Finite State Machine Description

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Peripherals

List of Used Peripherals: ‘

- Power Voltage Detector (PVD)
- Low-Power Timers (LPTIM1, LPTIM2)
- Real Time Clock (RTC)
- Comparator (COMP)
- GPIO

Implemented States

- Energy Harvesting (EH): The system is powered by the Solar Cell and the small capacitors are charged. The MCU is in Stop2 Mode.
- Energy Storage (ES): The energy provided by the solar cell is stored in a storage element. This could be done in Discontinuous Charging Mode (DCM) or in Continuous Charging Mode (CCM).
- Radio Transmission (RADIO_TX): LoRa Data Transmission in Authentication by Personalization (ABP).
- Dark (DARK): The FSM enters this state when the absence of light is detected.
- Check For Energy (CFE): The system checks if enough light to charge the small capacitors is present
- Impedance Measurement (IMP_MEAS): The system performs the impedance measurement.
- Dark Measurement (DARK_MEAS); The system performs impedance measurement during at night.

States Peripheral Description

- EH: System Powered by the Solar Cell
  - MCU in Stop2 Mode
  - PVD set in RISING mode with threshold equal to 3 V.
  - RTC alarm B active to detect the absence of light (DARK).
  - Radio Module turned off
  - SCap_Pin in analog state
  - LPTIM1 counting the TRise
- RADIO_TX:: System Powered by the Solar Cell
  - MCU in Run Mode
  - Radio Module on

States Peripheral Description

- ES: System Powered by the Solar Cell
  - MCU in Stop2 Mode
  - PVD:
    - DCM: PVD in FALLING with 2 V
    - CCM: PVD in RISING with EoC V.
  - LPTIM1: set in interrupt to count T_ES_W cycles to exit the energy storage window
  - RTC Alarm A: to allow the PVD setup time to detect the CCM to EoC change
  - RTC Alarm B: to detect the DCM to CCM.

States Peripheral Description

- DARK: System Powered by the Storage Element
  - MCU in Stop2 Mode
  - PVD: PVD in RISING with EoC V.
  - RTC Alarm B: set to enter CFE
  - RTC Alarm A: set to enter DARK_MEAS
- CFE: System Powered by the Solar Cell
  - MCU in Stop2 Mode
  - PVD: PVD in RISING with 3 V
  - LPTIM1 in interrupt to declare the CFE unsuccessful and return in DARK

States Peripheral Description

- IMP_MEAS: System Powered by the Solar Cell
  - MCU in Run Mode
  - LPTIM1 in interrupt to detect the measurement failure
  - COMP1 in interrupt with the RISING detection with threshold equal to 0.3 V
  - LPTIM2 at 1 MHz with the HSI as clock source
- DARK_MEAS: System Powered by the Storage Element
  - MCU in Run Mode
  - LPTIM1 in interrupt to detect the measurement failure
  - COMP1 in interrupt with the RISING detection with threshold equal to 0.3 V
  - LPTIM2 at 1 MHz with the HSI as clock source

Start-Up

When the supply voltage reaches 1.8 V the function *SystemInit* is executed:

- All the GPIOs are set in Analog Mode
- The system enters EH with PVD set to 3 V in interrupt mode

When the PVD interrupt is fired (supply voltage equal to 3 V) the MCU executes the *main.c* file and it initialize all the other peripherals.

LoRa Data Trasmission

The system enters alternatively in EH and RADIO_TX to send N_LORA_TX packets. During the EH the two small capacitors are charged until 3 V, than the PVD interrupt is fired and the system enters RADIO_TX. Between two consecutive data transmission the time needed to recharge the small capacitors (TRise) is evaluated with the LPTIM1.

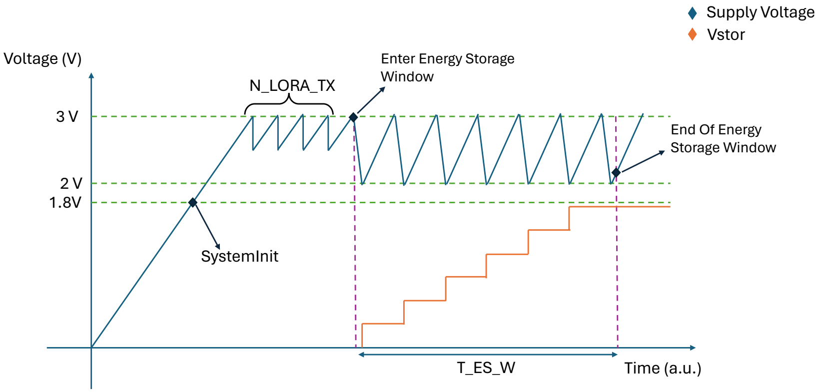
Energy Storage

After sending N_LORA_TX packets the systems enters the EH with PVD set to 3 V. When the PVD interrupt is fired the system enters the energy storage window. Its duration is limited by the LPTIM1 ($f_{LPTIM1} \simeq 256\,\mathrm{Hz}$). LPTIM1 counts T_ES_W cycles and fires an interrupt. This interrupt ends the energy storage window. Storage element is executed in 2 ways:

- If $V_{stor} < 2\,\mathrm{V} \rightarrow$ DCM: the storage element is short circuited through a GPIO (SCap_Pin) to the small capacitors and the PVD is set in falling edge with the thr equal to 2 V. When the PVD interrupt is fired the system enters EH and GPIO is set in Analog Mode.
- If $V_{stor} \geq 2\,\mathrm{V} - >$ CCM: The storage element is the storage element is short circuited through a GPIO (SCap_Pin) to the small capacitors and the PVD is set in interrupt in rising edge with the threshold equal to VEoC.

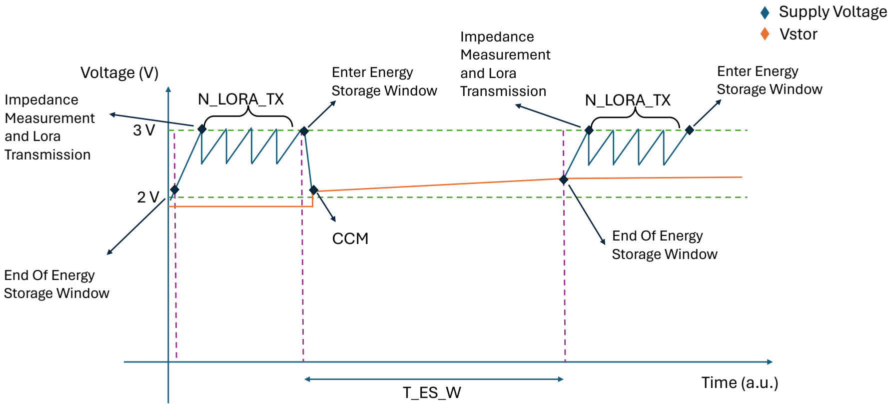
Sum-Up

The following figure summarizes the Start-Up, LoRa Data Trasmission, and Energy Storage (DCM).



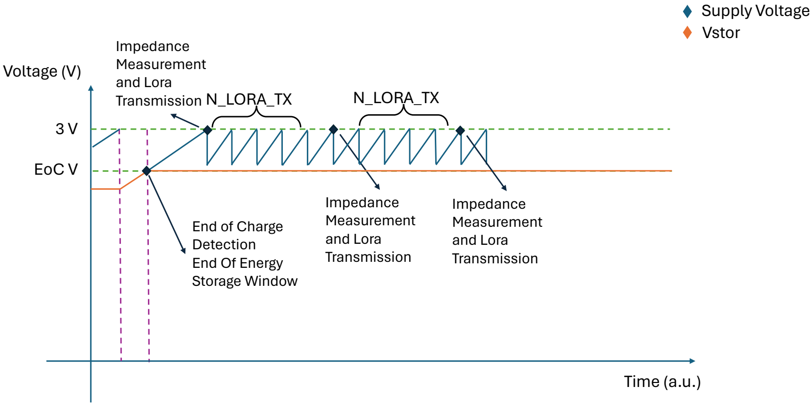
Impedance Measurement and DCM to CCM

When the Energy Storage Window expires the FSM enters EH. Then it enters IMP_MEAS, then, if the charging mdoe is not EoC another Energy Storage window is executed.



EoC Detection

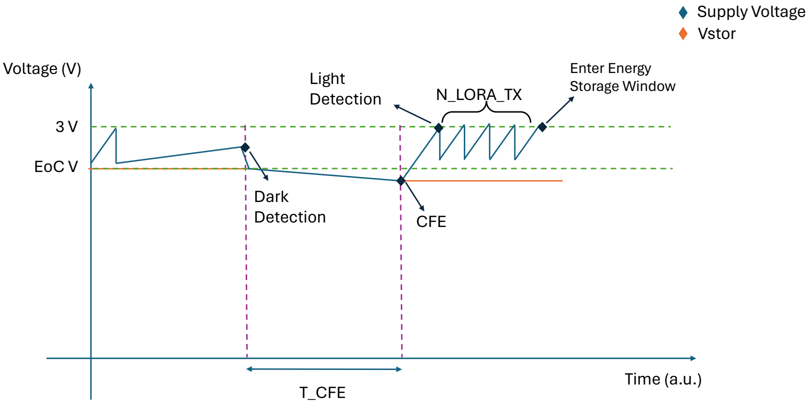
When the ES state is entered both the LPTIM1 and the PVD are configured in interrupt mode. If the PVD interrupt is fired while the Energy storage window has not expired: CCM $\rightarrow$ EoC. This means that the storage element is fully charged and no more ES are performed.



Dark State

When the system enters the EH state the RTC alarm B and the PVD are both armed. If the alarm is fired before the PVD the system enters the DARK state. During the DARK state both the RTC alarm A and B are armed. The alarm B is responsible for entering the CFE state, while the A for entering the DARK_MEAS. If the CFE is successful the storage element is considered in DCM mode.

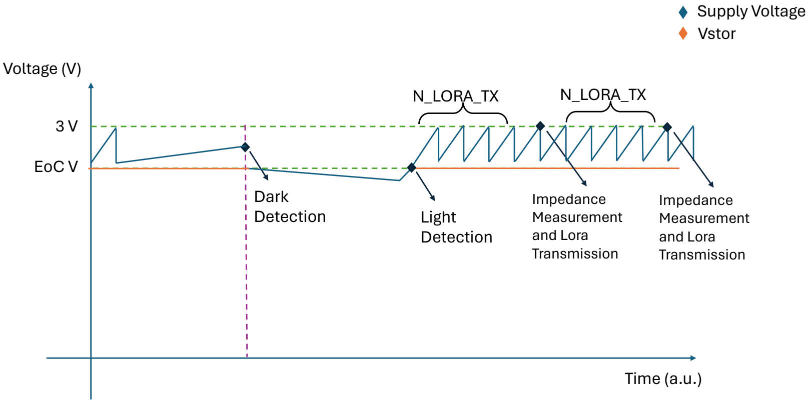
Dark State



Supply Voltage
Vstor
Voltage (V)
3 V
EoC V
Light
Detection
N_LORA_TX
Enter Energy
Storage Window
Dark
Detection
CFE
T_CFE
Time (a.u.)

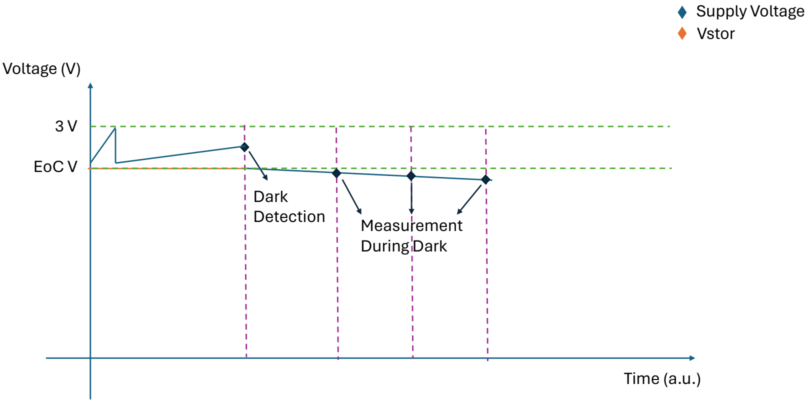
Light Detection

When the system enters the DARK state the PVD is armed in RISING with the threshold set equal to EoC. If the PVD interrupt is fired during the DARK state the system detects the presence of light and enters the EH state. The storage is set to EoC state.



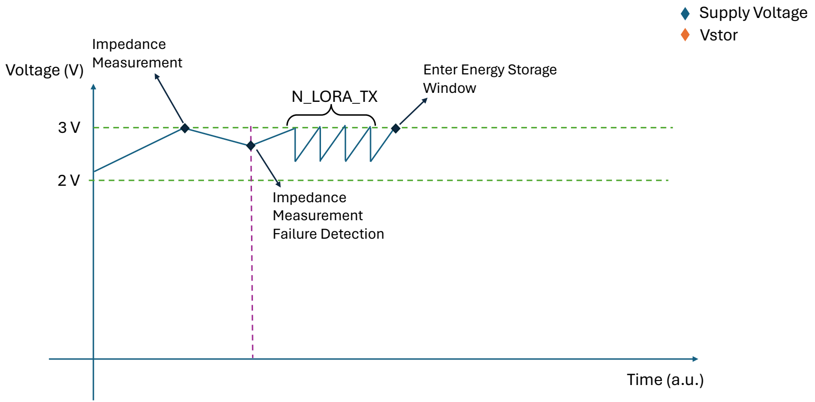
Dark Measurement

During the DARK state, when the RTC alarm A is fired, the system executes an impedance measurement and saves the result in a buffer that is filled until light is detected. When measurements are performed in DARK they are not followed by a data transmission even if they do not fail.



Impedance Measurement Failure

When the IMP_MEAS state is executed both the COMP1 and LPTIM1 interrupt are enabled. If the LPTIM1 interrupt is fired before the COMP1 it means that the measurement has failed and the system enters EH.



Code Description

- *my_lorawan.c* contains the functions responsible for the FSM implementation and all the callbacks (PVD, LPTIMs, COMP1, and RTC)
- *my_lorawan.h* contains all the user defined parameters (EoC, PVD thresholds, buffer dimensions, T_ES_W, dark alarm detection...) and it provides the possibility to enable or disable functionalities (storage element charger, impedance measurement, dark impedance measurement, debugger...). Moreover, it contains all the includes relative to files that manage the peripherals.
- *se-identity.h* contains all the LoRaWAN commissioning parameters.
- *lora_app.c* contains all the functions that manage the LoRaWAN stack and the tasks definition.
- *main.h* contains all the GPIOs labels
- *main.c* contains all the peripherals configuration functions and the LoRaWAN initialization function.

Adding Peripherals

The code generation tool launched from the *.ioc* file would completely destroy the FSM implementation. To enable any further peripheral:

- Create a new workspace for the STM32IDE.
- Open a new project in this workspace starting from the *LoRaWAN_End_Node* example project for the NUCLEO-WL55JC1.
- Open the *.ioc* file and configure the needed peripheral(s) and the relative GPIOs and generate the code.
- Copy all the newly generated driver files (*.c* and *.h*) in another folder
- Open the *stm32wlxx_it.c* file and copy in a txt file the IRQHandler relative to the peripheral.
- Open the workspace where your FSM is and copy in the *mylib* folder all the driver files relative to the wanted peripheral
- Open the *stm32wlxx_it.c* of the project containing the FSM and add the IRQHandler relative to the peripheral
- Add in the *main.c* file the function needed to configure this peripheral paying attention to correctly include all the driver files