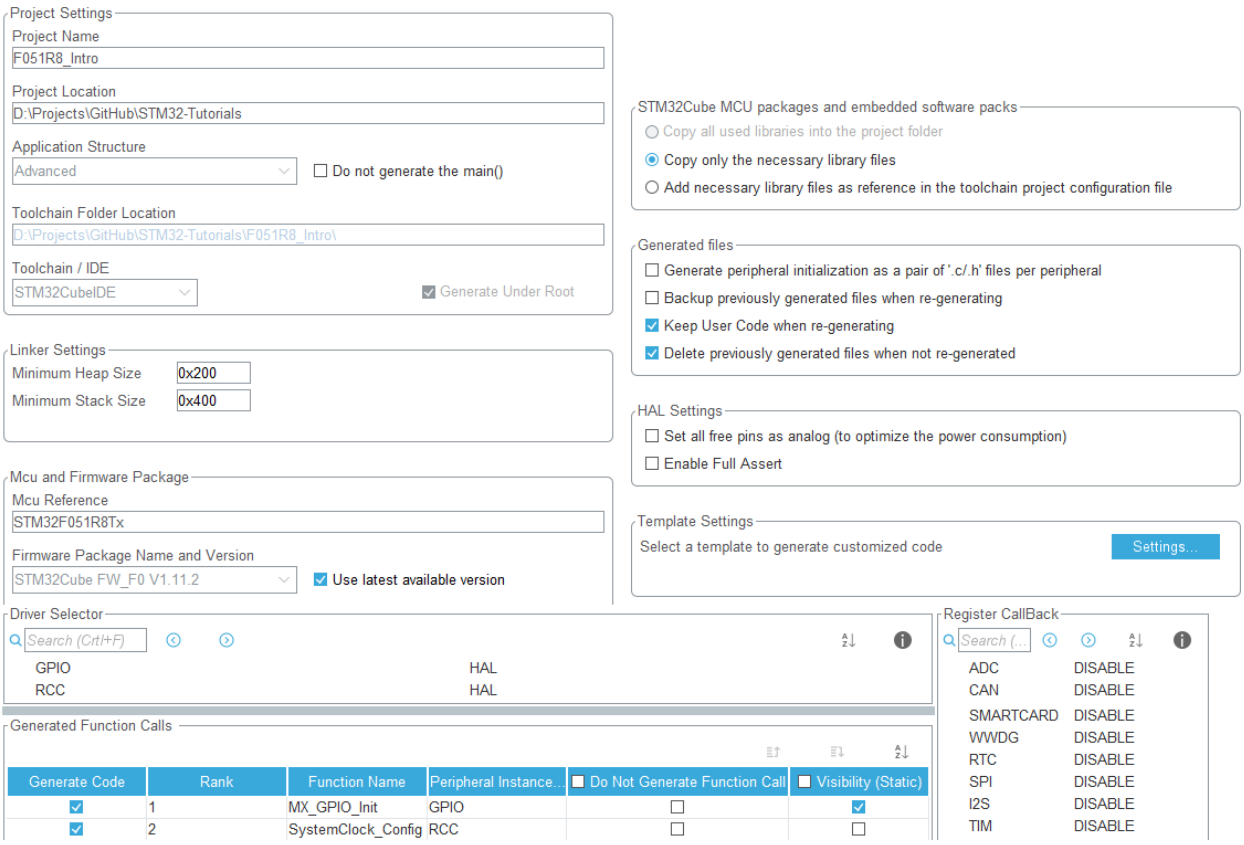
IDE has ability to automatically calculate multipliers and dividers to provide requested frequency, user can set a desired frequency in the clock node, and press enter, then IDE will re-configure the PLL, pre-scaler. The frequency on each node can be locked via the right-click menu.



The Clock config screen

2.4.3. Project Manager

This tab provides information about general project setting: to specify the project name, location, toolchain, and firmware version. It also has configs for code generation options such as the location of peripheral initialization code, library copy/link options, and to select templates for customized code.



The Project config view

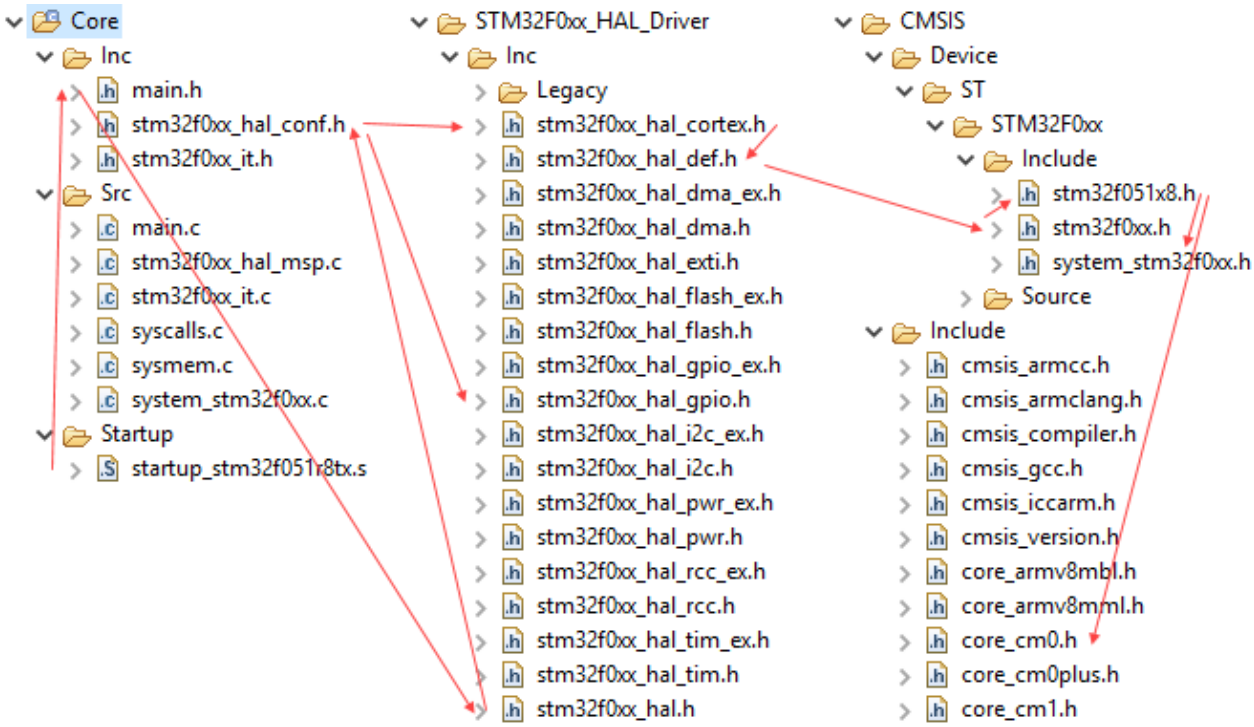
2.4.4. Code generation

After configuring pins, save the settings first and then start generating code. Manually request to generate code by pressing `Alt + K` or choosing menu **Project → Generate Code**. The tool will create sub-folders and add necessary files into project. The general file structure is:

```
└──Core
| ├──Inc
| ├──Src
| └──Startup
└──Drivers
└──CMSIS
| └──Device
| | └──ST
| | └──STM32F0xx
| | └──Include
| | └──Source
| | └──Templates
| └──Include
└──STM32F0xx_HAL_Driver
└──Inc
| └──Legacy
└──Src
```

When chosen to use a Firmware Library in the project, IDE automatically uses ST Hardware Abstract Layer (HAL) library as the main way of controlling the processor and peripherals. HAL also makes use of Cortex Microcontroller Software Interface Standard (CMSIS) library to access processor's registers. In the Project Manager tab, it can change to use Low-Level (LL) library instead of HAL.

Code dependency starts from the `main.h` source file. This file includes HAL files which eventually includes CMSIS files. The `main` function is called from the startup file `startup_*.s`.



Code dependency

A HAL driver includes the following set of files:

File	Description
`stm32f0xx_hal.h/.c`	This file is used for HAL initialization and contains DBGMCU, Remap and Time Delay based on SysTick APIs. This also include `stm32f0xx_hal_def.h`.
`stm32f0xx_hal_def.h`	Common HAL resources such as common define statements, enumerations, structures and macros. This includes CMSIS headers.
`stm32f0xx_hal_ppp.h/.c`	Main peripheral/module driver file. It includes the APIs that are common to all STM32 devices, example: `stm32f0xx_hal_adc.c`, `stm32f0xx_hal_irda.c`

File	Description
`stm32f0xx_hal_ppp_ex.h/.c`	Extension file of a peripheral/module driver. It includes the specific APIs for a given part number or family, as well as the newly defined APIs that overwrite the default generic APIs if the internal process is implemented in different way, for example: `stm32f0xx_hal_adc_ex.c`, `stm32f0xx_hal_flash_ex.c`.

The minimum files required to build an application using the HAL are listed in the table below:

File	Description
`startup_stm32f0xx.s`	Toolchain specific file that contains reset handler and exception vectors. For some toolchains, it allows adapting the stack/heap size to fit the application requirements
`system_stm32f0xx.c`	This file contains `SystemInit()` which is called at startup just after reset and before branching to the main program. It does not configure the system clock at startup (contrary to the standard library).This is to be done using the HAL APIs in the user files. It allows relocating the vector table in internal SRAM.
`stm32f0xx_hal_conf.h`	This file allows the user to customize the HAL drivers for a specific application. It is not mandatory to modify this configuration. The application can use the default configuration without any modification. This call to STM32F0 HAL headers.
`stm32f0xx_hal_msp.c`	This file contains the MSP initialization and de-initialization (main routine and callbacks) of the peripheral used in the user application.
`stm32f0xx_it.h/.c`	This file contains the exceptions handler and peripherals interrupt service routine, and calls `HAL_IncTick()` at regular time intervals to increment a local variable (declared in `stm32f0xx_hal.c`) used as HAL timebase. By default, this function is called each *1ms* in Systick ISR.The `PPP_IRQHandler()` routine must call `HAL_PPP_IRQHandler()` if an interrupt based process is used within the application.
`main.h/.c`	This file contains the main program routine, mainly: • call to `HAL_Init()` • set system clock configuration • declare peripheral HAL initialization • user application code.

2.5. Add user code

User code sections are marked with a pair of phrases `/* USER CODE BEGIN x */` and `/* USER CODE END x */`. User code inside those marks are kept remaining during code generation.

I am going to add a variable `counter` with type of `char`, then inside the main `while` loop in the `main()` function, increase it by `1` after 100ms. Don't mind the HAL function at this time.

main.c

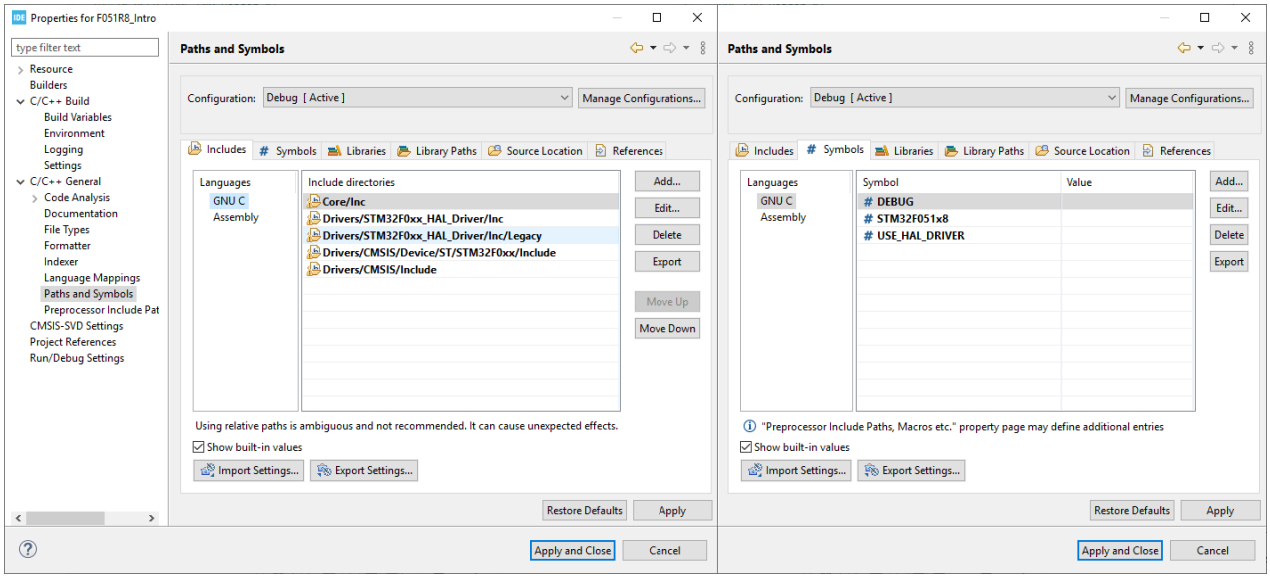
```
/* USER CODE BEGIN PV */
char counter = 0;
/* USER CODE END PV */
int main(void) {
  /* other setup function */
  /* USER CODE BEGIN WHILE */
  while (1) {
    counter++;
    HAL_Delay(100);
    /* USER CODE END WHILE */

    /* USER CODE BEGIN 3 */
  }
  /* USER CODE END 3 */
}
```

2.6. Compiler options

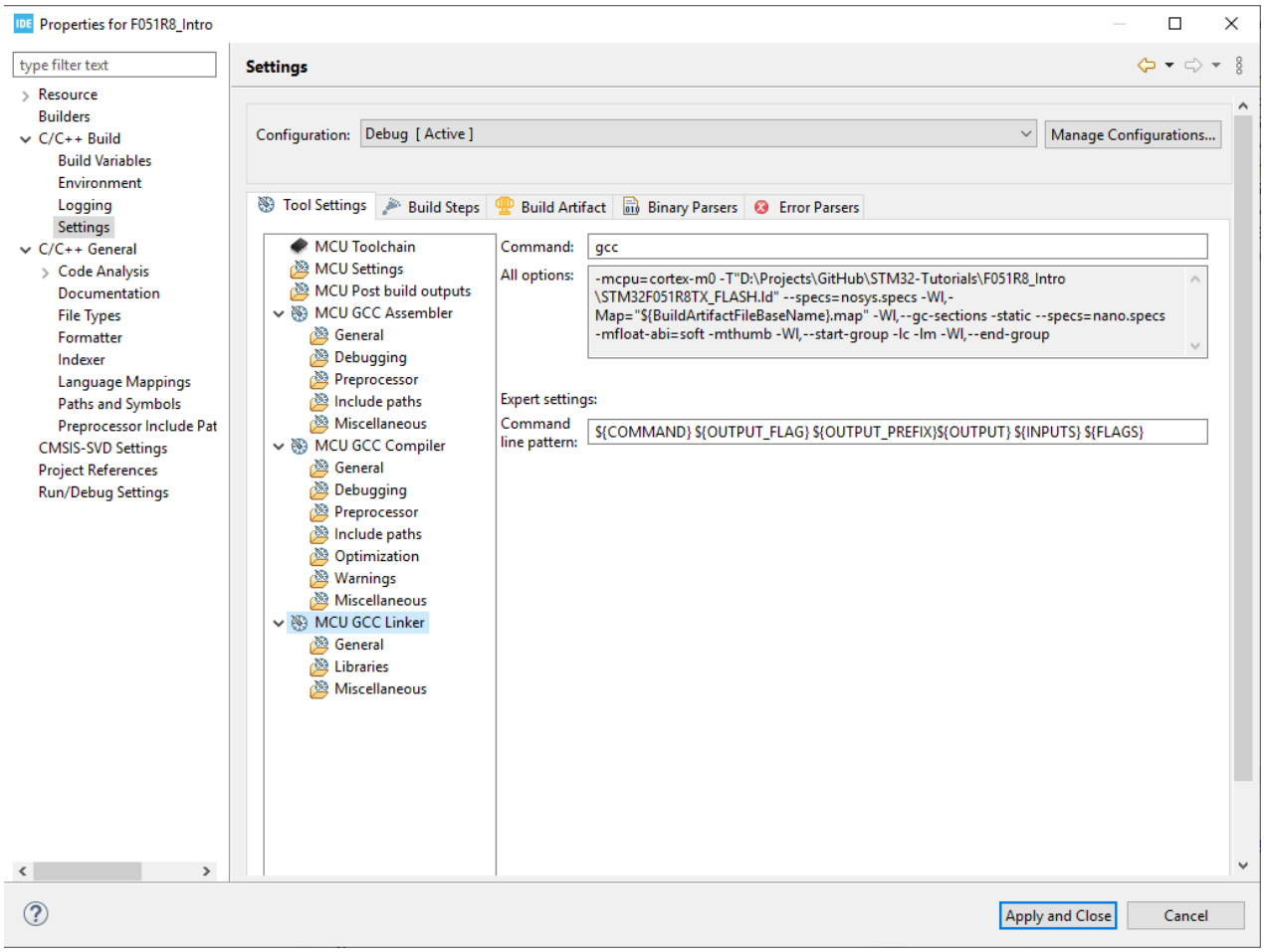
Project has options for the compiler under its properties. Right-click on the project name in the right panel, then select Properties menu.

The default included folders are all the folders created in the project by the CubeMX tool. There are also some symbols created for the project build, such `DEBUG` mode, or the MCU name `STM32F051x8`.



The including paths and symbols

Then in the Build Options, there are options to be used by GCC complier, GNU Linker, GNU Assembler.



Build options

2.7. Build Project

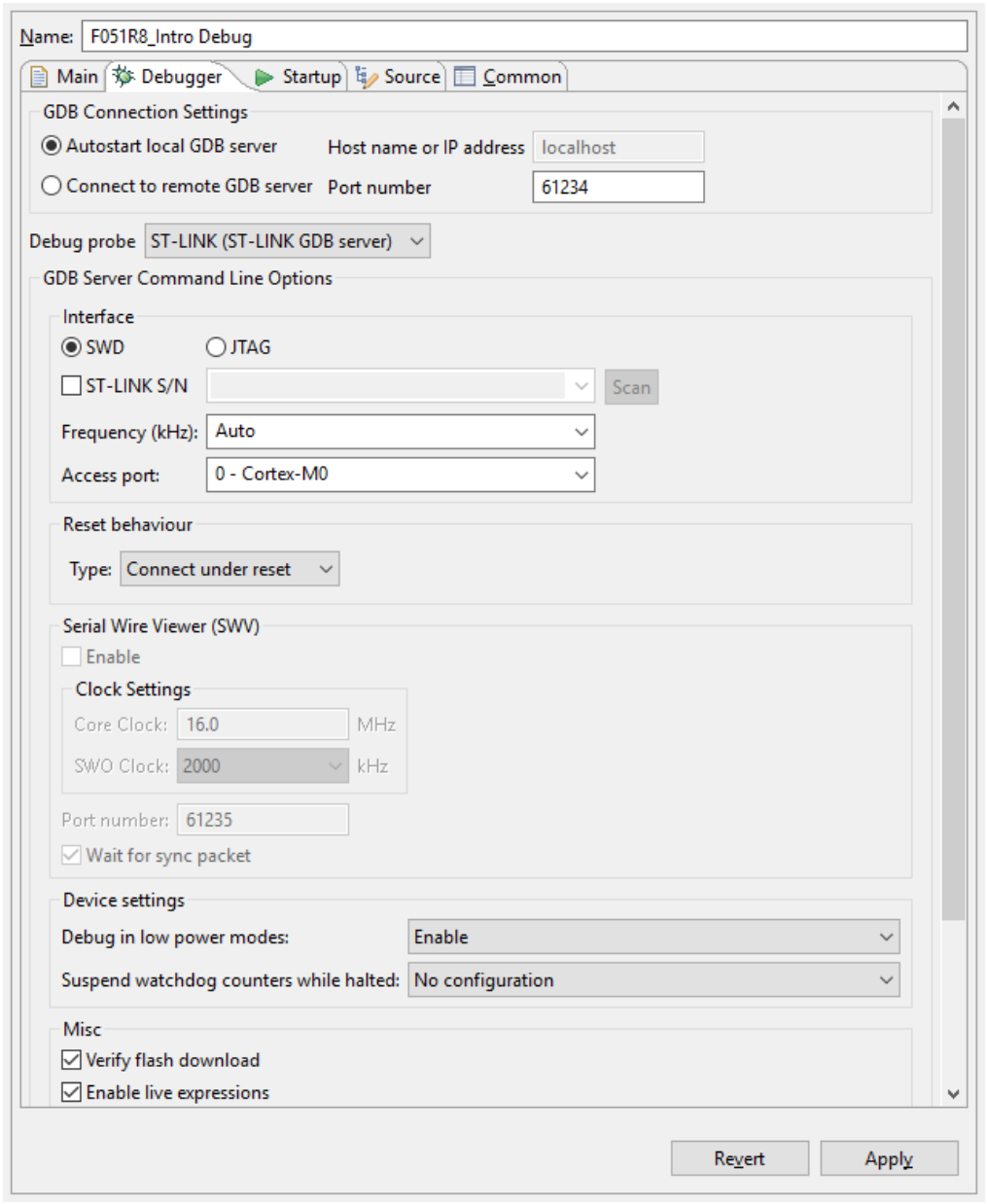
Build the application by pressing `Ctrl + B`, or in menu **Project** → **Build All**. There are some reports about the resource usage to check after the compilation. The first thing it reports is the memory usage, in term of RAM and FLASH free space.

2.8. Setup debugger

Before Run or Debug on the target chip, it is needed to configure the programming/ debugging interface. By default, the application code can be programmed through the debugger interface, therefore, in Run Config or Debug Config, there is a tab named **Debugger** to select:

- Debug Probe: ST-LINK GDB, ST-LINK OpenOCD, SEGGER J-LINK, or other available probes
- Interface: SWD or JTAG. If there are multiple boards connected, use debugger board Serial Number to choose the correct target

- Advanced features:
  - Serial Wire Viewer: read data from MCU in a dedicated *SWO* pin, available on Cortext-M3 and above
  - Live Expression: read out the value at a memory address without halting the CPU



Setup Debugger

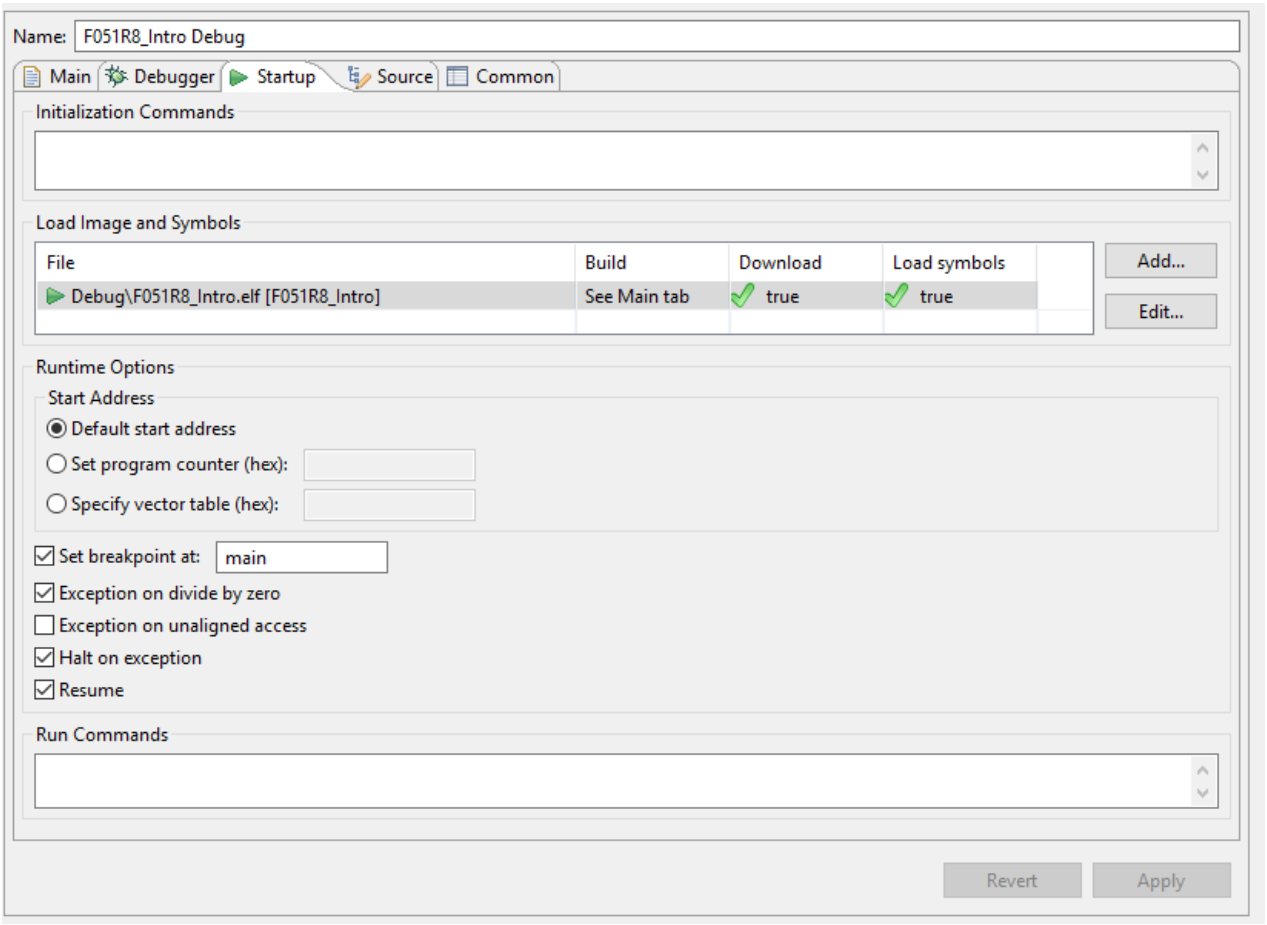
2.9. Run Mode

In the Run Mode, IDE flashes the firmware via the Debugging interface, and then disconnect the debugger to make the target board run freely. Just use the menu **Run → Run**.

2.10. Debug Mode

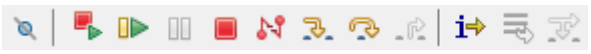
Putting the target under the Debug Mode is to control its execution, step by step. Breakpoint is where the CPU will be halted and debugger will inspect its current status: registers, memory values.

By default, the first breakpoint is right after entering the `main` function. The start address and the first break point can be set in the **Startup** tab in Debug Configurations.



Startup option for debug

When CPU is halted at a breakpoint, user can control the execution step by step, through the commands or buttons:



Debug controls

3. STM32CubeProgrammer

STM32CubeProgrammer (previous name was ST-Link Utility) provides an easy-to-use and efficient environment for reading, writing and verifying device memory through both the debug interface (JTAG and SWD) and the bootloader interface (UART, USB DFU, I2C, SPI, and CAN). STM32CubeProgrammer offers a wide range of features to program STM32 internal memories (such as Flash, RAM, and OTP) as well as external memories.

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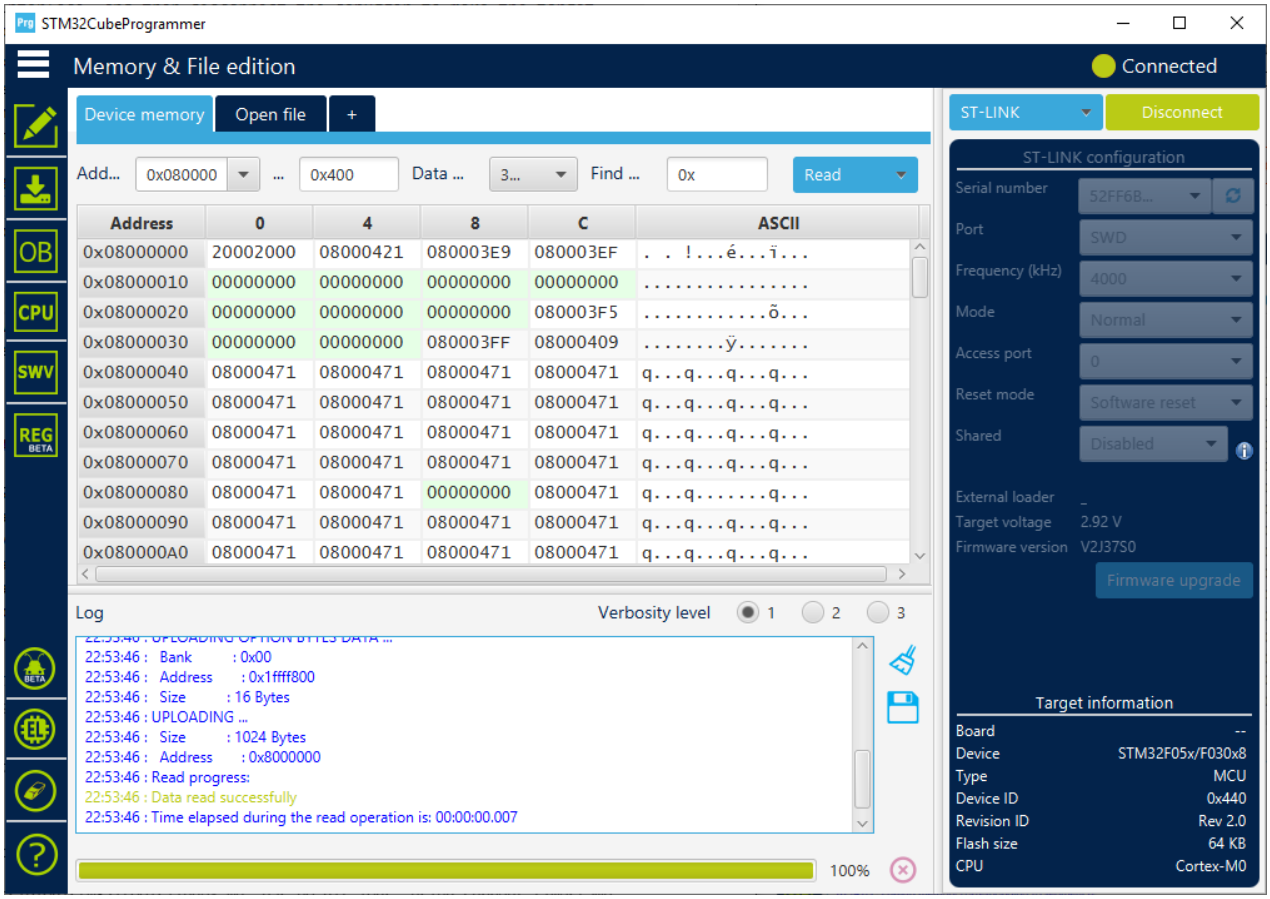
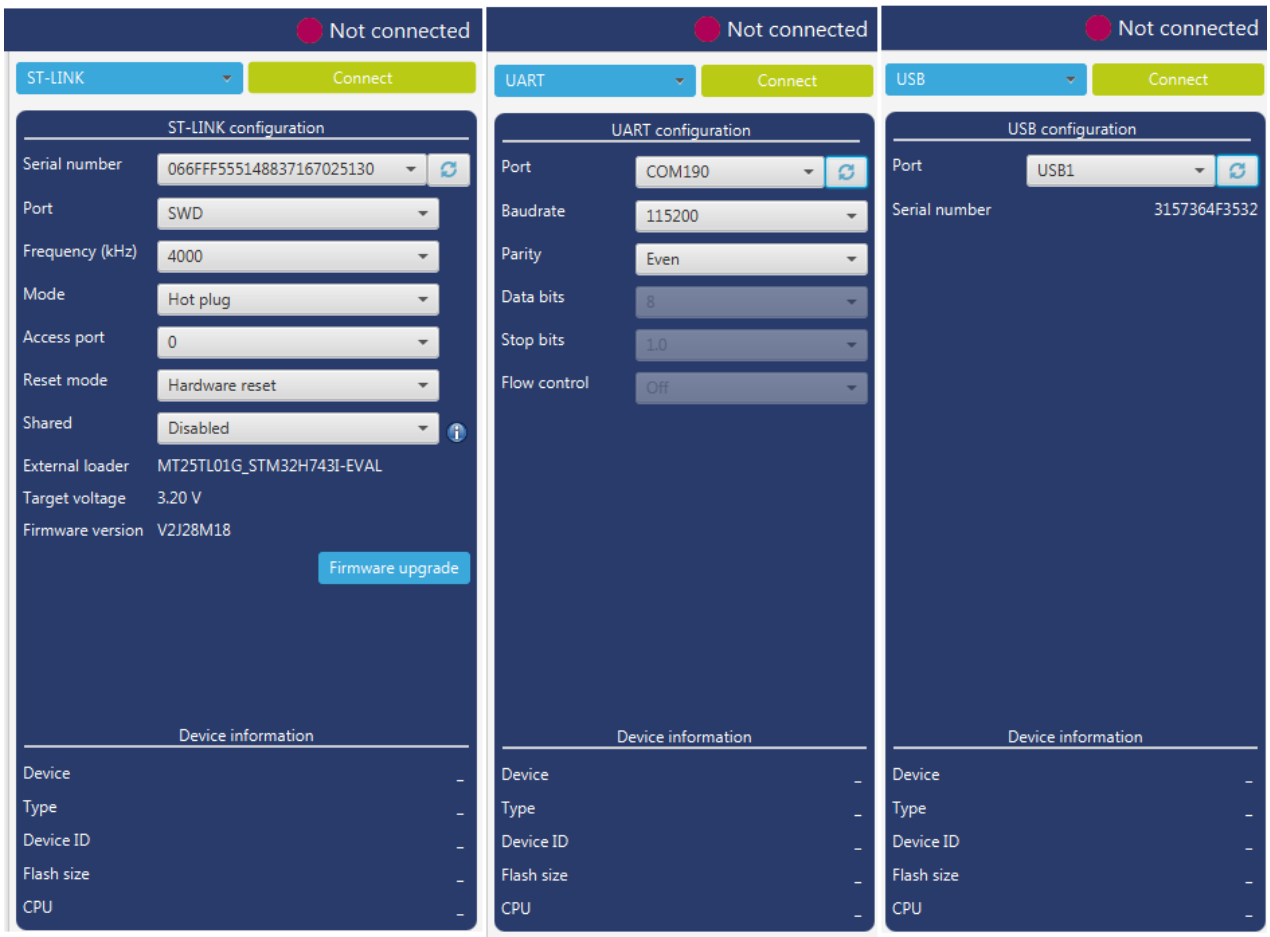


STM32 Programmer

3.1. Target connection

On the original development boards, please select ST-LINK interface, and then select either SWD or JTAG port.

If the custom board has an USB port with Device Firmware Update mode, it can be connected on the USB interface. Before pressing **Connect** on the software, find on the board to press and hold the **Boot** button (Boot0 or Boot1) and press **Reset** button (NRST) to make device run into DFU mode.



Different connections

3.2. Erase and Program

Once connected to a target, the memory sectors are displayed in the right-hand panel showing the start address and the size of each sector. To erase one or more sectors, select them in the first column and then click on the **Erase selected sectors** button.

To download firmware to the target chip, select the Erasing & Programming tab. Click on the browse button and select the file to be programmed. The file format supported are binary files (.bin), ELF files (.elf, .axf, .out), Intel hex files (.hex) and Motorola S-record files (.Srec).

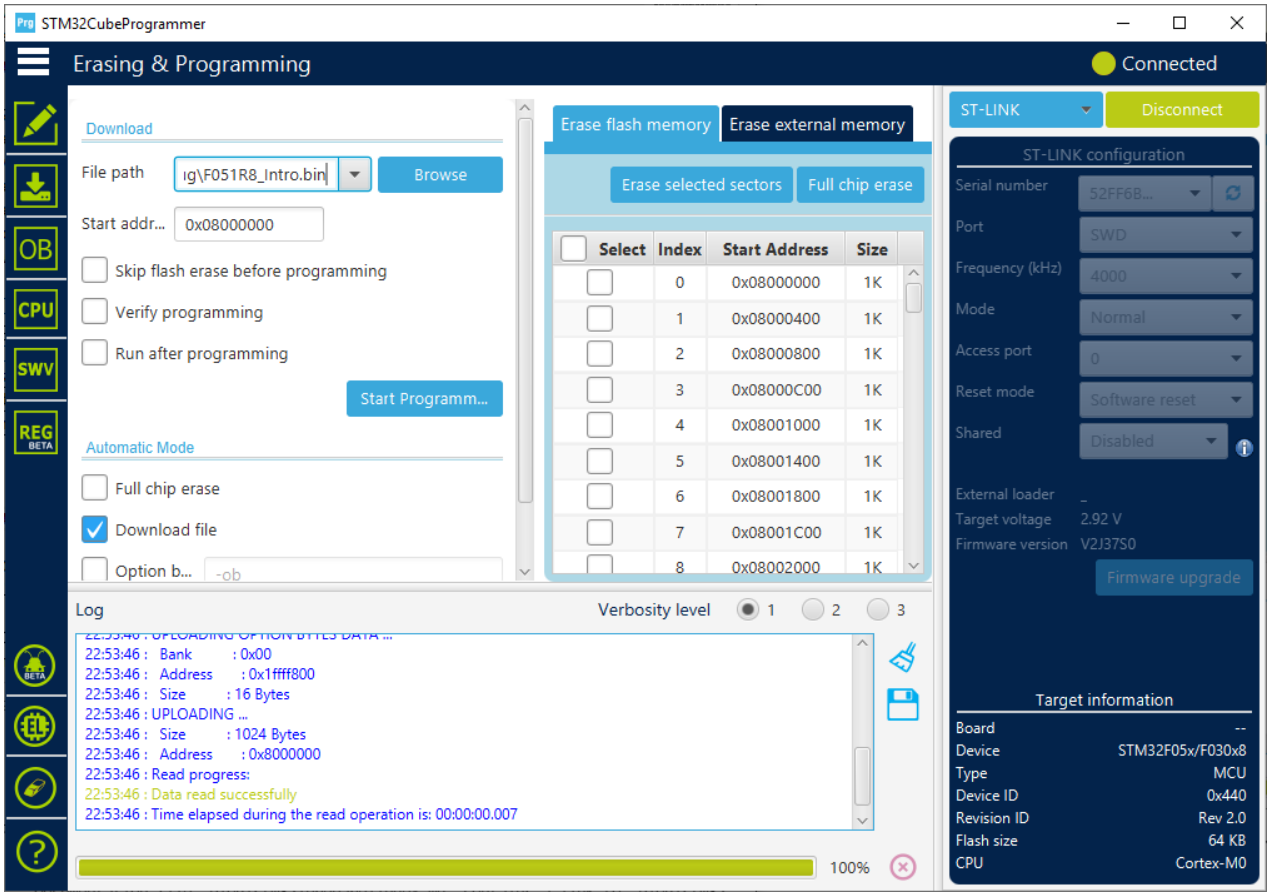
In case of programming a binary file, the address must be set.

3.3. Other features

Other advanced features will be covered in other posts. Here is the list of those features:

- Option Bytes
- CPU Instruction debug

- Serial Wire View
- Fault Analyzer
- External Flash programming



Program a binary file

4. STM32CubeMonitor

The STM32CubeMonitor helps to fine-tune and diagnose STM32 applications at run-time by reading and visualizing their variables in real-time. It provides a flow-based graphical editor to build custom dashboards simply, and quickly add widgets such as gauges, bar graphs and plots. With non-intrusive monitoring, STM32CubeMonitor preserves the real-time behavior of applications, and perfectly complements traditional debugging tools to perform application profiling.

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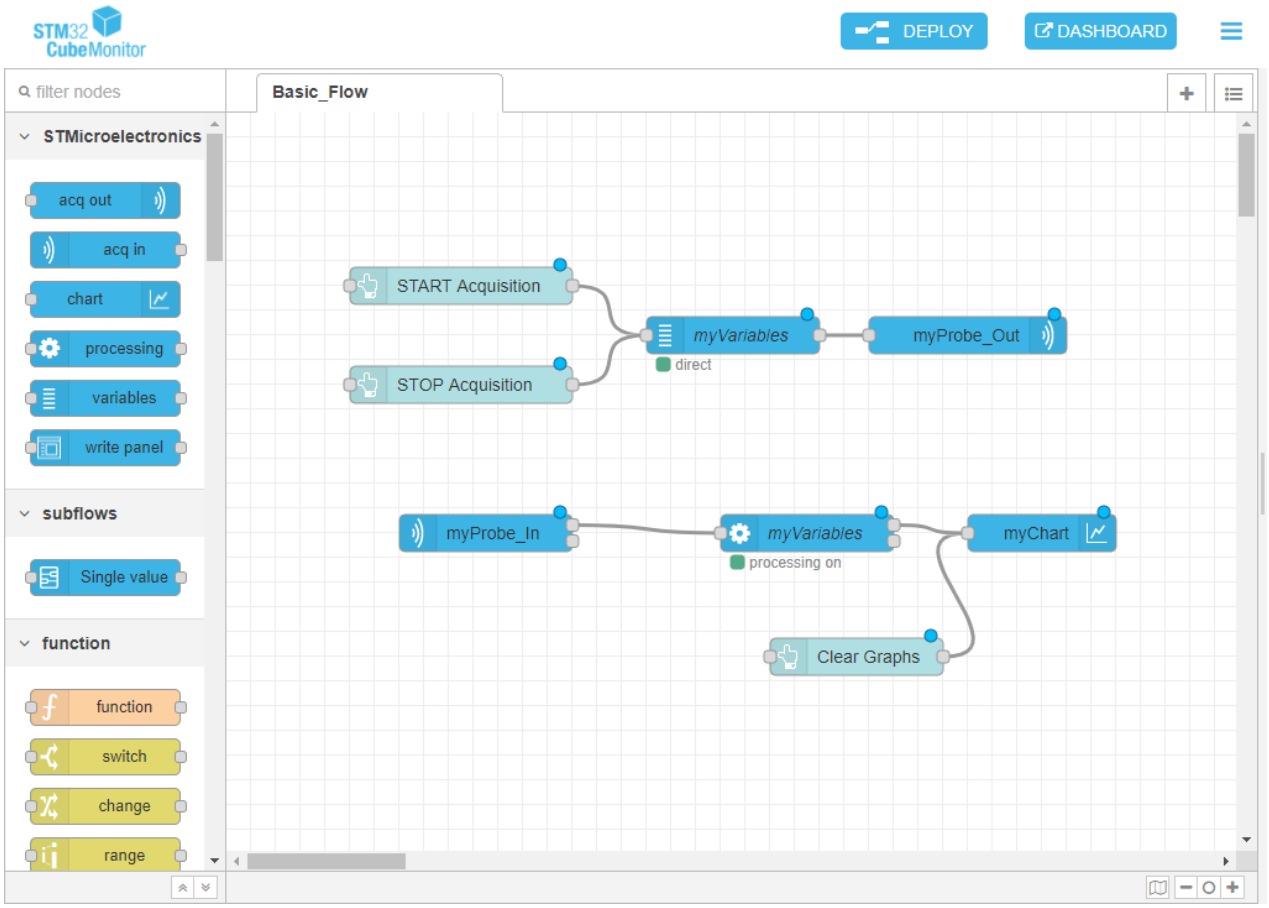
This tool use SWD/JTAG interface to access the memory addresses and read their value.



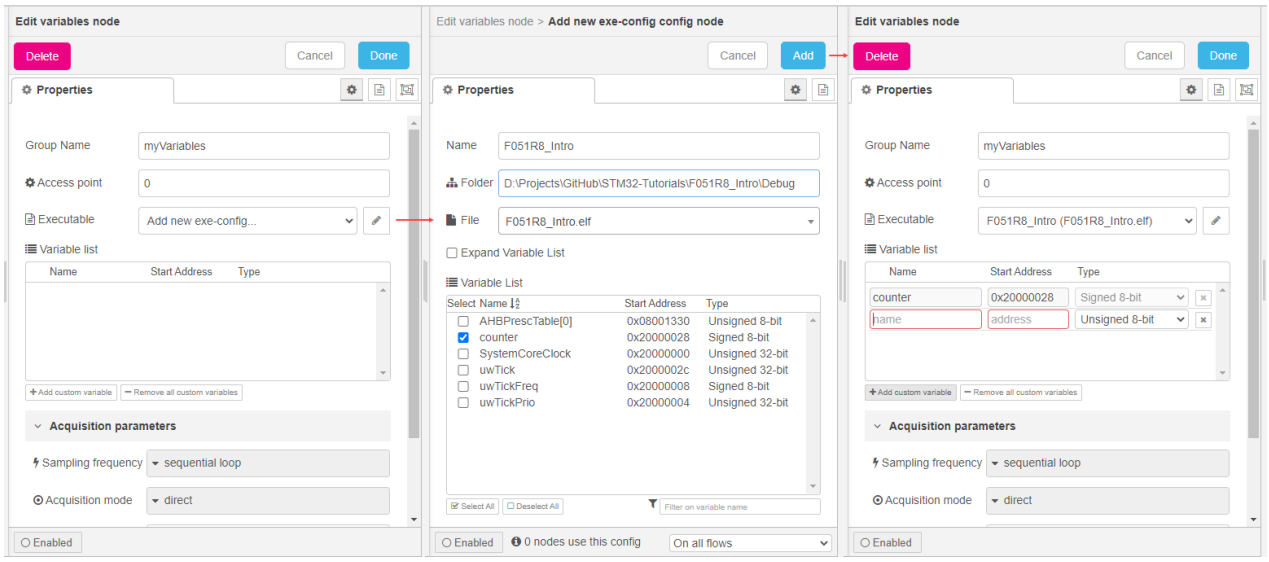
The block editor

When start the tool, there is a basic flow created with:

- Start/ Stop/ Clear buttons
- *myVariables* block holds the addresses under monitoring
- *myProbe_Out* block has configs to connect to the target device through debug interface
- *myProbe_In* block has script to read the value of the addresses listed in the *myVariables* block
- *myVariables* processing block read the captured value and process it
- *myChart* displays the dashboard which visualizes the processed data

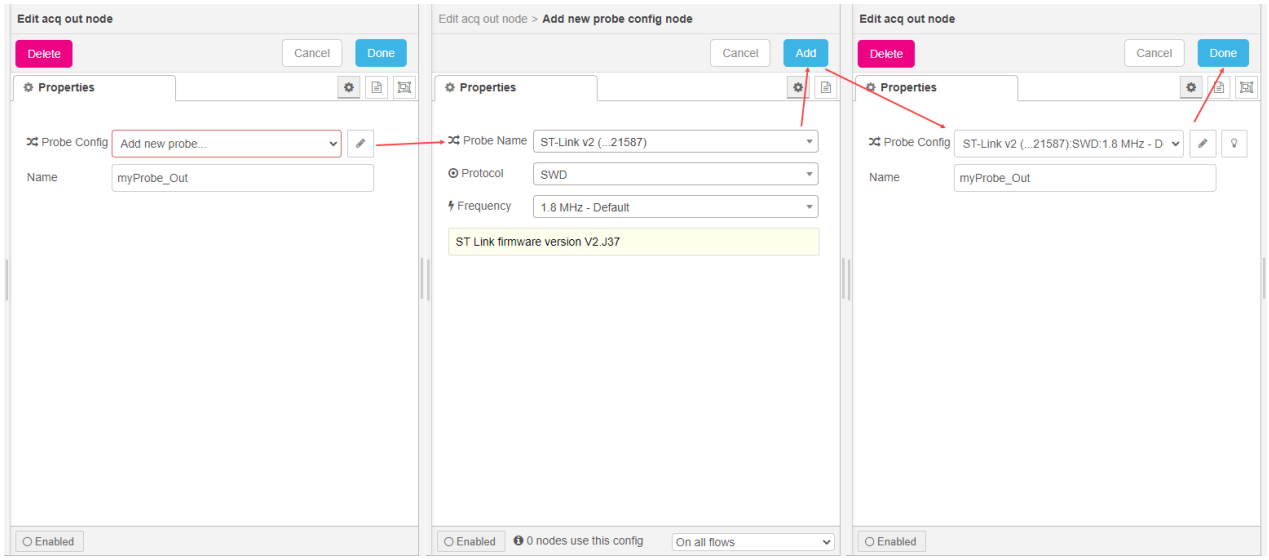
To configure a block, double click on it, and follow the guide. The steps go through file selection, variable list, connect probe, and assign probe.

To demonstrate how it works, add a `counter` variable of type `char` as a global variable in the `main.c` file. In the main loop, increase the `counter` value every 100ms. This variable will be shown in the list of variables after selecting the compiled `.elf` firmware file.



Configure the variable block

Connect the target board via ST-LINK or other SWD/ JTAG compatible debugger. The debugger will be shown a probe in Cube Monitor. Select the protocol and assign to the in or out probe.

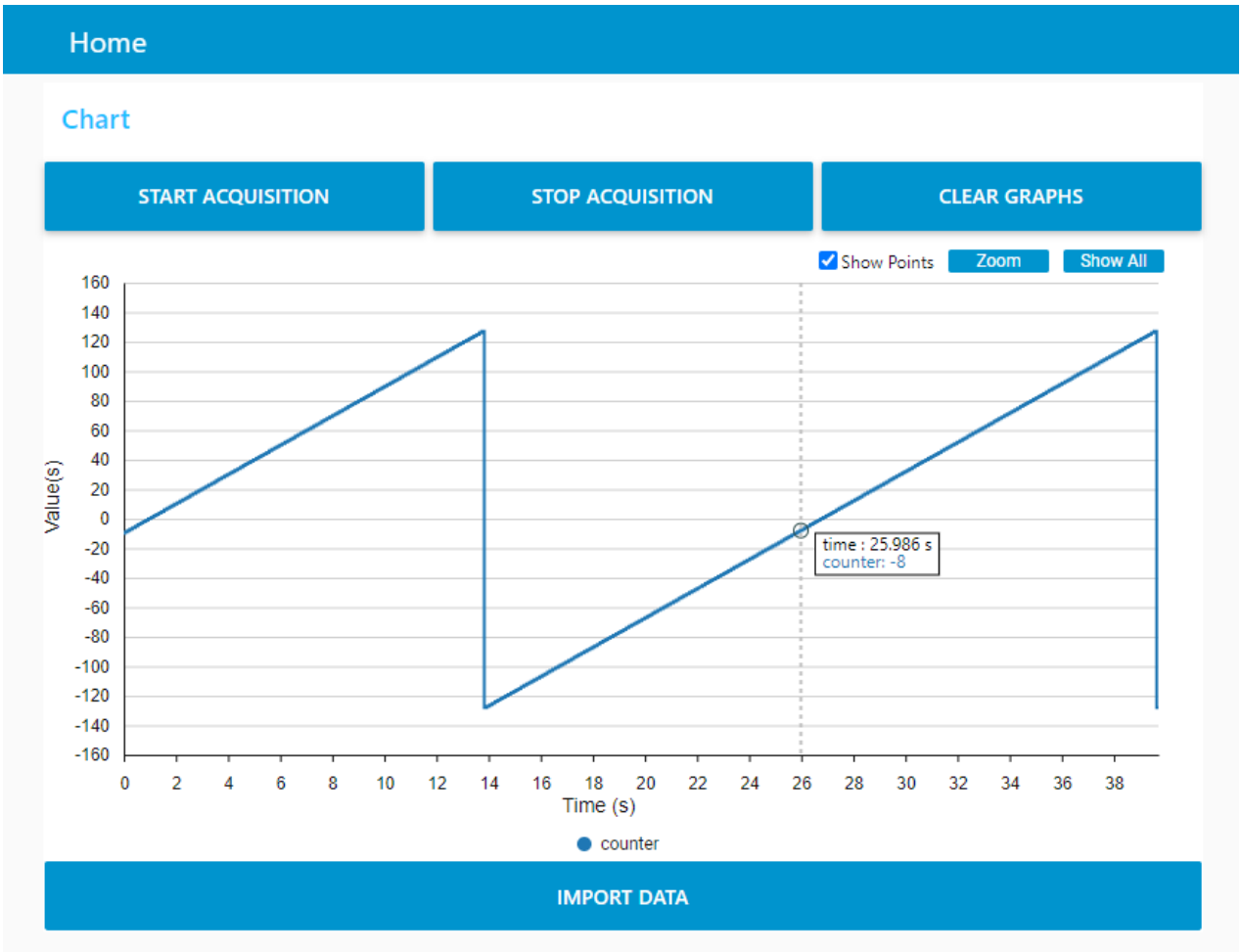


Configure the probe block

The chart can be drawn in line or bar chart. At this time, just use a default one.

Finally, press on **Deploy** to configure the probes, and then click on **Dashboard** to show the graphical interface.

Start button will send `start` message to the probe and variable processing block. The captured data will be drawn on the chart.



The interactive dashboard

5. Other tools

There are many other tools that work on ARM cores. I will have other posts to share about those tools such as Cross Compiler, Config File, Make File, or System View.