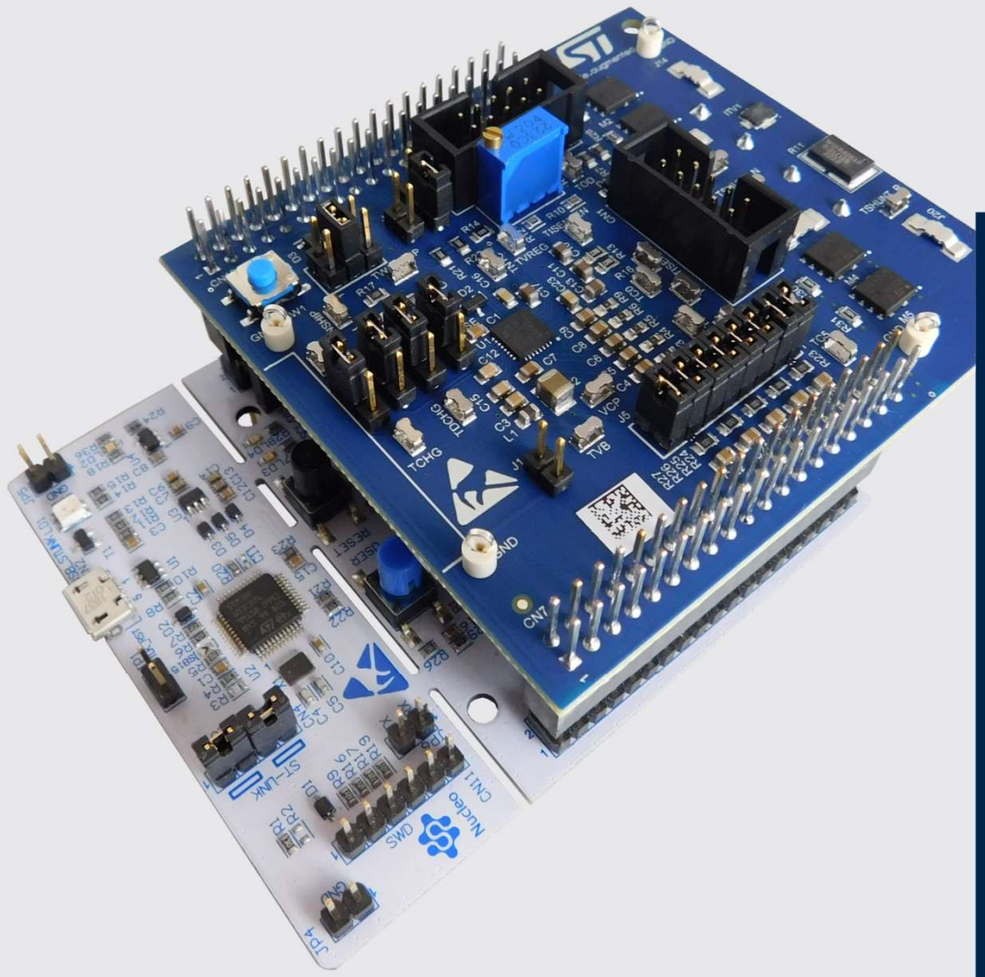

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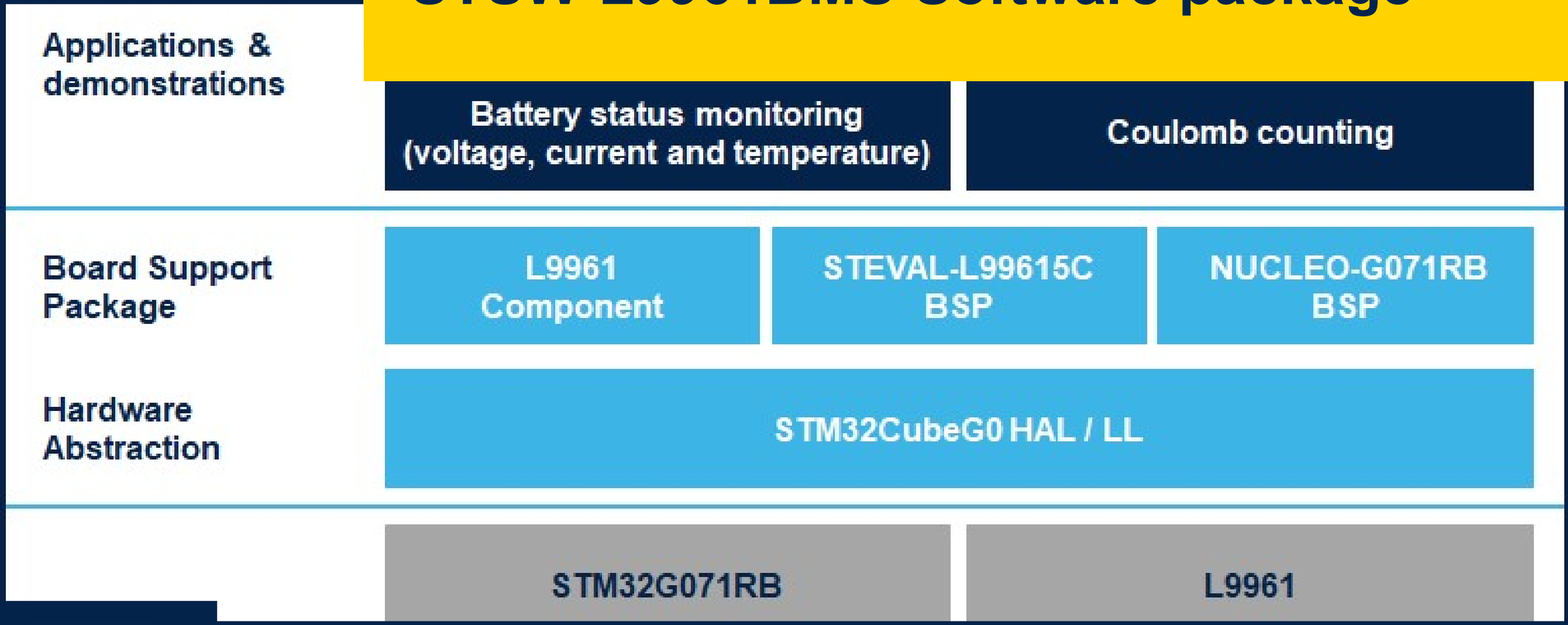
Quick Start Guide for STSW-L9961BMS

Software package for the STEVAL-L99615C kit - L9961 industrial battery management system

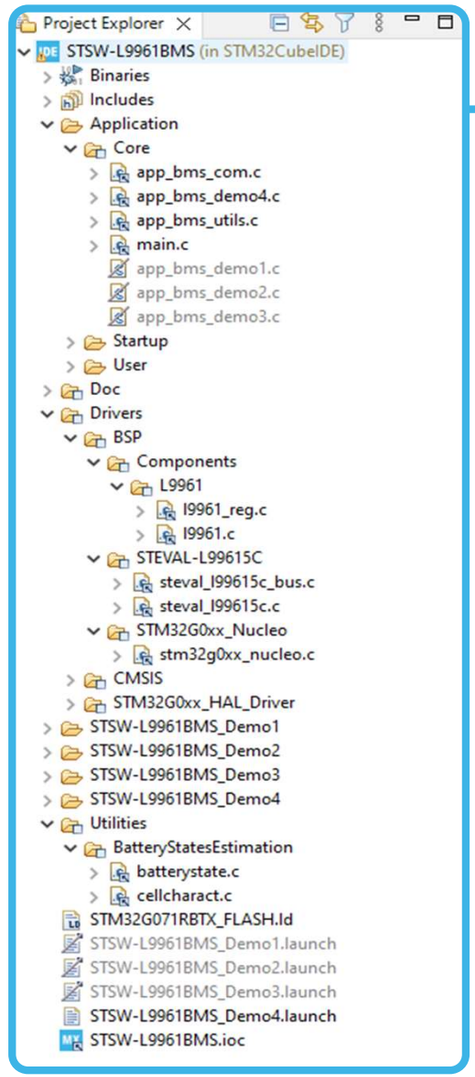
Ver.4.0 – December 2023

STSW-L9961BMS Software package



Key topics of the STSW-L9961BMS Software package

- Software package specifically designed for the STEVAL-L99615C kit to demonstrate the capabilities of the L9961 industrial BMS IC
- Includes the L9961 driver component, along with its register map and related basic APIs
- Application demos exploiting the key-features of the L9961 ICs
- Architecture compatible with STM32Cube Firmware BSP specification
- Use of a serial communication terminal to output data
- Contains demonstration project released for:
  - STM32CubeIDE v.1.14
  - EWARM (IAR) v. 9.20
  - uVision (Keil) v. 5.38



STM32 CubeIDE

IAR SYSTEMS

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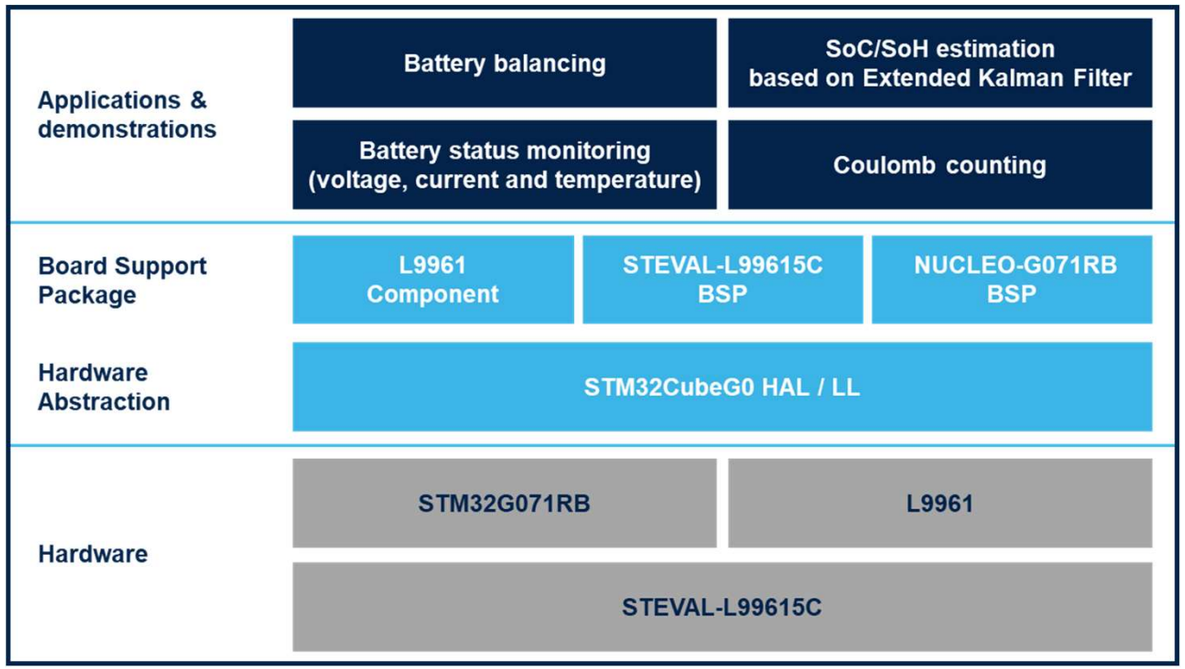
STSW-L9961BMS Software Architecture

Main SW functional layers are:

1. **Hardware abstraction** divided in
   - **STM32CubeG0 HAL and LL** Hardware Abstraction Layer for the STM32G0 microcontroller
   - **Board Support Package (BSP)** library layer containing the drivers of:
     - the L9961 component device
     - the STEVAL-L99615C expansion board
     - the NUCLEO-G071RB board
2. **Applications and demonstrations**
   - Battery status monitoring
   - Coulomb counting
   - Battery balancing
   - SoC/SoH estimation based on Kalman Filter



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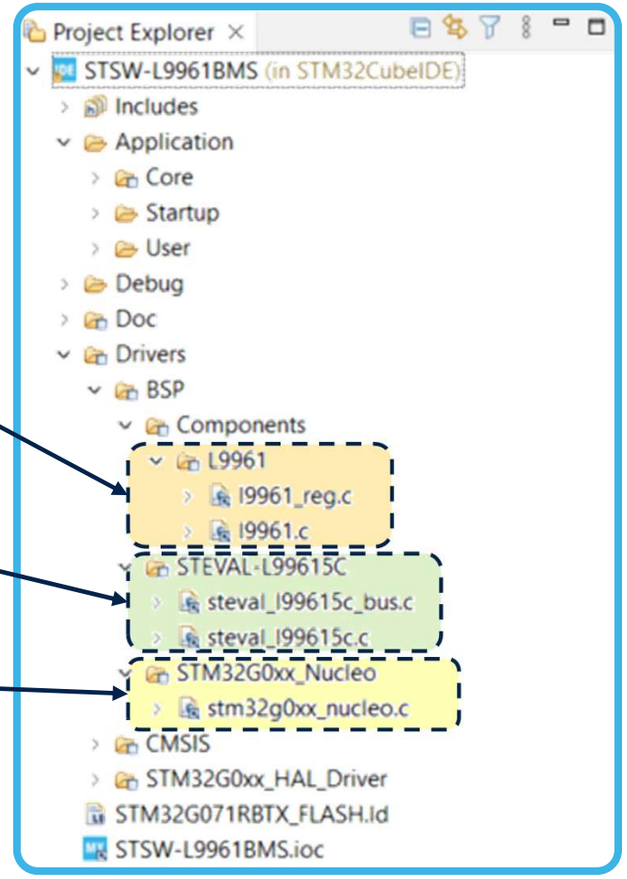
STSW-L9961BMS: BSP drivers

The Board Support Package comprises the following drivers:

- the **L9961 component device**, including the register map of the device, the basic functions to manage registers at bit level, the write/read functions (single-register and multi-registers), and the APIs to configure the device and manage its functionalities (i.e. Go-to-Normal, Change Address, Enable/Disable CRC,…)
- the **STEVAL-L99615C** expansion board support package that manages the configurations of the HW peripheral and GPIOs used by the application
- the **NUCLEO-G071RB Nucleo** board support package containing a set of minor functions connected to the microcontroller board



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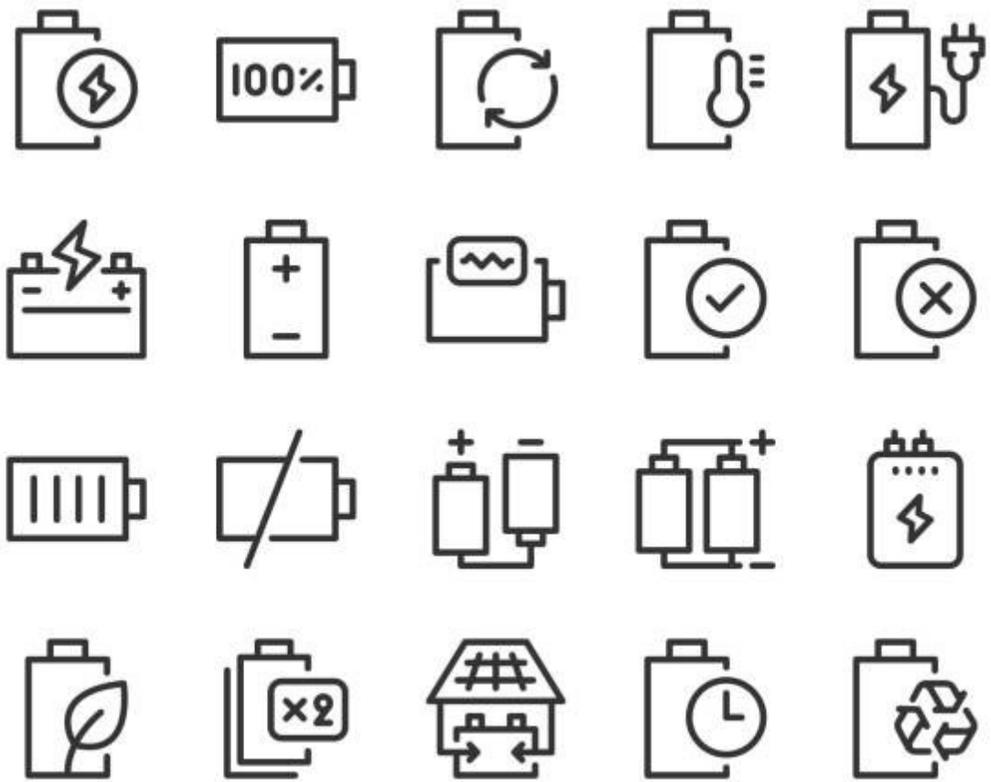
STSW-L9961BMS: Application Demos



- The application demos contained in STSW-L9961BMS package, have been designed to run within the STEVAL-L99615C, to evaluate the L9961 features and performances:
  - App Demo 1: **Battery status monitoring** demonstrating the acquisition of voltage, current and temperature from a 5-cell battery pack
  - App Demo 2: **Coulomb counting** mechanism monitoring the charges flowing through the battery cells
  - App Demo 3: **Battery balancing** mechanism to equalize the energy between the cells that constitute the battery pack.
  - App Demo 4: **SoC/SoH estimation based on Kalman Filter** providing an accurate status of the battery cells during their operativity.
- Each demo is selectable through the project compiler options and exploits the serial communication peripheral to return specific output data

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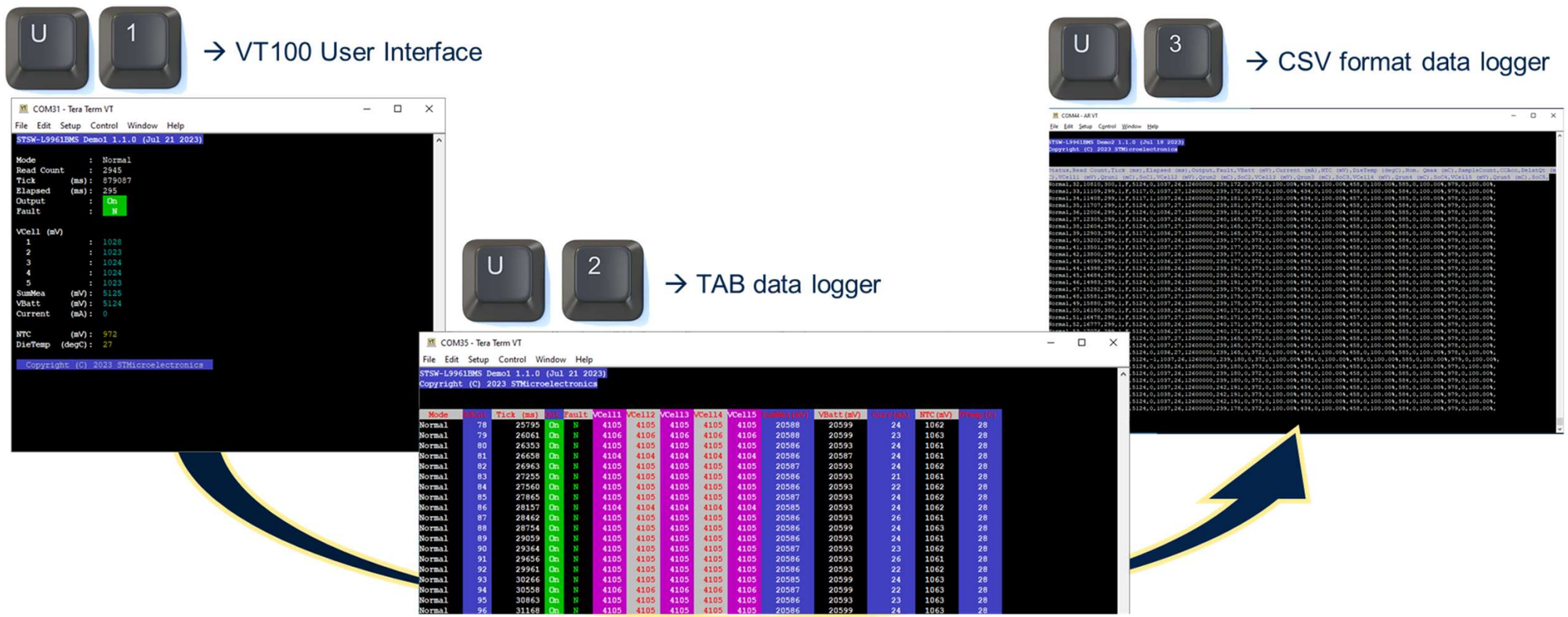
STSW-L9961BMS output data viewers

- Each demo is selectable through the project compiler options and exploits the serial communication peripheral to return specific output data
- Different viewer layouts allow live monitoring of the acquired data and elaborated data. For the selection, you may press the key ‘U’ and after ‘1’, ‘2’ or ‘3’, or alternatively press the Nucleo blue button for a long time.



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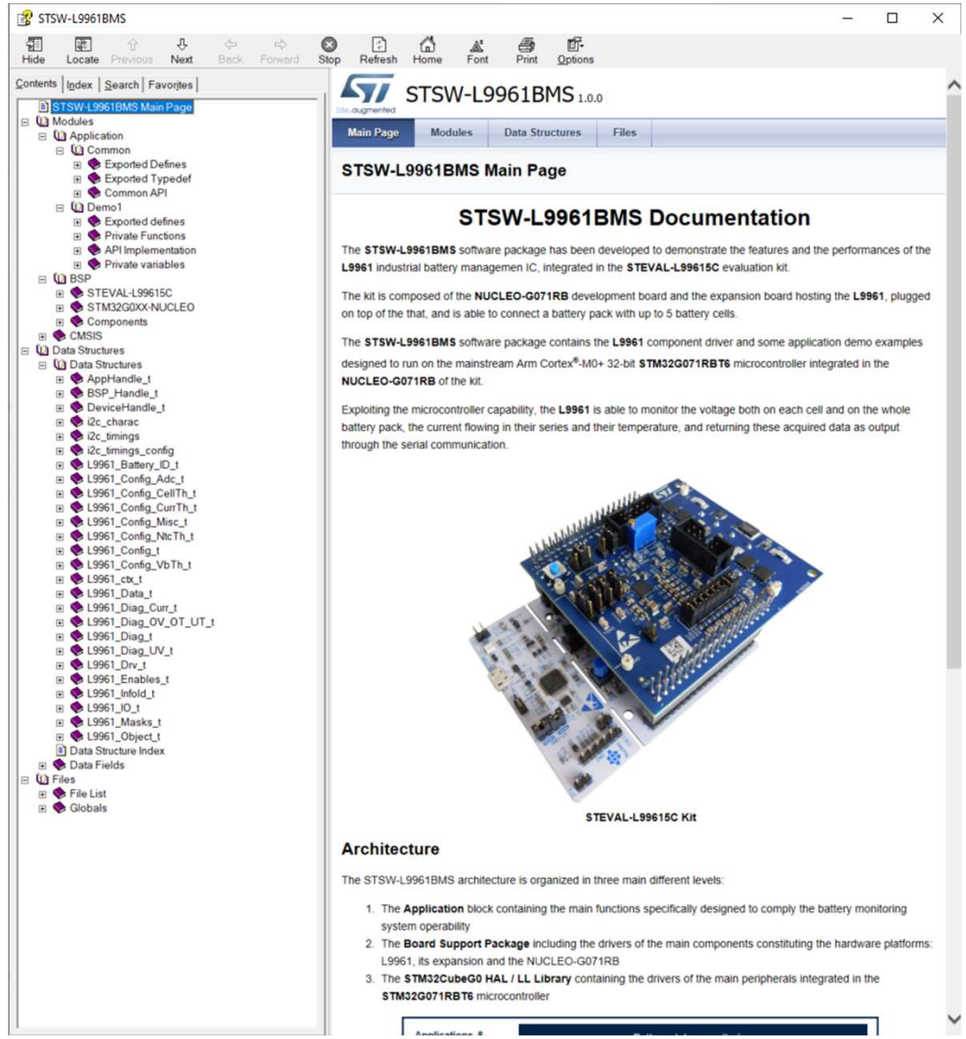
STSW-L9961BMS Doxy file

- The Application Demos and their related functions are fully described in the Application User source and header files of the project
- The project directory, in the Documentation sub-directory, contains the STSW-L9961BMS.chm Doxygen file
- The Doxy file enriches the code with relevant information about STSW-L9961BMS firmware architecture and functionalities



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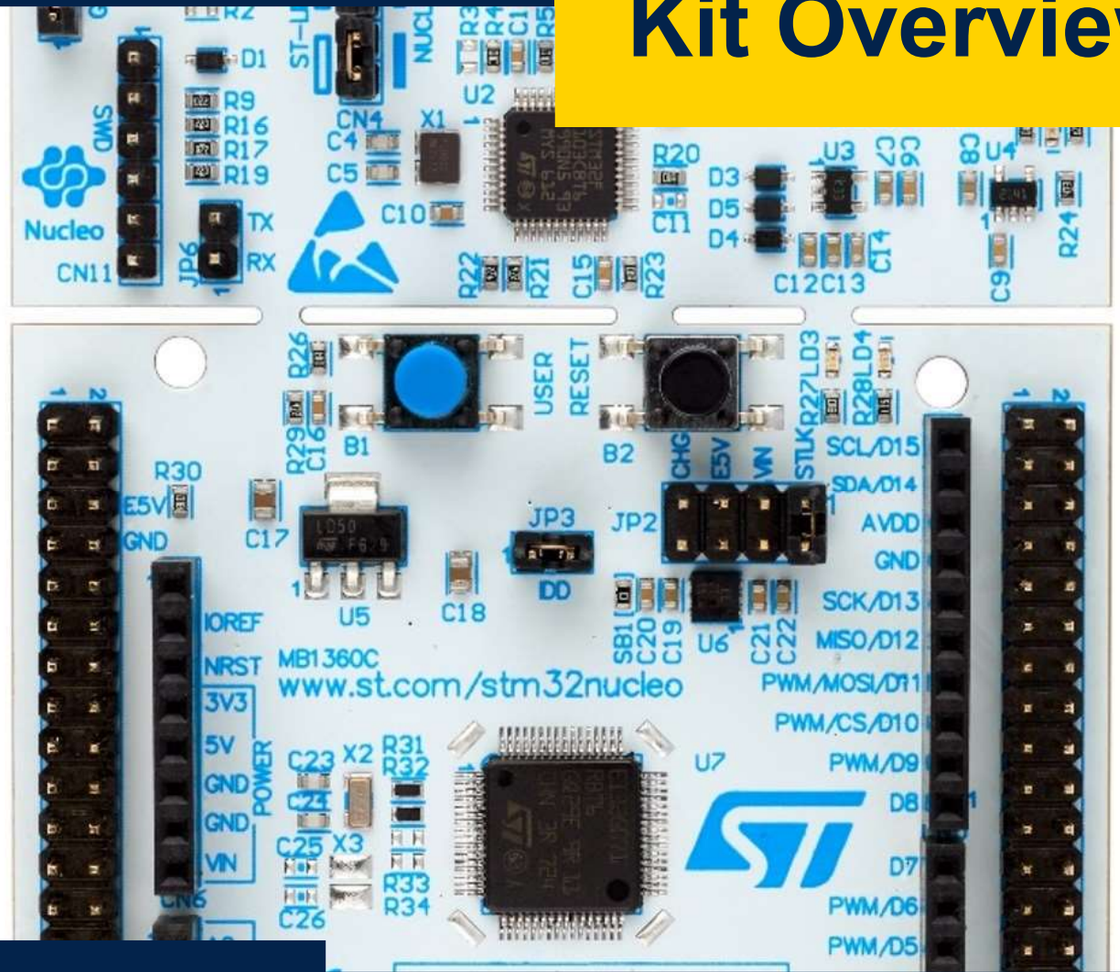
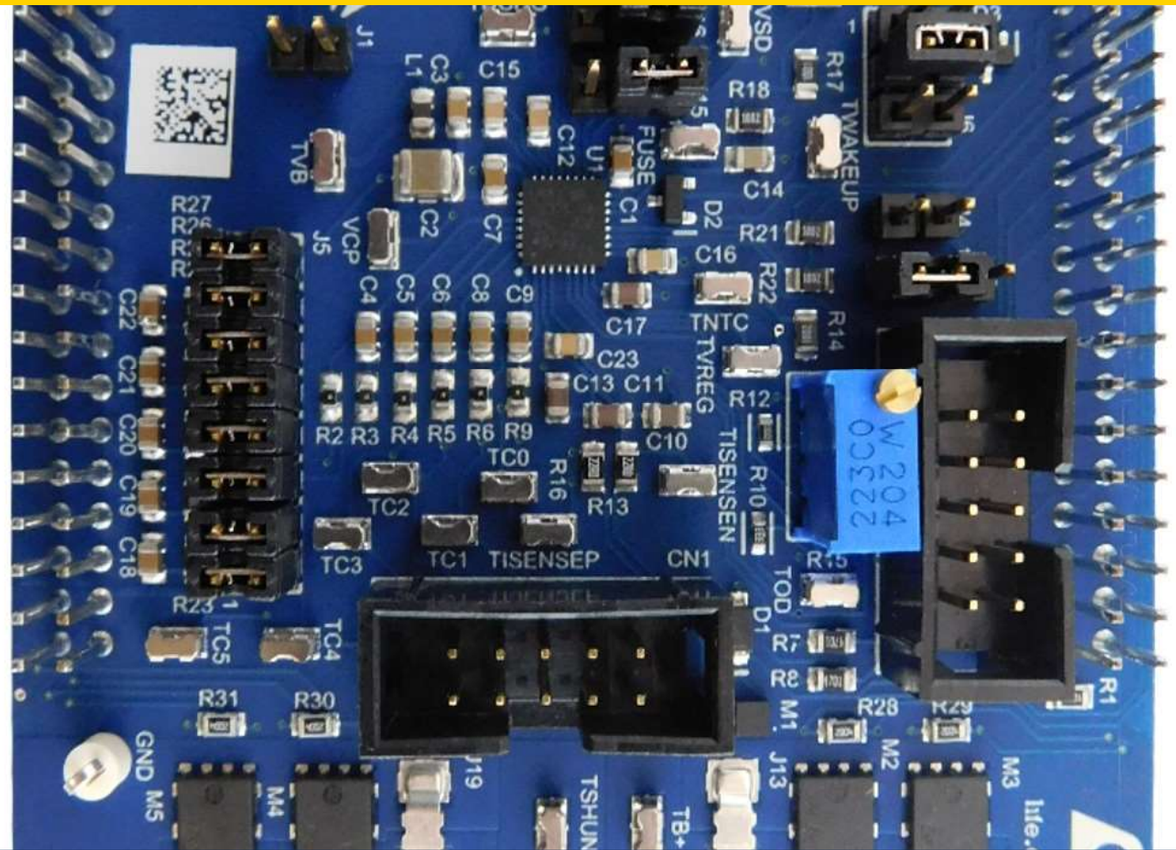
STEVAL-L99615C
Kit Overview





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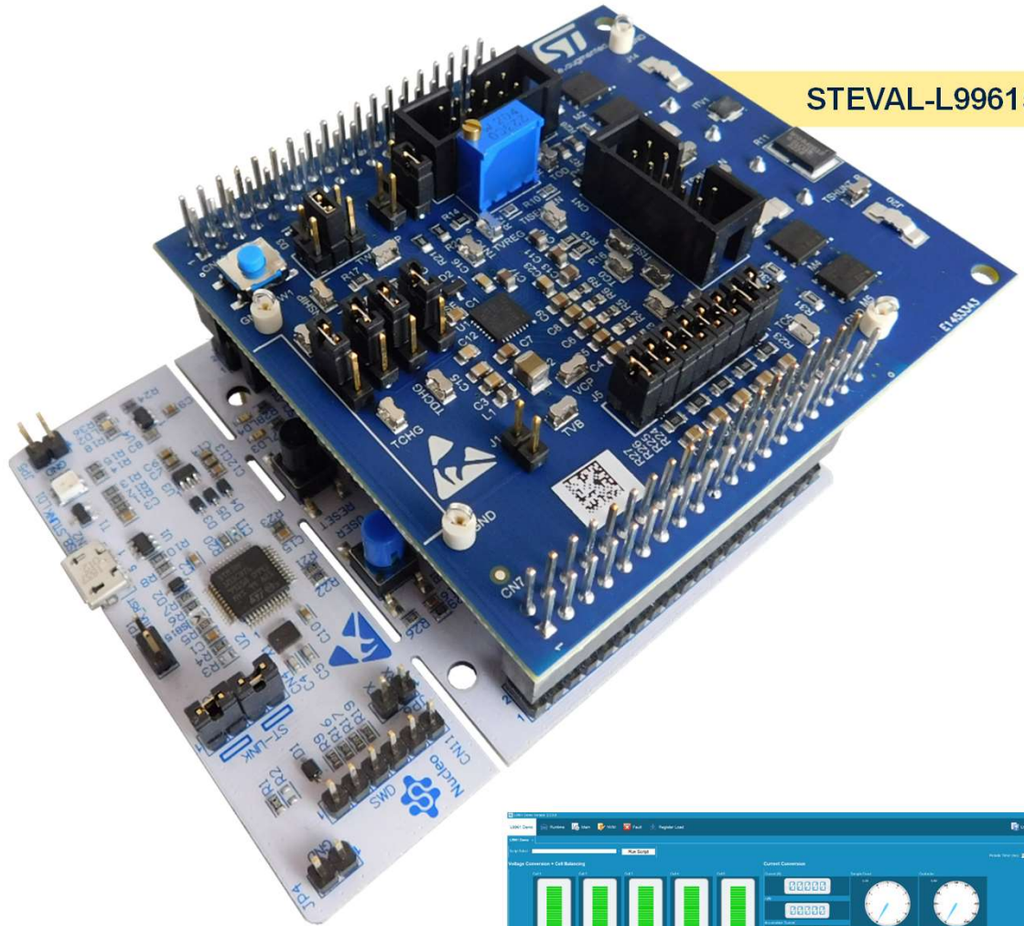
STEVAL-L99615C evaluation kit

- Demonstrating L9961 BMS IC performances and features with external 5-cell battery pack or with on-board pack simulation
- Kit main components:
  - **STEVAL-L99615C**: **NUCLEO-G071RB** development board with STM32G071RB MCU + **STEVAL-L99615CX** expansion board integrating the L9961 5-cell BMS IC
  - **STSW-L99615C**(*) SW GUI uses the PC serial communication to interface with the STM32 microcontroller and L9961
  - **STSW-L9961BMS**(*) SW package, containing source code and binaries, with standalone FW driver and application examples



STEVAL-L99615C

STSW-L99615C SW GUI

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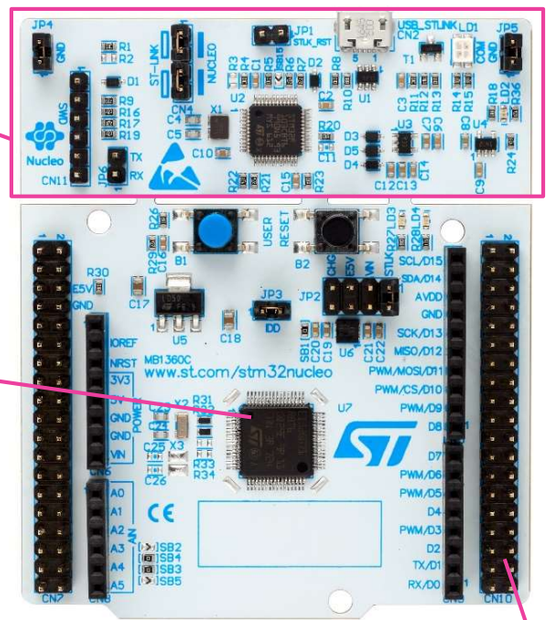
(*): the GUI contained in the STSW-L96615C is exclusive to the FW contained in the same SW package and cannot be used with the one of the STSW-L9961BMS packages.

STEVAL-L99615C at a glance!

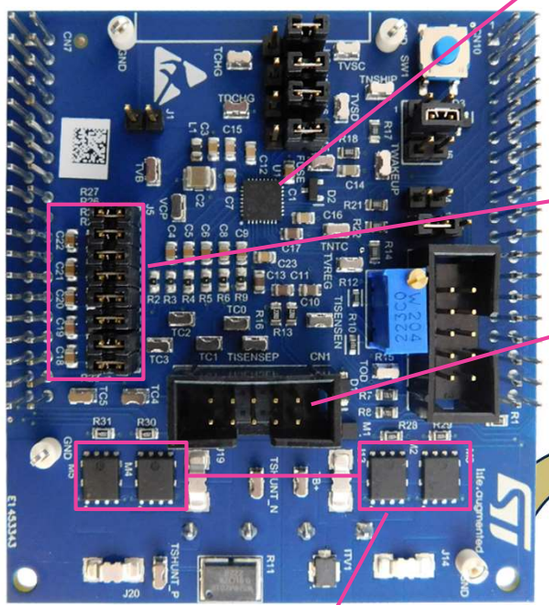
NUCLEO-G071RB



ST-Link V2 embedded programmer

STM32G071RB application MCU

STEVAL-L99615CX (top view)



L9961 5-cell BMS IC

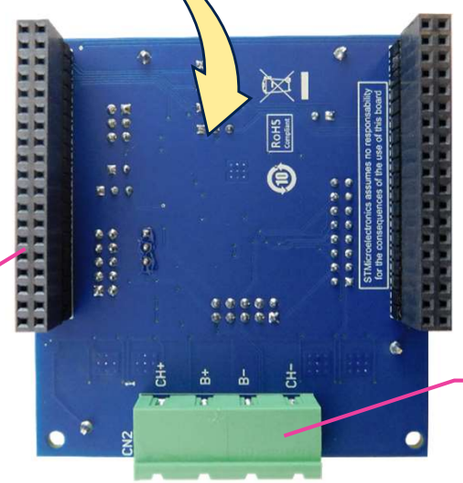
On-board Battery simulation stage

Cells connector

HS and LS pack relays

Morpho connectors

STEVAL-L99615CX (bottom view)



Battery pack connector

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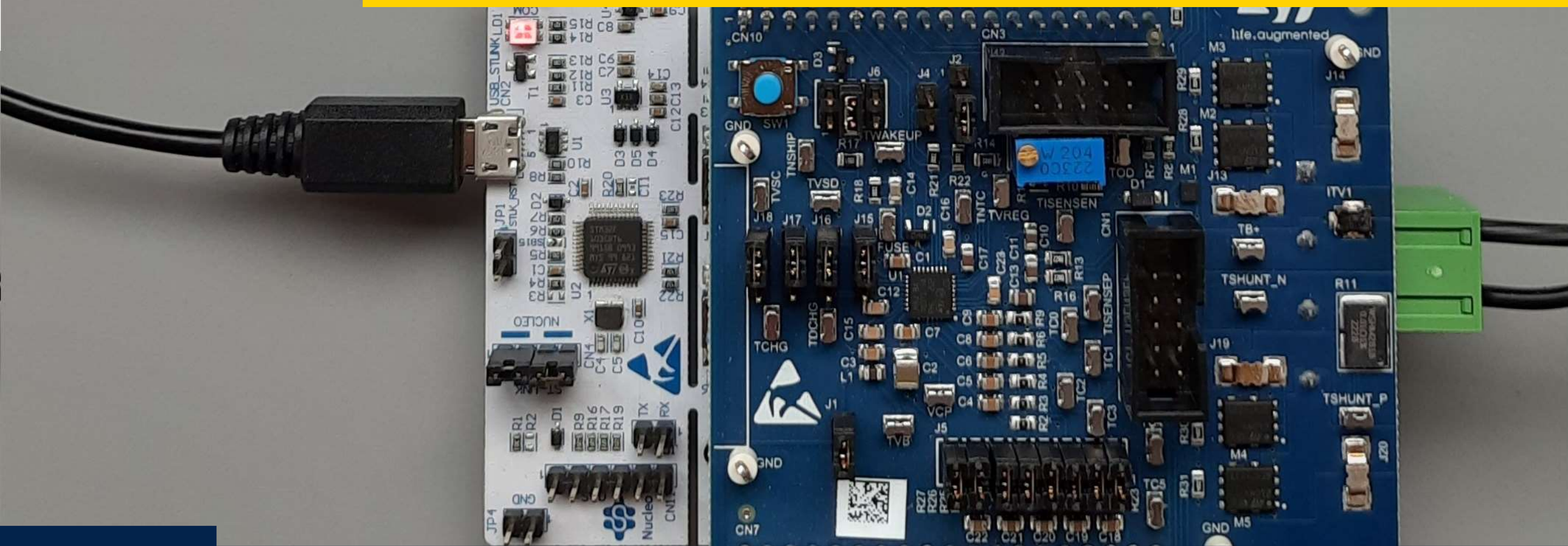
Application Demo 1:
Battery status monitoring



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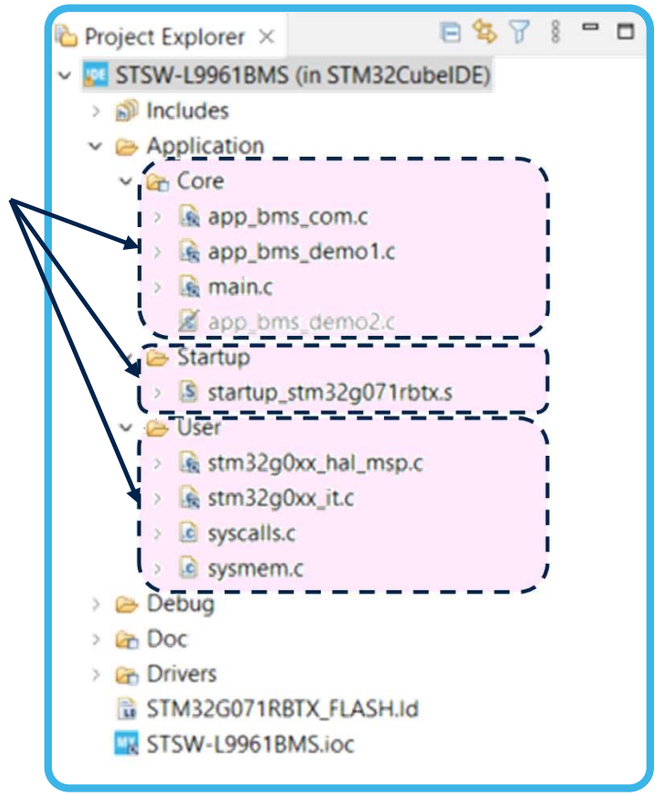
STSW-L9961BMS: Application Demo 1

- The Application Demo 1 demonstrates the L9961's capability to monitor the characteristics of a 5-cell battery pack, both as a whole and for each individual cell
- The Demo acquires:
  - the voltage on each cell
  - the voltage on the whole battery pack
  - the current flowing in the cell series
  - the temperature acquired by the NTC
  - the temperature measured on the die
- The demo outputs the collected data through a serial communication terminal

Application Core, User and Startup files



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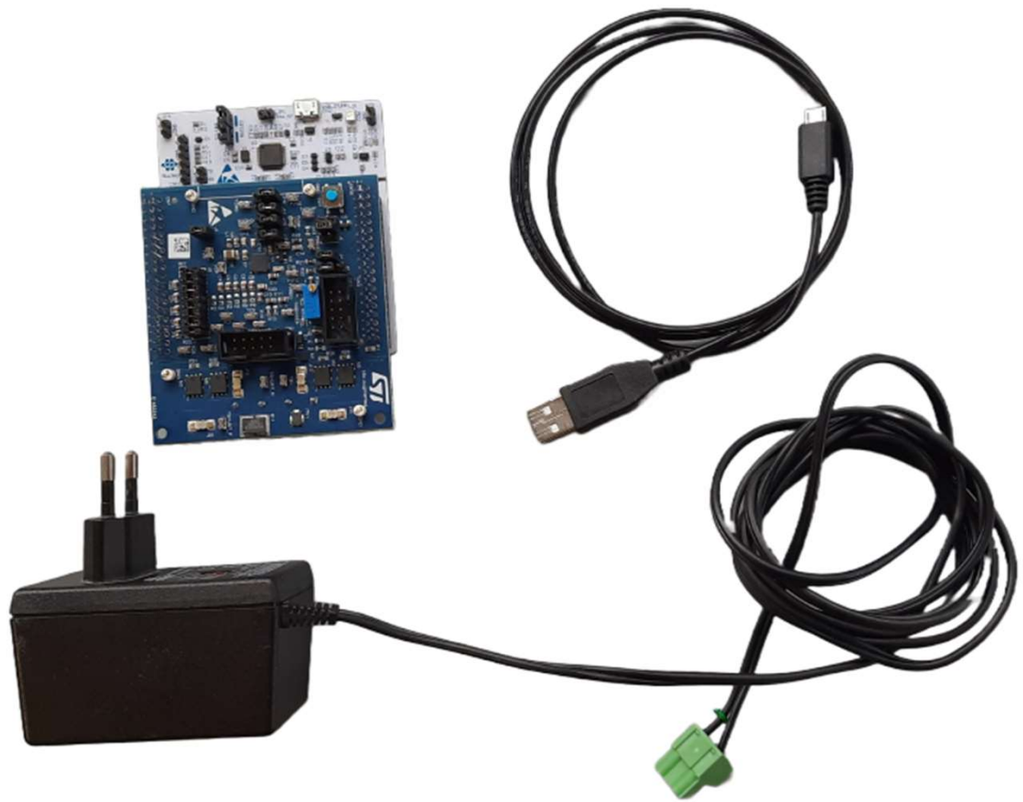
Application Demo 1 setup

To set up the demo and run the application with the evaluation kit, the following items are required:

- a STEVAL-L99615C kit
- the STSW-L9961BMS software package
- a USB Type-A to Micro-B cable
- a portable power supply(*) (for example, up to 20 V, 1 A) to feed the STEVAL-L99615C kit(**) (in case real batteries are not available)
- a laptop with the serial communication terminal already installed (Tera Term console, for example)



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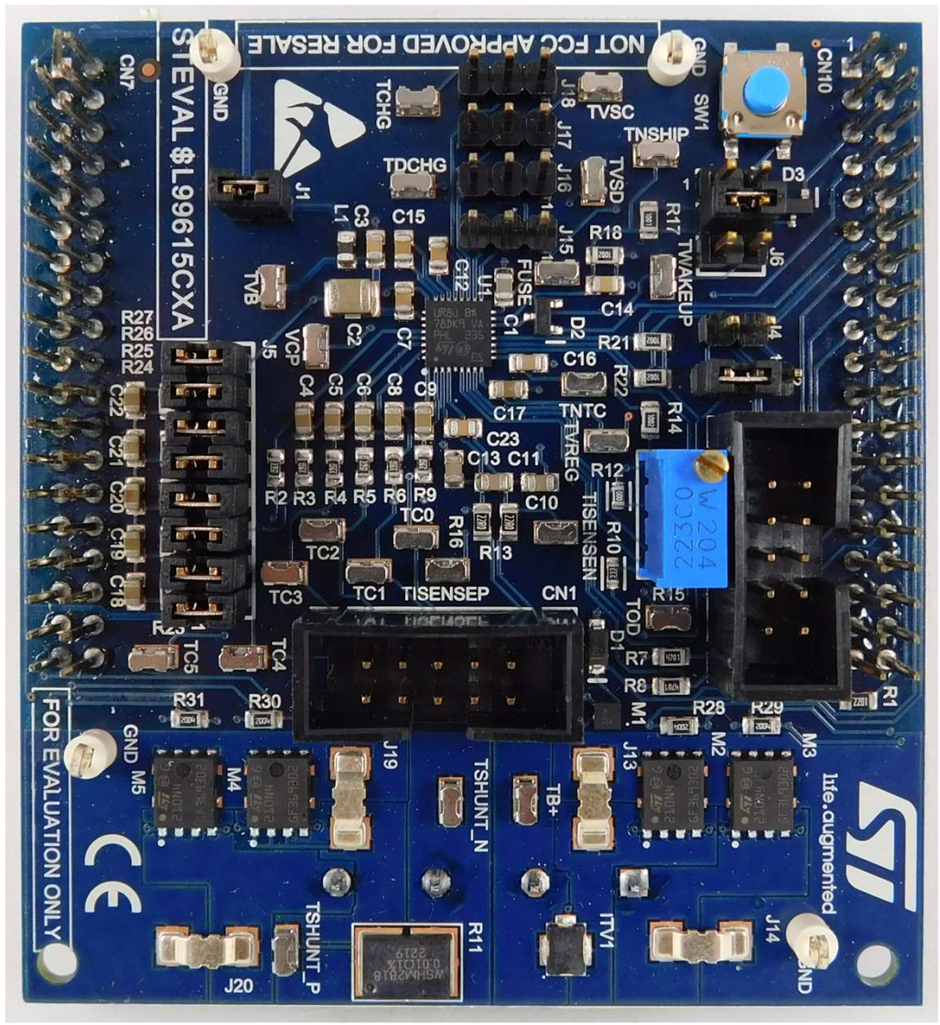
(*): to run the Application Demo 1, it is assumed to use the 5-cell battery emulating circuitry embedded in the expansion board, coupled with the external power supply that simulates the battery voltage.
(**): to facilitate the connection of the power supply, equip it with a two or four position plug 7.62MM connector as the Wurth 691351400002 or 691351400004.

Application Demo 1: jumpers' setup

- Verify that the setting of the STEVAL-L99615C jumpers respects the configuration depicted in the picture and reported in the following Table

Name	Board	Description	Configuration
J1	EXP. BOARD	Used to measure current flowing into VB pin	Closed
J2	EXP. BOARD	VIO voltage selector	2-3: 3.3 V from L9961 (VREG)
J4	EXP. BOARD	Used to select micro power source	Open
J5	EXP. BOARD	Battery simulator – used to simulate battery pack	Closed *Note: It is assumed that 5-cell battery board is not used.*
J6B	EXP. BOARD	Used to drive NSHIP pin from micro	Closed
J15, J16, J17, J18	EXP. BOARD	Used to configure the relay MOSFETs to either high or low-side usage	Open
J13, J14	EXP. BOARD	Used to bypass the HS relay MOSFETs	Closed
J19, J20	EXP. BOARD	Used to bypass the LS relay MOSFETs.	Closed
JP3	NUCLEO	STM32 VDD current measurement	Closed
JP2	NUCLEO	STM32 5 V jumper selection	1-2: 5 V from STLINK
CN4	NUCLEO	STM32 SWD interface	Closed



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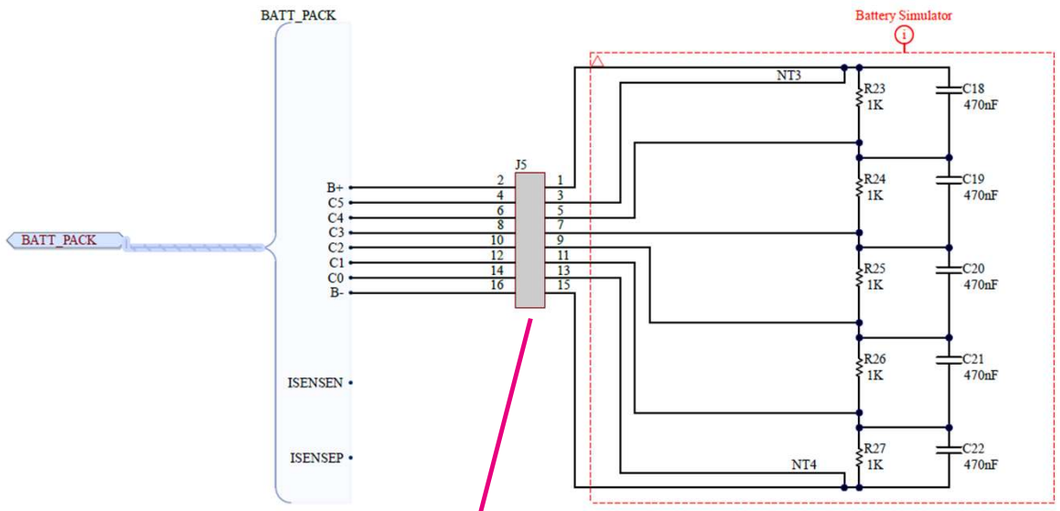
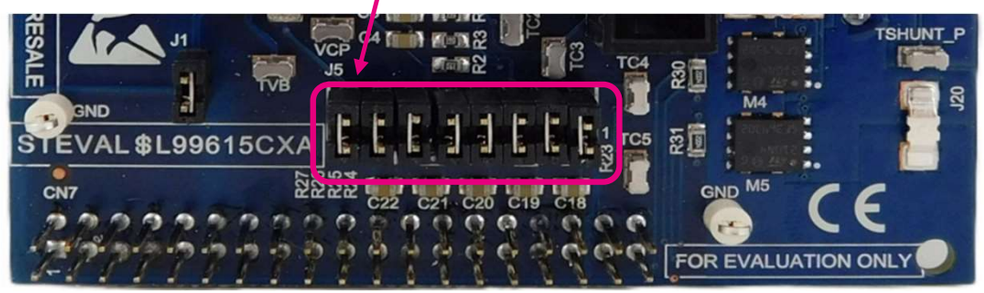
How the STEVAL-L99615C emulates a 5-cell battery pack

- Thanks to its design, the STEVAL-L99615C permits to simulate a 5-cell battery pack simply applying a voltage to the CN2 connector by an external power supply
- In fact, a network composed of a series of 5 resistance/capacitance parallel, integrated in the kit expansion board, acts by emulating the 5 cells of a battery pack
- When voltage is applied, it is equally distributed by the series. Thus, the Application Demo 1 acquires the voltages on each resistance representing the Cell voltages (Vcell1, Vcell2, .., Vcell5)
- To enable the internal 5-cell emulation network, verify that the headers J5 are fitted onto the jumpers in the STEVAL-L99615C expansion board

STEVAL-L99615C expansion board battery emulator schematic





Detail of headers J6 closed by jumpers on the STEVAL-L99615C expansion board

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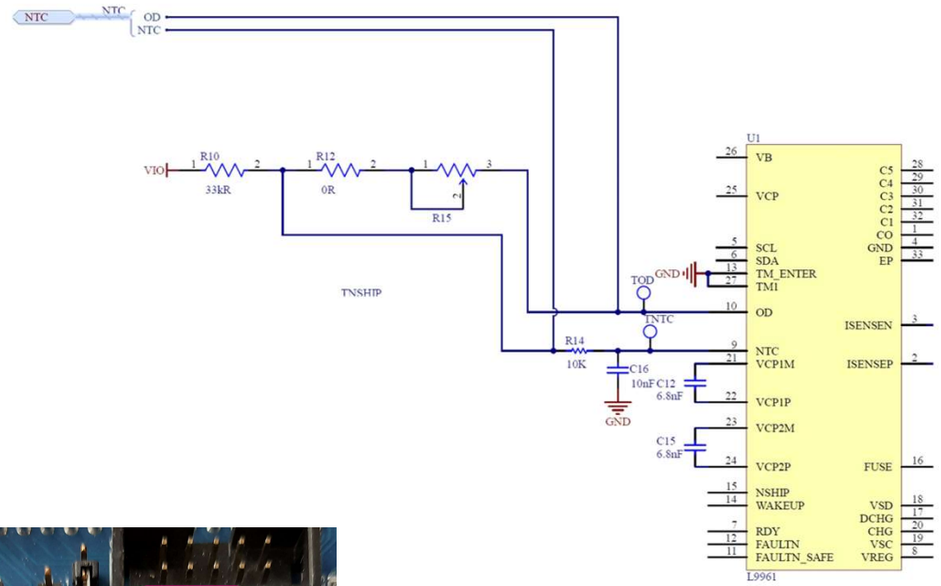
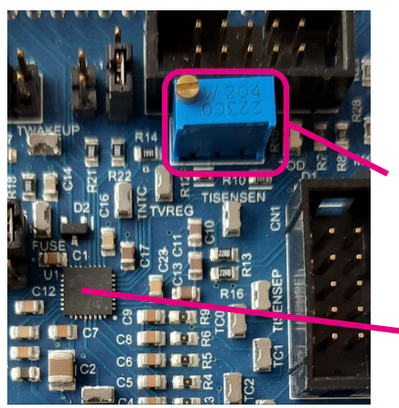
How the STEVAL-L99615C emulates the NTC acquisition

- For demonstrating how the L9961 measures the temperature of a battery pack via NTC, the STEVAL-L99615C embeds a variable resistor (referred to the internal LDO voltage)
- That permits to emulate how the resistor value changes (actually through a screwdriver) to a hypothetical temperature change
- So, as a standard NTC, the decrease of electrical resistance value (mechanically happens) corresponding to the acquired voltage increase, may be referred to the temperature rising
- Vice versa, the increase of the resistance value corresponding to the acquired voltage decrease refers to the temperature decrease
- This mechanism also enables the demonstration of over/under temperature detection operation carried out by the L9961

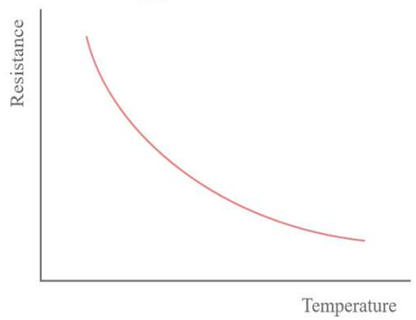
STEVAL-L99615C expansion board
NTC simulator schematic and on-board position





R15 variable resistor emulating an NTC

L9961



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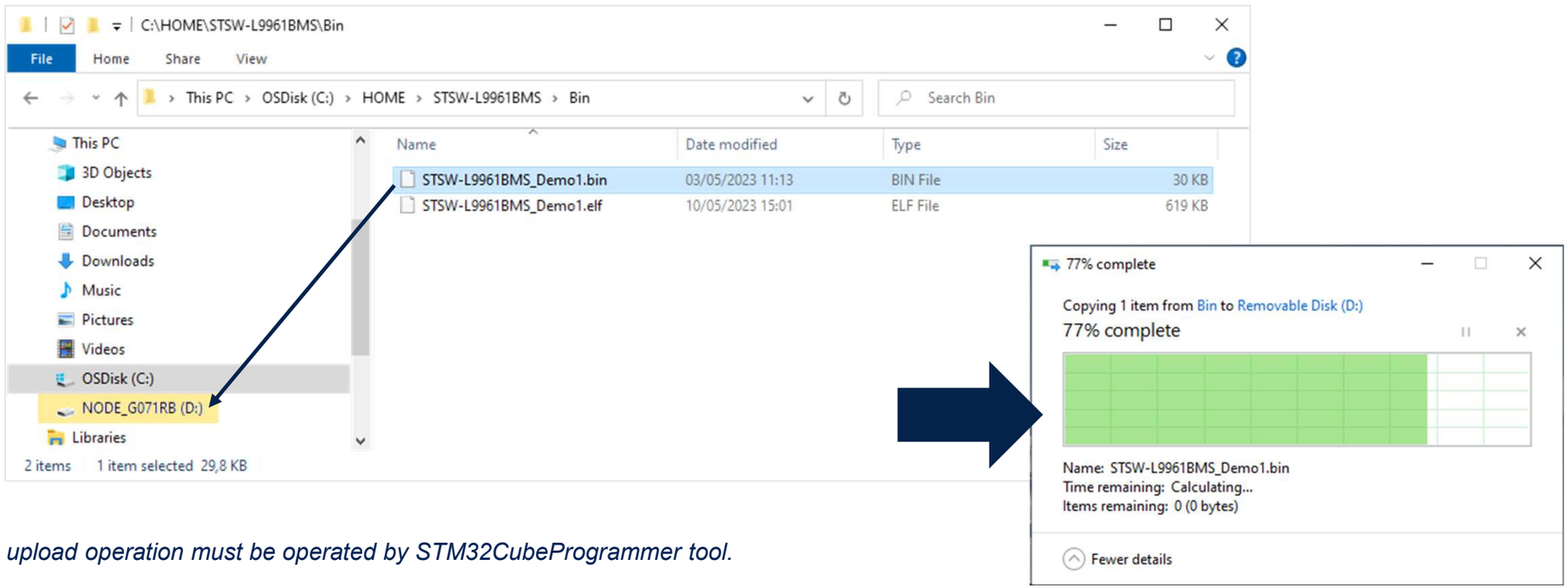
Application Demo 1: programming

- Connect the NUCLEO board of the STEVAL-L99615C kit to the laptop through the USB cable
- Drag and drop the Demo1 binary file of the STSW-L9961BMS application firmware(*), from the origin folder to the NUCLEO that has been mapped by the laptop OS as an external peripheral
- This operation permits to directly program the on-board STM32G071RB microcontroller of the NUCLEO-G071RB



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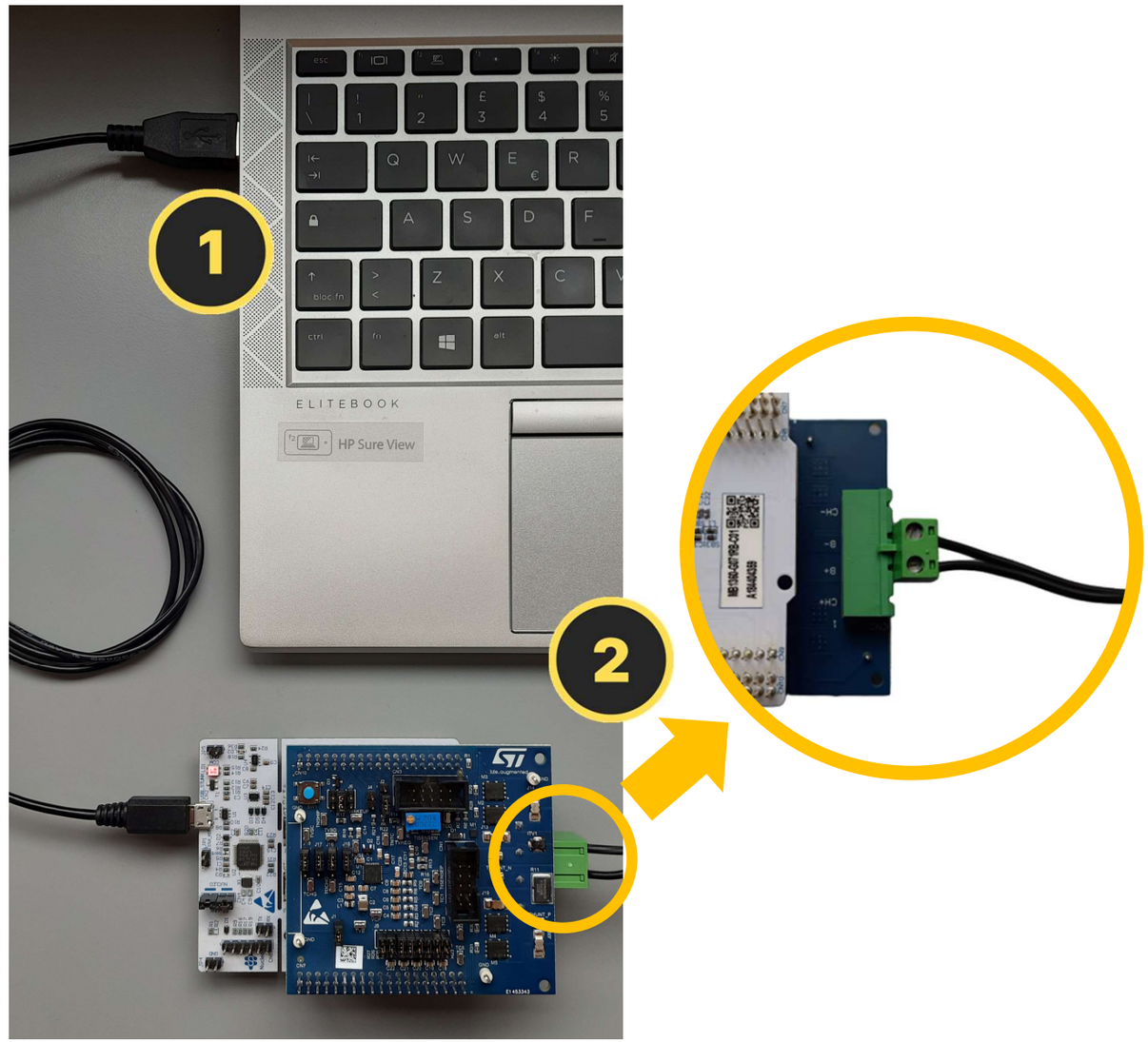
(*): .elf file upload operation must be operated by STM32CubeProgrammer tool.

Application Demo 1: power up

1. Connect the STEVAL-L99615C kit to the laptop using the USB Type-A to Micro-B cable

2. Connect the power supply terminals to the B+ and B- pins of the battery pack connector (CN2), and power on the appliance (in the example, the power supply has been set 12 V, 1 A as test rating)



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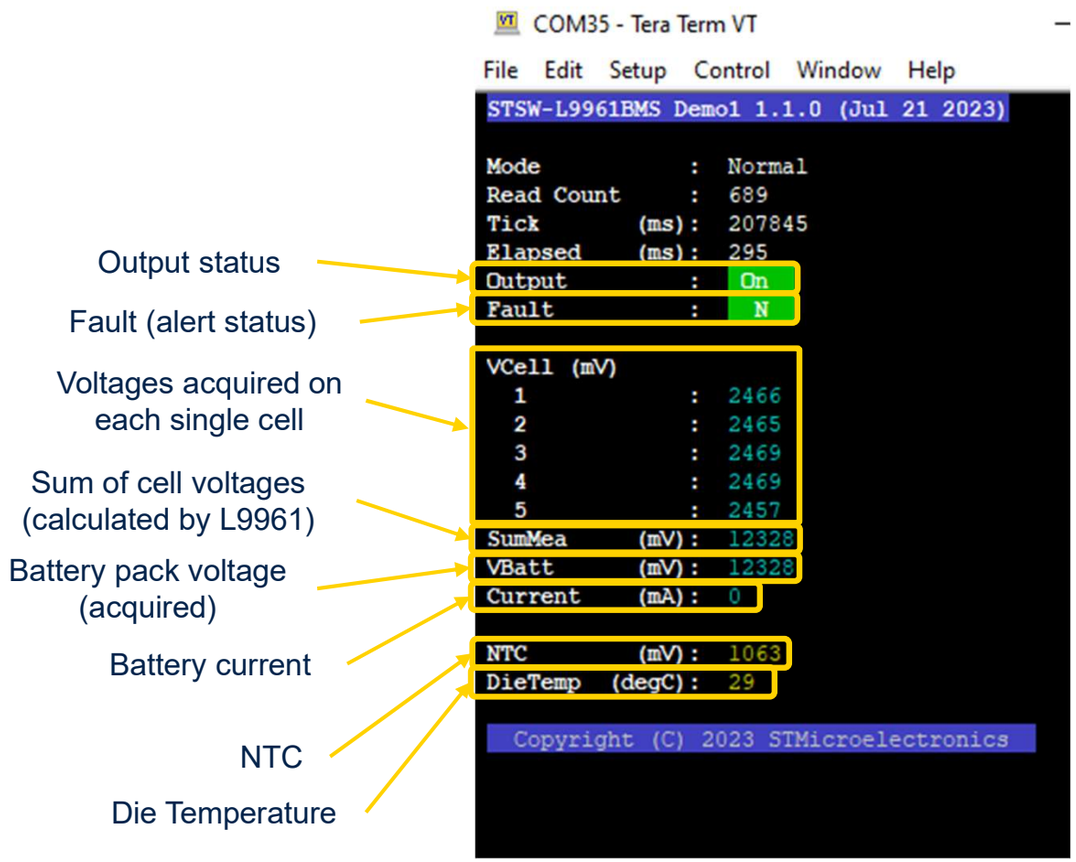
Application Demo 1: Output messages in Normal acquisition

Here is the GUI legenda (for the VT100 User Interface):

- The first three numbers represent the number of acquisitions, the microcontroller timing **Tick** (ms) and the **Elapsed** acquisition period (ms)
- Output represents the Load-switch status, as **ON** or **OFF** (Load-switch is always ON in this demo set-up)
- Fault flag warns about the status of Alert and the presence of faults in the running application (**N** stands for NORMAL, **F** for FAULT)
- The **VCell** values (mV) represent the cell voltages acquired on the battery cells emulation
- **SumMea** (mV) represents the sum value released by the L9961 after acquiring the Vcells, **VBatt** (mV) the value directly acquired on the battery pack (in our example the power supply voltage). **Current** (mA) is the current flowing from/on the battery pack (null due to no load connected for the demo)
- Temperature is dually expressed, by the external **NTC** (mV) emulated by trimmer, and by the **DieTemp** DIE internal sensor (degC)



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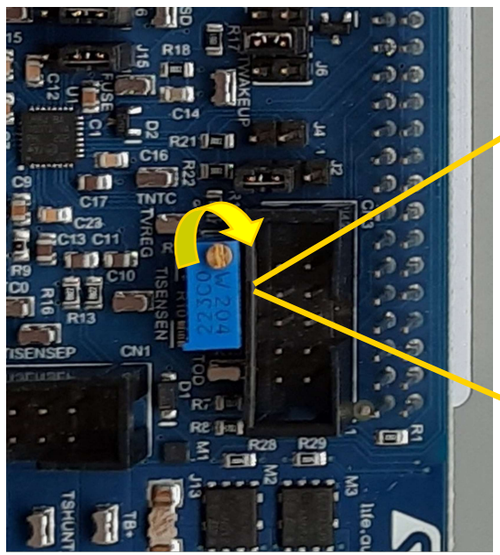
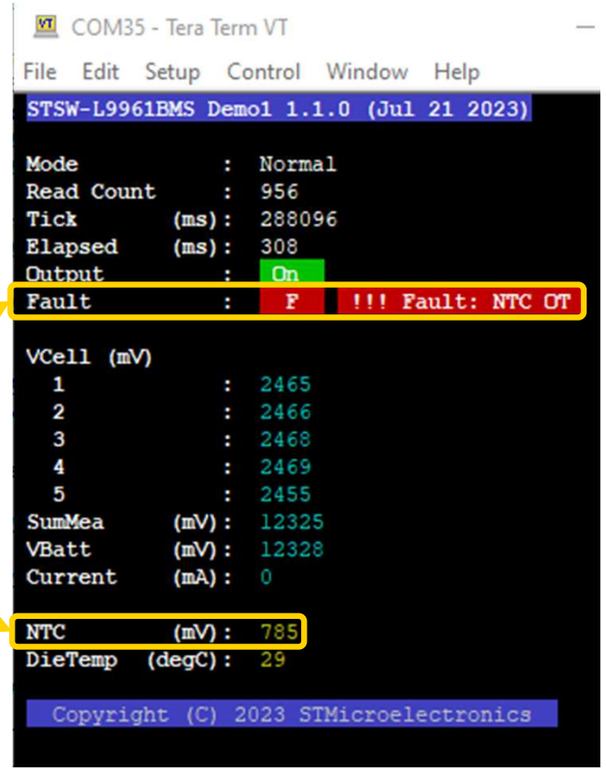
Application Demo 1: Output messages in Fault acquisition (1/2)

- Application Demo 1 has been set to release an Alert message when relevant events occur (for example, when the NTC OverTemperature Threshold is exceeded)
- In fact, turning the NTC screw clockwise, its value decreases and when it reaches 900mV, the demo releases a Fault message indicating the cause (**NTC_OT**), while the Fault character becomes **F**





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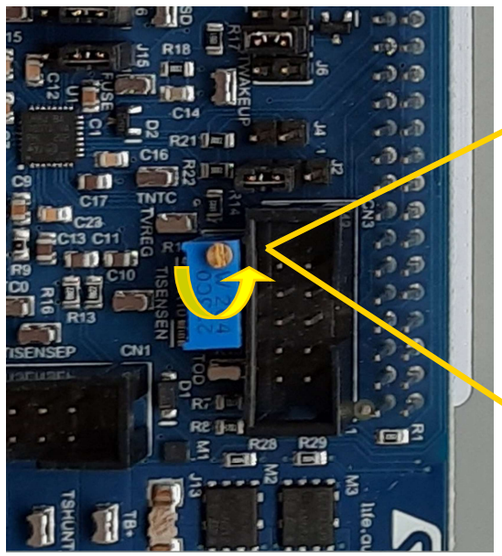
Application Demo 1: Output messages in Fault acquisition (2/2)

- Turning counterclockwise, till the NTC value exceeds the 900mV, a new message indicating the fault cleaned is released and the Fault character goes back to **N**



```
COM35 - Tera Term VT
File  Edit  Setup  Control  Window  Help
STSW-L9961BMS Demo1 1.1.0 (Jul 21 2023)

Mode            :  Normal
Read Count      :  1693
Tick       (ms) :  509479
Elapsed    (ms) :  307
Output          :  On
Fault           :  N   !!! Fault clean

VCell (mV)
  1             :  2466
  2             :  2465
  3             :  2468
  4             :  2469
  5             :  2457
SumMea     (mV) :  12326
VBatt      (mV) :  12328
Current    (mA) :  -2

NTC        (mV) :  1050
DieTemp  (degC) :  29

Copyright (C) 2023 STMicroelectronics
```

```
COM35 - Tera Term VT
File  Edit  Setup  Control  Window  Help
STSW-L9961BMS Demo1 1.1.0 (Jul 21 2023)

Mode            :  Normal
Read Count      :  1720
Tick       (ms) :  517582
Elapsed    (ms) :  295
Output          :  On
Fault           :  N

VCell (mV)
  1             :  2466
  2             :  2465
  3             :  2468
  4             :  2469
  5             :  2457
SumMea     (mV) :  12326
VBatt      (mV) :  12328
Current    (mA) :  0

NTC        (mV) :  1051
DieTemp  (degC) :  29

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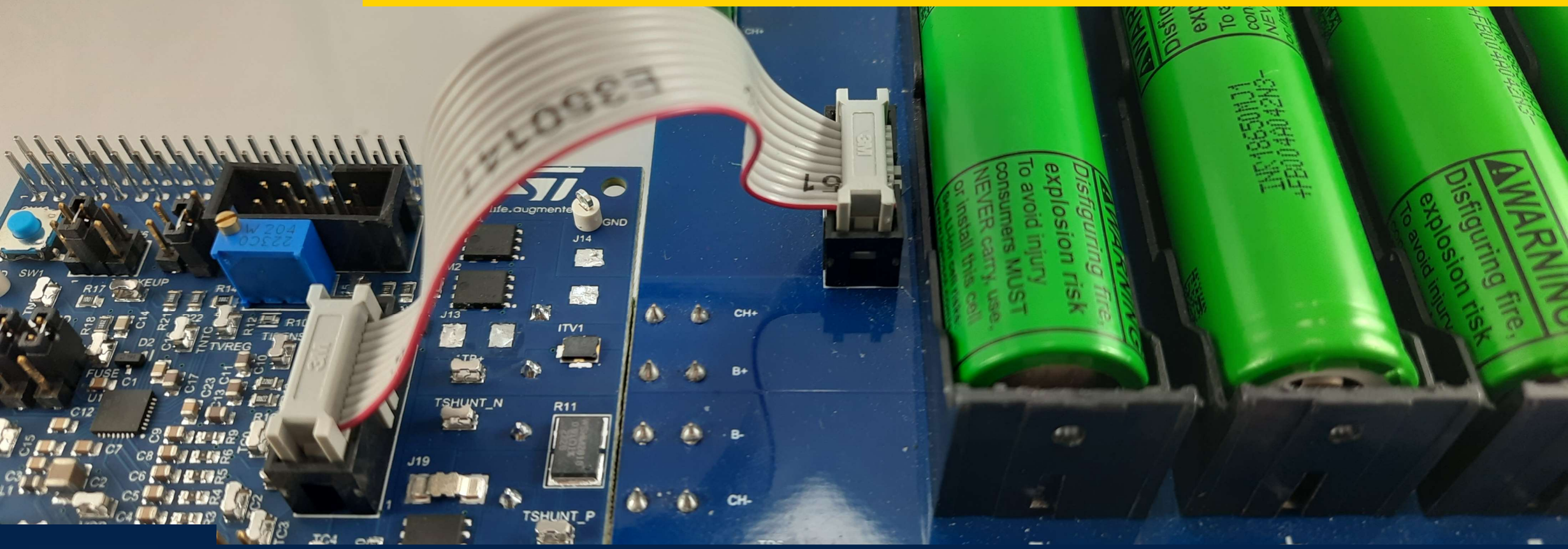
Application Demo 2:
Coulomb counting



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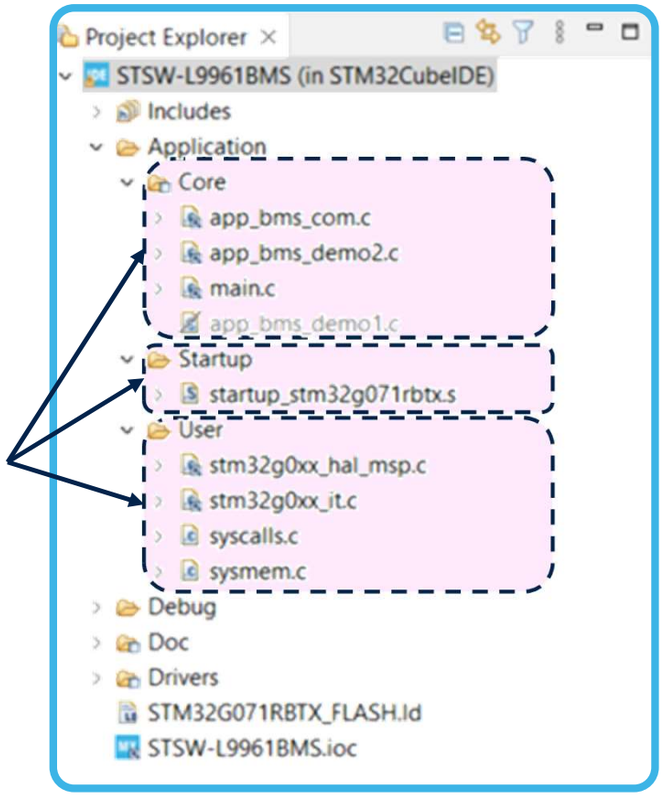
STSW-L9961BMS: Application Demo 2

- The Application Demo 2 utilizes the Coulomb counting mechanism integrated in the L9961 device, to measure the charges flowing through the five cells(*) composing a battery pack
- This demo estimates the initial residual charge of the battery cells in open load condition and matches it with the integral of the charge quantity flowing through the battery, calculated by means of the Coulomb counting function
- The demo outputs the estimated charge of each cell through a serial communication terminal

Application Core, User and Startup files



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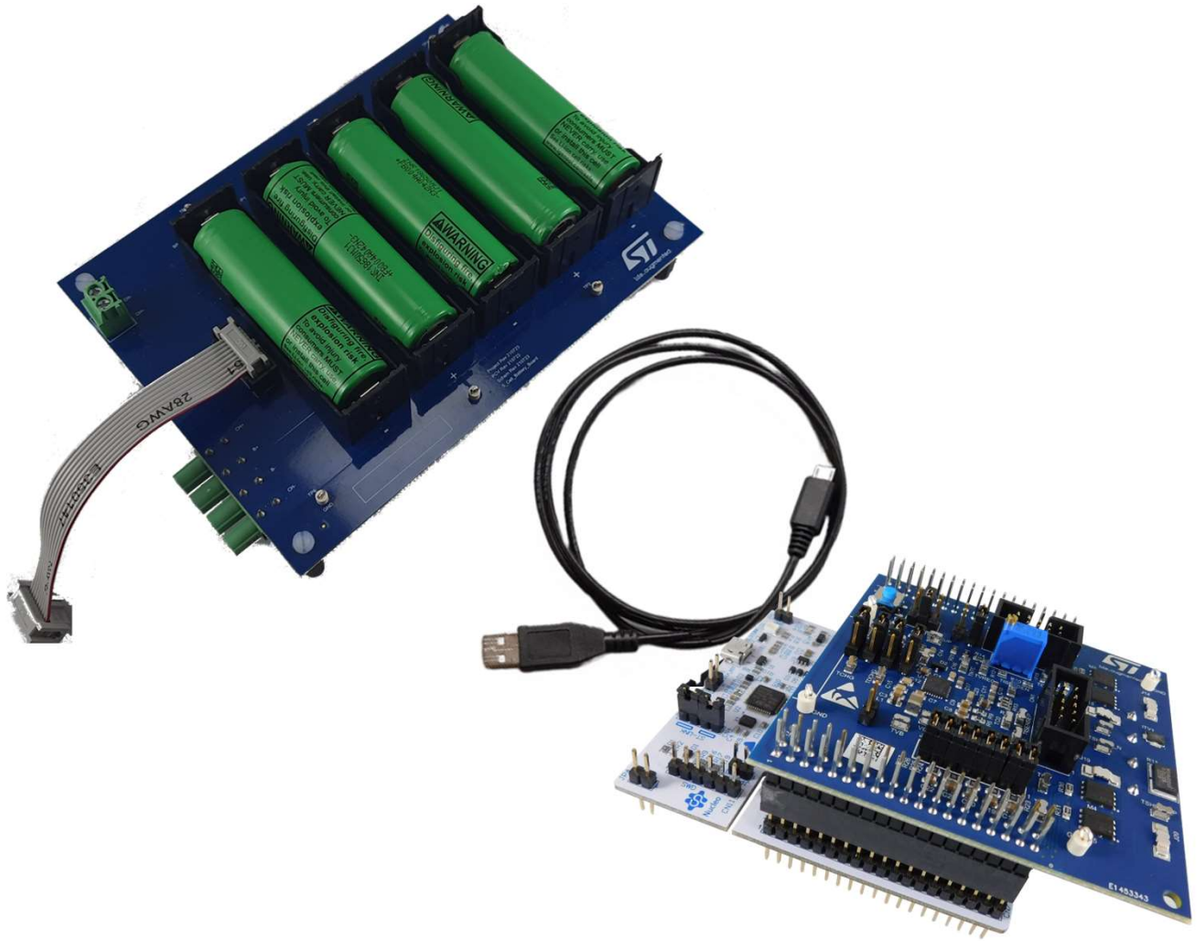
(*): *The LG Chem INR18650-MJ1 battery cells have been selected to develop the Application Demo 2. A look-up table matching the battery OCVs vs. SoC is included in application file.*

Application Demo 2 setup

To set up the demo and run the application with the evaluation kit, the following items are required:

- a STEVAL-L99615C kit
- the STSW-L9961BMS software package;
- a USB Type-A to Micro-B cable
- a battery pack(*) composed of five 18650 cells(**) and related connecting cables
- a laptop with the serial communication terminal already installed (i.e. Tera Term console)



(*): the battery pack described in this demo refers to the battery holder board reported in the UM3151 user manual. It has been developed to demonstrate the operability of the kit with five 18650 battery cells. Schematics and BOM are included in the UM.

(**): Battery reference: LG Chem INR18650-MJ1.

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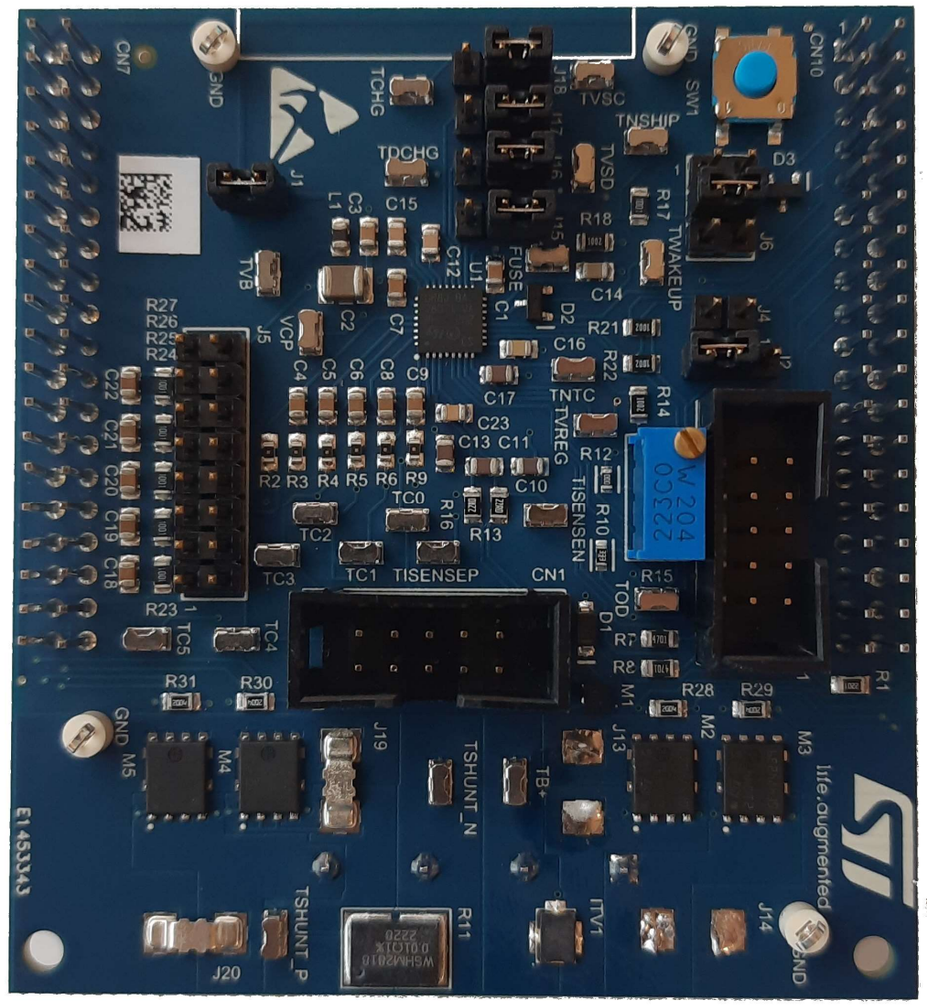
Application Demo 2: jumpers' setup

- Verify that the setting of the STEVAL-L99615C jumpers respects the configuration depicted in the picture and reported in the following Table

Name	Board	Description	Configuration
J1	EXP. BOARD	Used to measure current flowing into VB pin	Closed
J2	EXP. BOARD	VIO voltage selector	2-3: 3.3 V from L9961 (VREG)
J4	EXP. BOARD	Used to select micro power source	Open
J5	EXP. BOARD	Battery simulator – used to simulate battery pack	Open *Note: It is assumed that 5-cell battery board is used.*
J6B	EXP. BOARD	Used to drive NSHIP pin from micro	Closed
J15, J16, J17, J18	EXP. BOARD	Used to configure the relay MOSFETs to either high or low-side usage	1-2: HS configuration is selected
J13, J14	EXP. BOARD	Used to bypass the HS relay MOSFETs	Open
J19, J20	EXP. BOARD	Used to bypass the LS relay MOSFETs.	Closed
JP3	NUCLEO	STM32 VDD current measurement	Closed
JP2	NUCLEO	STM32 5 V jumper selection	1-2: 5 V from STLINK
CN4	NUCLEO	STM32 SWD interface	Closed



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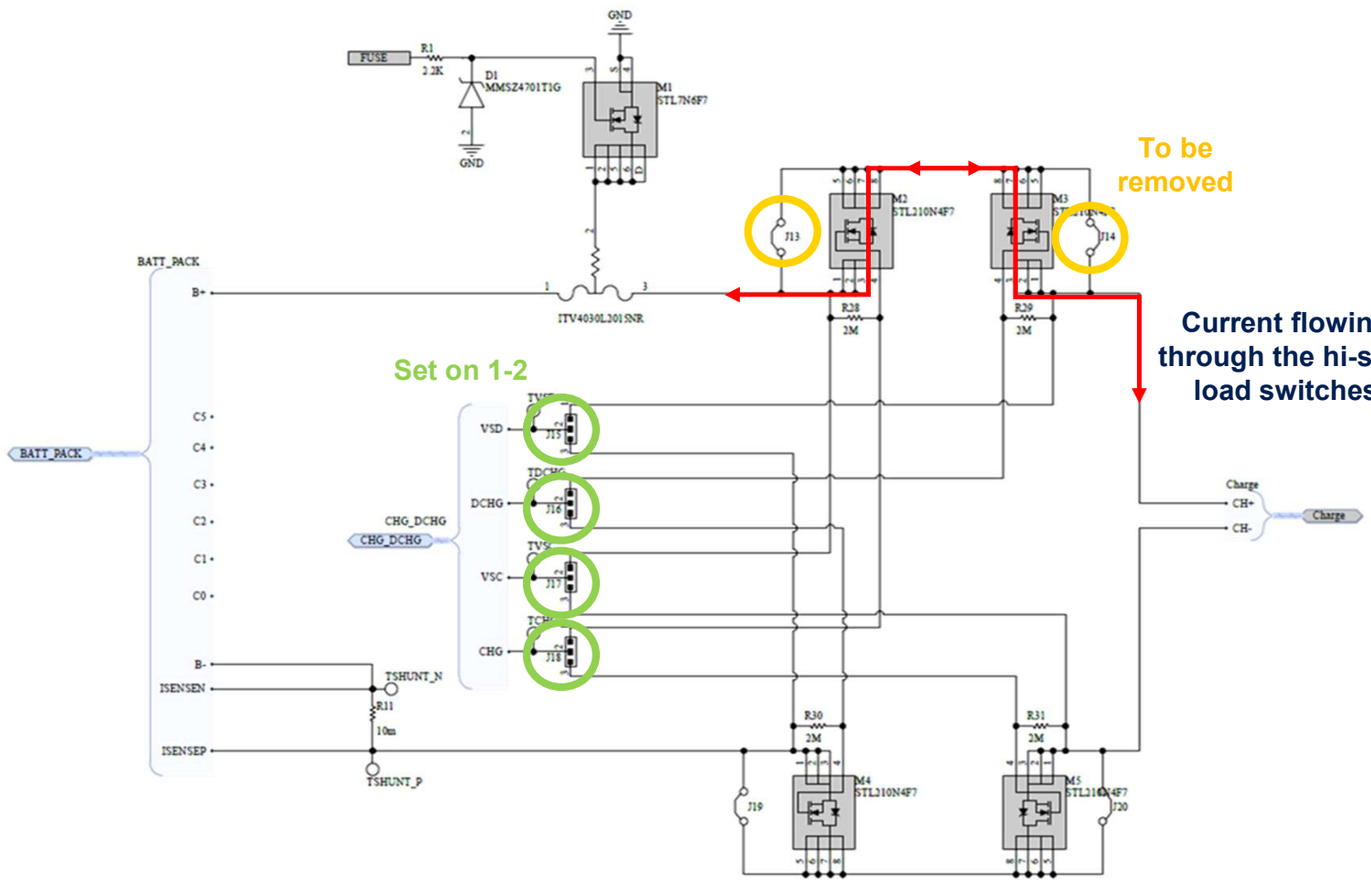
How the STEVAL-L99615C to drive the load-switches and the continuity with the load

- For estimating the initial residual charge of a battery, first it is necessary to acquire the VBAT without current flowing on the load, thus controlling the current path to the load
- For this reason, the J13 and J14 solder bridges must be removed, and the control of the high side load switches is transferred to the L9961 operation by setting the J15, J16, J17 and J18 headers with jumpers to 1-2 position
- Moreover, it's necessary to open all the jumpers from J5 headers to exclude the internal passive network that emulates the battery cells on the expansion board

STEVAL-L99615C expansion board
hi-side load switches and jumpers schematic



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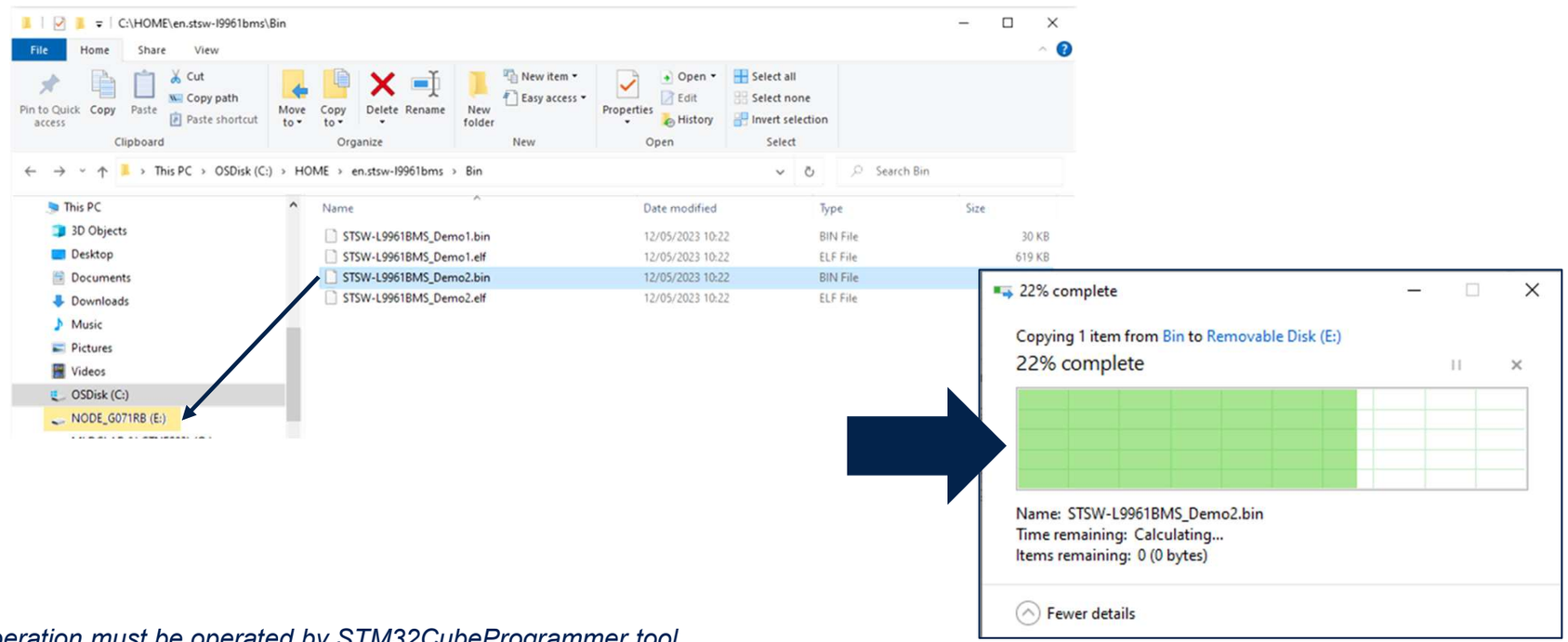
Application Demo 2: programming

- Connect the NUCLEO board of the STEVAL-L99615C kit to the laptop through the USB cable
- Drag and drop the Demo2 binary file of the STSW-L9961BMS application firmware(*), from the origin folder to the NUCLEO that has been mapped by the laptop OS as an external peripheral
- This operation permits to directly program the on-board STM32G071RB microcontroller of the NUCLEO-G071RB

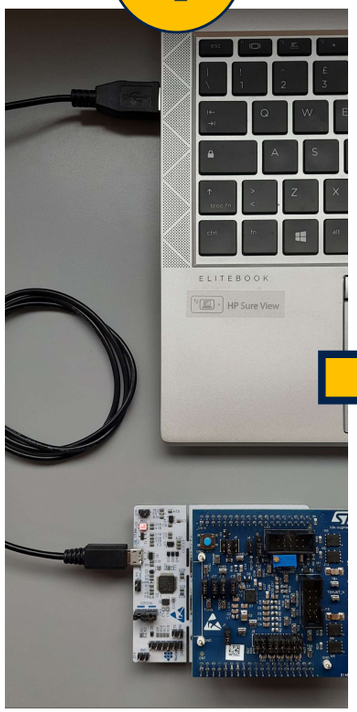


life.augmented

(*): .elf file upload operation must be operated by STM32CubeProgrammer tool.

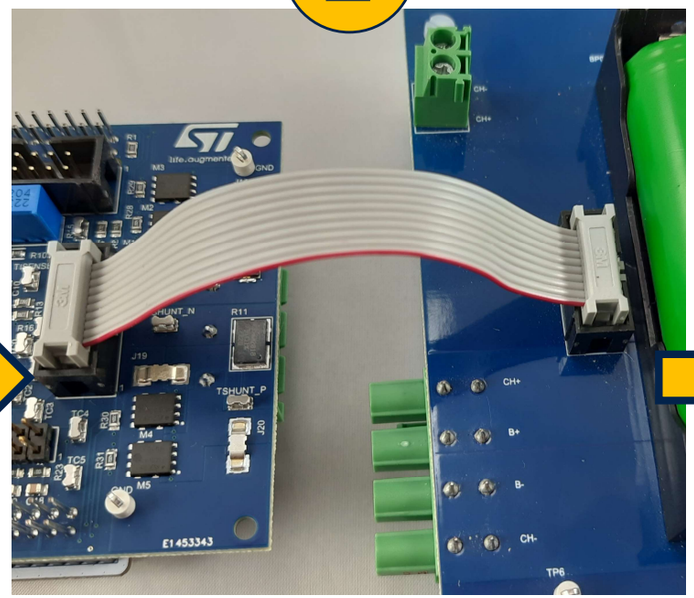
How connect the STEVAL-L99615C to the 5-cell battery pack

1



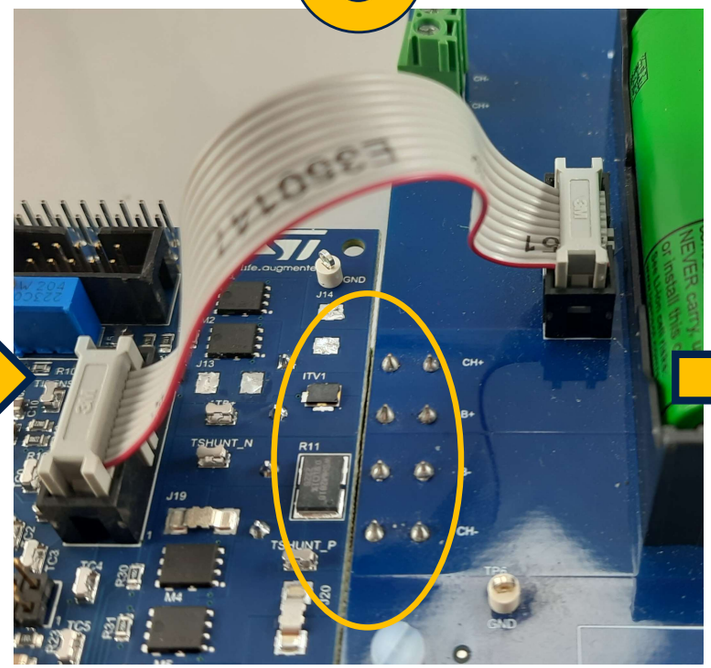
Connect the STEVAL-L99615C kit to the laptop through the USB cable

2



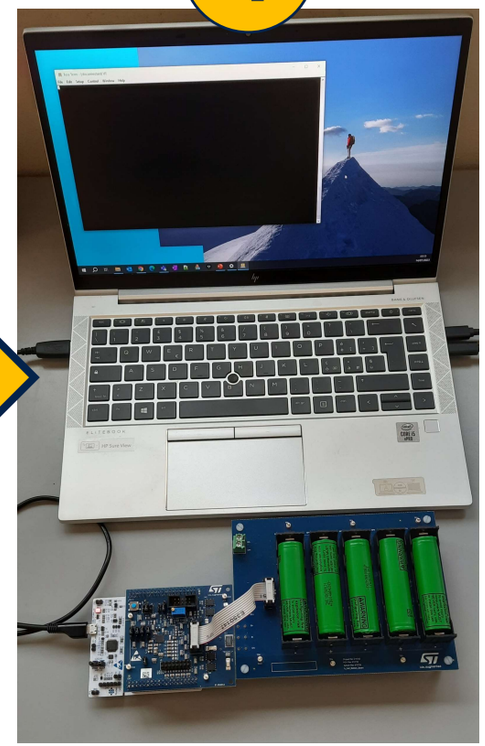
After assembling the battery holder(*) with five cells, first connect the STEVAL-L99615C kit to battery holder board through CN1 connectors (on the top) using flat cable.

3



Connect the STEVAL-L99615C kit to the battery holder board through CN2 connectors (located at the bottom)

4

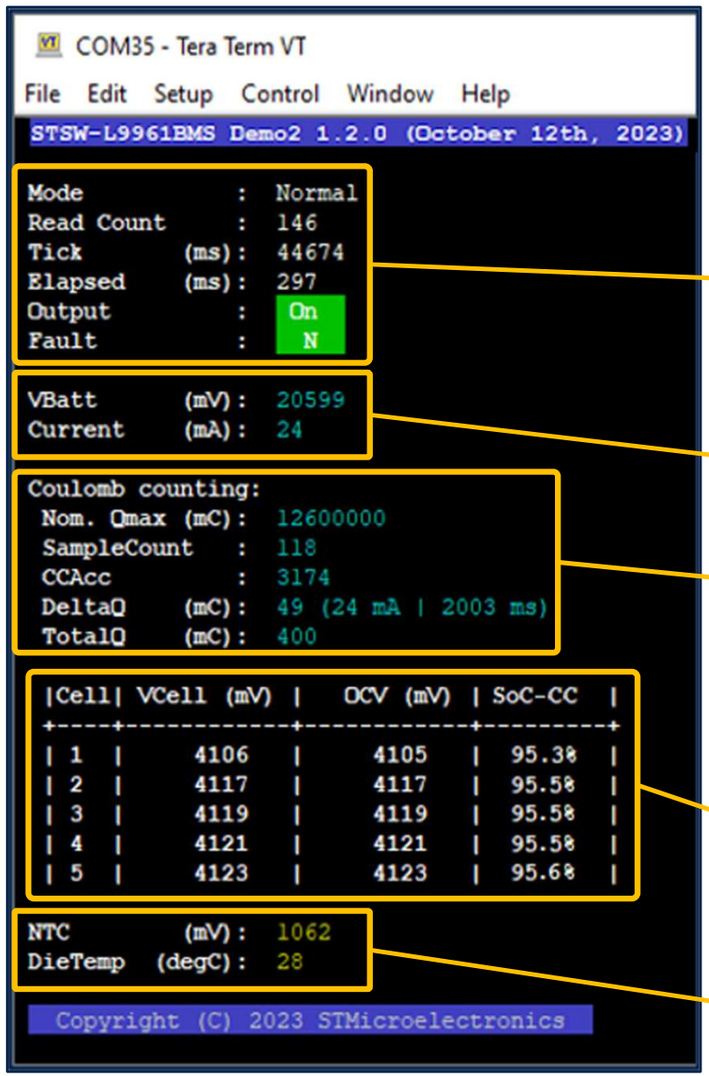


Open the terminal on the laptop and select the corresponding serial port (and set COM speed @ 115200)

life.augmented

(*): to properly run the demo measuring a significant amount of current (at least 10mA), it is suggested to connect to the battery holder CN3 connector a resistance of 2,2kΩ. Otherwise an electronic load is suggested.

Application Demo #2: running



Once connected the kit and setup the PC serial communication console, the Application Demo #2(*) displays four sets of information:

1. **Operation Status** that includes the Status of the L9961 device **Mode**, the **Read Count** as number of acquisition, the **Tick** microcontroller timing, the **Elapsed** acquisition period, the **Output** as Load-switch status and the **Fault** flag
2. **Battery monitoring** including data acquired from the battery pack as **VBatt** (mV) and **Current** (mA)
3. **Coulomb counting** (**) operation shows the Nominal Charge Quantity **Nom. Qmax** (mC), which is calculated from the battery's nominal capacity (mAh), the **Sample Count** numbered by the L9961, the **CCAcc** Coulomb Counting Accumulator by L9961 registers, the **DeltaQ** Incremental Charges quantity (mC) and the **TotalQ** Total Charges quantity (mC)
4. The monitoring table includes the voltage of each cell **Vcell** (mV), the initial acquired **OCV** (mV) and an estimation of the State of Charge **SoC** (%) for each cell
5. Temperature acquisition from **NTC** (mV) and **DieTemp** (degC)

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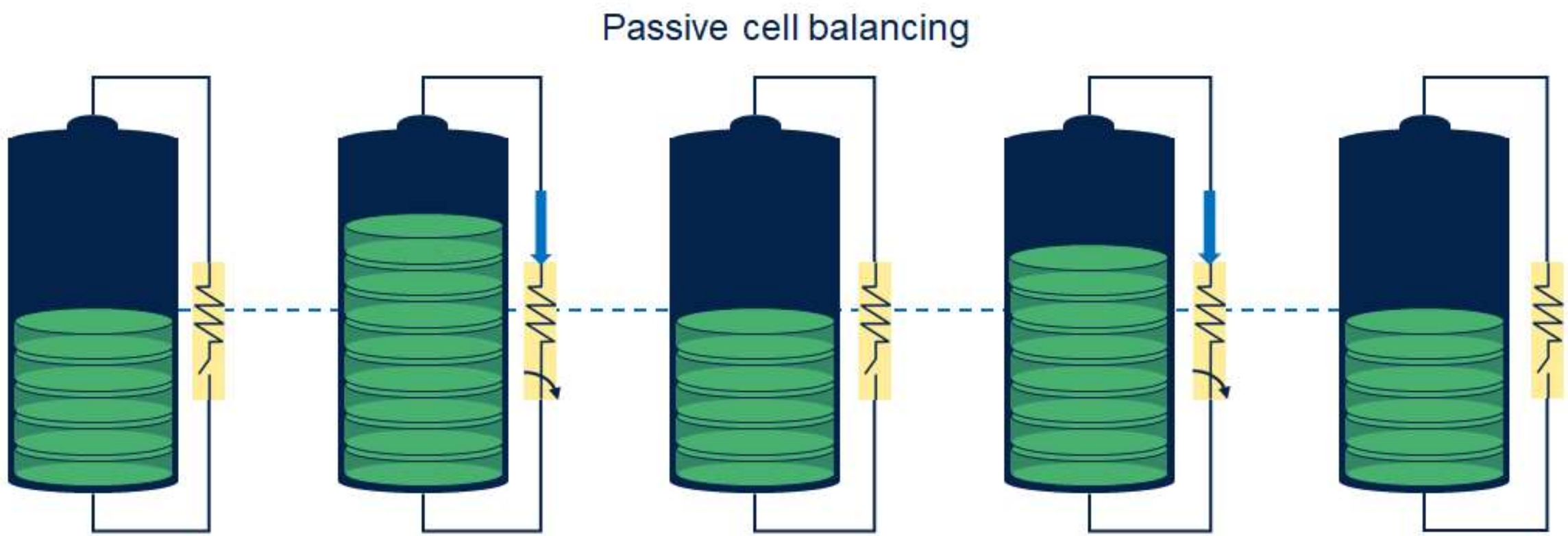
(*): this demo was run with the battery holder board hosting five LG Chem INR18650-MJ1 cells, and a programmable electronic load connected to its CN3 connector, sinking 25mA
(**): The L9961 Coulomb counting mechanism is described in all its components in paragraph 3.5.2 of the DS14012 datasheet.

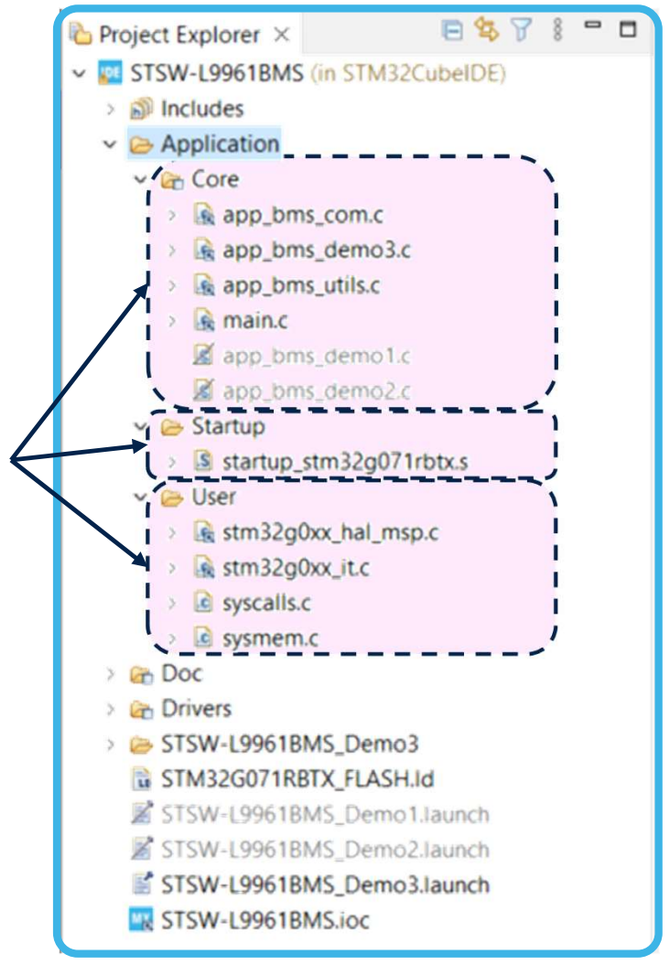
Application Demo 3: Battery balancing



STSW-L9961BMS: Application Demo 3

- The Application Demo 3 employs the passive battery cell balancing mechanism integrated in the L9961 device, to equalize the energy stored in the five cells(*) composing a battery pack
- This demo implements two balancing modes:
  - an Automatic mode that analyzes all the cells of the battery pack and activates the balancing mechanism on that cell presenting the highest energy
  - a Manual mode that allows the user to select the cell to be balanced
  - In both conditions, when a cell is activated, the adjacent cells are automatically de-activated and balancing cannot be performed on them.
- The demo outputs the status of the cells through a serial communication terminal, providing information about the cell under balancing

Application Core, User and Startup files



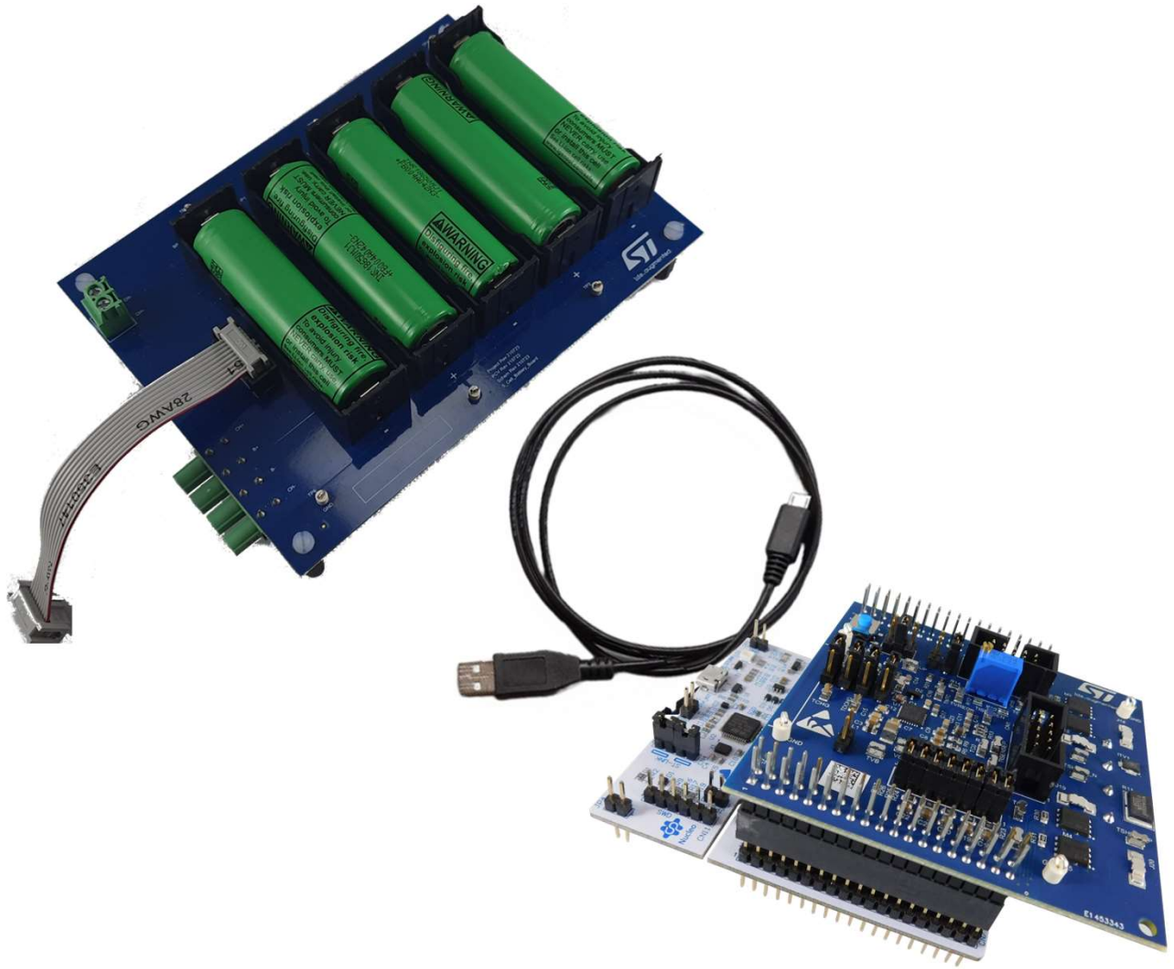
life.augmented

(*): The LG Chem INR18650-MJ1 battery cells have been selected to develop the Application Demo 2. A look-up table matching the battery OCVs vs. SoC is included in application file.

Application Demo 3 setup

To set up the demo and run the application with the evaluation kit, the following items are required:

- a STEVAL-L99615C kit
- the STSW-L9961BMS software package;
- a USB Type-A to Micro-B cable
- a battery pack(*) composed of five 18650 cells(**) and related connecting cables
- a laptop with the serial communication terminal already installed (i.e. Tera Term console)



life.augmented

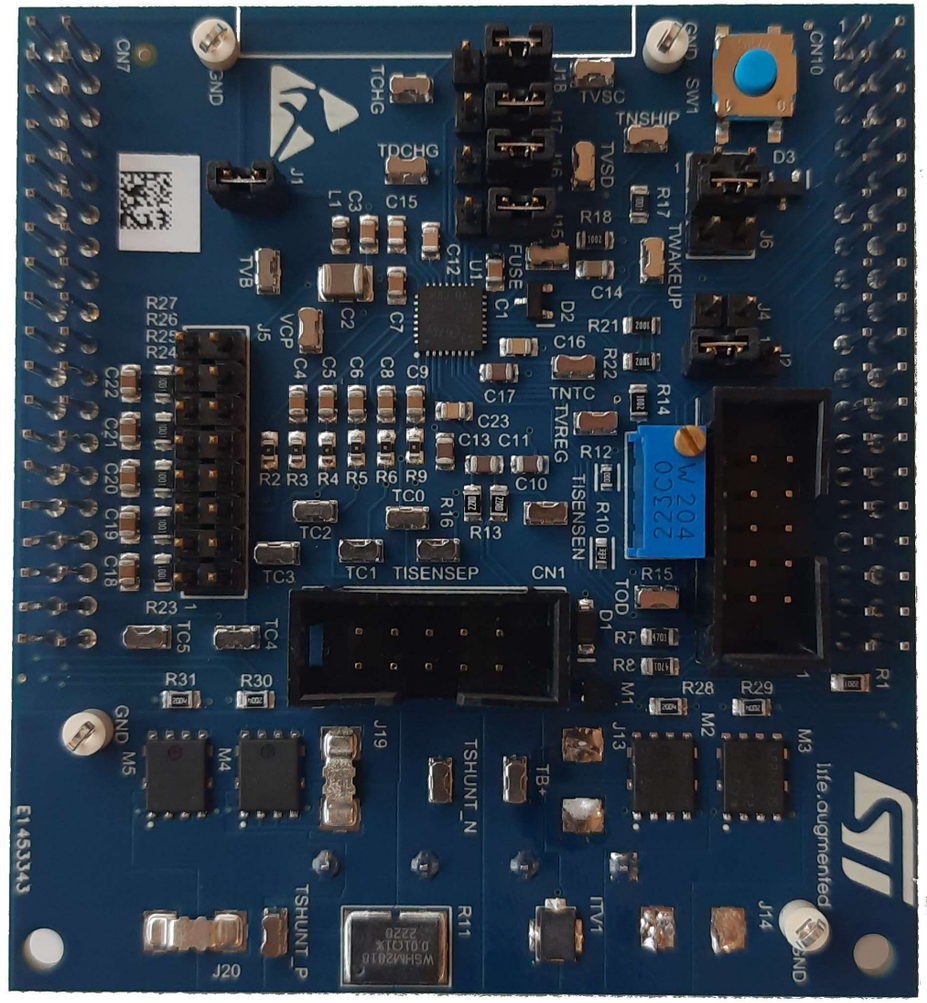
(*): the battery pack described in this demo refers to the battery holder board reported in the UM3151 user manual. It has been developed to demonstrate the operability of the kit with five 18650 battery cells. Schematics and BOM are included in the UM.

(**): Battery reference: LG Chem INR18650-MJ1.

Application Demo 3: jumpers' setup

- Verify that the setting of the STEVAL-L99615C jumpers respects the configuration depicted in the picture and reported in the following Table

Name	Board	Description	Configuration
J1	EXP. BOARD	Used to measure current flowing into VB pin	Closed
J2	EXP. BOARD	VIO voltage selector	2-3: 3.3 V from L9961 (VREG)
J4	EXP. BOARD	Used to select micro power source	Open
J5	EXP. BOARD	Battery simulator – used to simulate battery pack	Open *Note: It is assumed that 5-cell battery board is used.*
J6B	EXP. BOARD	Used to drive NSHIP pin from micro	Closed
J15, J16, J17, J18	EXP. BOARD	Used to configure the relay MOSFETs to either high or low-side usage	1-2: HS configuration is selected
J13, J14	EXP. BOARD	Used to bypass the HS relay MOSFETs	Open
J19, J20	EXP. BOARD	Used to bypass the LS relay MOSFETs.	Closed
JP3	NUCLEO	STM32 VDD current measurement	Closed
JP2	NUCLEO	STM32 5 V jumper selection	1-2: 5 V from STLINK
CN4	NUCLEO	STM32 SWD interface	Closed



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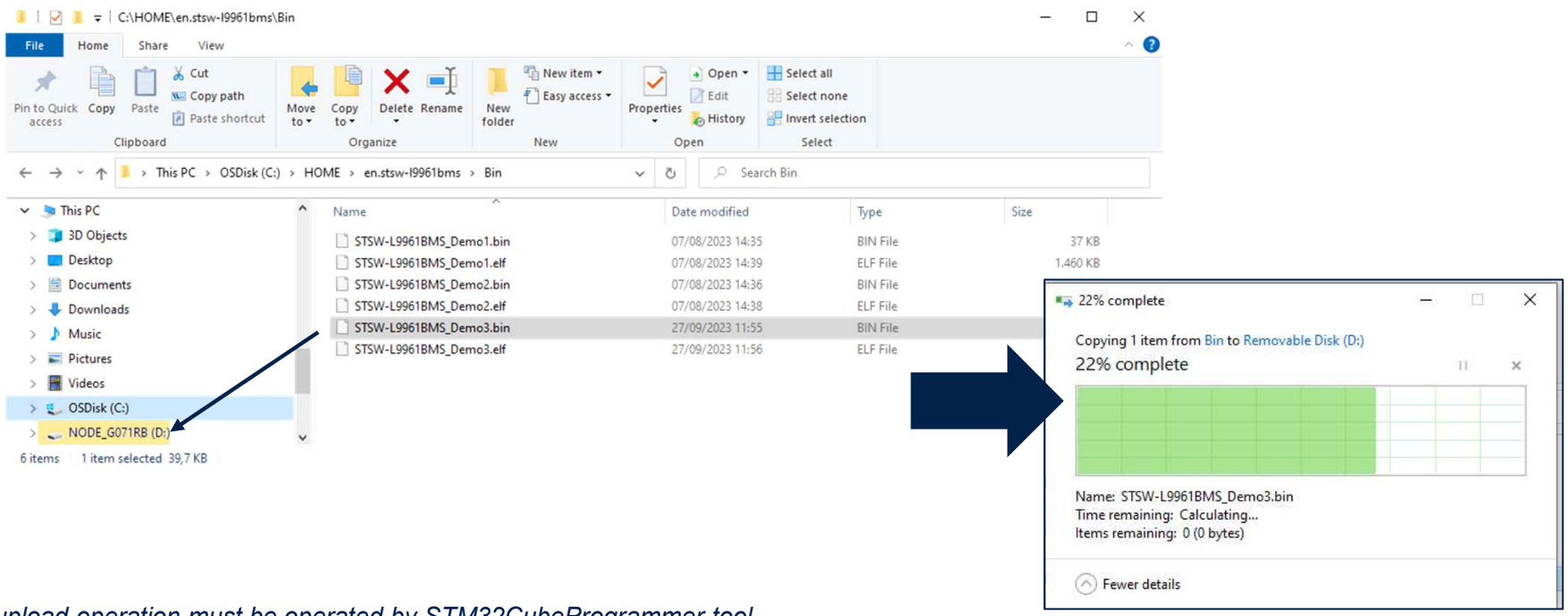
Application Demo 3: programming

- Connect the NUCLEO board of the STEVAL-L99615C kit to the laptop through the USB cable
- Drag and drop the Demo3 binary file of the STSW-L9961BMS application firmware(*), from the origin folder to the NUCLEO that has been mapped by the laptop OS as an external peripheral
- This operation permits to directly program the on-board STM32G071RB microcontroller of the NUCLEO-G071RB

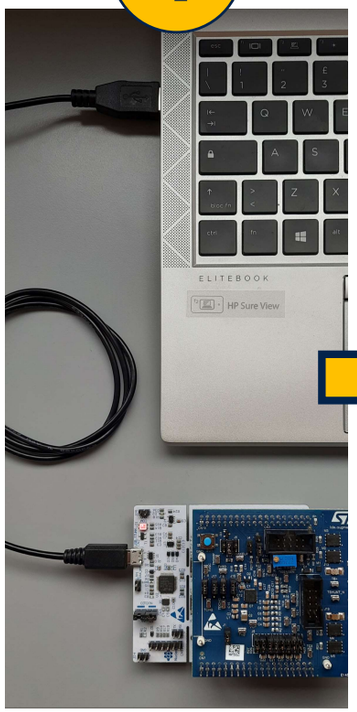


life.augmented

(*): .elf file upload operation must be operated by STM32CubeProgrammer tool.

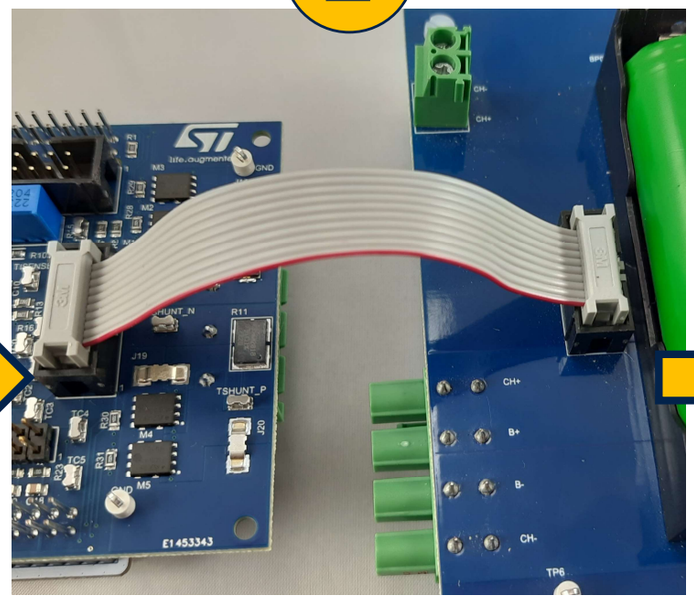
How connect the STEVAL-L99615C to the 5-cell battery pack

1



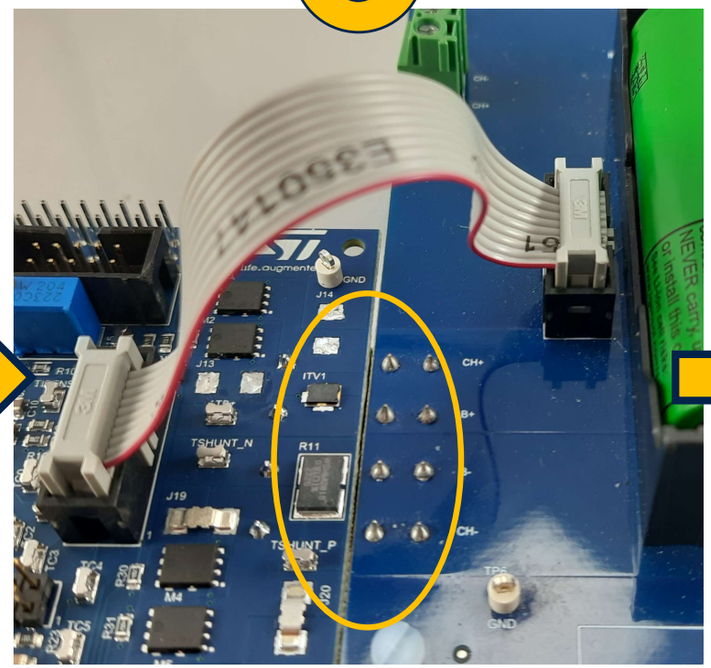
Connect the STEVAL-L99615C kit to the laptop through the USB cable

2



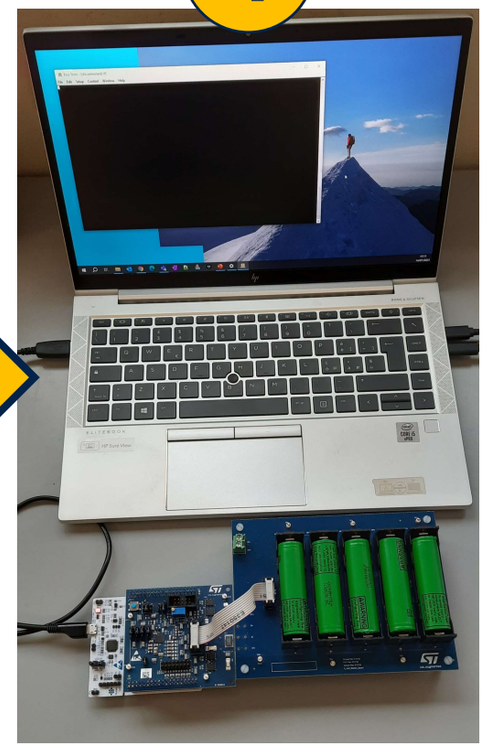
After assembling the battery holder(*) with five cells, first connect the STEVAL-L99615C kit to battery holder board through CN1 connectors (on the top) using flat cable.

3



Connect the STEVAL-L99615C kit to the battery holder board through CN2 connectors (located at the bottom)

4



Open the terminal on the laptop and select the corresponding serial port (and set COM speed @ 115200)

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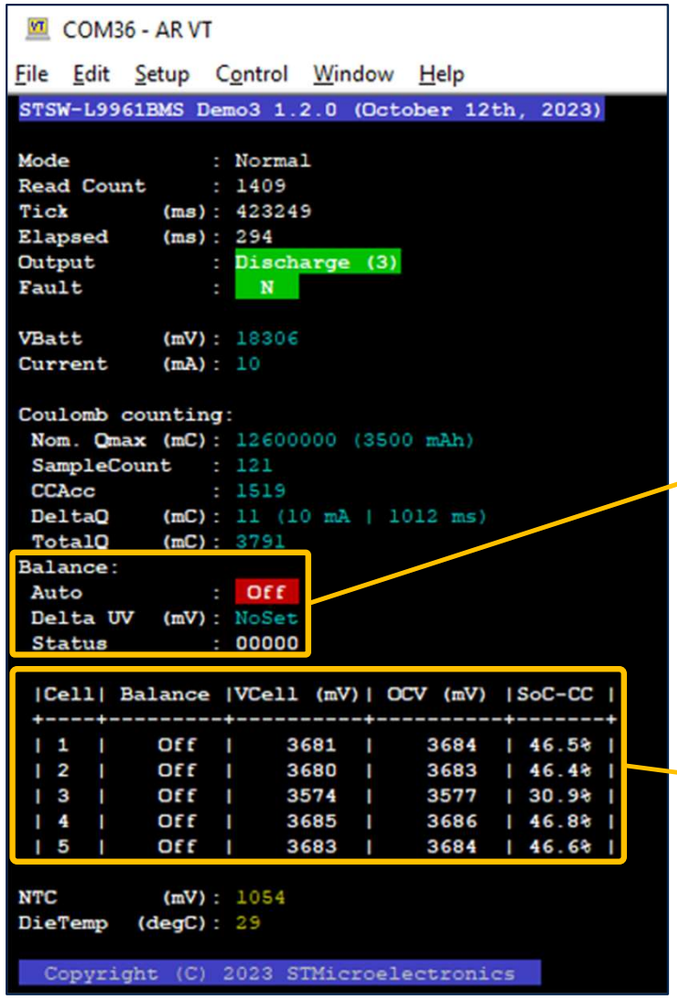
(*): to properly run the demo measuring a significant amount of current (at least 10mA), it is suggested to connect to the battery holder CN3 connector a resistance of 2,2kΩ. Otherwise an electronic load is suggested.

Application Demo 3 description



The Application Demo #3(*) displays following sets of information:

1. **Operation Status**, **Battery monitoring**, **Coulomb counting** and Temperature data describe the operation of these features as reported the previous demos.
2. The Balancing operation(**) data here reported are:
   a) **Auto** indicating whether the automatic selection of balancing mechanism is enabled (**ON**) or disabled (**OFF**): this is driven by pressing the 'B' key on the keyboard.

   b) **Delta UV (mV)** indicating the difference between the selected balancing voltage and the under-voltage threshold, to automatically turn-off the balancing when the target voltage is reached.
   c) **Status** representing the bit sequence of those cells where balancing has been enabled (coded as 1) versus the not ones (as 0)
3. The individual **Cell** information table including the Balancing status (ON, OFF and unavailable), the acquired voltage of each cell (**VCell** in mV), the initial acquired **OCV** (in mV), and the estimation of the State of Charge (**SoC** in %) for each cell

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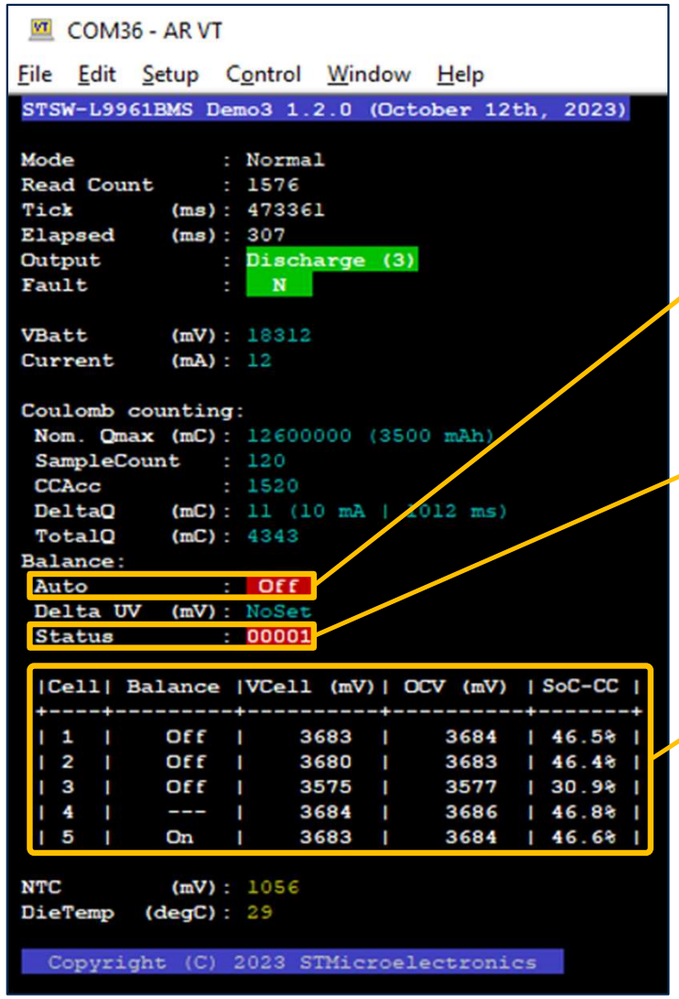
(*): this demo was run with the battery holder board hosting five LG Chem INR18650-MJ1 cells, and a programmable electronic load connected to its CN3 connector, sinking 10mA
(**): The L9961 Balancing mechanism is described in all its components in paragraph 3.6 of the DS14012 datasheet.

Application Demo 3: manual operation



- If Auto is OFF, the user can manually activate/disactivate the balancing mechanism on a specific cell, regardless of its energy level, by pressing ‘1’, ‘2’, .. ‘5’ on the keyboard
- The status always shows the activated cell as a binary value (1 indicating that balancing is activated and 0 indicating that it is not activated).
- The UI also shows the adjacent cells to the one selected for balancing, as disabled representing them with three dashes (-) in the balance column of the table

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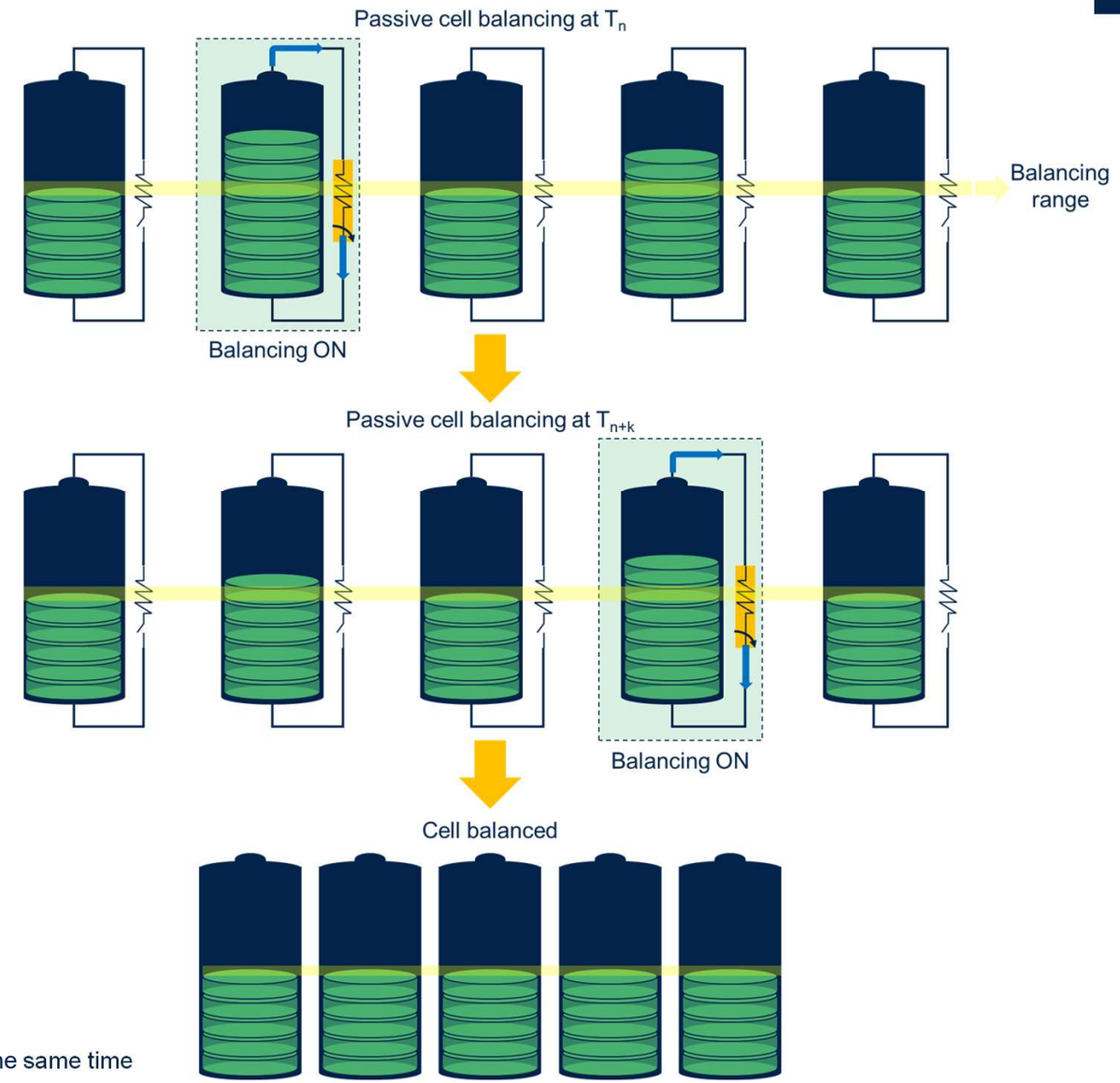
Automatic balancing implementation

- The balancing selection algorithm implemented in the demo enables the equalization of the battery pack one cell per time(*)
- When the automatic execution is ON, the algorithm will continuously work on cells equalization by identifying and balancing the most charged cell to slightly reduce its stored energy
- Once reduced, a new cell with higher charge than the minimum one, is identified and balanced.
- As result, the voltage value of the five cells will be included in a balancing range (based on the lowest voltage cell) configured by the user



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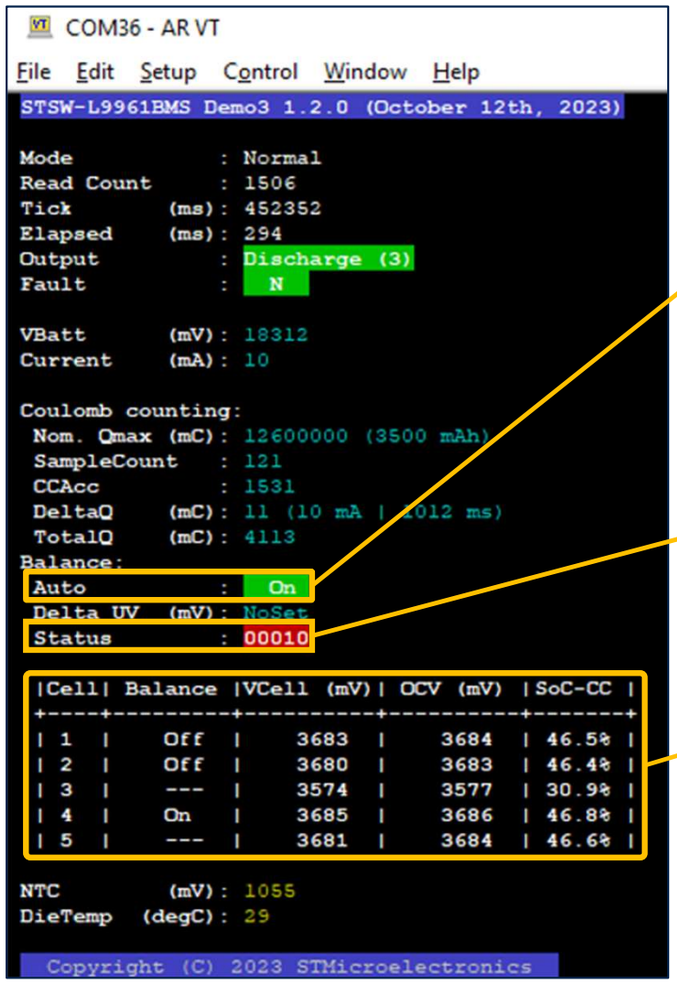
(*): The L9961 IC can manage the balancing operation on multiple not-adjacent cells at the same time

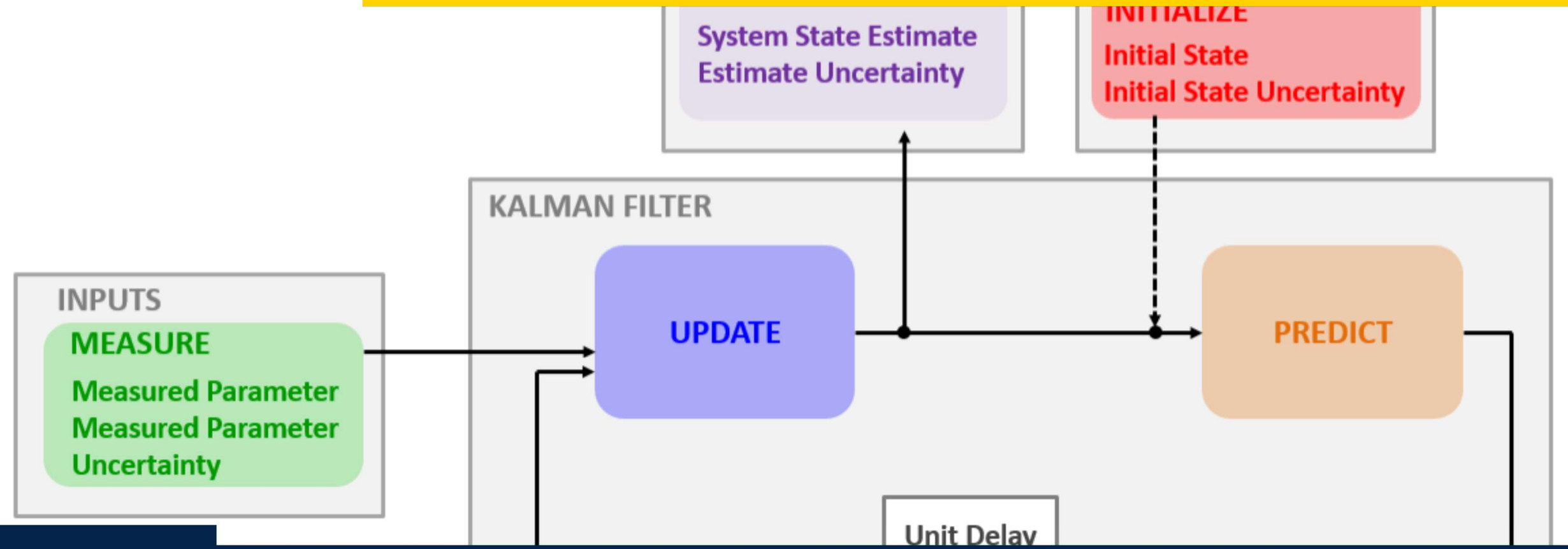
Application Demo 3: automatic operation



- During the automatic operation, the balancing mechanism routine identifies the cell with the highest energy in a battery pack (the fourth cell in the picture example), and activates the passive balancing on it until its energy is in line with the cell with the lowest energy
- The status shows the activated cell as a binary value, with 1 indicating that balancing is activated and 0 indicating that it is not activated.
- The UI also shows the adjacent cells to the one selected for balancing, as disabled representing them with three dashes (-) in the balance column of the table

life.augmented

Application Demo 4: SoC/SoH estimation based on Extended Kalman Filter

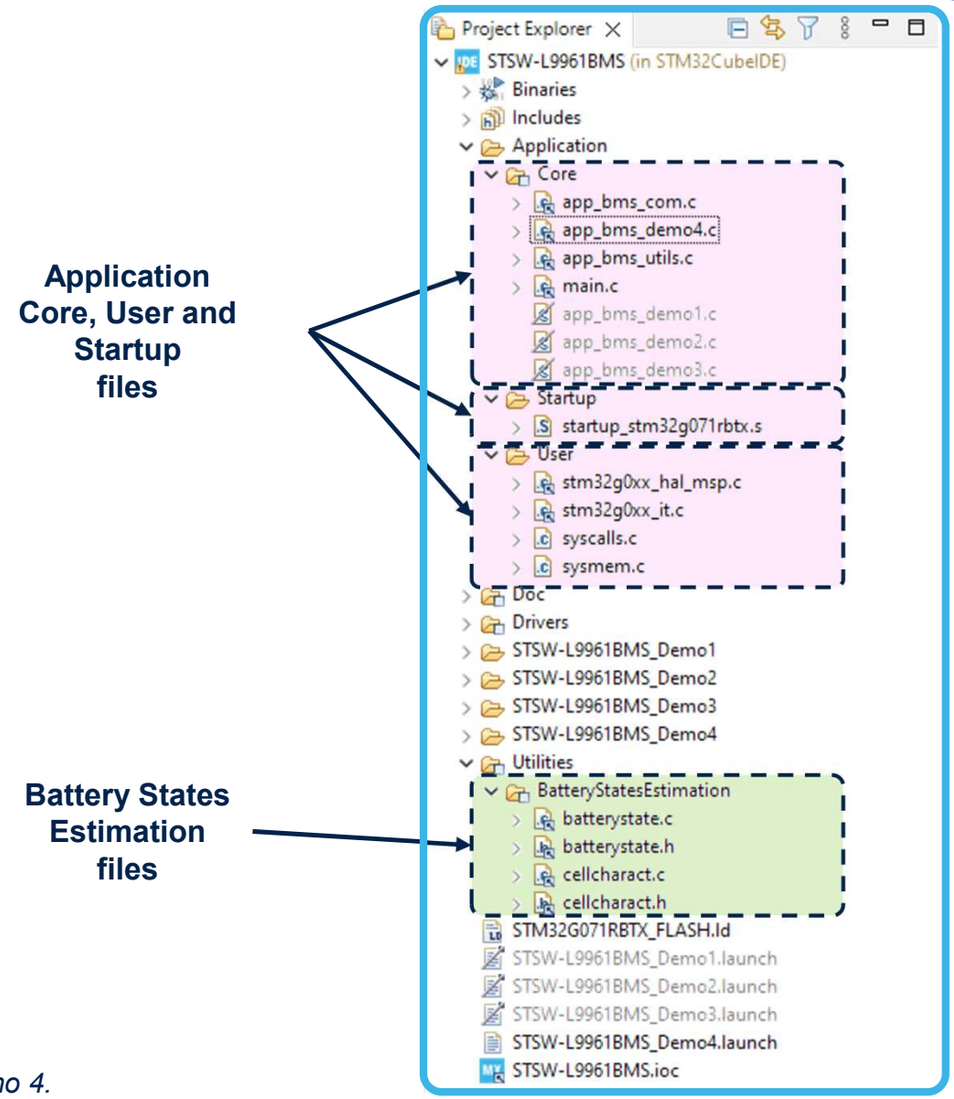


STSW-L9961BMS: Application Demo 4

- The Application Demo 4 aims to estimate the State of Charge (SoC) and the State of Health (SoH) of each of the five cells(*) composing a battery pack.

- The estimation is performed by an Extended Kalman Filter (EKF) that uses a second-order RC equivalent circuit model of lithium-ion battery cells(*) where SoC and SoH are defined inside the system states.

- The demo outputs the status of the cells through a serial communication terminal providing, for each cell, the percentages of the SoC and the SoH estimated by the Kalman Filter, and the comparable data of SoC calculated by mean of coulomb counting.



life.augmented

(*): The LG Chem INR18650-MJ1 battery cells have been selected to develop the Application Demo 4. A look-up table matching the battery OCVs vs. SoC is included in application file.

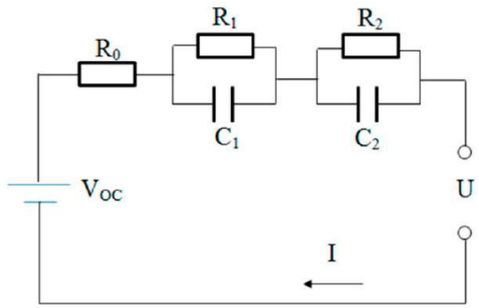
Extended Kalman Filter (EKF) for estimating SoC and SoH on Li-Ion Battery

The estimation of SoC and SoH in Li-Ion battery pack, can be addressed by using a model-based approach, that describes the inner electrical characteristics of the constituting cells.

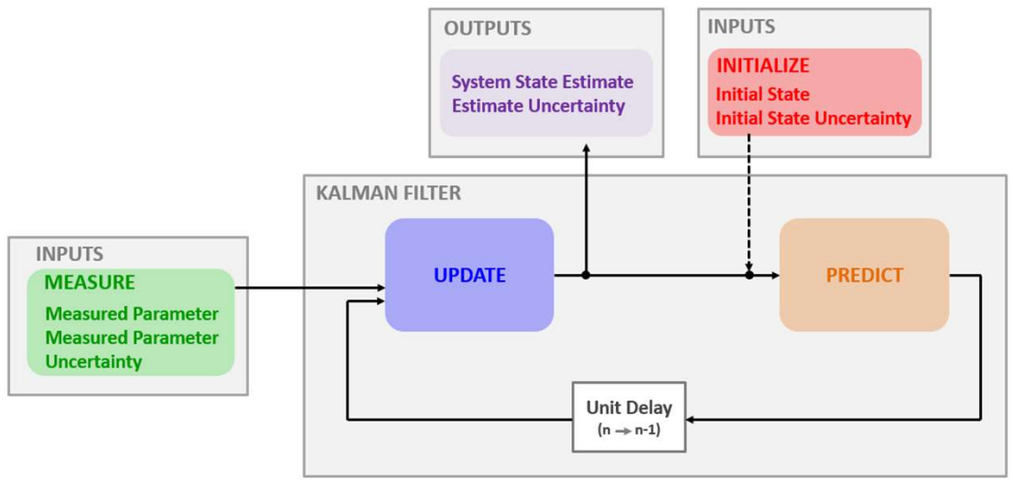
As approximate filter for non-linear systems, the EKF is applied in joint parameter and state estimation problems for linear systems with unknown parameters.

The EKF is a powerful model-based estimator able to manage the non-linear OCV vs. SoC relation.

In terms of estimation error, the EKF tends to minimize the estimation error while increasing the precision of SoC and SoH



The second order RC Equivalent Circuit Models for Lithium-Ion



Kalman Filter block scheme

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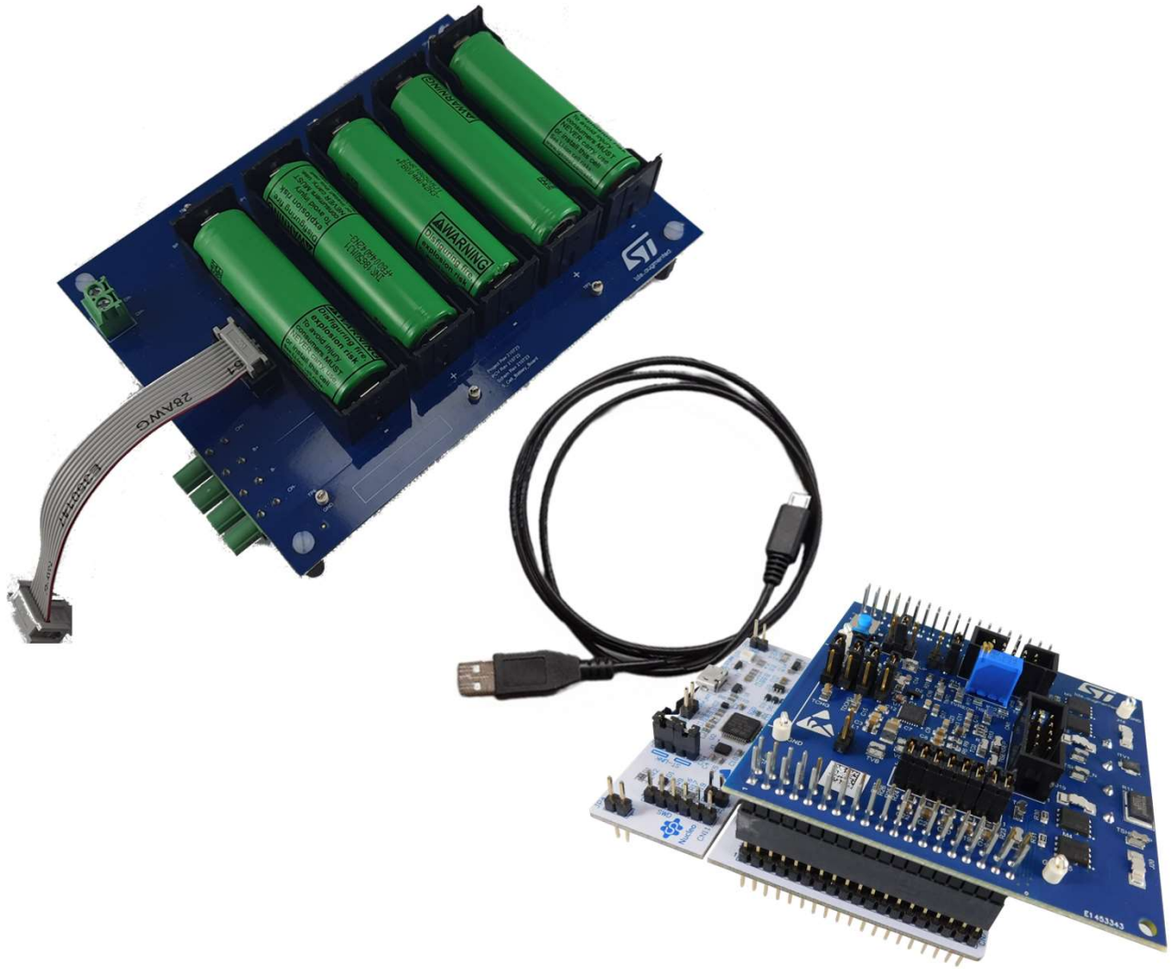
Application Demo 4 setup

To set up the demo and run the application with the evaluation kit, the following items are required:

- a STEVAL-L99615C kit
- the STSW-L9961BMS software package;
- a USB Type-A to Micro-B cable
- a battery pack(*) composed of five 18650 cells(**) and related connecting cables
- a laptop with the serial communication terminal already installed



life.augmented

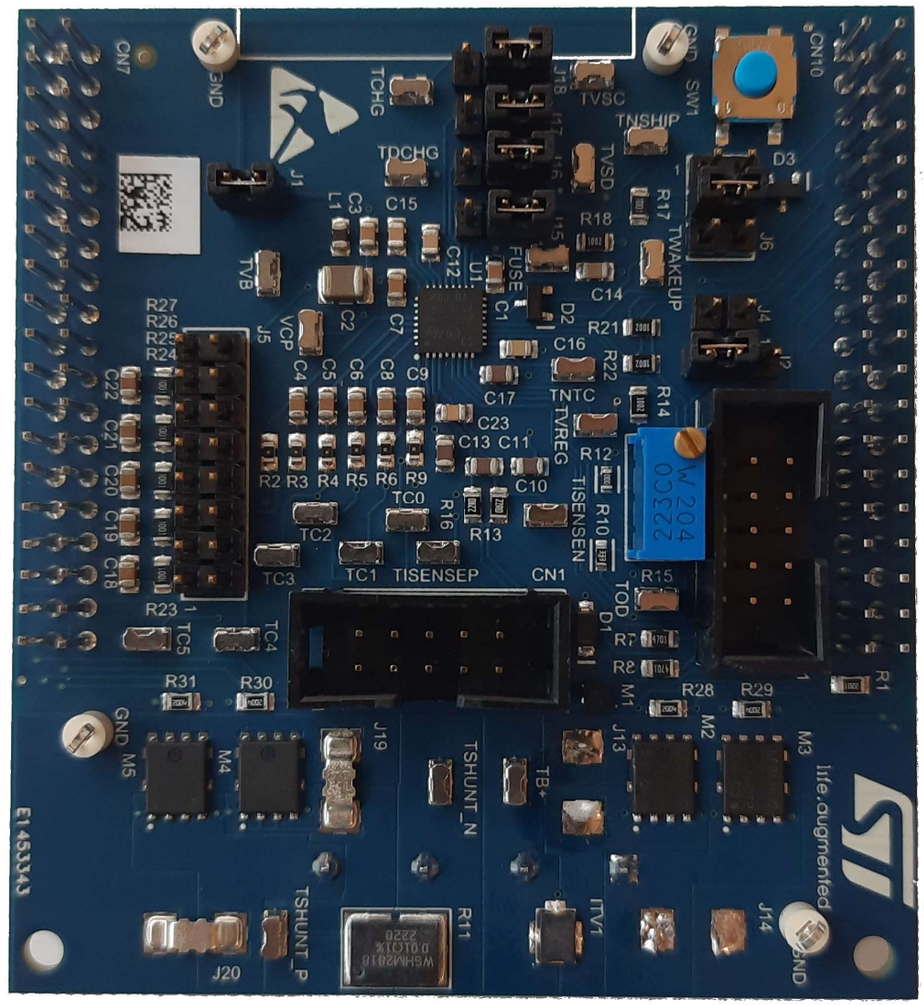
(*): the battery pack described in this demo refers to the battery holder board reported in the UM3151 user manual. It has been developed to demonstrate the operability of the kit with five 18650 battery cells. Schematics and BOM are included in the UM.

(**): Battery reference: LG Chem INR18650-MJ1.

Application Demo 4: jumpers' setup

- Verify that the setting of the STEVAL-L99615C jumpers respects the configuration depicted in the picture and reported in the following Table

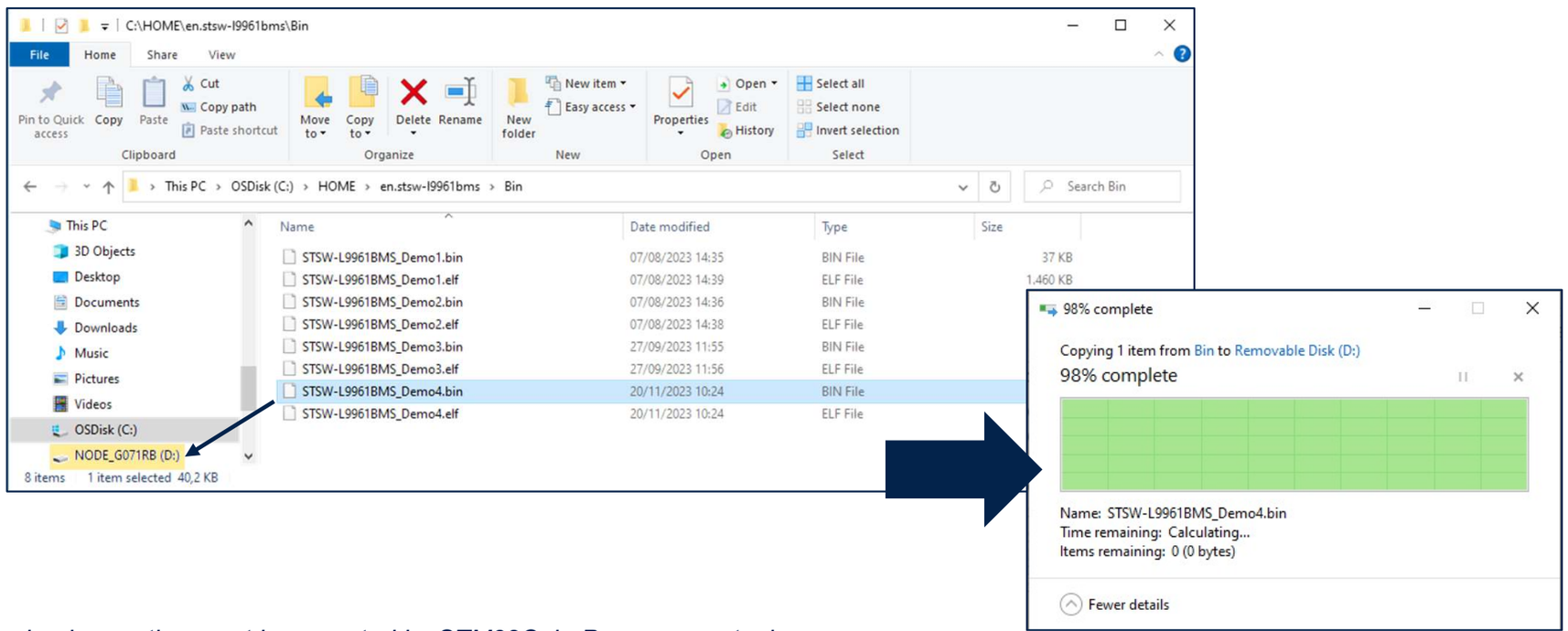
Name	Board	Description	Configuration
J1	EXP. BOARD	Used to measure current flowing into VB pin	Closed
J2	EXP. BOARD	VIO voltage selector	2-3: 3.3 V from L9961 (VREG)
J4	EXP. BOARD	Used to select micro power source	Open
J5	EXP. BOARD	Battery simulator – used to simulate battery pack	Open *Note: It is assumed that 5-cell battery board is used.*
J6B	EXP. BOARD	Used to drive NSHIP pin from micro	Closed
J15, J16, J17, J18	EXP. BOARD	Used to configure the relay MOSFETs to either high or low-side usage	1-2: HS configuration is selected
J13, J14	EXP. BOARD	Used to bypass the HS relay MOSFETs	Open
J19, J20	EXP. BOARD	Used to bypass the LS relay MOSFETs.	Closed
JP3	NUCLEO	STM32 VDD current measurement	Closed
JP2	NUCLEO	STM32 5 V jumper selection	1-2: 5 V from STLINK
CN4	NUCLEO	STM32 SWD interface	Closed



life.augmented

Application Demo 4: programming

- Connect the NUCLEO board of the STEVAL-L99615C kit to the laptop through the USB cable
- Drag and drop the Demo4 binary file of the STSW-L9961BMS application firmware(*), from the origin folder to the NUCLEO that has been mapped by the laptop OS as an external peripheral
- This operation permits to directly program the on-board STM32G071RB microcontroller of the NUCLEO-G071RB

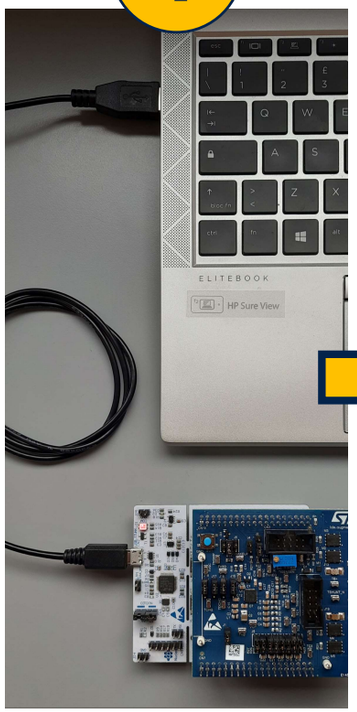


life.augmented

(*): .elf file upload operation must be operated by STM32CubeProgrammer tool.

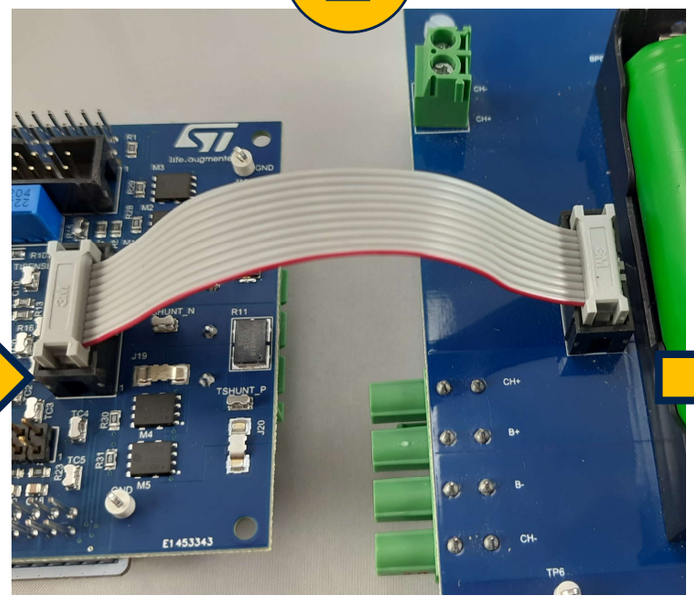
How connect the STEVAL-L99615C to the 5-cell battery pack

1



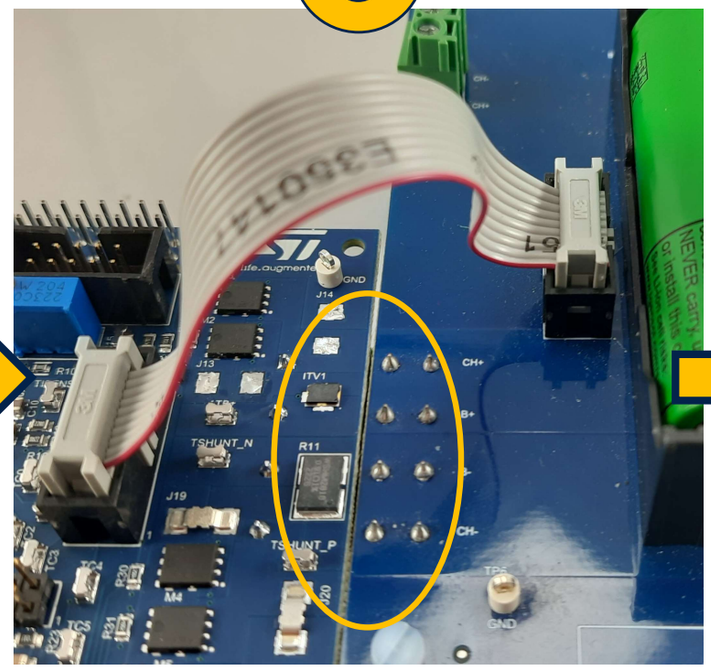
Connect the STEVAL-L99615C kit to the laptop through the USB cable

2



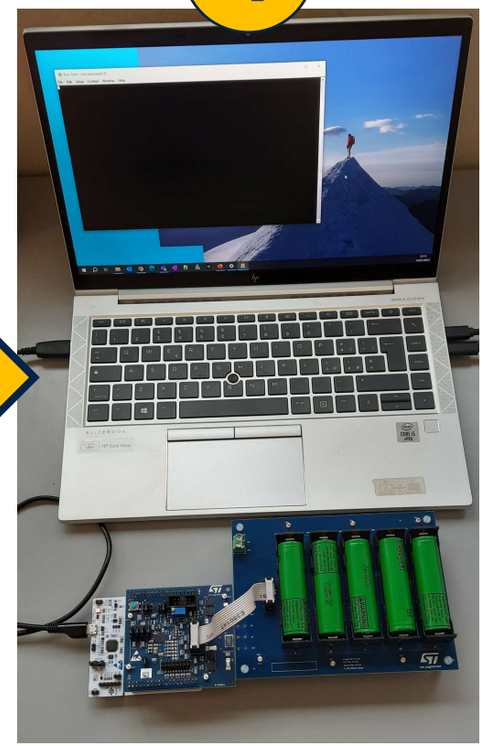
After assembling the battery holder(*) with five cells, first connect the STEVAL-L99615C kit to battery holder board through CN1 connectors (on the top) using flat cable.

3



Connect the STEVAL-L99615C kit to the battery holder board through CN2 connectors (located at the bottom)

4



Open the terminal on the laptop and select the corresponding serial port (and set COM speed @ 115200)

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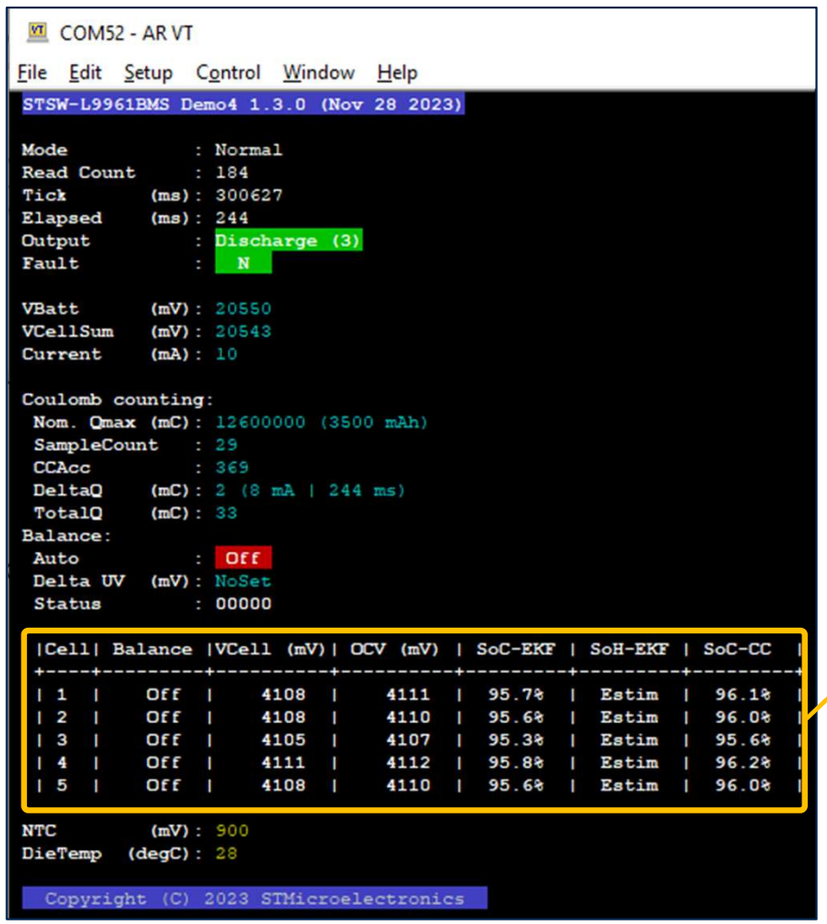
(*): to properly run the demo measuring a significant amount of current (at least 10mA), it is suggested to connect to the battery holder CN3 connector a resistance of 2,2kΩ. Otherwise an electronic load is suggested.

Application Demo 4 description



The Application Demo 4(*) displays following sets of information:

1. **Operation Status**, **Battery monitoring**, **Coulomb counting, Balancing** (**) and Temperature data describe the operation of these features as reported the previous demos.
2. The individual **Cell** information table including
   a) The Cell number referred to the battery pack
   b) the Balancing status (ON, OFF and unavailable),
   c) the acquired voltage of each cell (**VCell** in mV),
   d) the initial **OCV** (in mV),
   e) the estimation of the State of Charge for each cell, carried out by the Extended Kalman Filter (**SoC-EKF** %)
   f) the estimation of the State of Health for each cell, carried out by the Extended Kalman Filter (**SoH-EKF** %)
   g) the estimation of the State of Charge for each cell, carried out by the Coulomb counting (**SoC-CC** %)

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(*): this demo was run with the battery holder board hosting five LG Chem INR18650-MJ1 cells, and a programmable electronic load connected to its CN3 connector, sinking 10mA

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