Tshwane University of Technology

Advanced Diploma in Computer Systems Engineering

Embedded Systems Design (**EBD117V**)

LAB MANUAL
NUCLEO-F401RE BOARD

for

Advanced Embedded Computing

Semester 2, 2024

Compiled by: S. Lefophane

GETTING STARTED

1. Setup

- Install (if Keil IDE is not installed) the Nucleo USB driver before connecting the board (for correct identification of the device interface to the host PC) obtained from: https://www.st.com/en/development-tools/stsw-link009.html
- Jumper Position 1 (JP1) must be off, Jumper Position 5 (JP5) must be ON (U5V), Jumper Position 6 (JP6) must be ON (IDD), and CN2 must be ON (Nucleo)
- Connect the Nucleo board to the PC with the USB MINI-B through connector CN1 to power the board.
- The red LED (LED3 – PWR) and LD1 (COM) must light up (LD2 (Green) can light up depending on demo app loaded on MCU)
- By pressing button B1 (Blue button – left button), LD2 might change (depending on demo app loaded on MCU).
- The board version is: MB1136-C04.

2. Hardware Layout

- The Nucleo board is divided into the ST-LINK part (ST-LINK/V2-1) and the target STM32 part (STM32F401RET6)
- The ST-Link part is used to program the onboard target STM32 and only support the SWD for external STM32 devices
- The target STM32 part host the *STM32F401RE* microcontroller (U5:*64-pin LQFP package*), Morpho connectors (CN7 & CN10), Arduino connectors (CN5, CN6, CN8 & CN9), two push buttons(B1,B2), (U3:*regulator*), (U4:*regulator*), (LD2:*user led*), (LD3:*pwr led*), JP5 (Power-related jumper), JP6 (IDD), (X2:*32.768kHz crystal*), (D4:*Schottky rectifier*) and (X3:*8mHz crystal*) connection points.
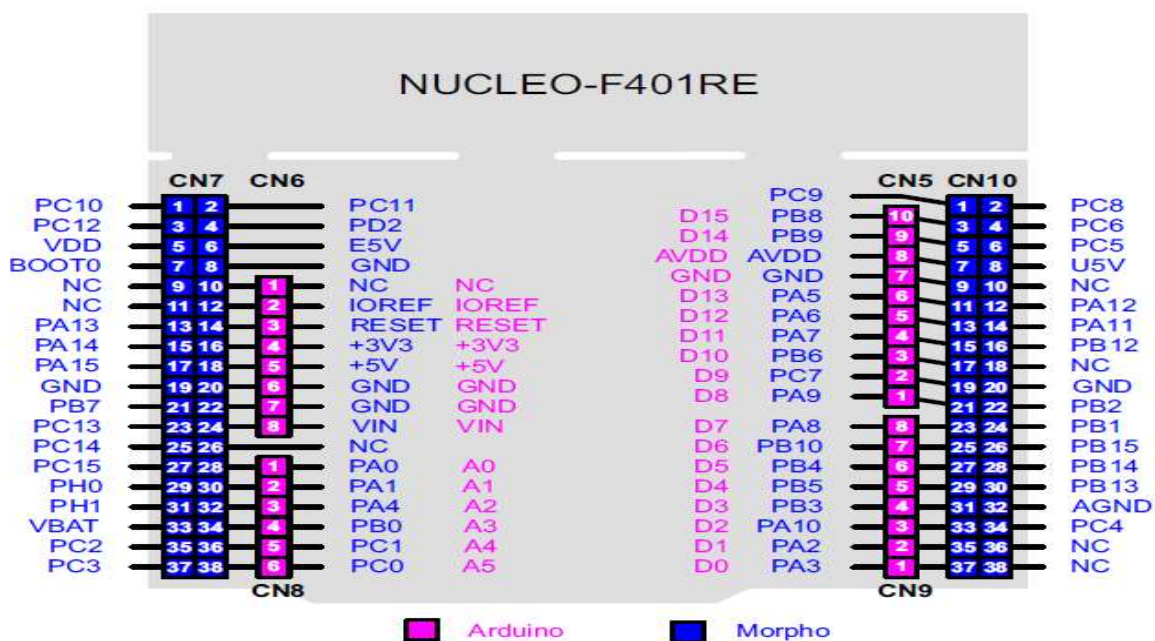

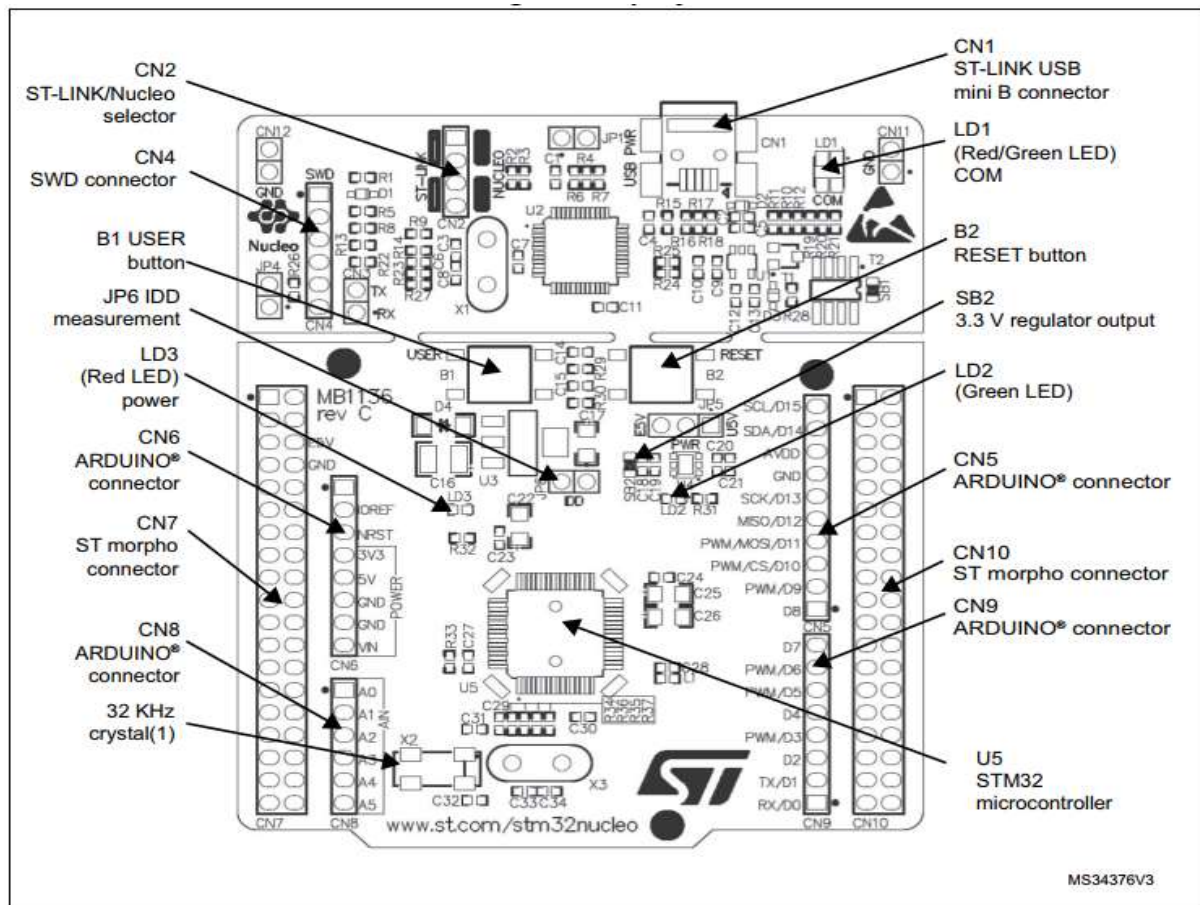*Figure 1: Extension connectors with pin numbers*

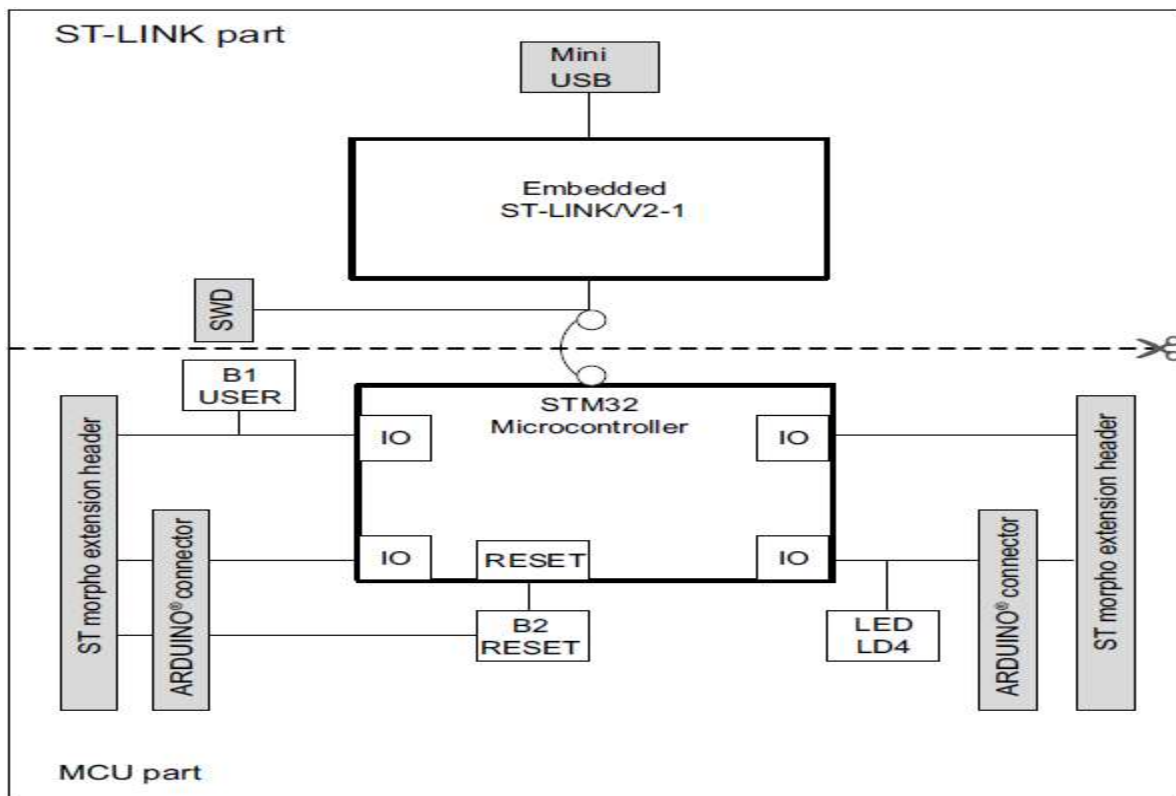*Figure 2: STM32 Nucleo Board hardware layout*

Figure 3: STM32 Block diagram

3. ST Morpho connectors on Nucleo-F401RE

- ST morpho connector (CN7 and CN10) provide all signals and power pins of the STM32
- The I/Os of STM32 microcontroller are 3.3V compatible

CN7 odd pins		CN7 even pins		CN10 odd pins		CN10 even pins	
Pin	Name	Name	Pin	Pin	Name	Name	Pin
1	PC10	PC11	2	1	PC9	PC8	2
3	PC12	PD2	4	3	PB8	PC6	4
5	VDD	E5V	6	5	PB9	PC5	6
7	BOOT0[1]	GND	8	7	AVDD	U5V[2]	8
9	-	-	10	9	GND	-	10
11	-	IOREF	12	11	PA5	PA12	12
13	PA13[3]	RESET	14	13	PA6	PA11	14
15	PA14[3]	+3.3V	16	15	PA7	PB12	16
17	PA15	+5V	18	17	PB6	-	18
19	GND	GND	20	19	PC7	GND	20
21	PB7	GND	22	21	PA9	PB2	22
23	PC13	VIN	24	23	PA8	PB1	24
25	PC14	-	26	25	PB10	PB15	26
27	PC15	PA0	28	27	PB4	PB14	28
29	PH0	PA1	30	29	PB5	PB13	30
31	PH1	PA4	32	31	PB3	AGND	32
33	VBAT	PB0	34	33	PA10	PC4	34
35	PC2	PC1 or PB9[4]	36	35	PA2	-	36
37	PC3	PC0 or PB8[4]	38	37	PA3	-	38

1. The default state of BOOT0 is LOW. It can be set to HIGH when a jumper is on pin5-7 of CN7. Two unused jumpers are available on CN11 and CN12 (bottom side of the board).
2. U5V is 5 V power from ST-LINK/V2-1 USB connector and it rises before +5V.
3. PA13 and PA14 share with SWD signals connected to ST-LINK/V2-1, it is not recommended to use them as IO pins if the ST-LINK part is not cut.

Figure 4: Morpho connectors on Nucleo-F401RE

4. ARDUINO connectors on NUCLEO-F401RE

- CN5, CN6, CN8 and CN9 are female connectors compatible with ARDUINO (Uno v3) and shields designed for ARDUINO
- The I/Os of ARDUINO are 5V compatible as per Uno v3 (**N.B**: Solder Bridge 57 (SB57) must be removed before implementing)

Connector	Pin	Pin name	STM32 pin	Function
			Left connectors	
CN6 power	1	NC	-	-
	2	IOREF	-	3.3V Ref
	3	RESET	NRST	RESET
	4	+3.3V	-	3.3V input/output
	5	+5V	-	5V output
	6	GND	-	ground
	7	GND	-	ground
	8	VIN	-	Power input
CN8 analog	1	A0	PA0	ADC1_0
	2	A1	PA1	ADC1_1
	3	A2	PA4	ADC1_4
	4	A3	PB0	ADC1_8
	5	A4	PC1 or PB9[1]	ADC1_11 (PC1) or I2C1_SDA (PB9)
	6	A5	PC0 or PB8[1]	ADC1_10 (PC0) or I2C1_SCL (PB8)
			Right connectors	
CN5 digital	10	D15	PB8	I2C1_SCL
	9	D14	PB9	I2C1_SDA
	8	AREF	-	AVDD
	7	GND	-	ground

Connector	Pin	Pin name	STM32 pin	Function
CN5 digital	6	D13	PA5	SPI1_SCK
	5	D12	PA6	SPI1_MISO
	4	D11	PA7	TIM1_CH1N or SPI1_MOSI
	3	D10	PB6	TIM4_CH1 or SPI1_CS
	2	D9	PC7	TIM3_CH2
	1	D8	PA9	-
CN9 digital	8	D7	PA8	-
	7	D6	PB10	TIM2_CH3
	6	D5	PB4	TIM3_CH1
	5	D4	PB5	-
	4	D3	PB3	TIM2_CH2
	3	D2	PA10	-
	2	D1	PA2	USART2_TX
	1	D0	PA3	USART2_RX

Figure 5: Arduino Connector on Nucleo-F401RE

5. ST-LINK/V2

There are two different ways to use the embedded ST-LINK/V2-1 depending on the jumper states as per **Table 1** below.

Table 1: ST-LINK/V2-1 jumper status on CN2 descriptions

Jumper State	Description
Both CN2 jumpers ON	ST-LINK/V2-1 functions enabled for on-board programming (default)
Both CN2 jumpers OFF	ST-LINK/V2-1 functions enabled for external CN4 connector (SWD supported)

- ST-Link is a programming and debugging tool integrated into the STM32 Nucleo board (makes the STM32 Nucleo board Mbed enabled)
- Before connecting the Nucleo board to a PC via USB cable, a driver for ST-LINK/V2-1 must be installed (https://www.st.com/en/development-tools/stsw-link009.html)
- The embedded ST-LINK/V2-1 supports only SWD for STM32 devices.
- The target readout protection must be kept disabled on ST-LINK/V2-1 boards

5.1. STLINK-V2-1 Firmware Upgrade

- Download the firmware upgrade application (STSW-LINK007) for ST-LINK/V2-1 boards (https://www.st.com/en/development-tools/stsw-link007.html)
- Extract the folder and launch the ST-LinkUpgrade application from the Windows folder.
- Connect the board to the PC and the firmware version must be:
  - Current firmware: V2.J33.M25
  - Type: STM32 Debug + Mass Storage + VCP

5.2. Using STLINK-V2-1 to program and debug external STM32 application

- Remove the two jumpers from CN2 and connect the application to the CN4 debug connector according to **Table 2** below

Table 2: Debug connector CN4 (SWD)

Pin	CN4	Designation
1	VDD_TARGET	VDD from application
2	SWCLK	SWD clock
3	GND	Ground
4	SWDIO	SWD data input/output
5	NRST	RESET of target STM32
6	SWO	Reserved

- SB12 NRST (target STM32 RESET) must be OFF if CN4 pin 5 is used in the external application

6. OSC Clock
6.1. OSC Clock Supply

There are four ways to configure the pins corresponding to the external high-speed clock (HSE):

- **MCO from ST-LINK:**
  - MCO output of STLINK MCU is used as an input clock.
  - This frequency cannot be changed, it is fixed at 8MHz
  - Connected to PF0/PD0/PH0-OSC_IN of the STM32 microcontroller
  - The following configuration is needed:
    - SB55 OFF and SB54 ON
    - SB16 and SB50 ON
    - R35 and R37 removed

- **HSE oscillator on board from X3 crystal (not provided):**
  - The X3 crystal has the following characteristics: 8MHz, 16pF, 20ppm and DIP footprint.
  - Recommended to use 9SL8000016AFXHF0 manufactured by Hong Kong X'tals limited
  - The following configuration is needed:
    - SB54 and SB55 OFF
    - R35 and R37 soldered
    - C33 and C34 soldered with 20pF capacitors
    - SB16 and SB50 OFF
- **Oscillator from external PF0/PD0/PH0:**
  - From external oscillator through pin 29 of the CN7 connector
  - The following configuration is needed:
    - SB55 ON
    - SB50 OFF
    - R35 and R37 removed
- **HSE not used:**
  - PF0/PD0/PH0 and PF1/PD1/PH1 are used as GPIOs instead of clocks
  - The following configuration is needed:
    - SB54 and SB55 ON
    - SB16 and SB50 (MCO) OFF
    - R35 and R37 removed

Depending on the board version used, there are two possible default configurations of the HSE pins:

- board marking MB1136-C01 corresponds to configuration HSE not used
- board marking MB1136-C02 or higher corresponds to configuration ST-LINK MCO as the clock input.

6.2. OSC 32 KHz Clock Supply

There are three ways to configure the pins corresponding to the low-speed clock (LSE):

- **On-board oscillator:**
  - X2 crystal and it is recommended to use ABS25-32.768KHz-6-T, manufactured by Abracon Corporation
- **Oscillator from external PC14:**
  - From external oscillator through pin 25 of CN7 connector
  - The following configuration is needed:
    - SB48 and SB49 ON
    - R34 and R36 removed
- **LSE not used:**
  - PC14 and PC15 are used as GPIOs instead of low-speed clocks.
  - The following configuration is needed:
    - SB48 and SB49 ON
    - R34 and R36 removed

Depending on the board version used, there are three possible default configurations of the LSE pins:

- Board marking MB1136-C01 corresponds to a board configured as LSE not used
- Board marking MB1136-C02 or higher corresponds to a board configured with on-board 32kHz oscillator
- Board marking MB1136-C03 or higher corresponds to a board using new LSE crystal (ABS25) and C26, C31, and C32 value update.

7. USART Communication

The USART2 interface available on PA2 and PA3 of the STM32 microcontroller can be connected to ST-LINK MCU, ST morpho connector or to Arduino connector.

- By default, the USART2 communication between the STM32 and ST-LINK MCU is enabled in order to support virtual COM port for Mbed (SB13 and SB14 ON, SB62 and SB63 OFF).
- If communication between STM32 PA2 (D1) or PA3 (D0) and shield or extension board is required, SB62 and SB63 must be ON, while SB13 and SB14 must be OFF.
    - o In this case, it is possible to connect another USART to ST-LINK MCU using flying wires between the morpho connector and CN3.
    - o Two flying wires must be connected as follows:
        - ▪ PC10 (USART3_TX) available on CN7 pin1 to CN3 pin RX
        - ▪ PC11 (USART3_RX) available on CN7 pin2 to CN3 pin TX

8. Solder Bridges

All STM32 Nucleo boards are configured with solder-bridges according to the target STM32.
- Used to configure several I/Os and power supply pins for compatibility of features and pinout with STM32 supported
- The default SBx state is shown in bold

Table 3: Solder bridges

Bridge	State	Description
SB3, SB5, SB7, SB9 (Default)	**ON**	Reserved, do not modify
SB4, SB6, SB8, SB10 (Reserved)	OFF	Reserved, do not modify
SB1 (USB-5V)	OFF	USB power management is functional
	ON	USB power management is disabled
SB2 (3.3V)	OFF	Output of voltage regulator (LD39050PU33R) is not connected
	ON	Output of voltage regulator (LD39050PU33R) is connected to 3.3V
SB11 (STM_RST)	**OFF**	No incidence on STM32F103CBT6 (STLINK MCU) NRST signal
	ON	STM32F103CBT6 (STLINK MCU) NRST signal is connected to GND
SB12 (NRST)	OFF	The NRST signal of the CN4 connector is not connected to the NRST pin of the STM32
	ON	The NRST signal of the CN4 connector is connected to the NRST pin of the STM32
SB13, SB14 (ST-LINK-USART)	OFF	PA2 and PA3 on STM32F103CBT6 (STLINK MCU) are disconnected to PA3 and PA2 on STM32
	ON	PA2 and PA3 on STM32F103CBT6 (STLINK MCU) are connected to PA3 and PA2 on STM32 to have USART communication between them. Thus SB61, SB62, and SB63 must be OFF.
SB15 (SWO)	OFF	The SWO signal is not connected
	ON	The SWO signal of the CN4 connector is not connected to PB3
SB16, SB50 (MCO)	OFF	MCO on STM32F103CBT6 (STLINK MCU) are disconnected to PF0/PD0/PH0 on STM32
	ON	MCO on STM32F103CBT6 (STLINK MCU) are connected to PF0/PD0/PH0 on STM32
SB17 (B1-USER)	OFF	B1 push button is not connected to PC13
	ON	B1 push button is connected to PC13

SB21 (LD2-LED)	OFF	Green user LED LD2 is not connected
	ON	Green user LED LD2 is connected to D13 of Arduino signal
SB45 (VBAT/VLCD)	OFF	VBAT or VLCD on STM32 is not connected to VDD
	ON	VBAT or VLCD on STM32 is connected to VDD
SB46, SB52 (I2C on A4 and A5)	OFF	PB9 and PB8 (I2C) are disconnected to A4 and A5 (pin5 and pin6) on Arduino connector CN8 and morpho connector CN7.
	ON	PB9 and PB8 (I2C) are connected to A4 and A5 (pin5 and pin6) on Arduino connector CN8 and morpho connector CN7 as I2C signals. Thus, SB56 and SB51 must be OFF
SB48, SB49 (X2 crystal)	OFF	X2, C31, C32, R34, and R36 deliver a 32kHz clock. PC14, PC15 are not connected to CN7
	ON	PC14 and PC15 are only connected to CN7. Remove only R34, R36
SB51, SB56 (A5 and A4)	OFF	PC1 and PC0 (ADC in) are disconnected to A4 and A5 (pin5 and pin6) on Arduino connector CN8 and morpho connector CN7
	ON	PC1 and PC0 (ADC in) are connected to A4 and A5 (pin5 and pin6) on Arduino connector CN8 and morpho connector CN7. Thus, SB46 and SB52 must be OFF
SB54, SB55 (X3 crystal)	OFF	X3, C33, C34, R35, and R37 provide a clock. PF0/PD0/PH0, PF1/PD1/PH1 are disconnected from CN7
	ON	PF0/PD0/PH0, PF1/PD1/PH1 are connected to CN7. R35, R37 and SB50 must not be fitted.
SB57 (VDDA/VREF+)	OFF	VDDA/VREF+ on STM32 is not connected to VDD and can be provided from pin8 of CN5 (used for external VREF+ provided by Arduino shield)
	ON	VDDA/VREF+ on STM32 is connected to VDD
SB62, SB63 (USART)	**OFF**	PA2 and PA3 on STM32 are disconnected to D1 and D0 (pin2 and pin1) on Arduino connector CN9 and morpho connector CN10
	ON	PA2 and PA3 on STM32 are connected to D1 and D0 (pin2 and pin1) on Arduino connector CN9 and morpho connector CN10 as USART signals. Thus, SB13 and SB14 must be OFF

9. IDD

- Used to measure the STM32 current consumption by connecting the ammeter through JP6 connectors

Table 4: JP6 connector status descriptions

Jumper State	Description
Jumper ON	STM32 MCU is powered (default)
Jumper OFF	An ammeter must be connected to measure the MCU current, if not connected the MCU is not powered

10.   Push Buttons

Table 5: Push Buttons status descriptions

Buttons	Description
User Button (B1)	is connected to the I/O PC13 of the MCU
Reset Button (B2)	is connected to NRST, and is used to RESET the MCU

11.   LEDs

Table 6: LEDs status descriptions

LEDs	Color	Description
LD1 (USB Communication LED)	Red ON (default)	when the initialization between the PC and ST-LINK/V2-1 is complete
	Green ON	successful target communication finished
	Orange ON	Communication failure
	Blinking Red/Green	during communication with the target
	Blinking Red/OFF	after the first correct communication between the PC and ST-LINK/V2-1 (enumeration)
LD2 (User LED)	Green	is a user LED connected to ARDUINO signal D13 corresponding to STM32 I/O PA5 (pin 21) or PB13 (pin 34)
LD3 (Power LED)	Red	indicates that the STM32 part is powered and +5V power is available

12.   Power Supply and Power Selection

The power supply is provided either by:

- Host PC through the USB cable
- Or by an external source (VIN: 7V to 12V), (CN6: E5V) or (CN7: 3.3V)

12.1.   Host PC input power supply

- Powered from ST-LINK USB connector CN1 (U5V)
  - o A jumper must be connected between pin 1 and pin 2 of JP5
  - o STM32 Nucleo board requires 300mA to power ON and the red LED (LD3) turns ON.
  - o If <300mA is supplied by host PC, LD3 remains OFF and the board is not turned ON.
- JP1 is configured according to the maximum current consumption of the board
  - o JP1 sets the allowed maximum current consumption of the board

Table 7: JP1 configuration table

Jumper state	Power supply	Allowed current
JP1 jumper OFF	USB power through CN1	300mA max
JP1 jumper ON		100mA max

12.2.   External power supply (VIN and E5V)

When the board is power supplied by VIN or E5V, the jumper's configuration must be the following:

- Jumper on JP5 pin 2 and pin 3
- Jumper removed on JP1

Table 8: External power sources

Input power name	Connector pins	Voltage range	Max current	Limitations
VIN	CN6 pin 8 CN7 pin 24	7V to 12V	800mA	• 800mA when VIN=7V • 450mA when 7V<VIN<=9V • 250mA when 9V<VIN<=12V
E5V	CN7 pin 6	4.75V to 5.25V	500mA	

VIN and E5V can be used as external power supply in case the current consumption of the Nucleo board and extension boards exceeds the allowed current from USB power supply.

- In this condition, the USB is used for communication, for programming or debugging only.
- The following power procedures must be respected:
  - Connect the jumper between pin 2 and pin 3 of JP5
  - Check that JP1 is removed
  - Connect the external power source to VIN or E5V
  - Power on the external power supply 7V < VIN < 12V to VIN or 5V for E5V
  - Check that LD3 is turned ON
  - Connect the PC to USB connector CN1

Table 9: Power related jumper

Jumper	Description
JP5	U5V(STLINK VBUS) is used as power source when JP5 Pin1 is connected to Pin2
	VIN or E5V is used as power source when JP5 Pin2 is connected to Pin3

12.3.   3.3V external power supply

CN6 pin 4 or CN7 pin 12 and pin 16 supply 3.3V to the Nucleo board. When the Nucleo board is powered by 3.3V, the STLINK is not powered, thus programming and debug features are unavailable.

Two different configurations are possible when using 3.3V to power the board:

- STLINK is removed or
- SB2 (3.3V regulator) and SB12 (NRST) are OFF

Table 10: 3.3V external power source

Input power name	Connector pins	Voltage range	Limitations
3.3V	CN6 pin 4 CN7 pin 12 and pin 16	3V to 3.6V	Used when ST-LINK part of PCB is cut or SB2 and SB12 are OFF

12.4. External power supply output

- When powered by USB, VIN or E5V:
    - CN6 pin 5 or CN7 pin 18 can be used as an output power supply for Arduino or an extension board
    - Maximum current of the power source as per **Table 8** must be respected.
- When powered by 3.3V:
    - CN6 pin 4 or CN7 pin 12 and pin 16 can be used as power supply output.
    - The current is limited to 500mA max by the regulator U4.

13. Nucleo Bootloader

- Boot from system flash memory (protected against write and erase) results in executing bootloader code stored in the system flash memory.
- Bootloader version is identified by reading the bootloader ID at the address 0x1FFF6FFE
- STM32F/L4xx parts with date code prior or equal to week 22 of 2015 are fitted with bootloader v9.0 (contains known limitations)
    - RAM data get corrupted when written via SPI/I2C/USART/USB interface
- STM32F/L4xx parts with date code starting from week 23 of 2015 are fitted with bootloader v9.2 (addresses the limitations)

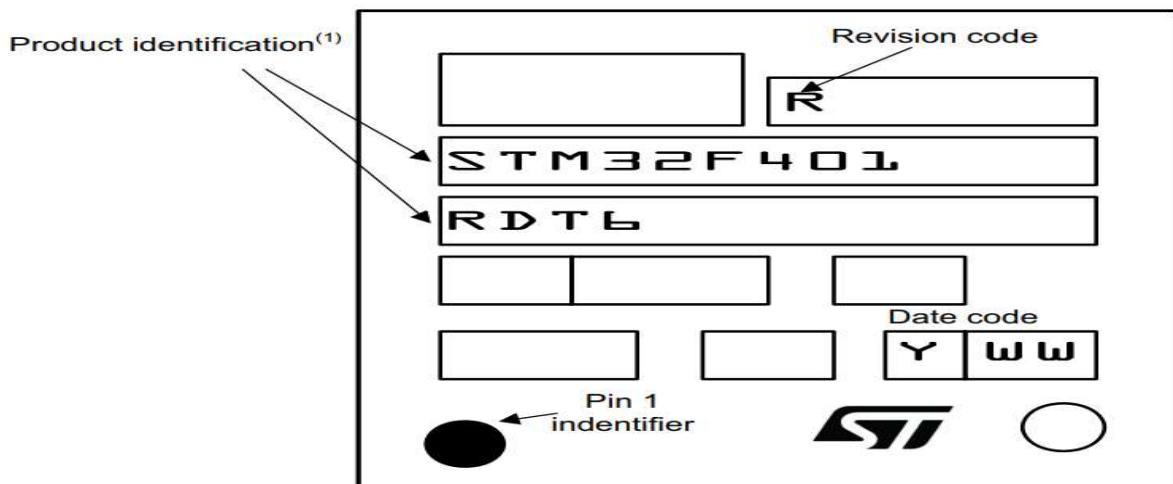# 14. STM32F401 RET6U (U5)

14.1. Device Marking

Figure 6: STM32F401 LQFP64 Marking (Top-view)

- Y – *Year last digit* and
- WW – *is the week*
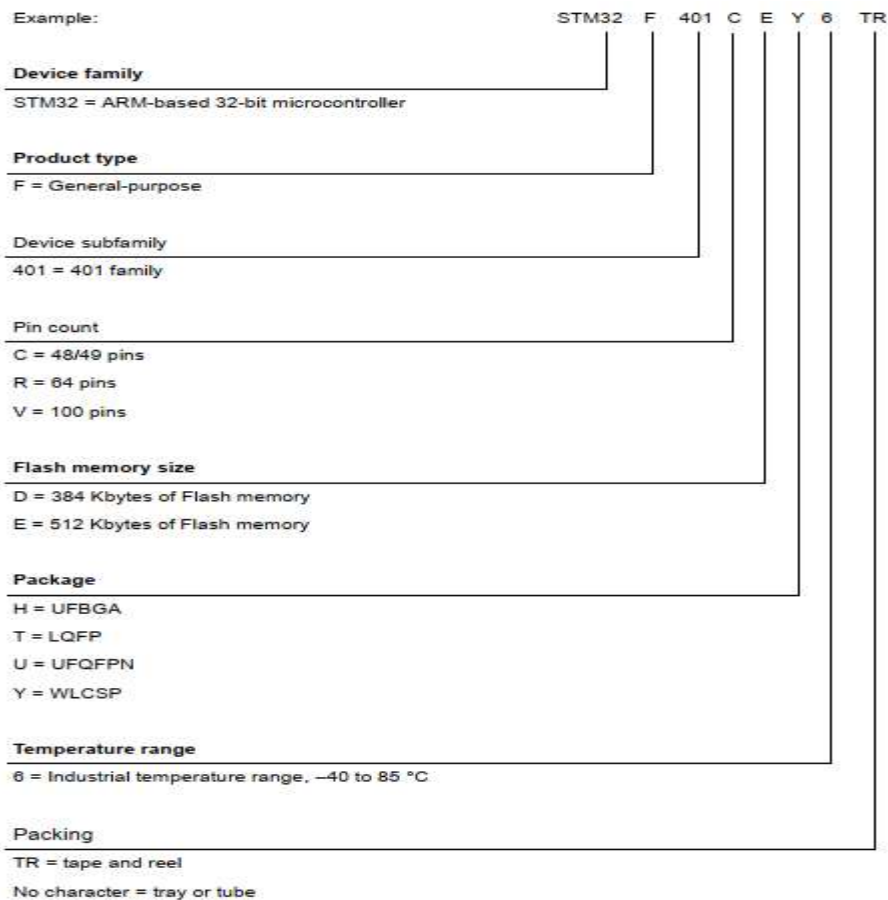   - (e.g., 523 is *2015 week 23*)

14.2.   Part Numbering

Figure 7: Part numbering

14.3.   Nucleo-board Marking Explanation

Table 11: Nucleo board marking explanations

NUCLEO-XXYYRT	Description	Example
XX	MCU Series	STM32F4
YY	Product line in the series	STM32F401
R	Package pin out -C for 48 pins -R for 64 pins	64 pins
T	Flash memory size: -6 for 32Kbytes -8 for 64 Kbytes -B for 128 Kbytes -C for 256 Kbytes -E for 512 Kbytes -G for 1Mbytes -Z for 192 Kbytes	512 Kbytes
-P	STM32 has external MPS function	No SMPS

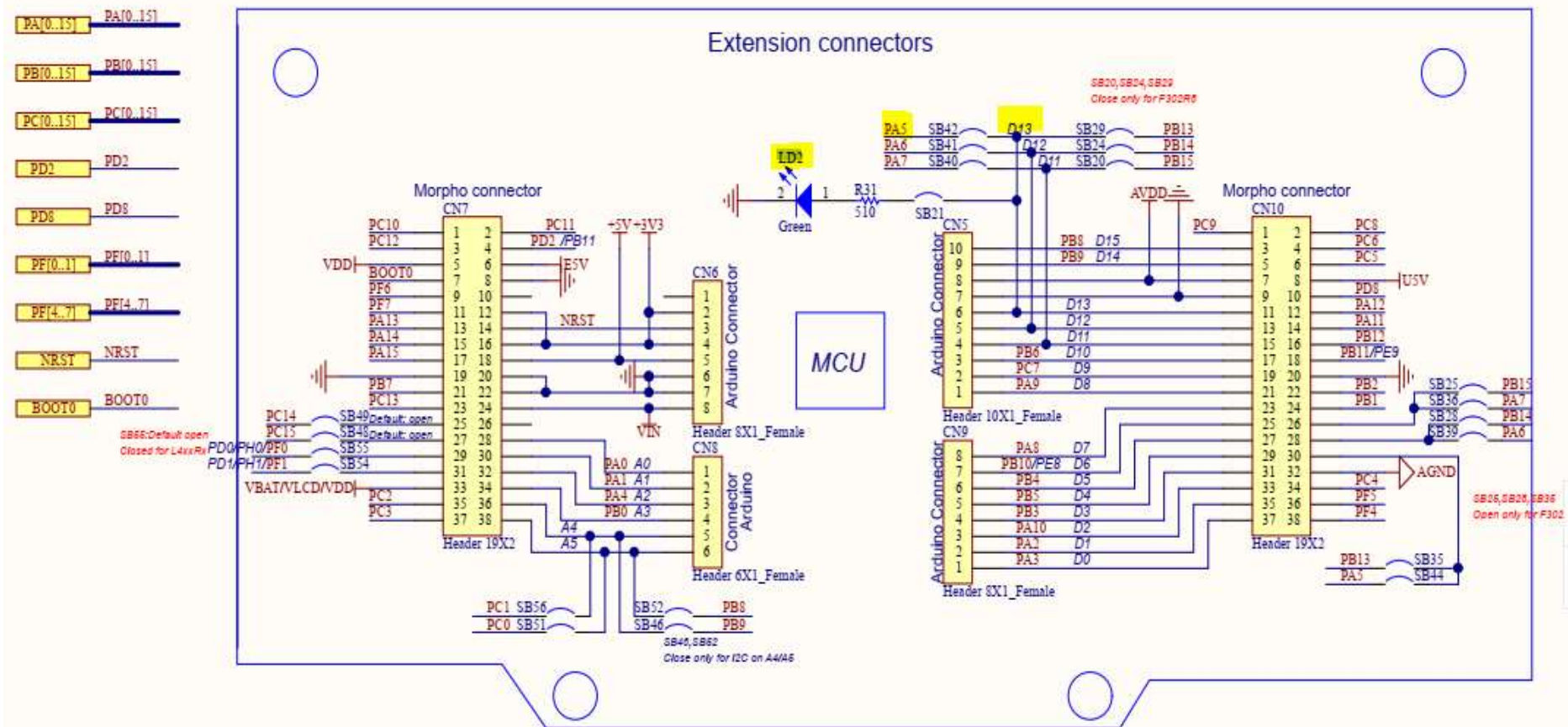## 15.   LD2 and B1 default schematic
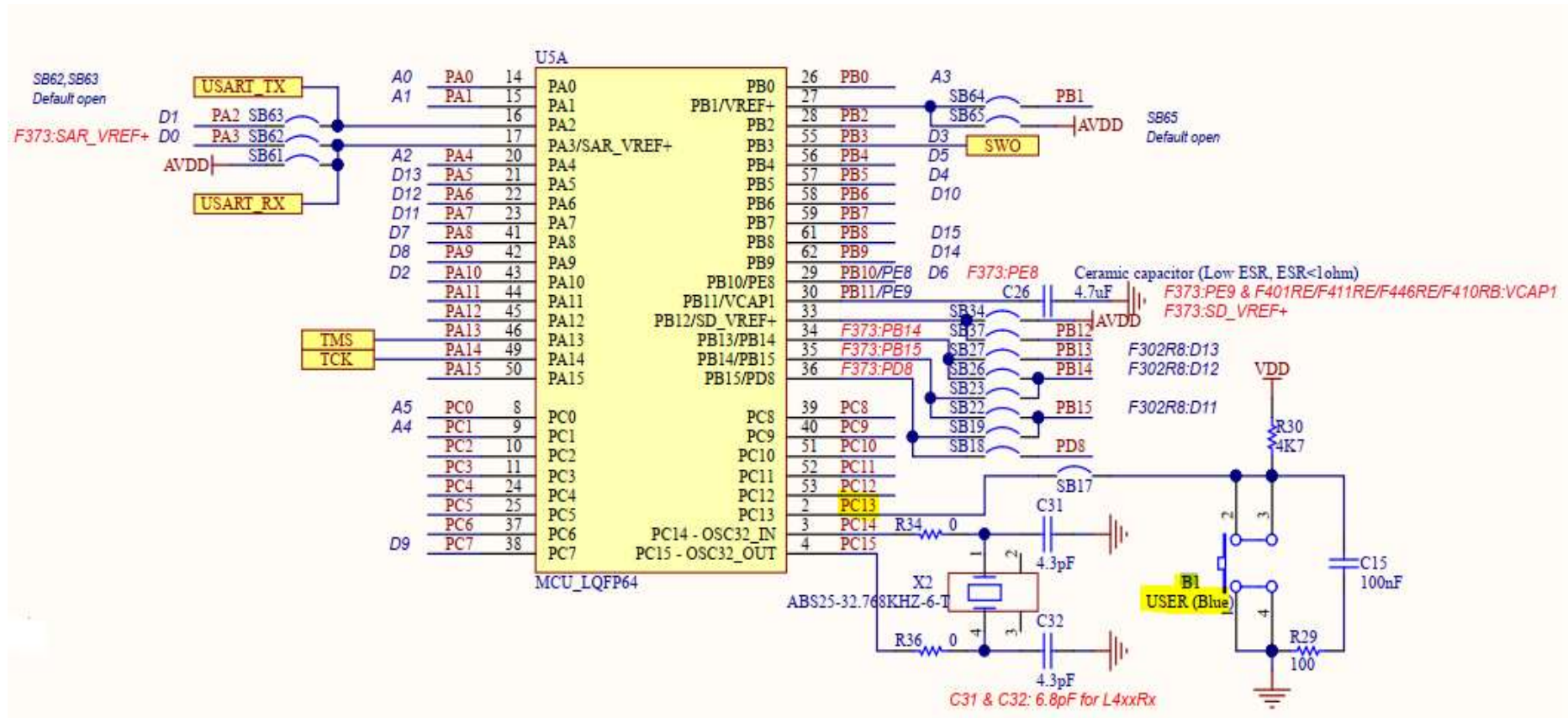

Figure 8: LD2 connection schematic to GPIO Pin

Figure 9: User Button (B1) connection schematic to GPIO Pin

References

1) UM1724: User Manual – STM32 Nucleo-64 boards (MB1136)
2) STM32 Nucleo-64 boards (data brief)
3) TN1235: Overview of ST-LINK derivatives (Technical note)
4) UM1727: Getting started with STM32 Nucleo board software development tools (User manual)