General Purpose Input/Output pins

Understand about GPIO hardware, working modes and speeds, alternative function and input interrupts. Steps to control a GPIO using HAL. Example to blink LEDs and get input from a button.

#arm #stm32 #gpio

Last update: April 28, 2021

Table of Content

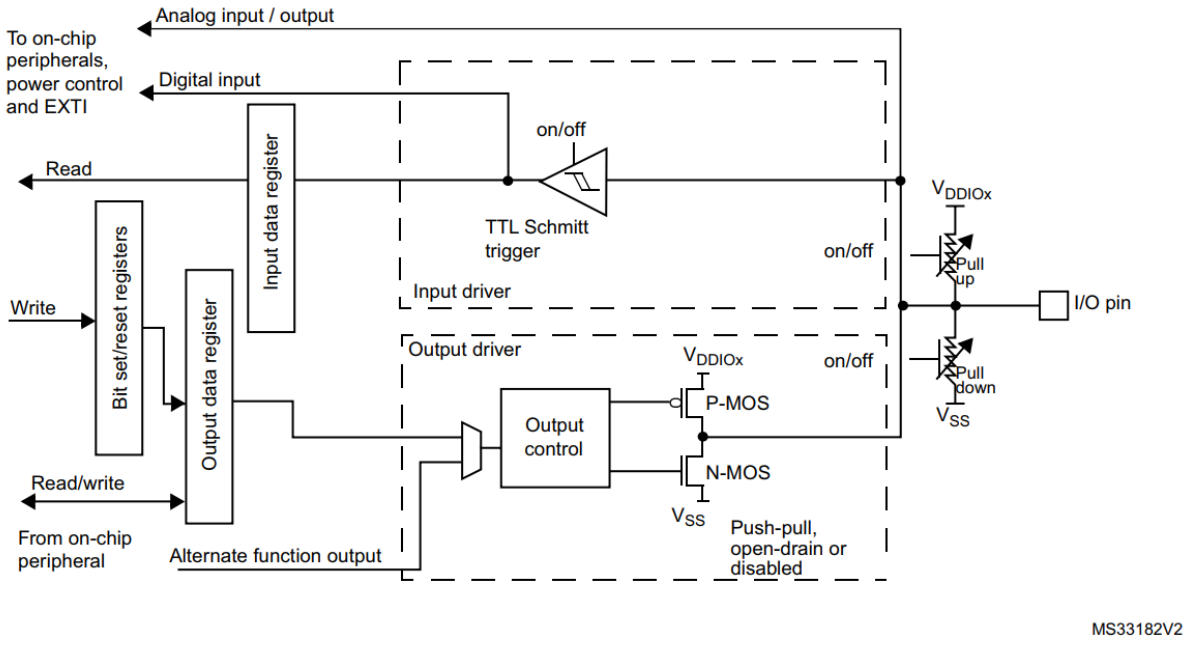
GPIO notes

- Enable clock source on GPIO port when use it
- APB2 bus speed determines the sampling rate of all GPIO inputs
- Can select mode, speed, alternative function on a GPIO pin
- Can have external interruption
- Can lock a GPIO after initializing
- Disconnect a GPIO pin by setting it into input floating mode
- Save power by setting GPIO pins to Analog mode (Schmitt trigger is disabled)

1. Hardware

Each GPIO Pin has a complex structure to function as both input and output:

- Protection Diodes
- Pull-up and Pull-down resistors on input
- Schmitt trigger to convert input to digital value
- Open-Drain or Push-Pull gate on output
- Multiplexer for Alternate Function
- Input and Output data registers
- Control registers



A GPIO pin structure

1.1. Voltage and Current

Always assume that all GPIO pins are **NOT 5V tolerant** by default until find out in the datasheet (such as DS8668 for STM32F0x) that a specific pin is 5V tolerant, only then it can be used as a 5V pin.

The maximum current that could be sourced or sunk into any GPIO pin is *25mA* as mentioned in the datasheet.

1.2. Input mode

- Input Floating (Hi-Z)
- Input Pull-Up
- Input Pull-Down

Read about Pull-Up/ Pull-Down

When a GPIO pin is set to the input mode, the data present on the I/O pin is sampled into the Input Data Register (IDR) every APB2 clock cycle. This means the APB2 bus speed determines the input sampling speed for the GPIO pins.

1.3. Output mode

- Output Open-Drain
- Output Push-Pull

Read about Open-Drain and Push-pull

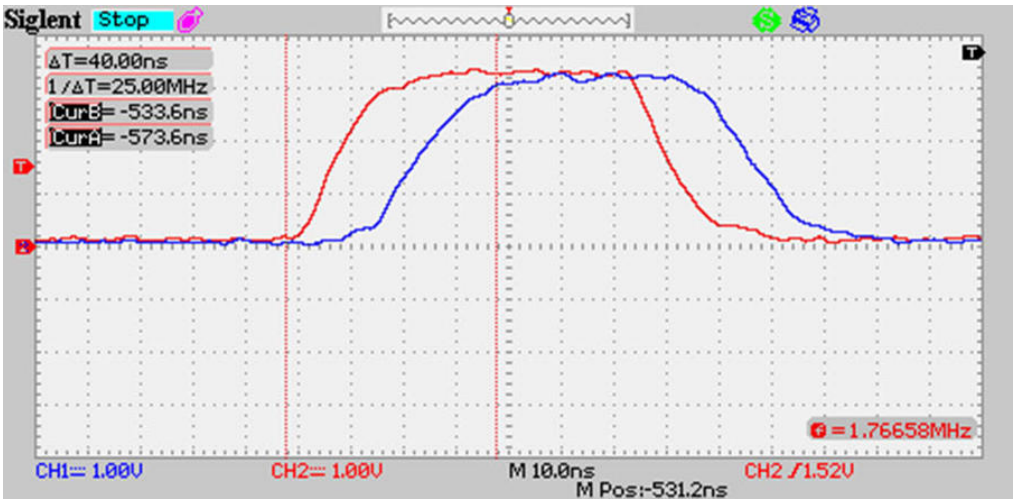
When a GPIO pin is set to the output mode, there is an option to configure the pin speed mode. Refer to datasheet (e.g. DS8668) to check the I/O AC characteristics table to note the maximum frequency in different conditions.

1.4. Output Speed

GPIO speed is not related to switching frequency, it defines the slew rate of a GPIO, that is how fast it goes from the 0V level to VDD one, and vice versa.

Below image shows the slew rate of 2 speed modes:

- Red line: high speed
- Blue line: low speed



Slew rate of 2 speed modes

1.5. Bit atomic operation

There is no need for the software to disable interrupts when programming the Output Data Register (ODR) at bit level. Use Bit Set/Reset Register (BSRR) to select individual bit operation.

1.6. Input interrupt

When in input mode, all ports have external interrupt capability. Read more about Interrupt.

1.7. Alternate function

- Alternate Function Push-Pull
- Alternate Function Open-Drain

Pin can be used for an alternate function from a peripheral by setting the Alternate Function register (AF).

1.8. Analog input/output

In analog mode, pin is directly wired to a analog module (ADC, DAC)

1.9. Locking pin

The locking mechanism allows the IO configuration to be frozen. When the LOCK sequence has been applied on a port bit, it is no longer possible to modify the value of the port bit until the next reset.

2. Memory Map

Program memory, data memory, registers and I/O ports are organized within the same linear 4GB address space. The bytes are coded in memory in Little Endian format.

Refer to the document RM0091 for STM32F0xto see the memory map for GPIO ports:

```
Boundary Address            Size    Peripheral
-----------------------------------------------
0x4800 1400 - 0x4800 17FF   1KB     GPIOF
0x4800 1000 - 0x4800 13FF   1KB     GPIOE
0x4800 0C00 - 0x4800 0FFF   1KB     GPIOD
0x4800 0800 - 0x4800 0BFF   1KB     GPIOC
0x4800 0400 - 0x4800 07FF   1KB     GPIOB
0x4800 0000 - 0x4800 03FF   1KB     GPIOA
```

3. Register Map

```
Register        Offset  Description
-----------------------------------
GPIOx_MODER     0x00    I/O mode:
                            00: Input mode (reset state)
                            01: General purpose output mode
                            10: Alternate function mode
                            11: Analog mode
GPIOx_OTYPER    0x04    Output type:
                            0: Output push-pull (reset state)
                            1: Output open-drain
GPIOx_OSPEEDR   0x08    Output speed:
                            x0: Low speed
                            01: Medium speed
                            11: High speed
GPIOx_PUPDR     0x0C    Pull-up/ pull-down
                            00: No pull-up, pull-down
                            01: Pull-up
                            10: Pull-down
                            11: Reserved
GPIOx_IDR       0x10    Input data
GPIOx_ODR       0x14    Output data
GPIOx_BSRR      0x18    Bit Set/Reset
                            0: No action on the corresponding ODRx bit
                            1: Set/Reset the corresponding ODRx bit
GPIOx_LCKR      0x1C    Configuration lock
GPIOx_AFRL      0x20    Alternate Function low register
GPIOx_AFRH      0x24    Alternate Function high register
                            0000: AF0
                            0001: AF1
                            0010: AF2
                            0011: AF3
                            0100: AF4
```

```
                            0101: AF5
                            0110: AF6
                            0111: AF7
GPIOx_BRR       0x28    Bit Reset
                            0: No action on the corresponding ODx bit
                            1: Reset the corresponding ODx bit
```

4. HAL Software

The Hardware Abstract Layer (HAL) is designed so that it abstracts from the specific peripheral memory mapping. But, it also provides a general and more user-friendly way to configure the peripheral, without forcing the programmers to now how to configure its registers in detail.

excerpt from Description of STM32F0 HAL and low-layer drivers

How to use GPIO HAL

1. Enable the GPIO AHB clock using the following function : `__HAL_RCC_GPIOx_CLK_ENABLE()`.
2. Configure the GPIO pin(s) using `HAL_GPIO_Init()`.
   - Configure the IO mode using `Mode` member from `GPIO_InitTypeDef` structure
     - Analog mode is required when a pin is to be used as ADC channel or DAC output.
     - In case of external interrupt/event, select the type (interrupt or event) and the corresponding trigger event (rising or falling or both).
   - Activate Pull-up, Pull-down resistor using `Pull` member from `GPIO_InitTypeDef` structure.
   - In case of Output or alternate function mode selection: the speed is configured through `Speed` member from `GPIO_InitTypeDef` structure.
   - In alternate mode is selection, the alternate function connected to the IO is configured through `Alternate` member from `GPIO_InitTypeDef` structure.
3. In case of external interrupt/event mode selection, configure NVIC IRQ priority mapped to the EXTI line using `HAL_NVIC_SetPriority()` and enable it using `HAL_NVIC_EnableIRQ()`.
4. `HAL_GPIO_DeInit` allows to set register values to their reset value. It's also recommended to use it to unconfigure pin which was used as an external interrupt or in event mode. That's the only way to reset corresponding bit in `EXTI` & `SYSCFG` registers.
5. To get the level of a pin configured in input mode use `HAL_GPIO_ReadPin()`.
6. To set/reset the level of a pin configured in output mode use `HAL_GPIO_WritePin()` or `HAL_GPIO_TogglePin()`.
7. To lock pin configuration until next reset use `HAL_GPIO_LockPin()`.

8. During and just after reset, the alternate functions are not active and the GPIO pins are configured in input floating mode (except JTAG pins).
9. The LSE oscillator pins `OSC32_IN` and `OSC32_OUT` can be used as general purpose (`PC14` and `PC15` ,respectively) when the LSE oscillator is off. The LSE has priority over the GPIO function.
10. The HSE oscillator pins `OSC_IN` and `OSC_OUT` can be used as general purpose `PF0` and `PF1` , respectively, when the HSE oscillator is off. The HSE has priority over the GPIO function.

5. Lab: Toggle LEDs

This project aims to learn how to configure GPIO via STM32CubeIDE and STM32CubeMX.

Target board: STM32F0 Discovery

Application requirements:

- Turn on Green LED and Blue LED at startup
- In main loop, toggle Green LED every 500ms
- If user press User button, toggle the Blue LED

5.1. Create project

Create new project via CubeMX and setup GPIO for LEDs and button.

- Green Led is on PC9, select *GPIO_Output*
- Blue Led is on PC8, select *GPIO_Output*
- Button is on PA0, select *GPIO_EXTI0* /* do not select GPIO_Input */ to detect interruption

5.2. Setup button's interrupt

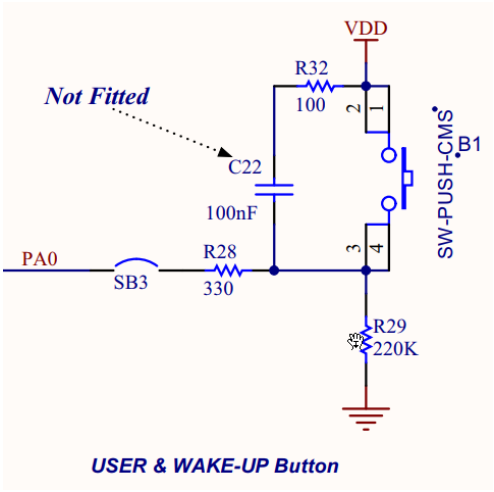
Check the board schematic to know how the button is wired. As seen below, the button is pulled to GND by default, and then connected to VDD when pressed. Therefore, to capture the action of pressing down the button, rising edge will be used to detect the transition.

Select **GPIO** in *Pinout and Configuration* tab, then click on PA0 pin config:

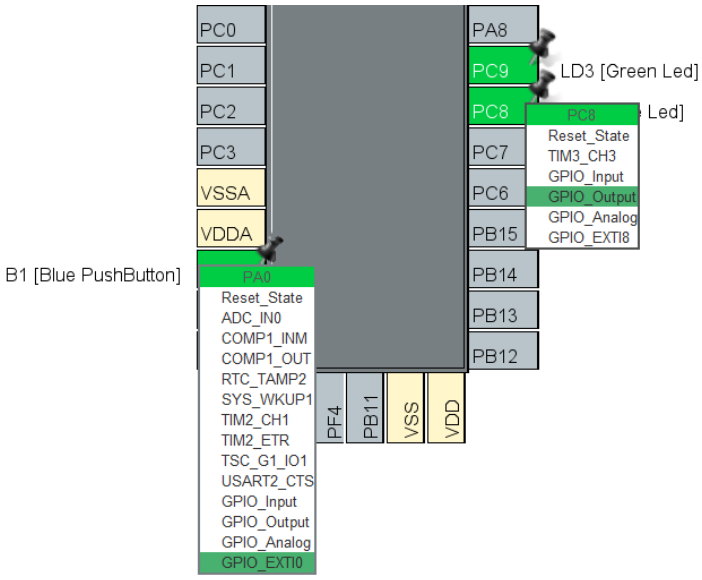
- GPIO Mode: External Interrupt Mode with Rising Edge trigger
- GPIO PU/PD: No

Move to **NVIC** tab:

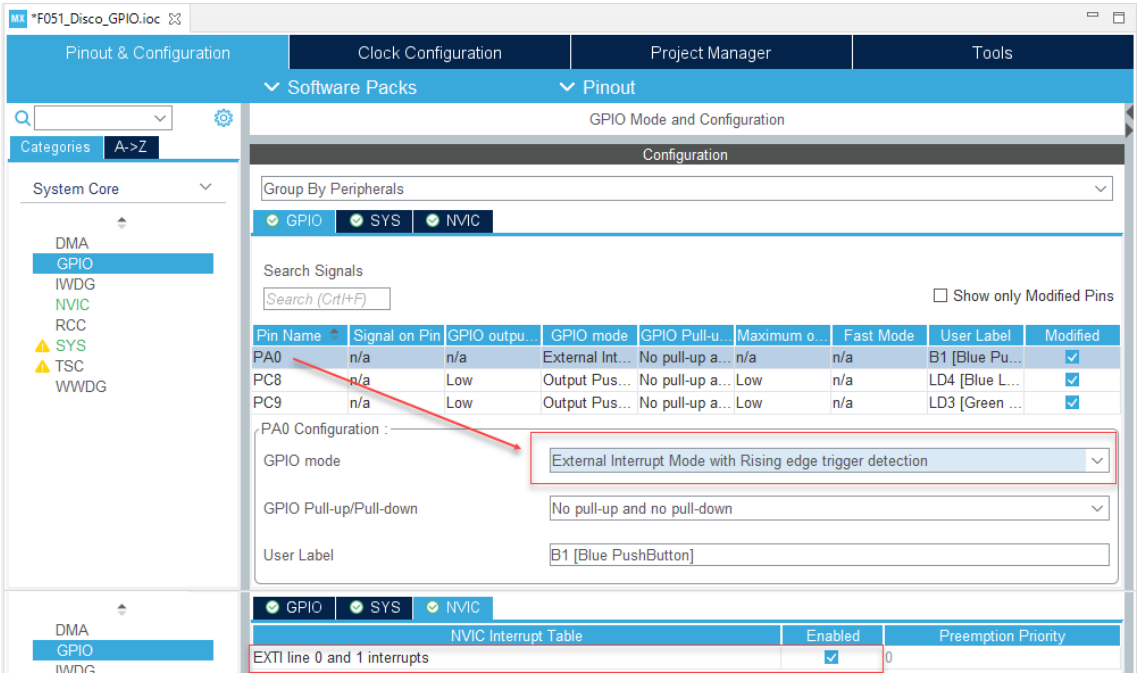
- Check on EXTI line 0 and 1 interrupts



Schematic of User button on pin PA0



Assign GPIO to Leds and button



Enable interrupt on button

5.3. Generated code

Generate code with `alt` + `k`.

Custom defines

Any custom name for a pin will be defined in *main.h*:

main.h

```
#define B1_Pin GPIO_PIN_0
#define B1_GPIO_Port GPIOA
#define LD4_Pin GPIO_PIN_8
#define LD4_GPIO_Port GPIOC
#define LD3_Pin GPIO_PIN_9
#define LD3_GPIO_Port GPIOC
```

Init functions

In the *main.c*, IDE generates `SystemClock_Config()` to setup system clocks, and `MX_GPIO_Init()` to initialize GPIOs.

main.c

```
static void MX_GPIO_Init(void)
{
  GPIO_InitTypeDef GPIO_InitStruct = {0};

  /* GPIO Ports Clock Enable */
  __HAL_RCC_GPIOA_CLK_ENABLE();
  __HAL_RCC_GPIOC_CLK_ENABLE();

  /*Configure GPIO pin Output Level */
  HAL_GPIO_WritePin(GPIOC, LD4_Pin|LD3_Pin, GPIO_PIN_RESET);

  /*Configure GPIO pin : B1_Pin */
  GPIO_InitStruct.Pin = B1_Pin;
  GPIO_InitStruct.Mode = GPIO_MODE_IT_RISING;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(B1_GPIO_Port, &GPIO_InitStruct);

  /*Configure GPIO pins : LD4_Pin LD3_Pin */
  GPIO_InitStruct.Pin = LD4_Pin|LD3_Pin;
  GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_LOW;
  HAL_GPIO_Init(GPIOC, &GPIO_InitStruct);

  /* EXTI interrupt init*/
  HAL_NVIC_SetPriority(EXTI0_1_IRQn, 0, 0);
  HAL_NVIC_EnableIRQ(EXTI0_1_IRQn);
}
```

Interrupt handlers

The the override function of the EXTI0 interrupt handler is implemented in `_it.c` file:

stm32f0xx_it.c

```
void EXTI0_1_IRQHandler(void)
{
  HAL_GPIO_EXTI_IRQHandler(GPIO_PIN_0);
}
```

When tracing the code of the function `HAL_GPIO_EXTI_IRQHandler()`, it will call to the callback function `HAL_GPIO_EXTI_Callback()` which should be overridden in *main.c*.

5.4. User code

Add some lines of code to implement the application requirements:

Turn on all leds at startup

Before main while loop:

```
HAL_GPIO_WritePin(GPIOC, GPIO_PIN_8 | GPIO_PIN_9, GPIO_PIN_SET);
```

Toggle the green led every 500ms

Inside the main while loop:

```
while (1)
{
    HAL_GPIO_TogglePin(GPIOC, GPIO_PIN_9);
    HAL_Delay(500);
}
```

Toggle the blue led when press on button

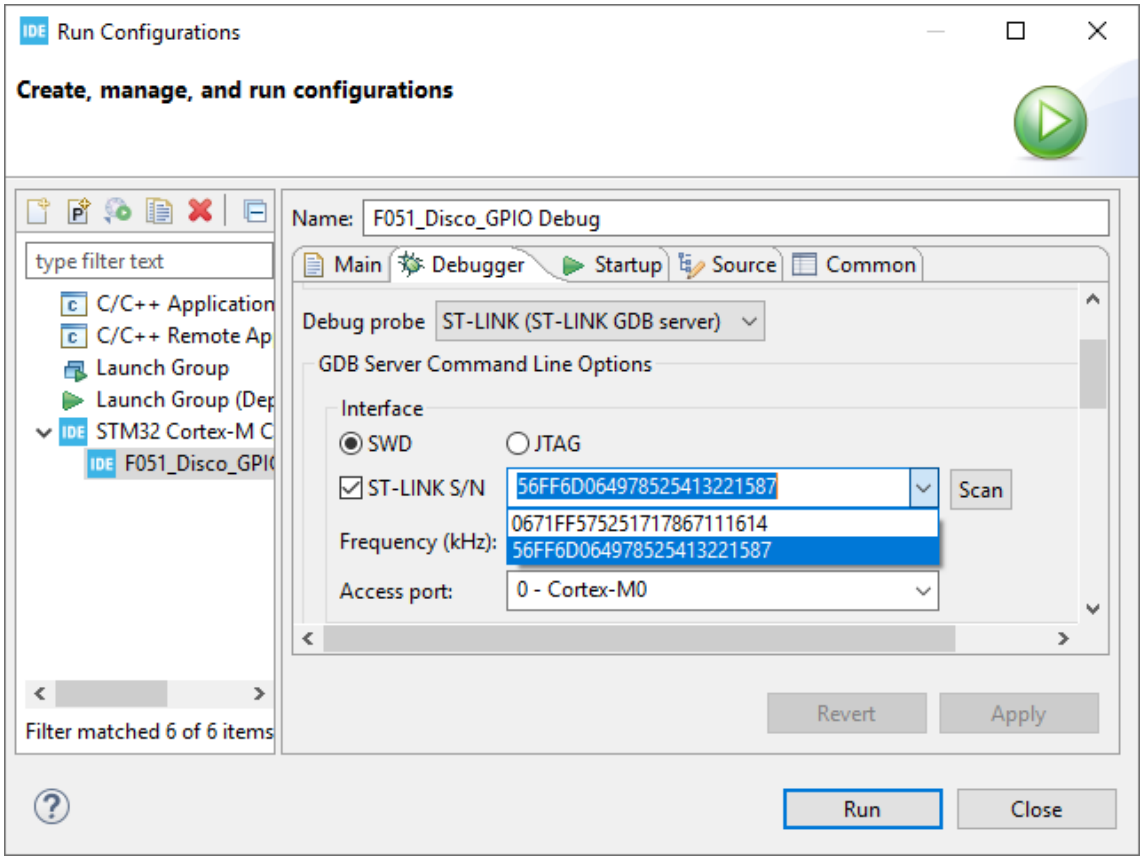
Override `HAL_GPIO_EXTI_Callback` and call to HAL function to toggle the pin state:

```
void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin)
{
    if (GPIO_PIN_0 == GPIO_Pin) {
        HAL_GPIO_TogglePin(GPIOC, GPIO_PIN_8);
    }
}
```

5.5. Build and Run

Press `ctrl` + `b` to build the project and run on the target board.

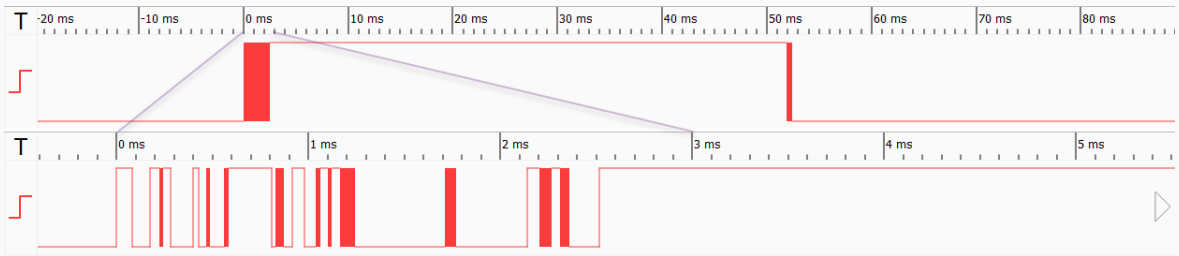
If having multiple boards connected, select the target board by selecting its ST-LINK Serial Number



Select target board

Bouncing input

Sometimes, the blue led does not toggle correctly. It toggles more than once. This happens because of input bouncing: the logic level is unstable during the transition.



Bouncing input on button

To eliminate it, debounce the input by additional hardware or internal timer.

6. Appendix

6.1. Bare-metal

Bare-metal means accessing to the registers directly to read or write value.

Here is an example to turn on PC9 pin /* GPIO C, pin 9 */:

```
#define GPIOC_BASE  (0x48000800UL)
#define GPIOx_ODR   0x14
volatile uint32_t *GPIOC_ODR = (uint32_t *)(GPIOC_BASE + GPIOx_ODR);
*GPIOC_ODR |= (1<<9);
```

However, it should be better to use *struct* to manage a GPIO port. ST HAL library has defined `GPIO_TypeDef` struct as below:

```
typedef struct {
    volatile uint32_t MODER;
    volatile uint32_t OTYPER;
    volatile uint32_t OSPEEDR;
    volatile uint32_t PUPDR;
    volatile uint32_t IDR;
    volatile uint32_t ODR;
    volatile uint32_t BSRR;
    volatile uint32_t LCKR;
    volatile uint32_t AFR[2];
    volatile uint32_t BRR;
} GPIO_TypeDef;
```

Then, define a struct pointer pointing to the base address of the target GPIO port, and use it as a GPIO object:

```
#define GPIOC_BASE  (0x48000800UL)
#define GPIOC       ((GPIO_TypeDef *) GPIOC_BASE)
GPIOC->ODR |= (1 << 9);
```