University of Antwerp
Faculty of Applied Engineering

Simple Stupid Rover

Robbe Elsermans, Adam Hejduk, Thomas Kramp

Adam Hejduk

- Environmental Sensing
- Energy harvesting
- Energy output management
- Soldering man

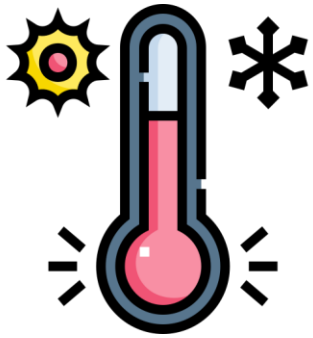
Robbe Elsermans

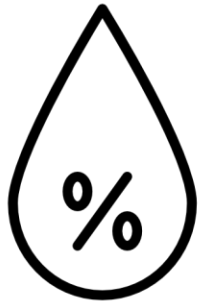
- Project Manager
- Energy Awareness
- BLE intercommunication
- Power Profiling

Thomas Kramp

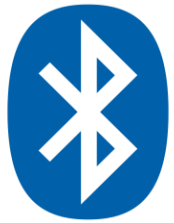
- Gyroscope
- LineBot
- LoRa
- Dashboard

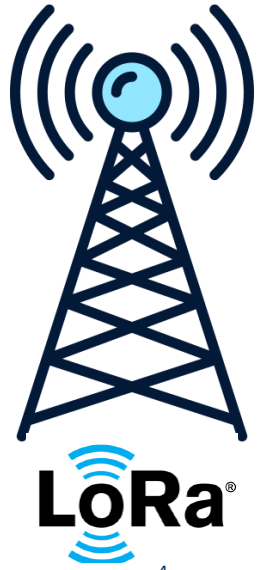
Concept



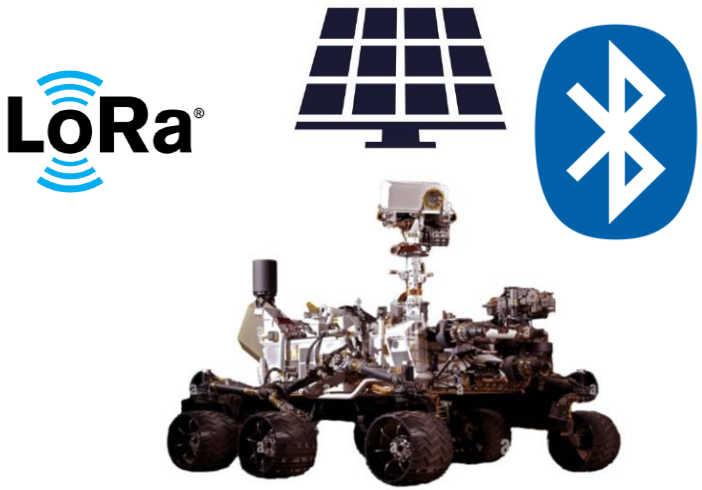


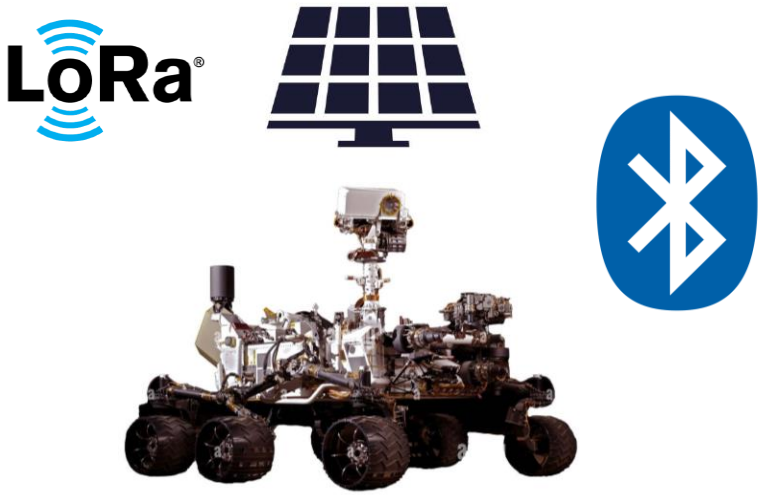
Concept

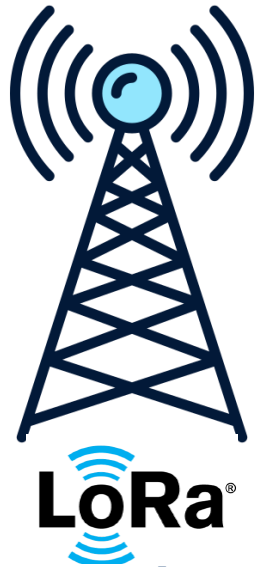




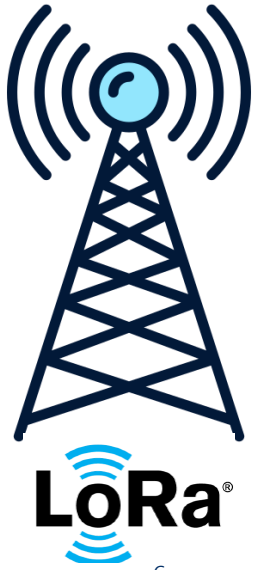
Concept







Concept



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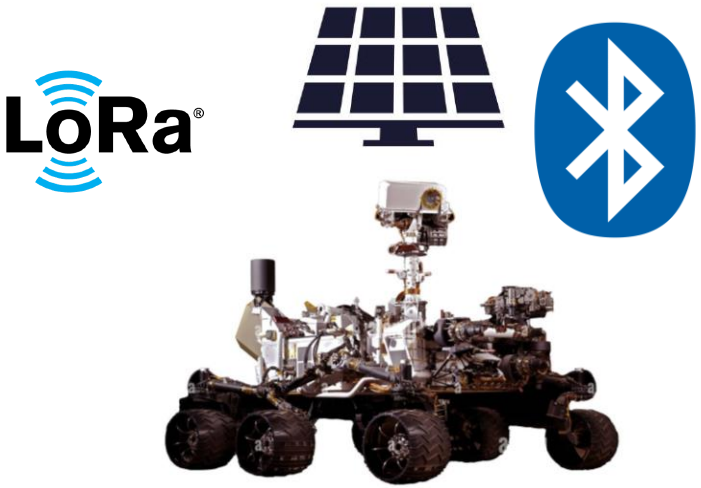
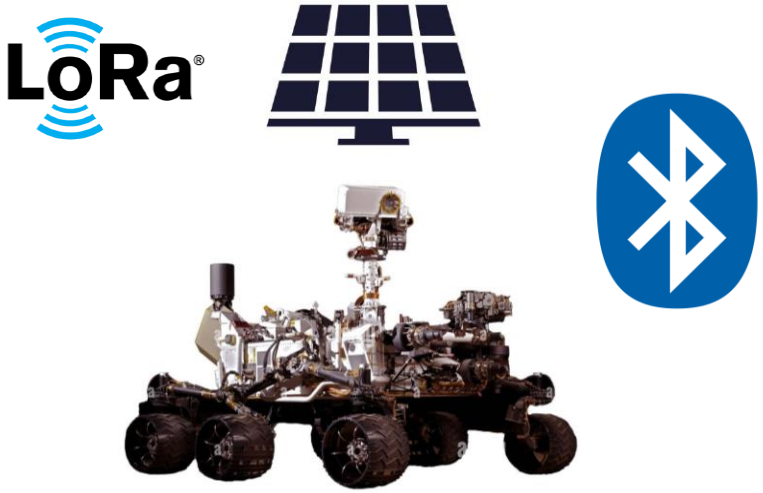
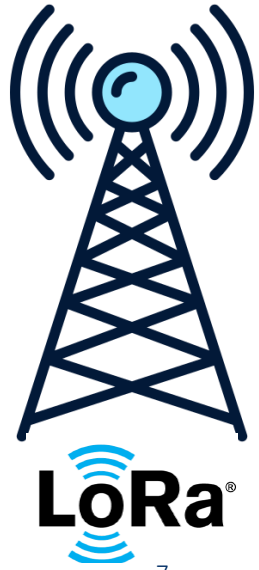
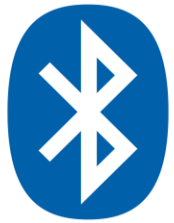
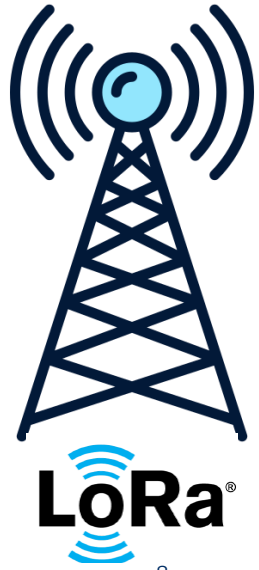




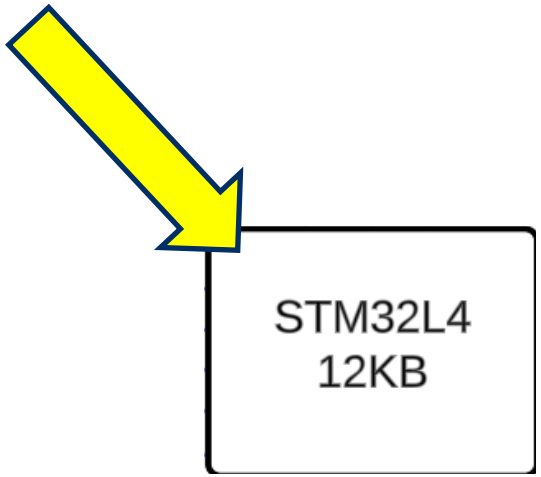


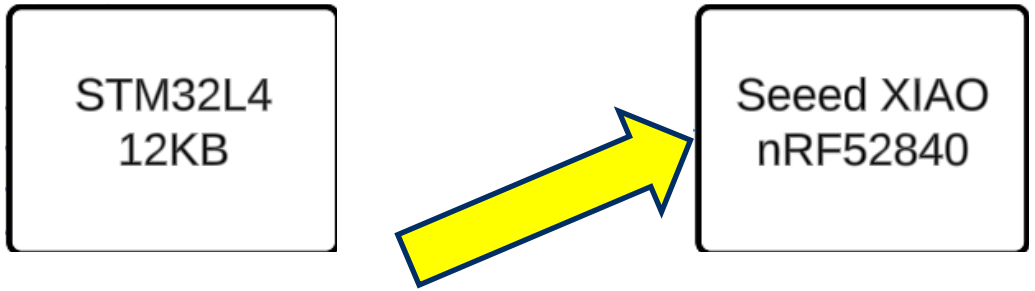
Concept

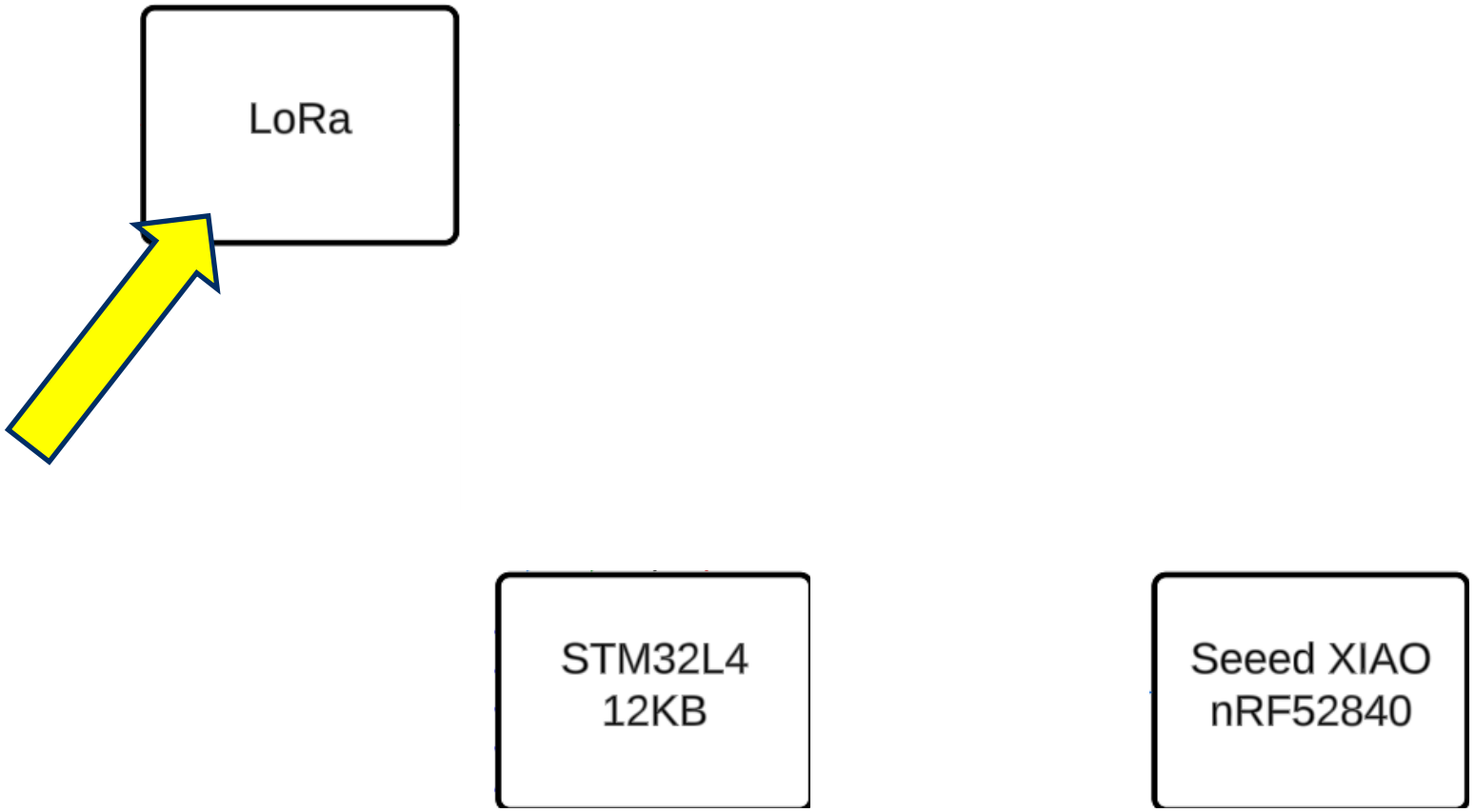


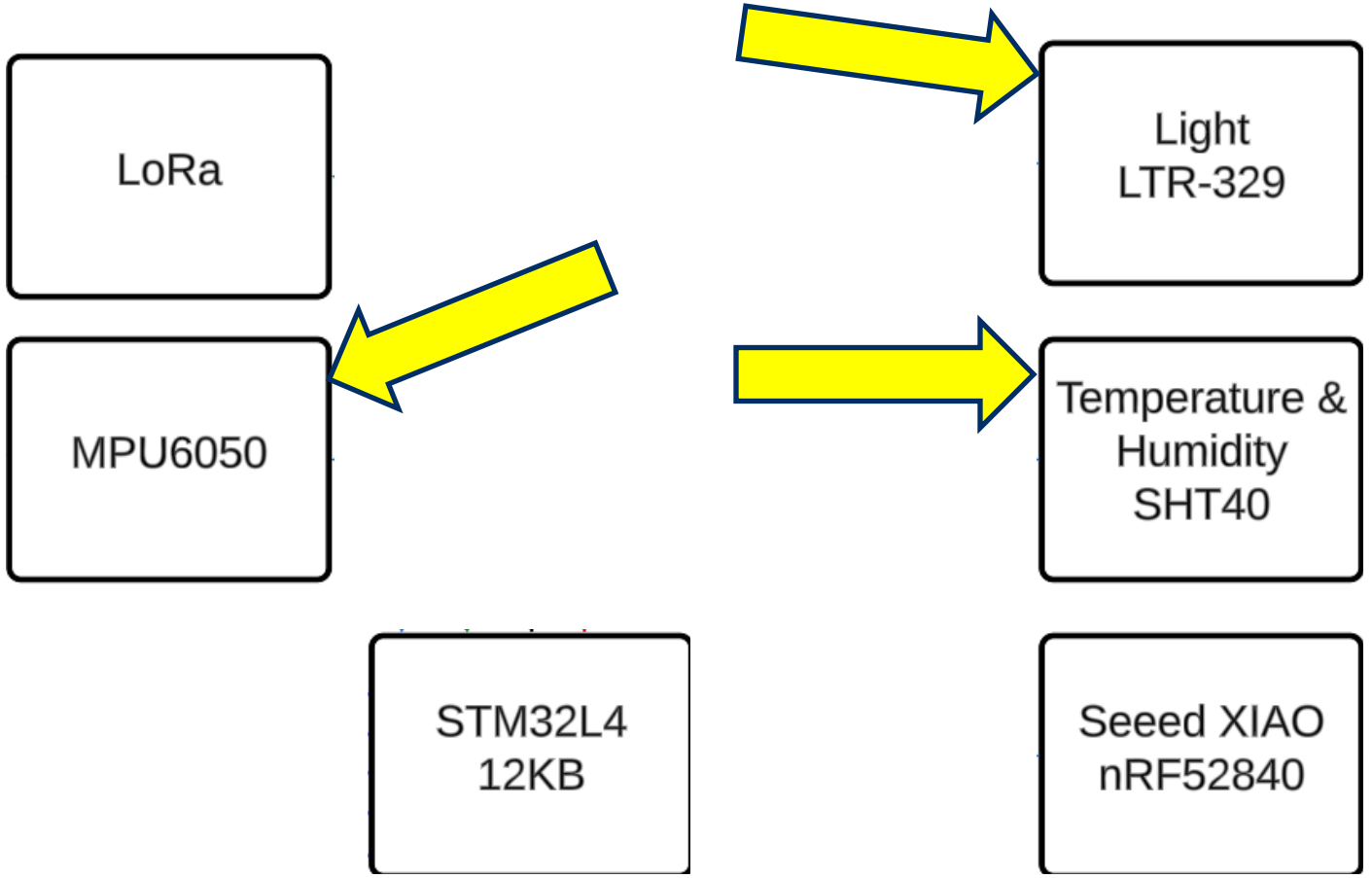


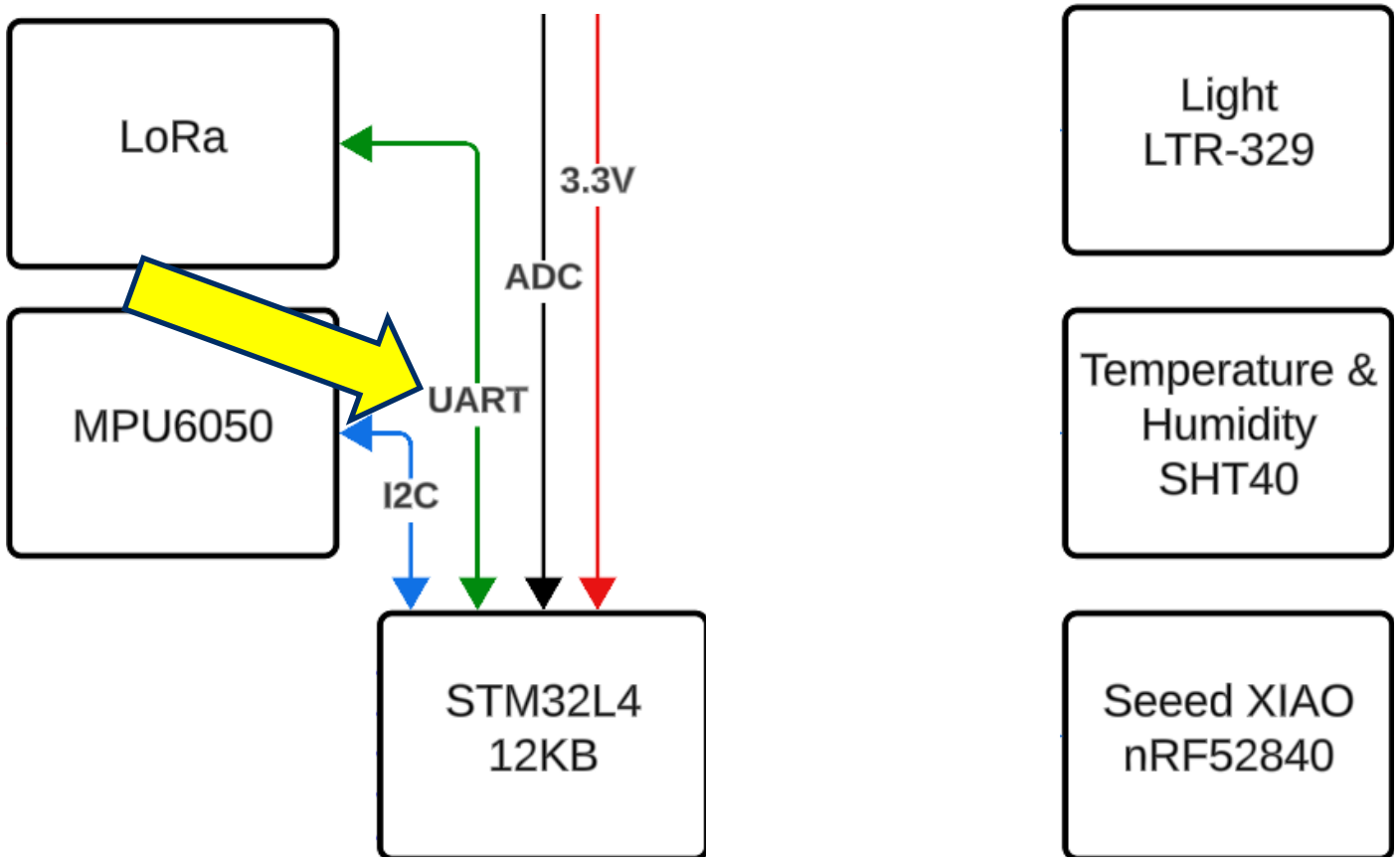
System Description

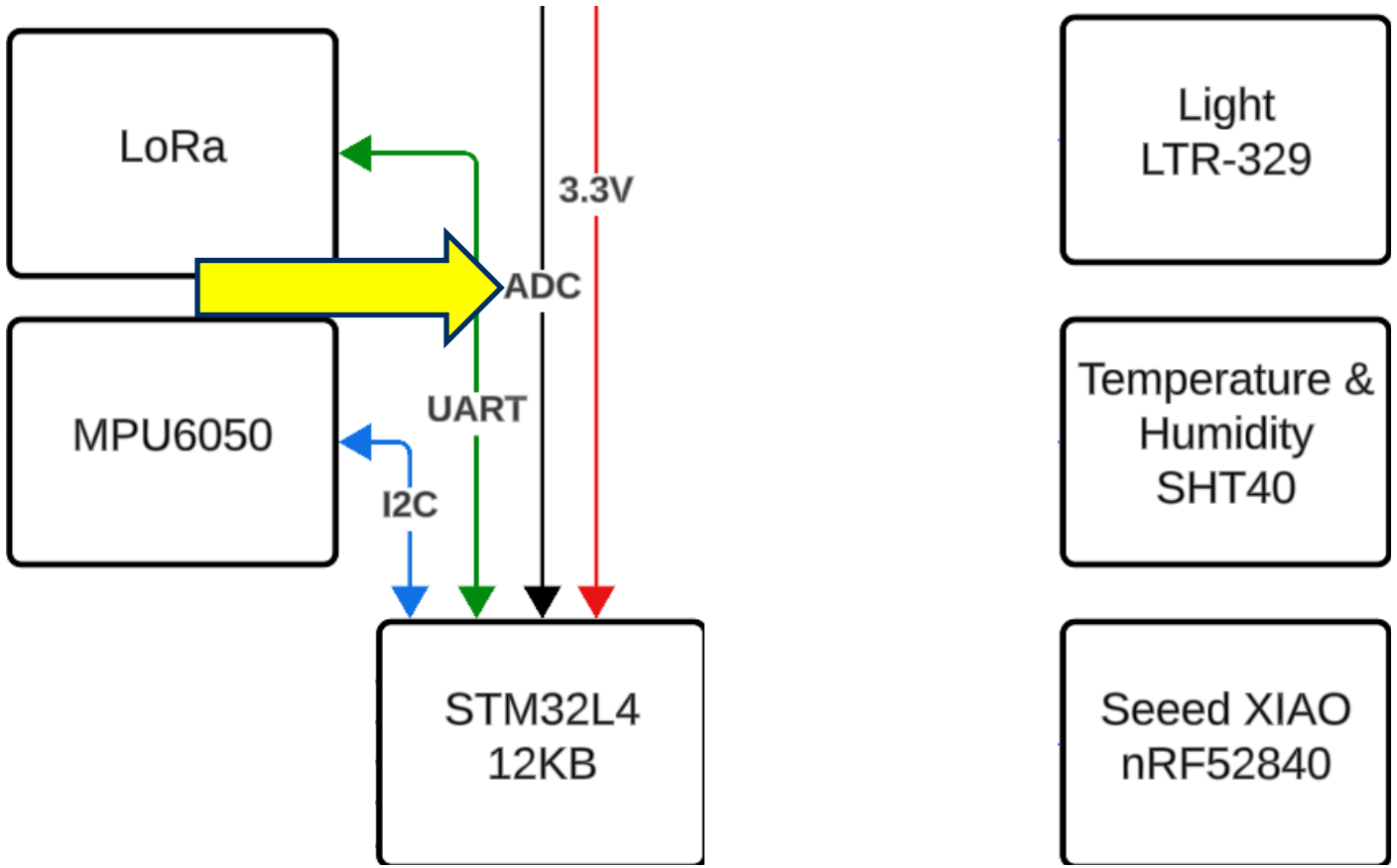

STM32L4
12KB

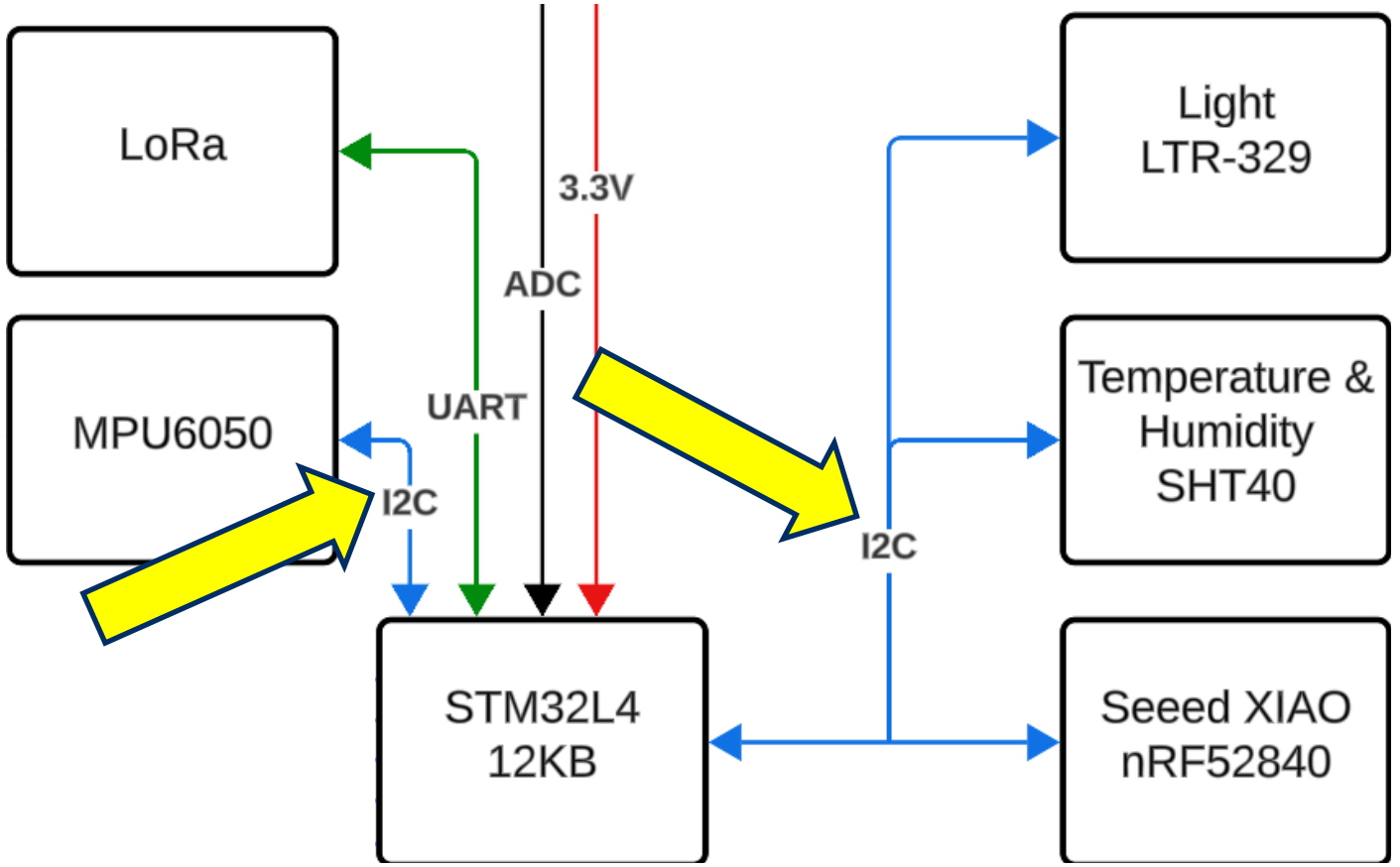

STM32L4
12KB
Seeed XIAO
nRF52840

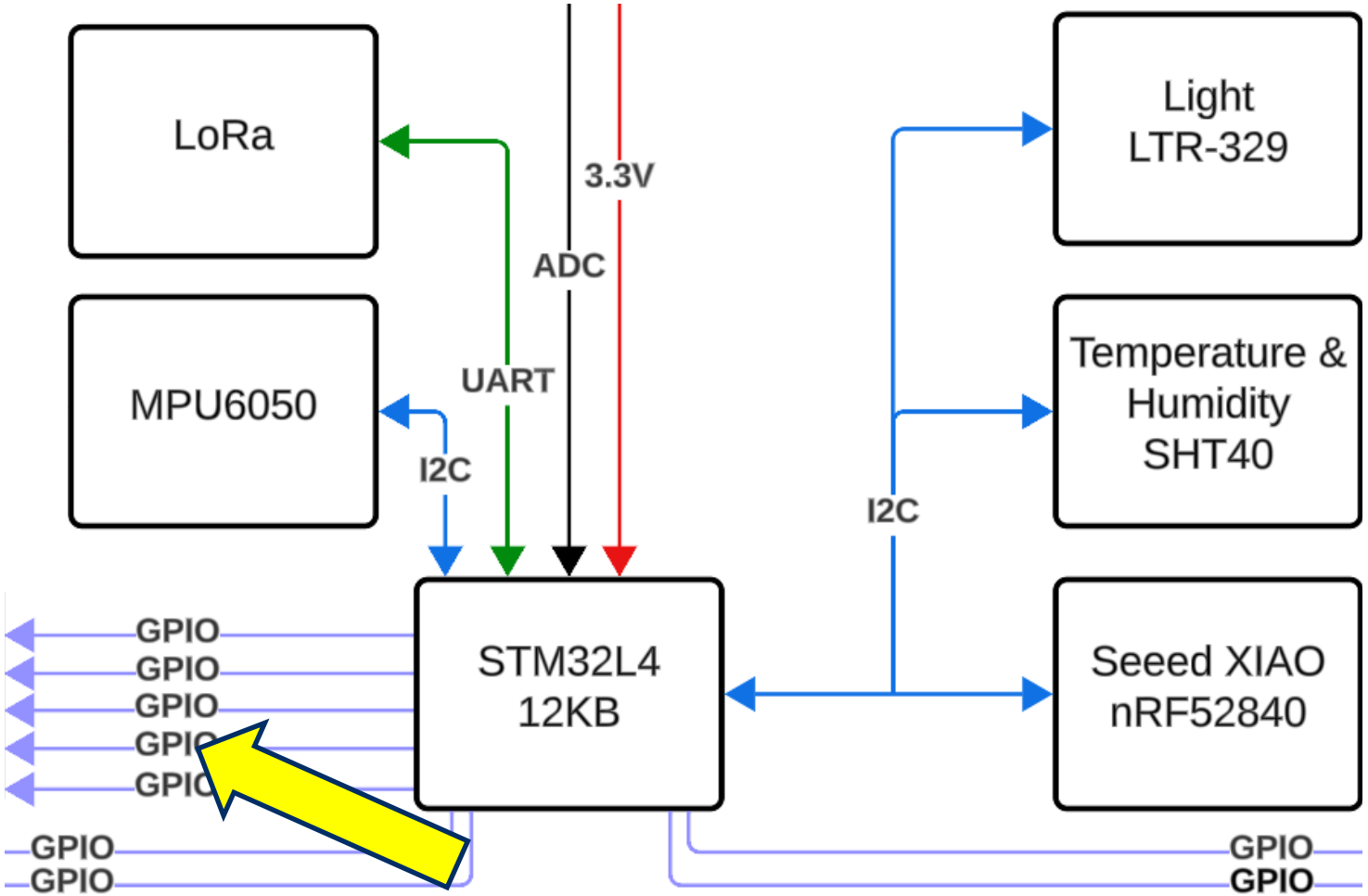

LoRa
STM32L4
12KB
Seeed XIAO
nRF52840

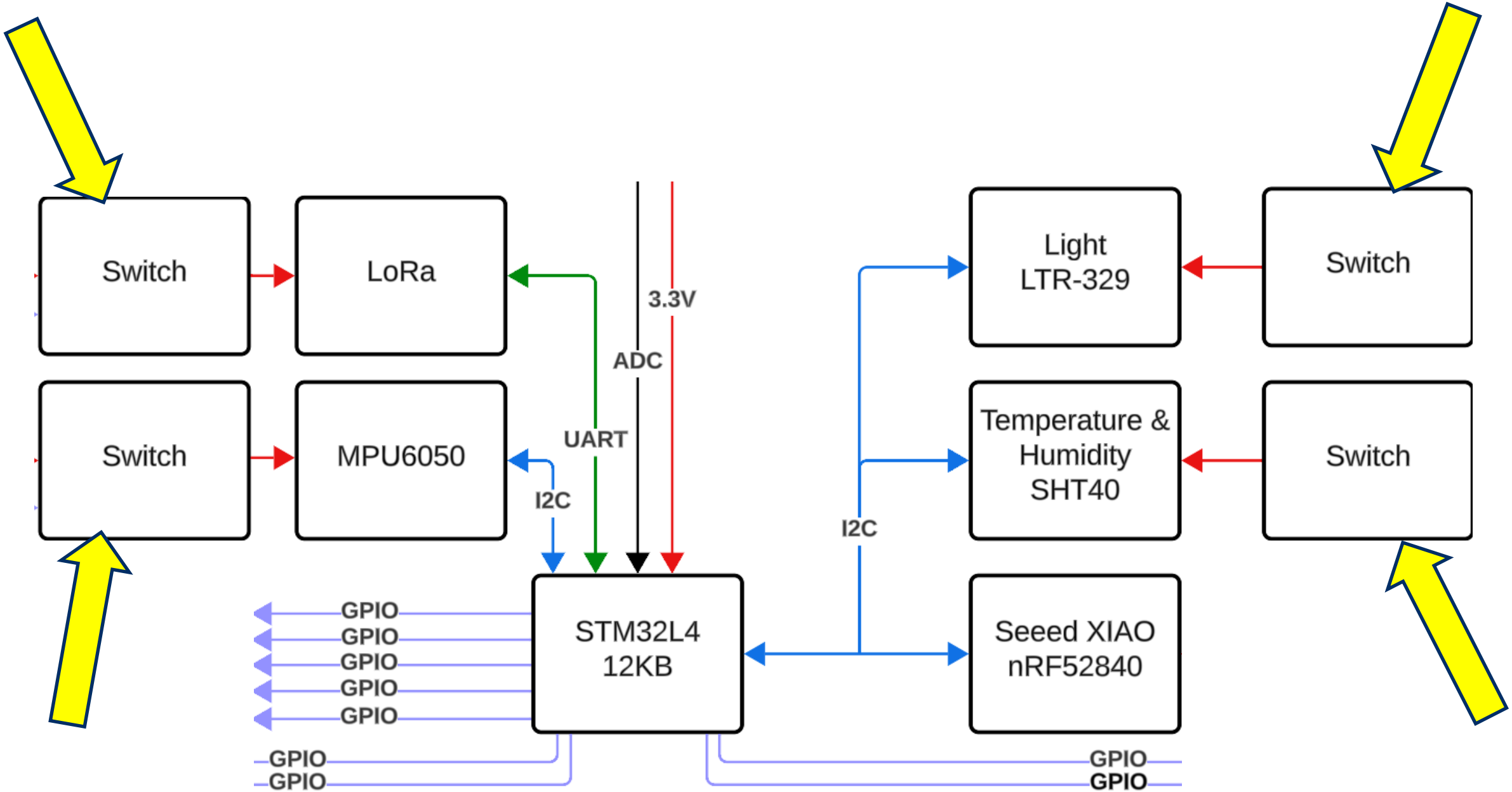

LoRa
MPU6050
STM32L4
12KB
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840

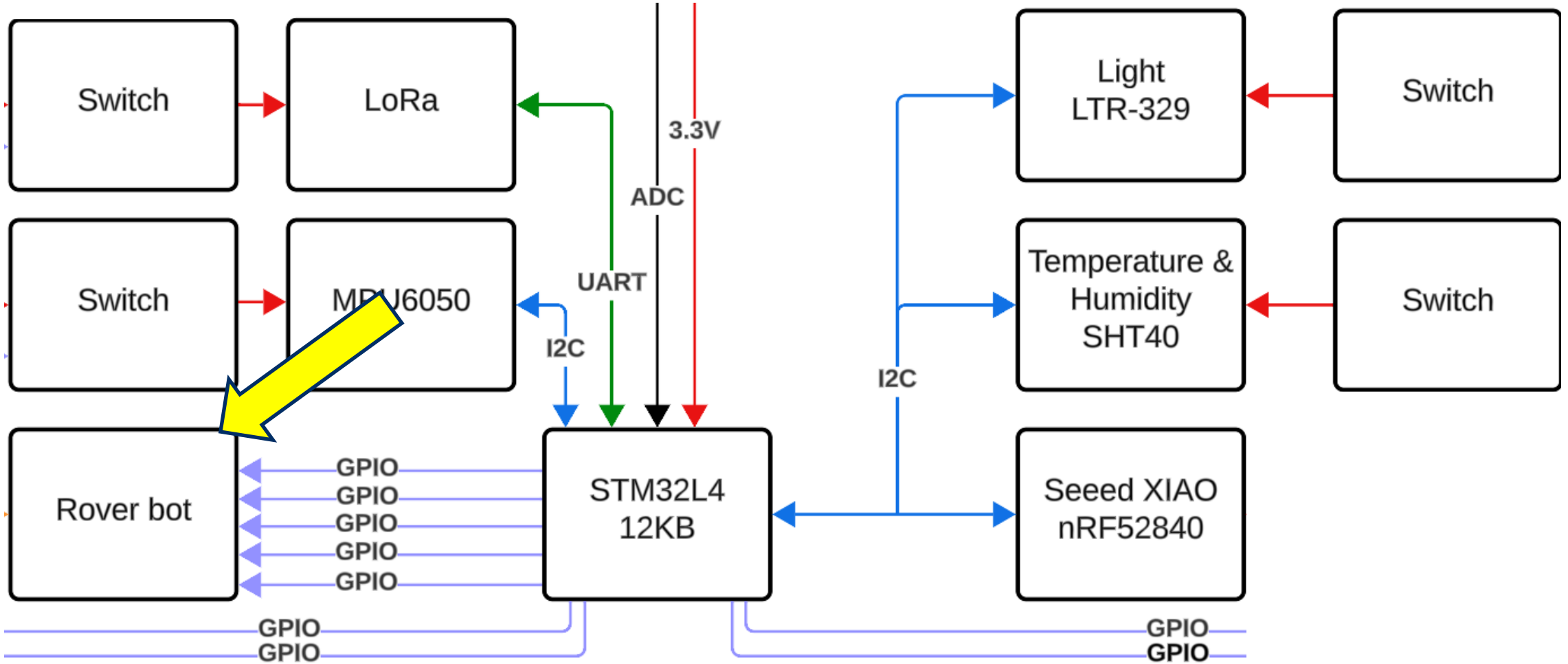

LoRa
MPU6050
STM32L4
12KB
3.3V
ADC
UART
I2C
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840

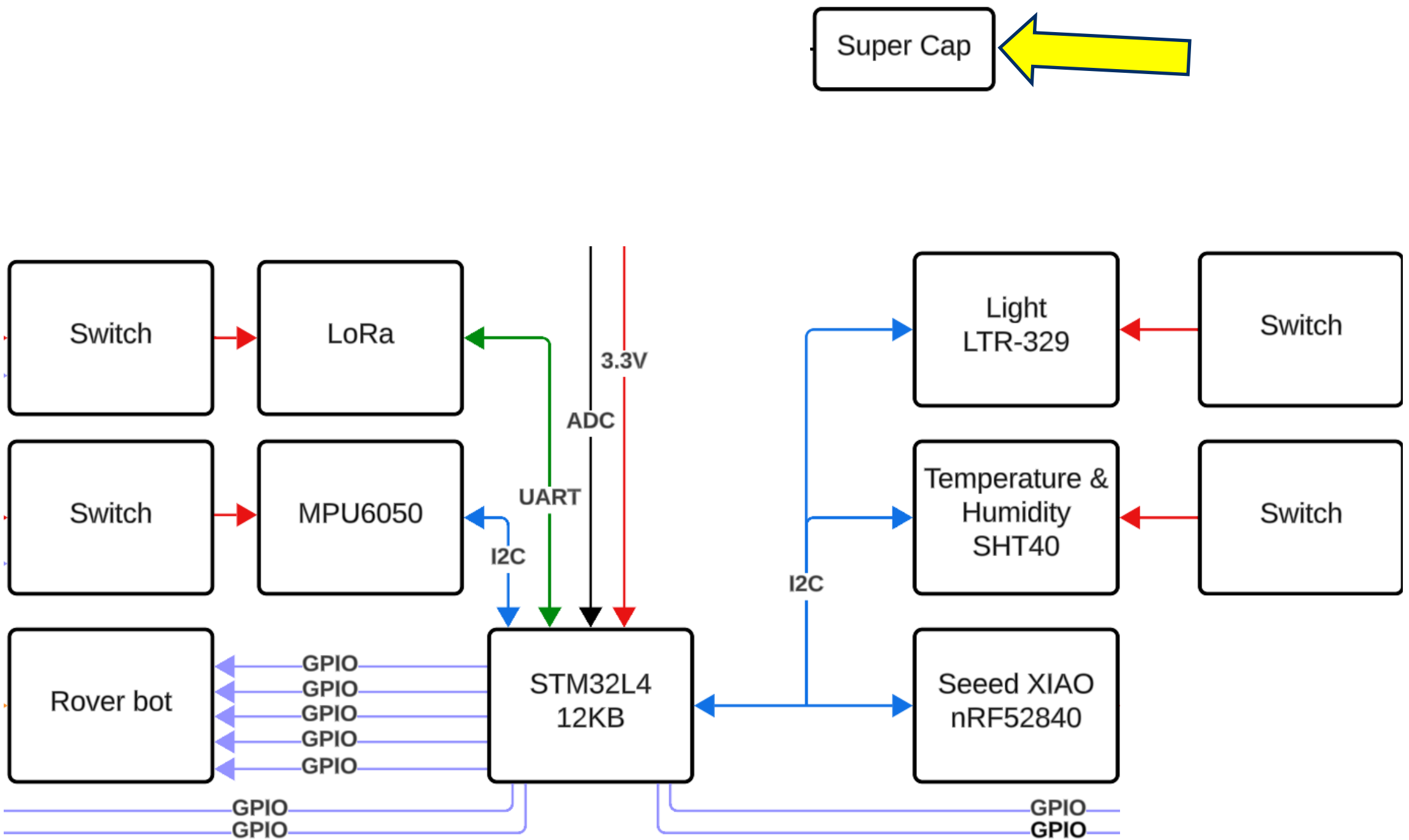

LoRa
MPU6050
3.3V
ADC
UART
I2C
STM32L4
12KB
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840

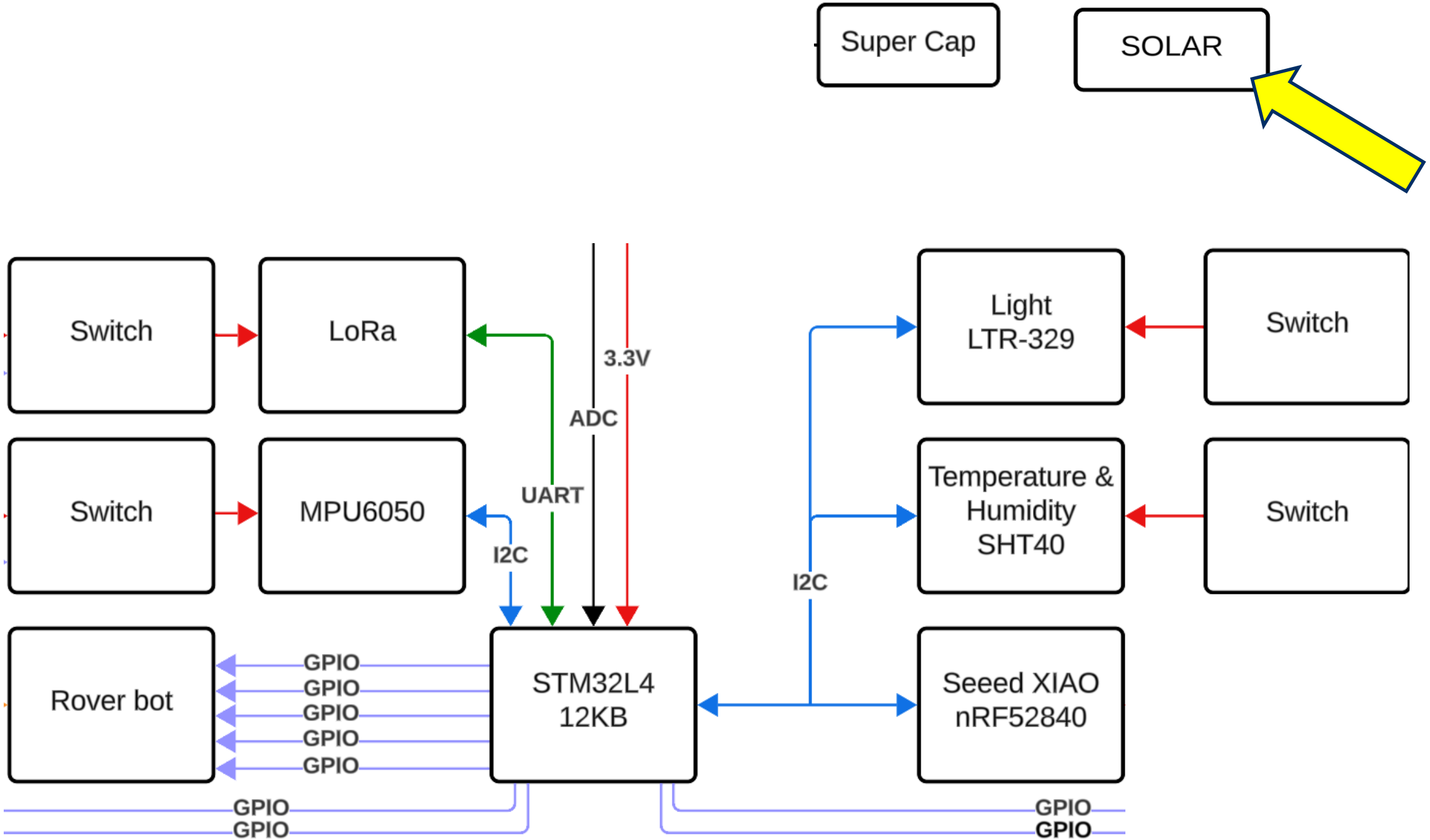

LoRa
MPU6050
STM32L4
12KB
3.3V
ADC
UART
I2C
I2C
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840


LoRa
MPU6050
3.3V
ADC
UART
I2C
I2C
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840
STM32L4
12KB
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO


Switch
LoRa
Switch
MPU6050
3.3V
ADC
UART
I2C
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
STM32L4
12KB
I2C
Light
LTR-329
Temperature &
Humidity
SHT40
Seeed XIAO
nRF52840
GPIO
GPIO
Switch
Switch


Switch
LoRa
Switch
MPU6050
Rover bot
3.3V
ADC
UART
I2C
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
STM32L4
12KB
I2C
Light
LTR-329
Switch
Temperature &
Humidity
SHT40
Switch
Seeed XIAO
nRF52840
GPIO
GPIO


Super Cap
Switch
LoRa
Switch
MPU6050
Rover bot
3.3V
ADC
UART
I2C
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
STM32L4
12KB
I2C
Light
LTR-329
Switch
Temperature &
Humidity
SHT40
Switch
Seeed XIAO
nRF52840
GPIO
GPIO


Super Cap
SOLAR
Switch
LoRa
3.3V
ADC
Light
LTR-329
Switch
Switch
MPU6050
UART
I2C
Temperature &
Humidity
SHT40
Switch
I2C
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GPIO
GPIO
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GPIO
STM32L4
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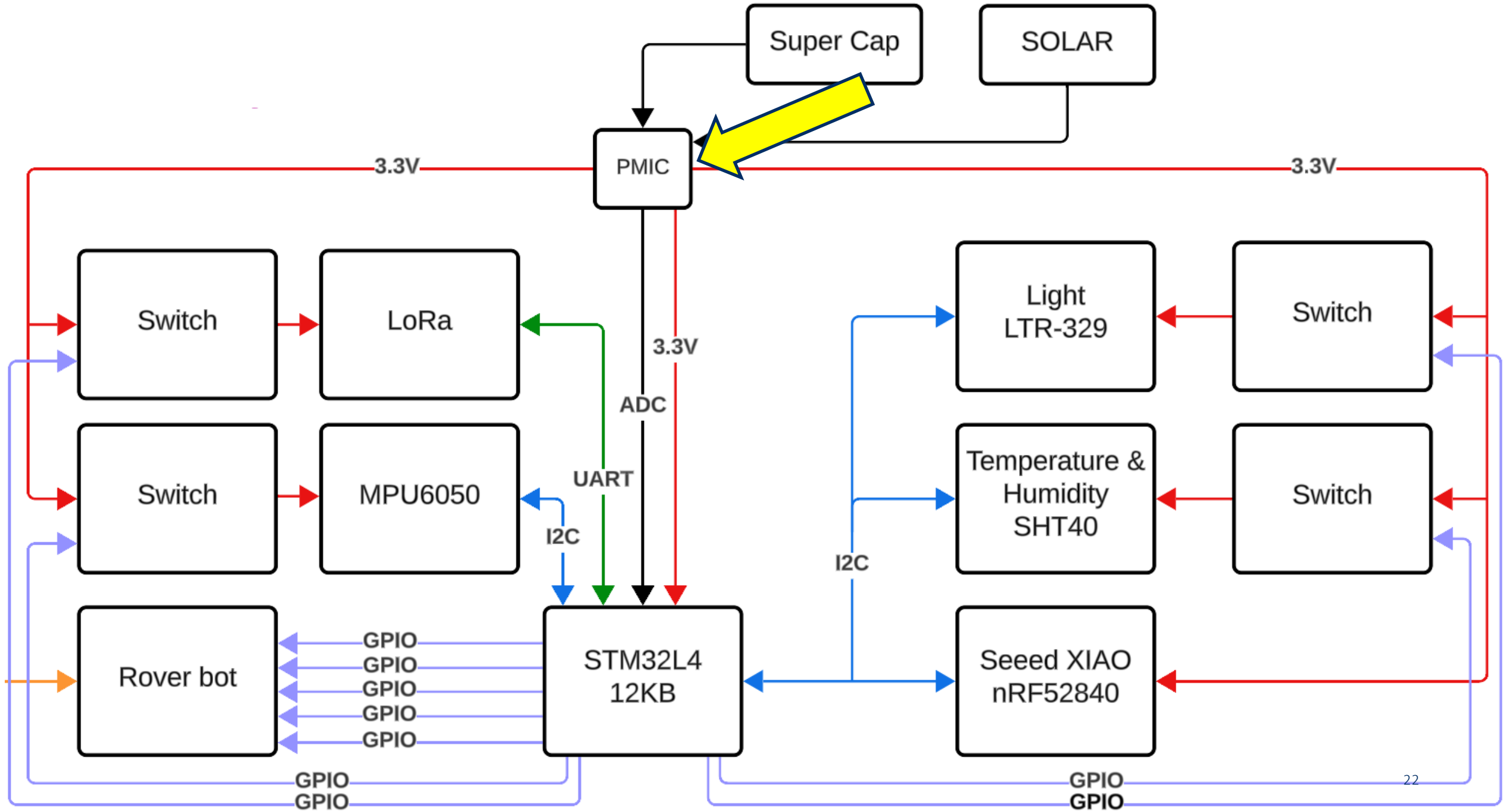
GPIO
GPIO
GPIO
GPIO


Super Cap
SOLAR
PMIC
3.3V
3.3V
Switch
LoRa
Switch
MPU6050
Switch
Rover bot
3.3V
ADC
UART
I2C
I2C
GPIO
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Switch
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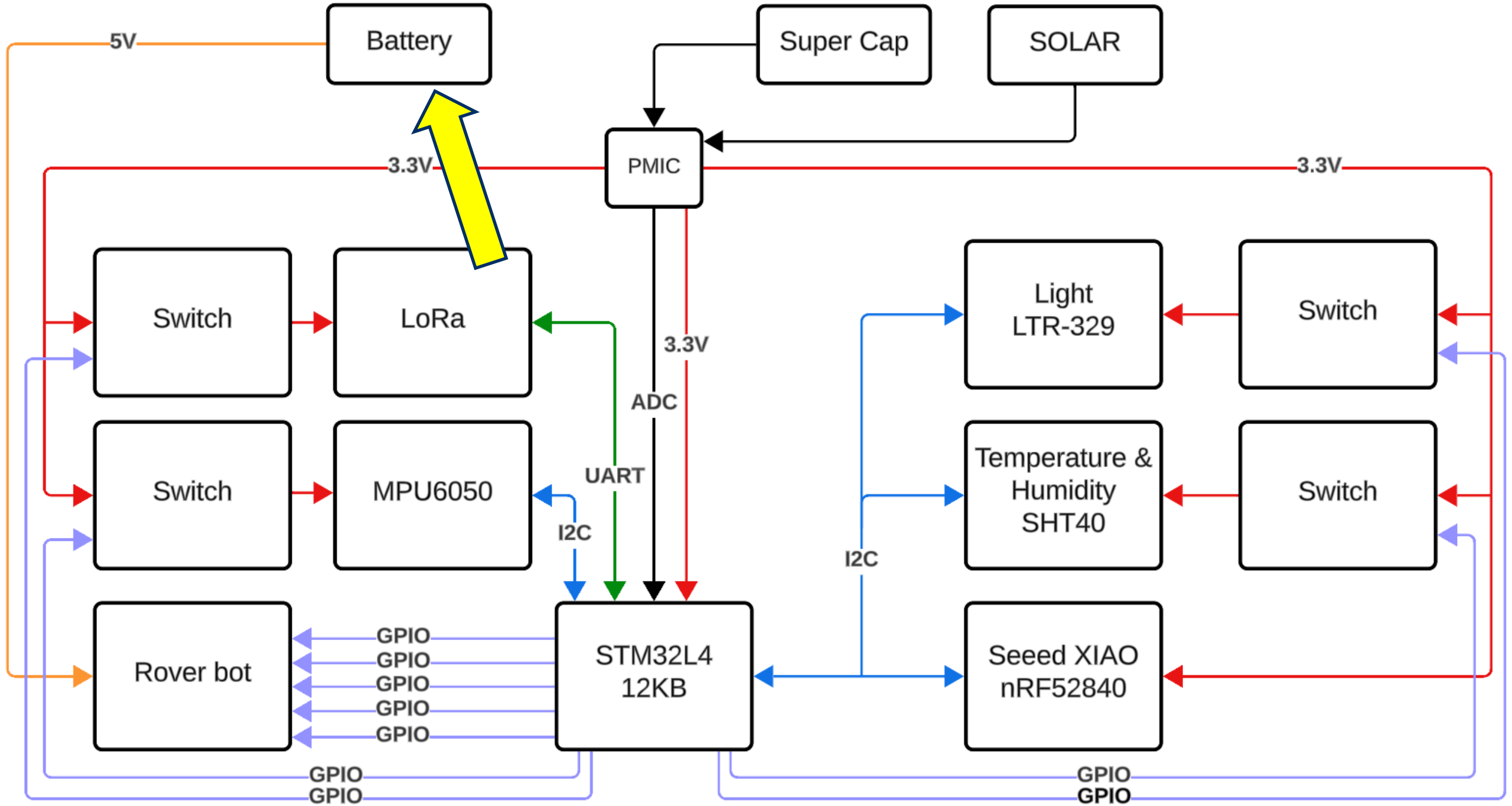
Battery
Super Cap
SOLAR
5V
PMIC
3.3V
3.3V
Switch
LoRa
3.3V
ADC
Light
LTR-329
Switch
Switch
MPU6050
UART
I2C
Temperature &
Humidity
SHT40
Switch
I2C
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GPIO
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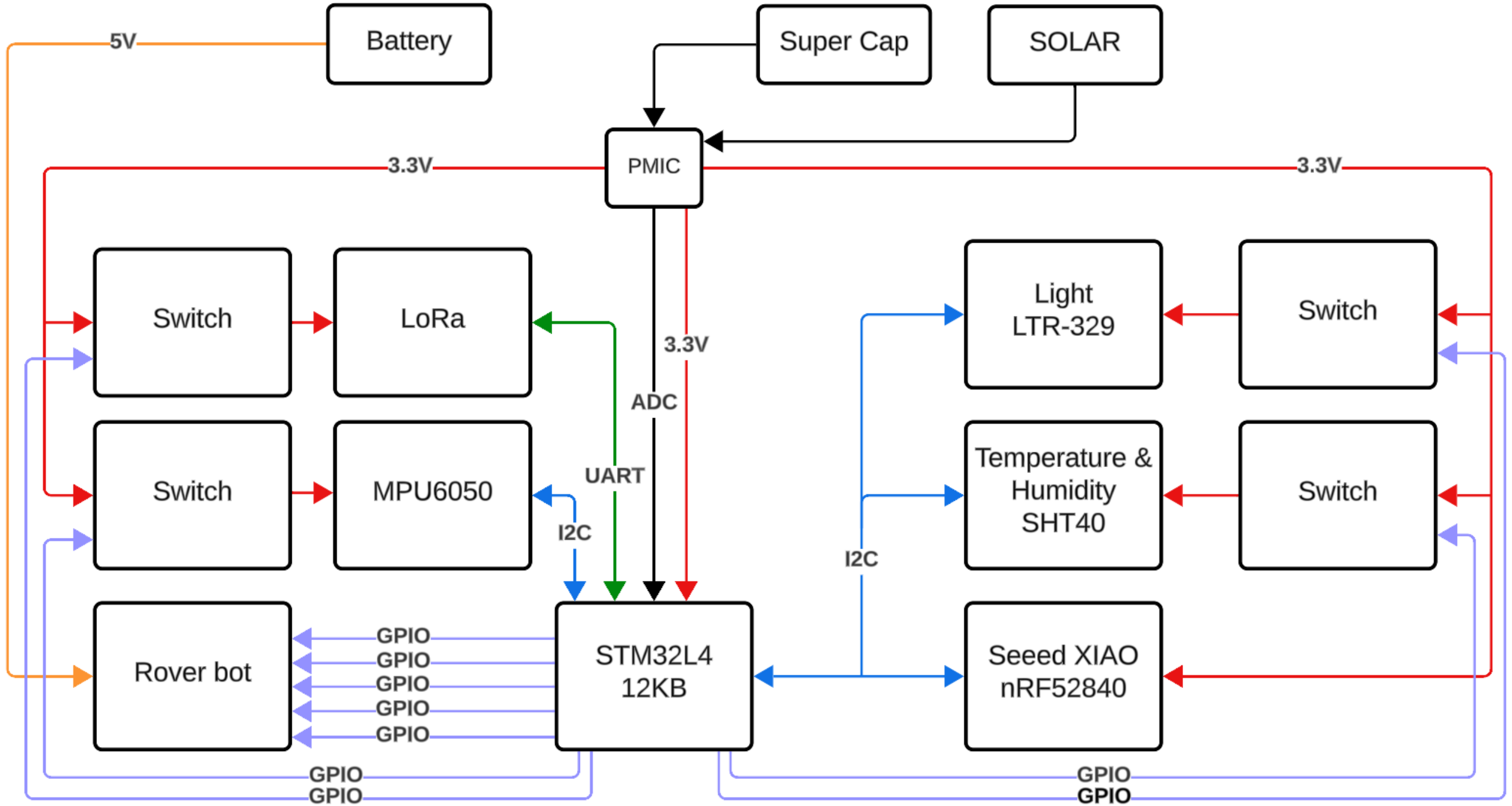
GPIO
STM32L4
12KB
Seeed XIAO
nRF52840
GPIO
GPIO
GPIO
GPIO


Battery
Super Cap
SOLAR
5V
PMIC
3.3V
3.3V
Switch
LoRa
Switch
MPU6050
Switch
Rover bot
3.3V
ADC
UART
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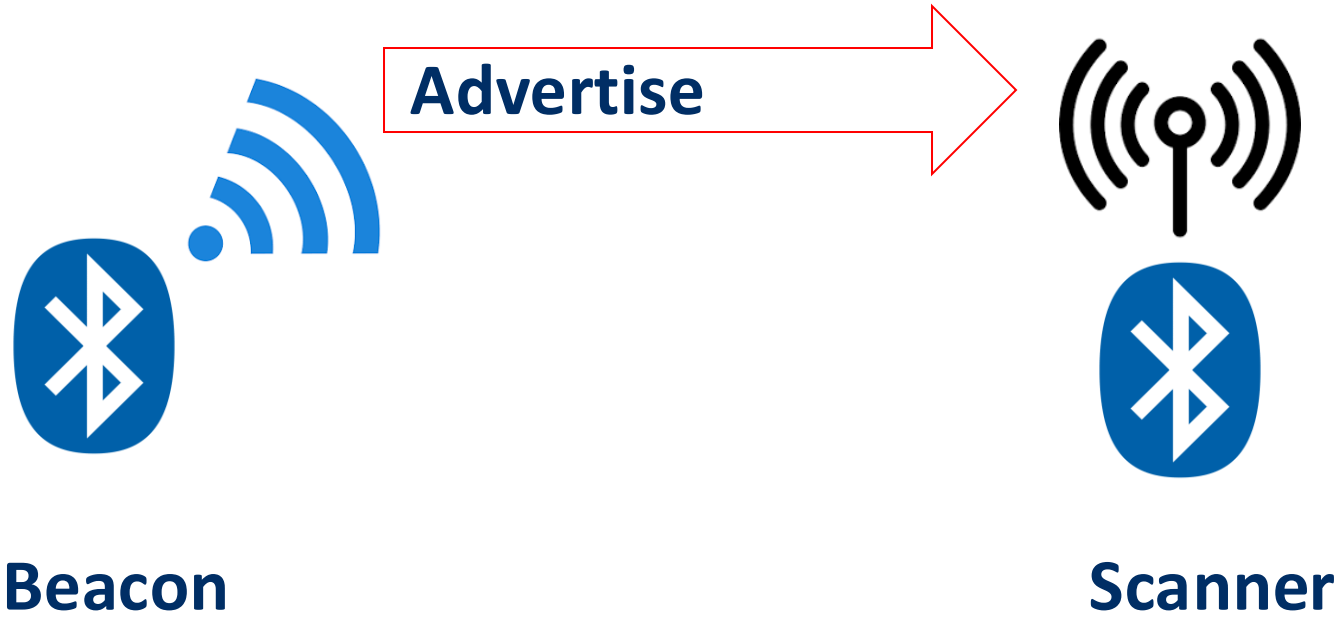
Switch
Temperature &
Humidity
SHT40
Switch
STM32L4
12KB
Seeed XIAO
nRF52840
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO
GPIO

LPPAN communication

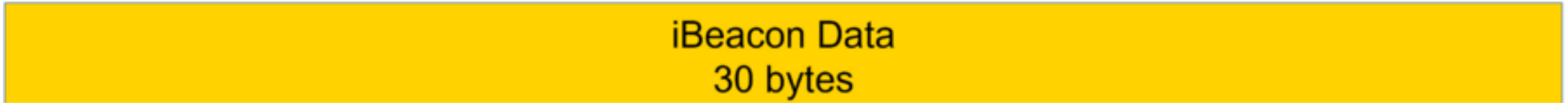
BLE

BLE Communication system



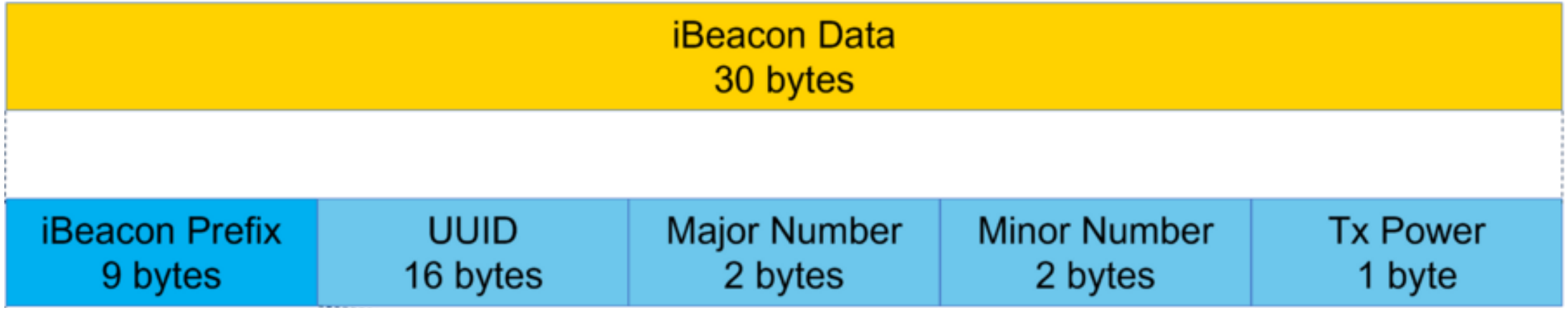
BLE Communication system

Advertise -> IBeacon



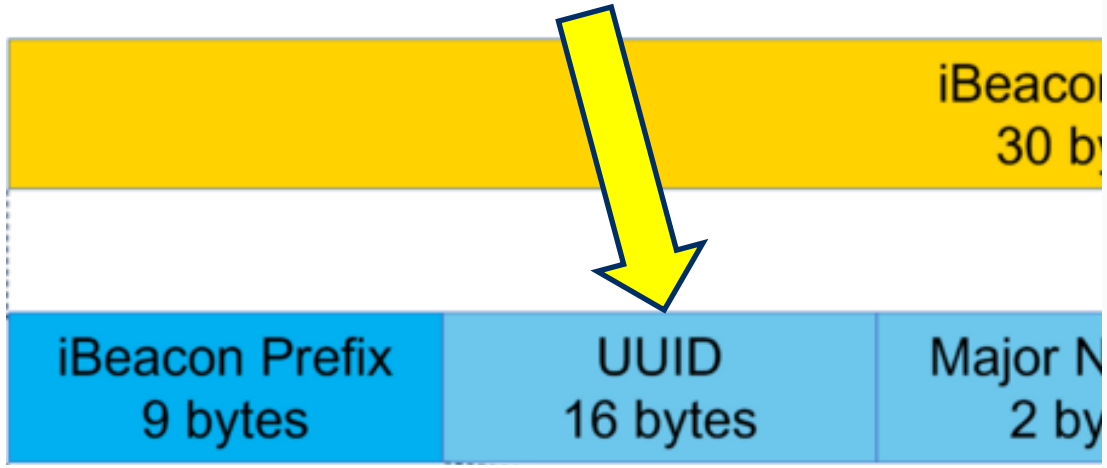
BLE Communication system

Advertise -> IBeacon



BLE Communication system

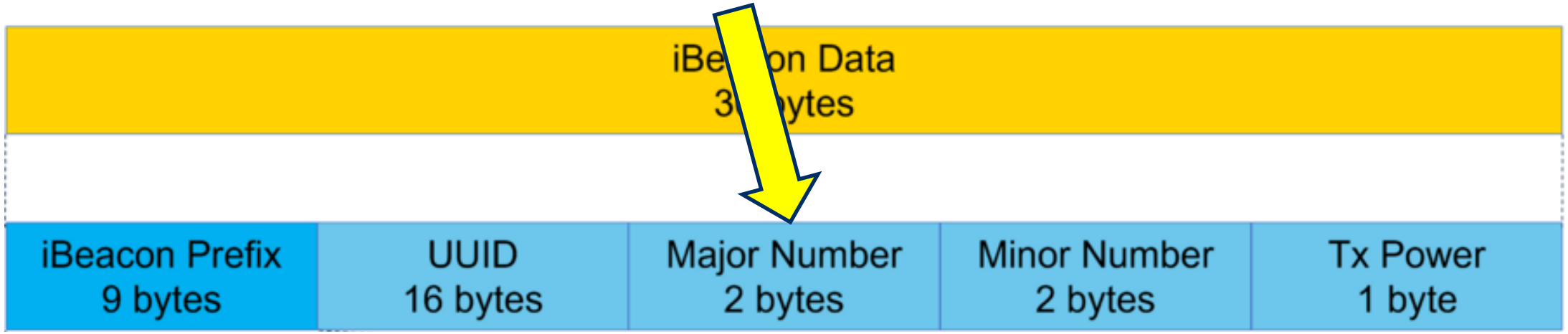
Advertise -> IBeacon




```
[0] ->  Temperature MSB(yte)
[1] ->  Temperature LSB(yte)
[2] ->  Humidity
[3] ->  Lux MSB(yte)
[4] ->  Lux LSB(yte)
[5] ->  Device Supercap Voltage MSB(yte)
[6] ->  Device Supercap Voltage LSB(yte)
[7] ->  gyro-x
[8] ->  gyro-y
[9] ->  gyro-z
[10] -> /0xFF
[11] -> /0xFF
[12] -> /0xFF
[13] -> /0xFF
[14] -> /0xFF
[15] -> /0xFF
```

BLE Communication system

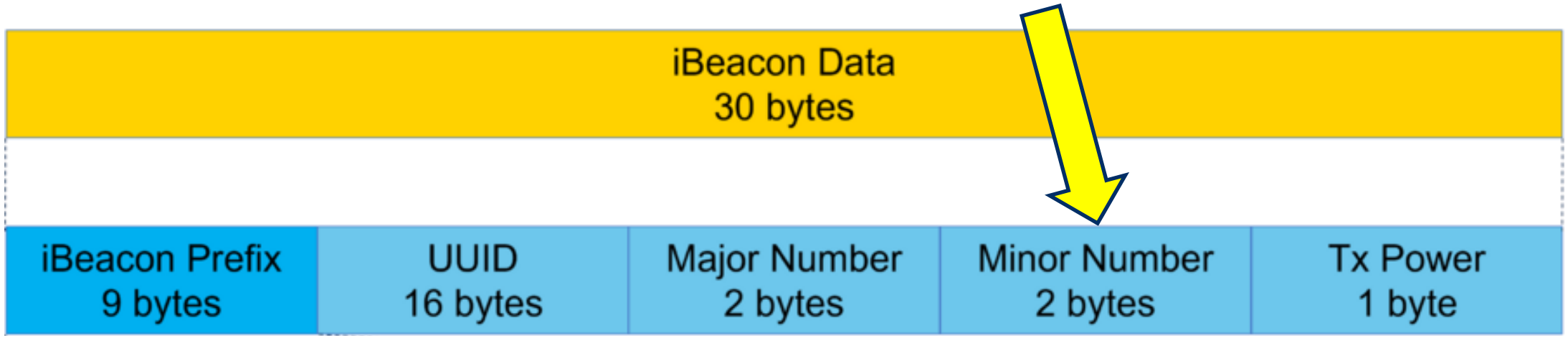
Advertise -> IBeacon




```
beacon.setMajorMinor((BEACON_SSR_ID << 8 |i2c_data.ssr_id), 0x0000);
```

BLE Communication system

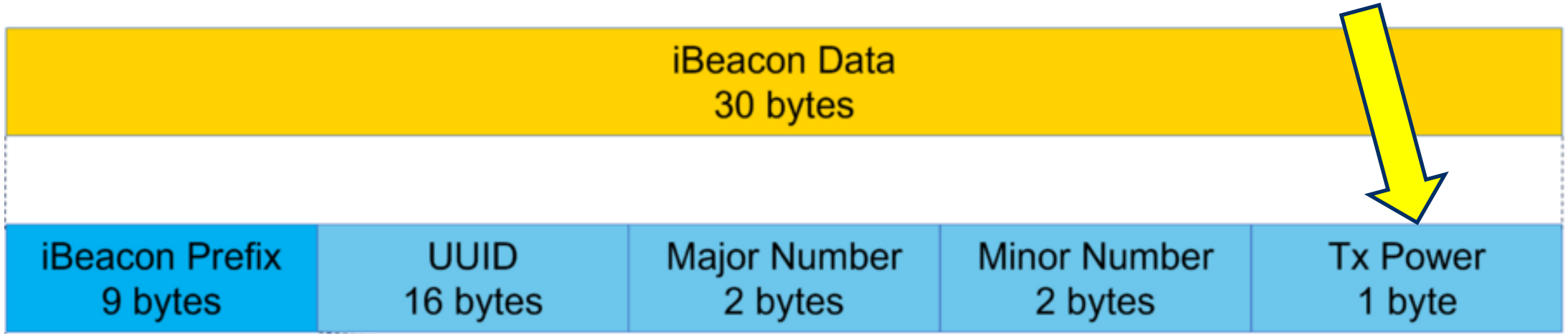
Advertise -> IBeacon




```
beacon.setMajorMinor((BEACON_SSR_ID << 8 |i2c_data.ssr_id), 0x0000);
```

BLE Communication system

Advertise -> IBeacon



@ 1 m

BLE Communication system

Orientation

BLE Communication system

Optimal Transmission

BLE Communication system

Optimal Transmission

LPWAN Communication

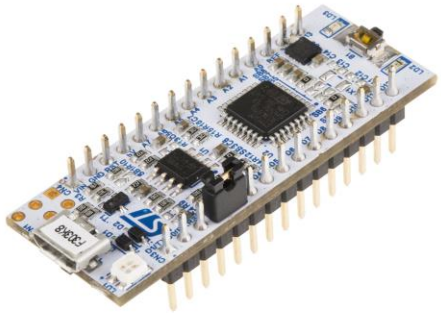
LoRa

LoRa Communication system

AT-command

LoRa

MQTT



THE THINGS NETWORK

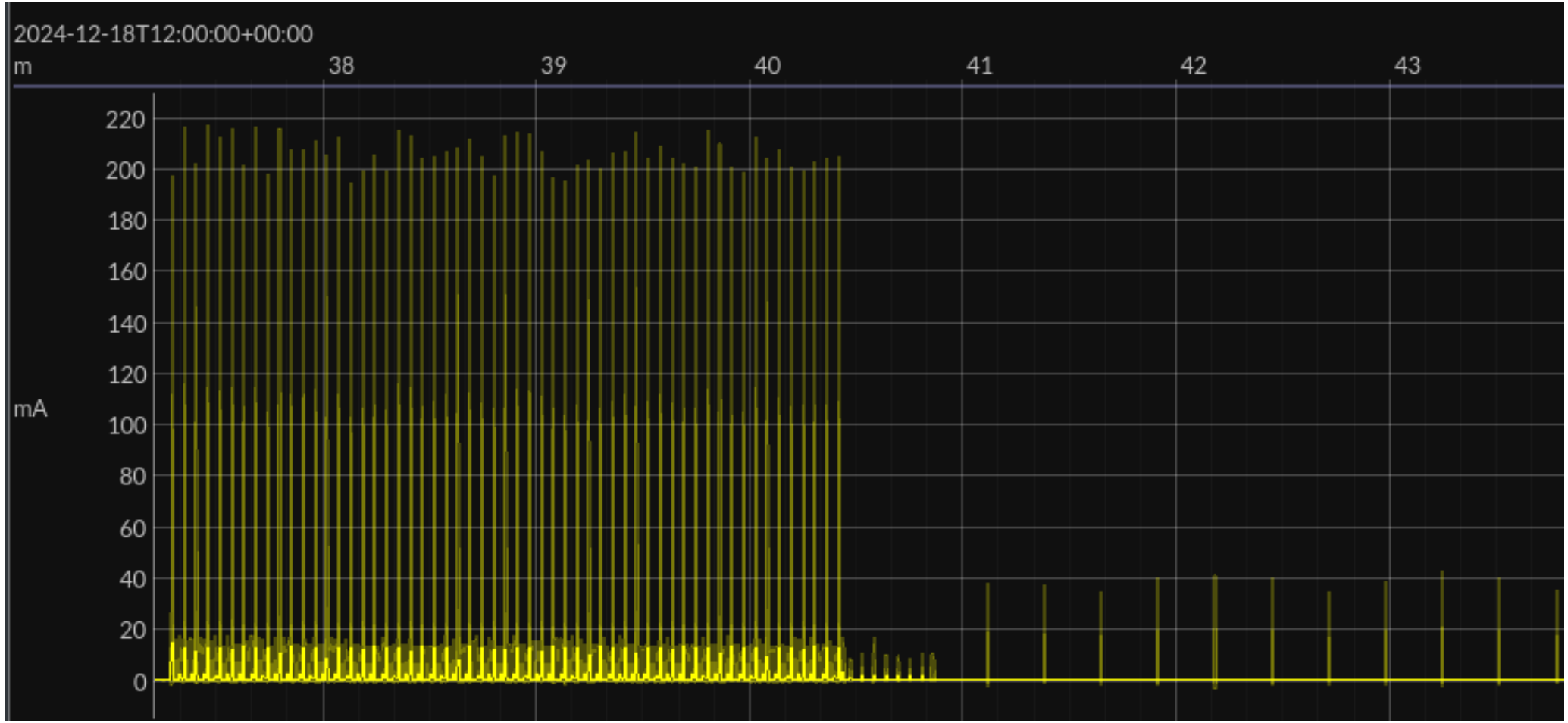
Node-RED

Data to dashboard

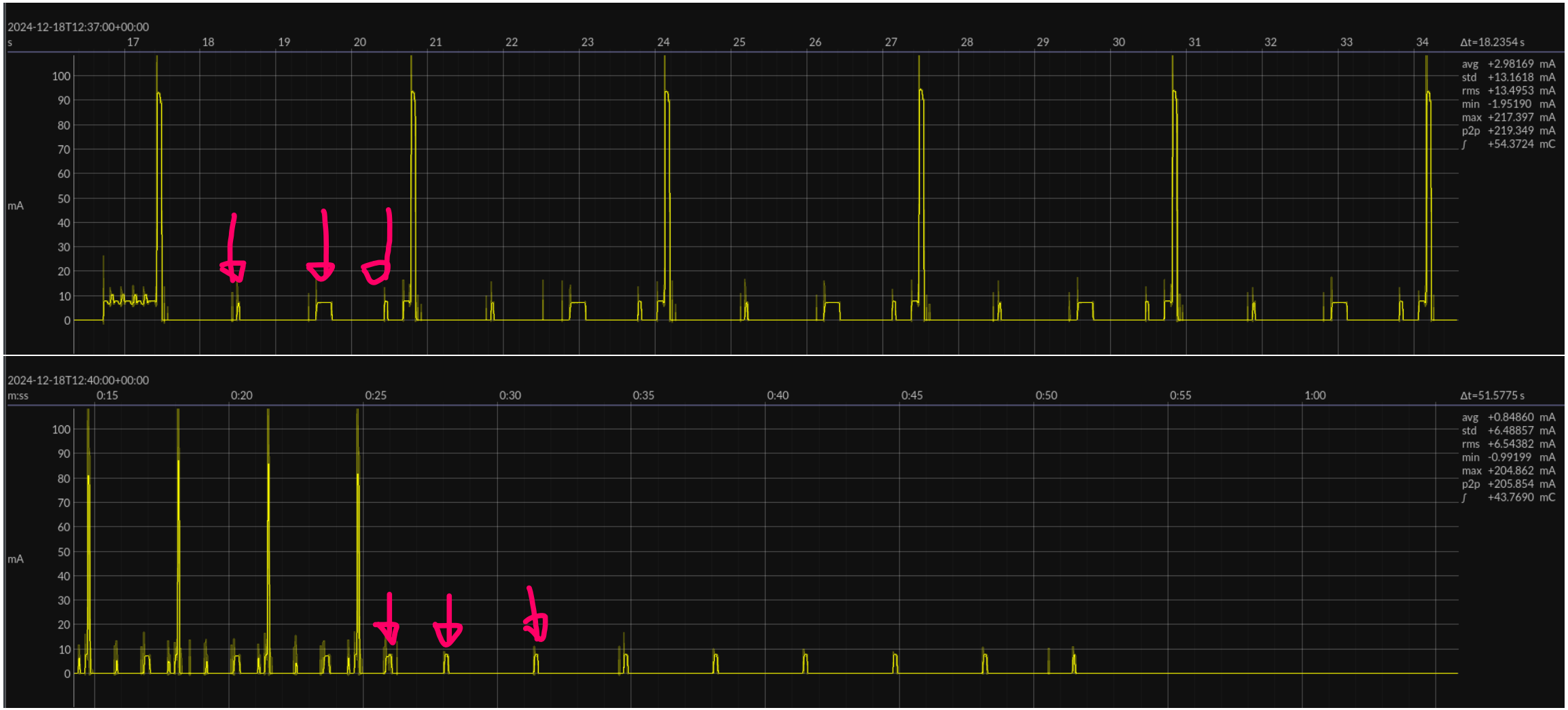
```
struct ssr_data
{
    uint16_t seq_number; // R
    int16_t env_temperature;
    uint8_t env_humidity; //
    uint16_t env_lux; // Rang
    uint16_t dev_voltage; //
    int8_t dev_gyro_x; // Ran
    int8_t dev_gyro_y; // Ran
    int8_t dev_gyro_z; // Ran
};
typedef struct ssr_data ssr_d
```

How it should have worked

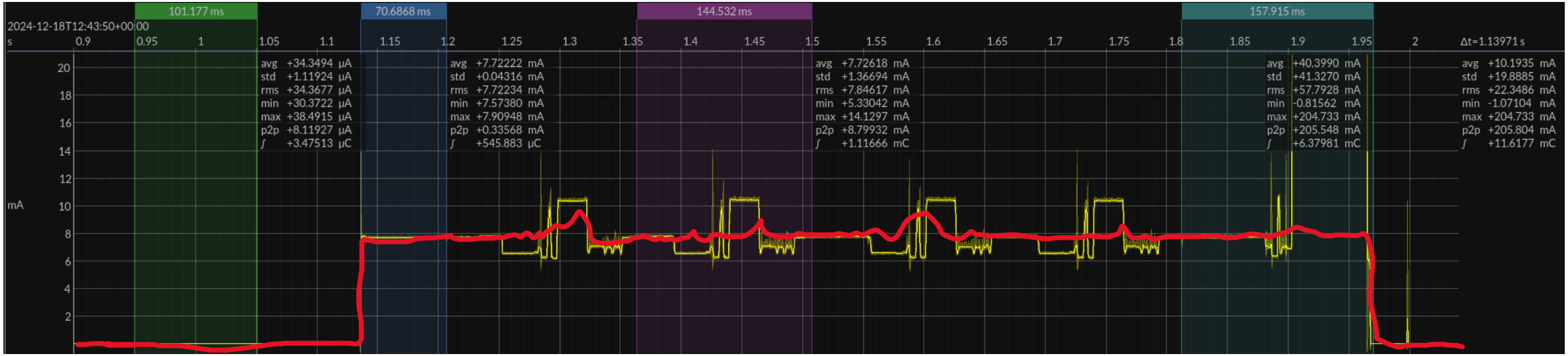
Repeated transmissions



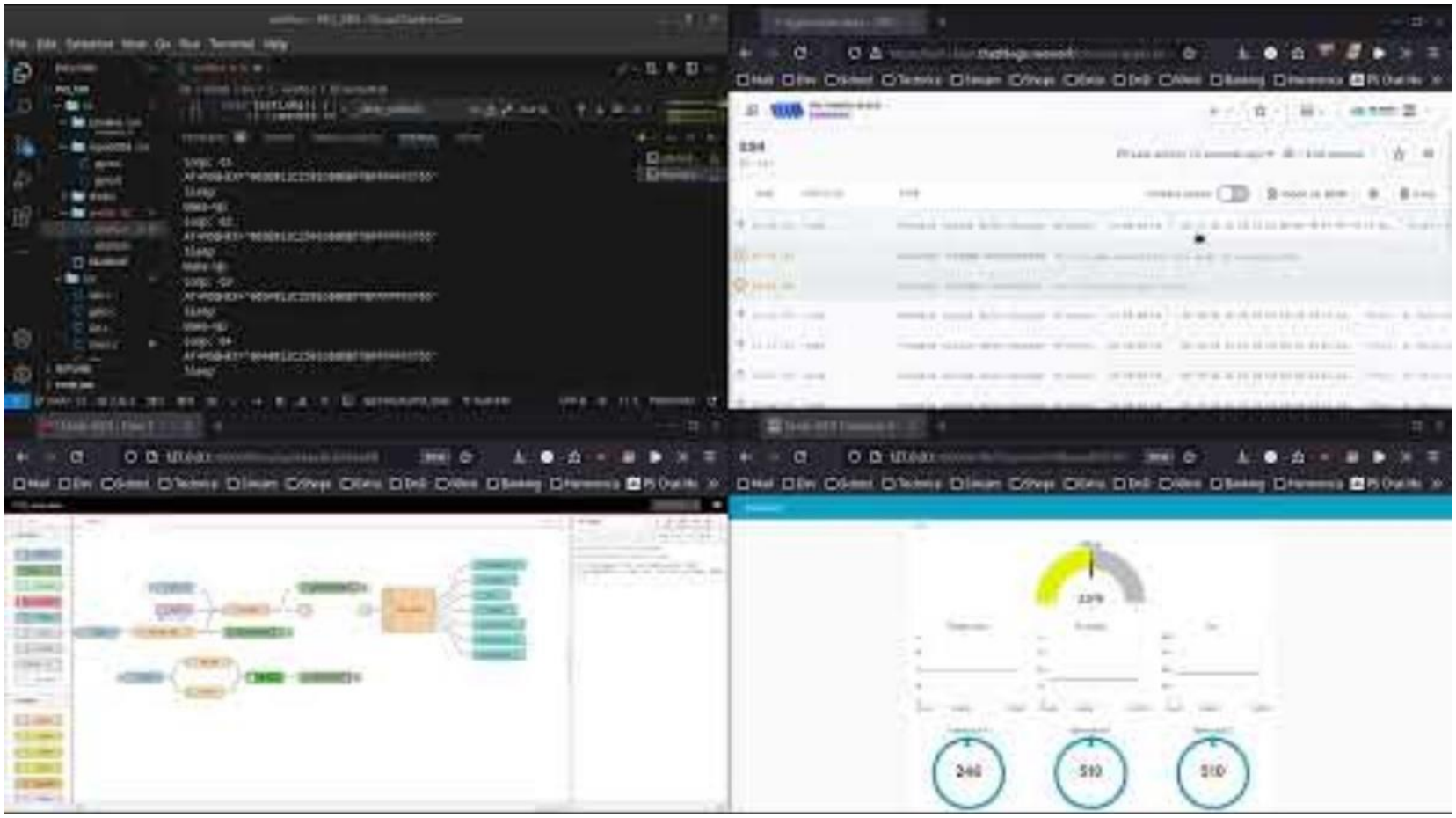
Active time during sleep



Reinitialize settings after long sleep

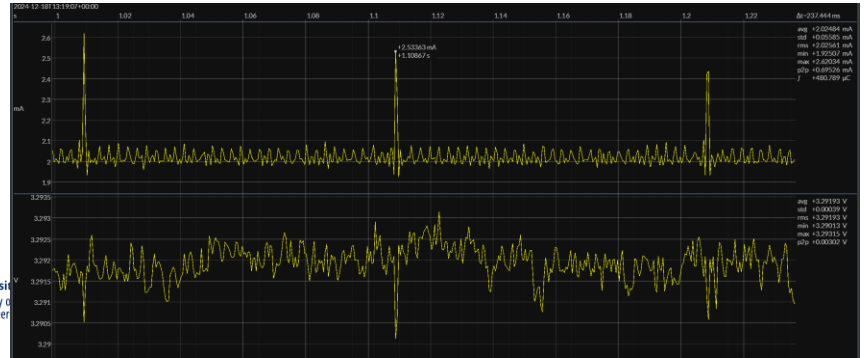


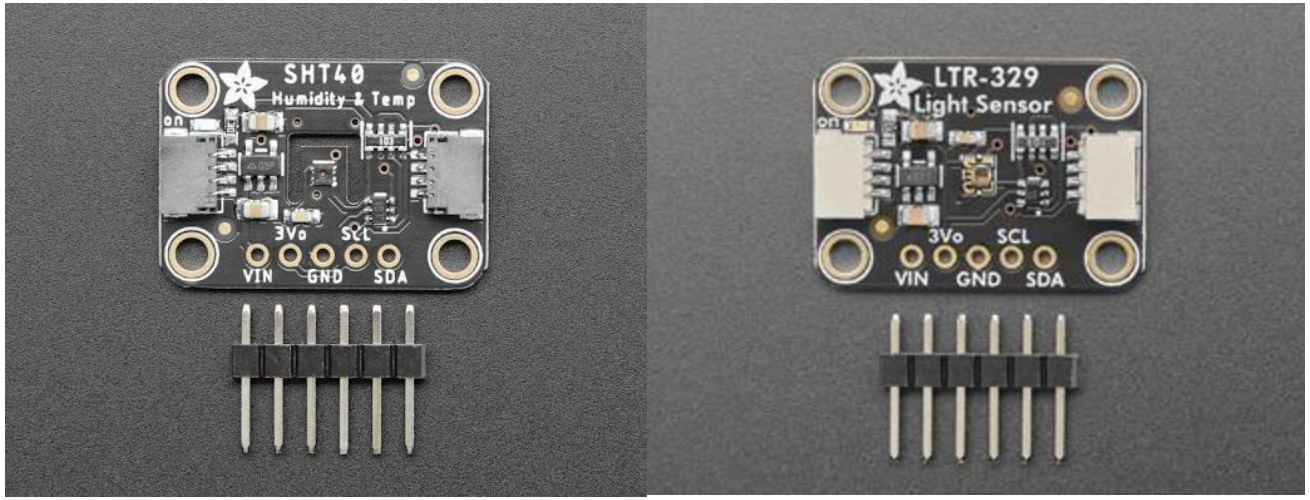
Demo



Sensing

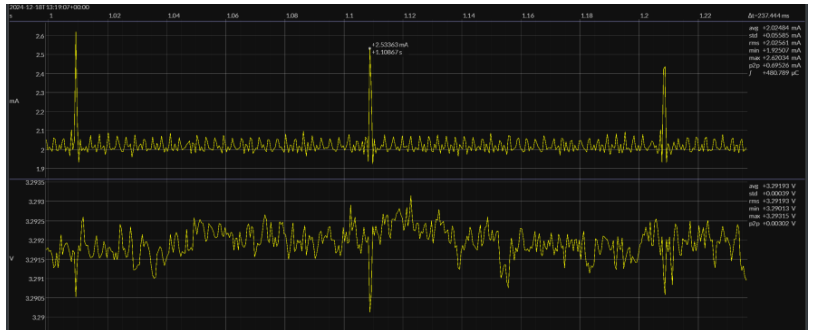
Sensing (SHT40)

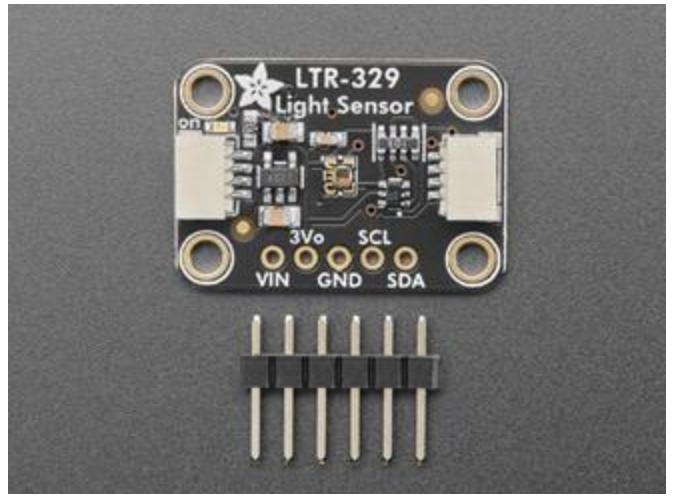




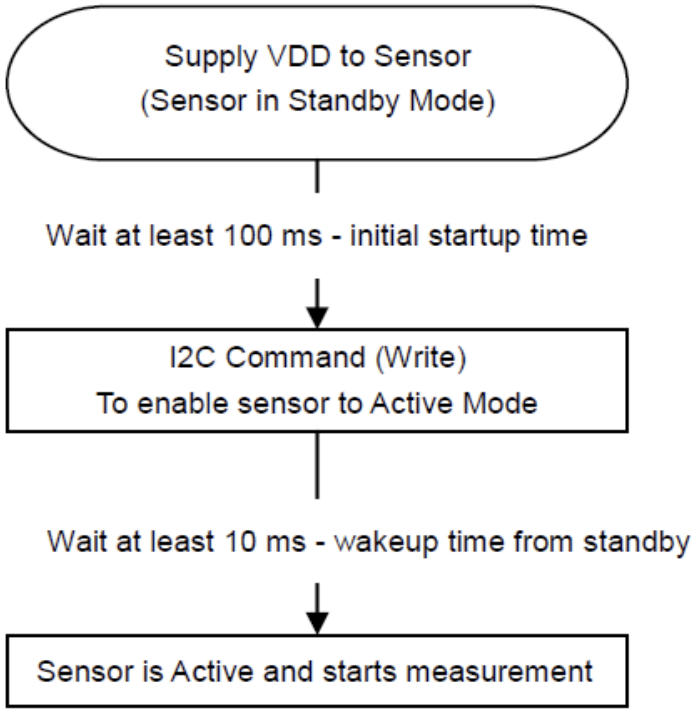
Sensing (LTR-329)

- STM communicates with Enviromental sensors with I2C protocol.
- 0.01 lux – 64k lux





1. **Startup Sequence**



Standbymode

Standbymode

Standbymode

Standbymode

Standbymode

Standbymode

Sensing (PMU6050)

- STM communicates with gyroscope via I2C
- Temperature and acceleration sensors deactivated
- The gyroscope measurements are a difference measurement
- High sleep mode consumption (1.4mA)

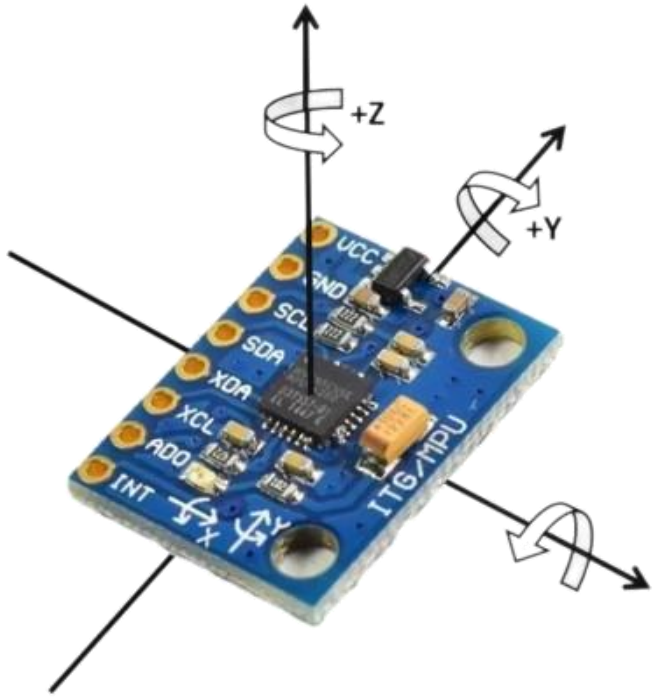
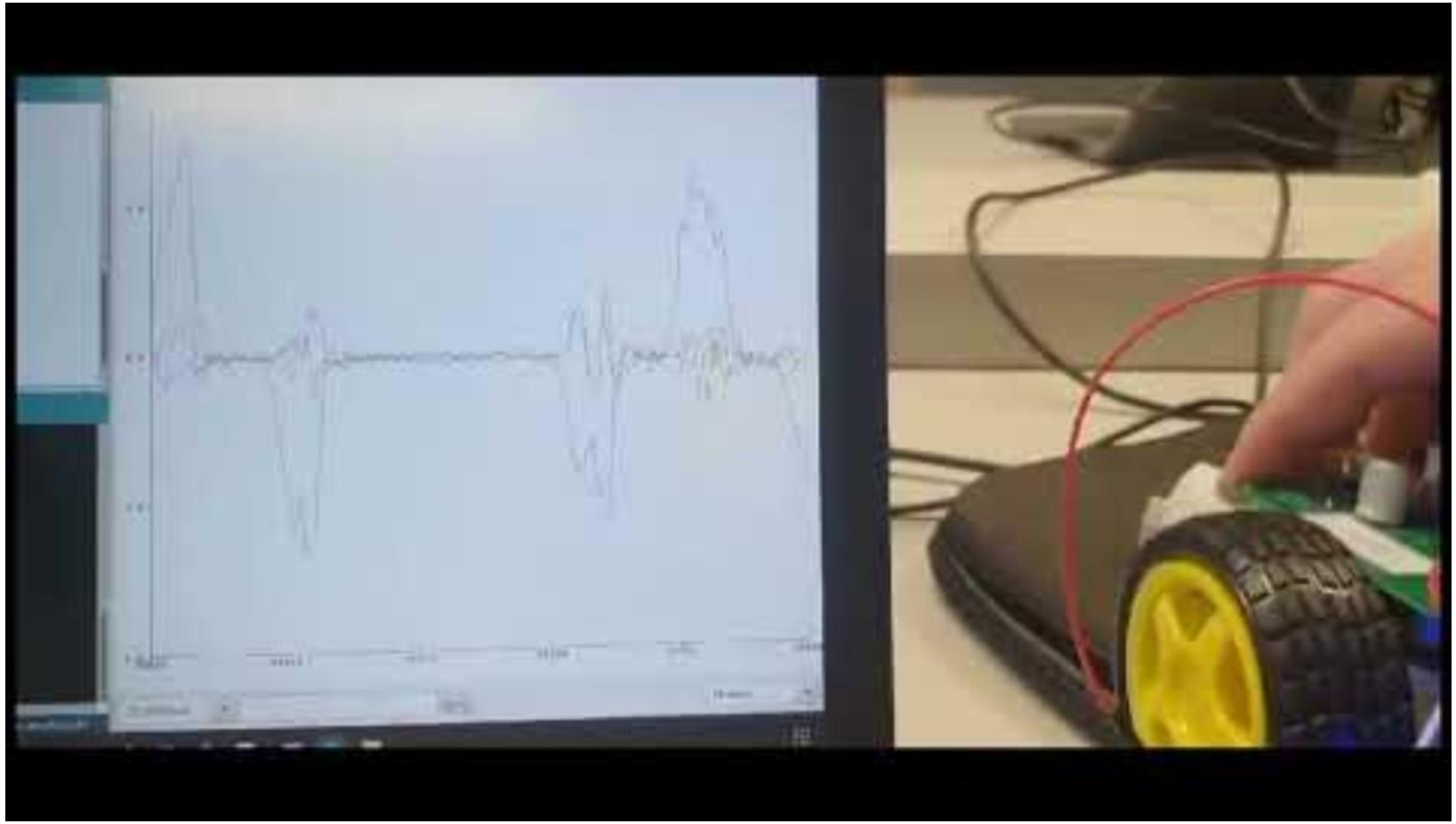


Image from: https://user-images.githubusercontent.com/107638696/241324971-43b8fe88-447d-4c2d-9296-4b3aaa50f4ce.png

Sensing (PMU6050)

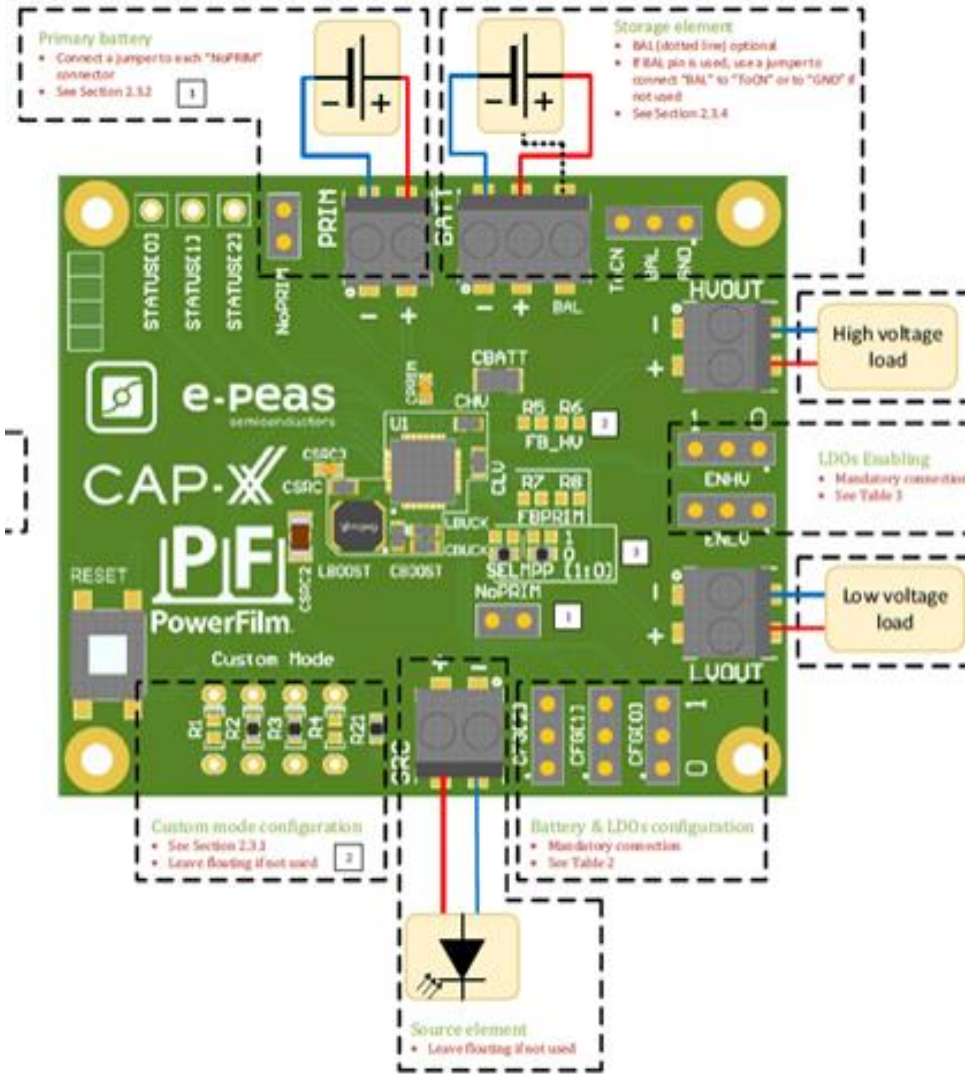


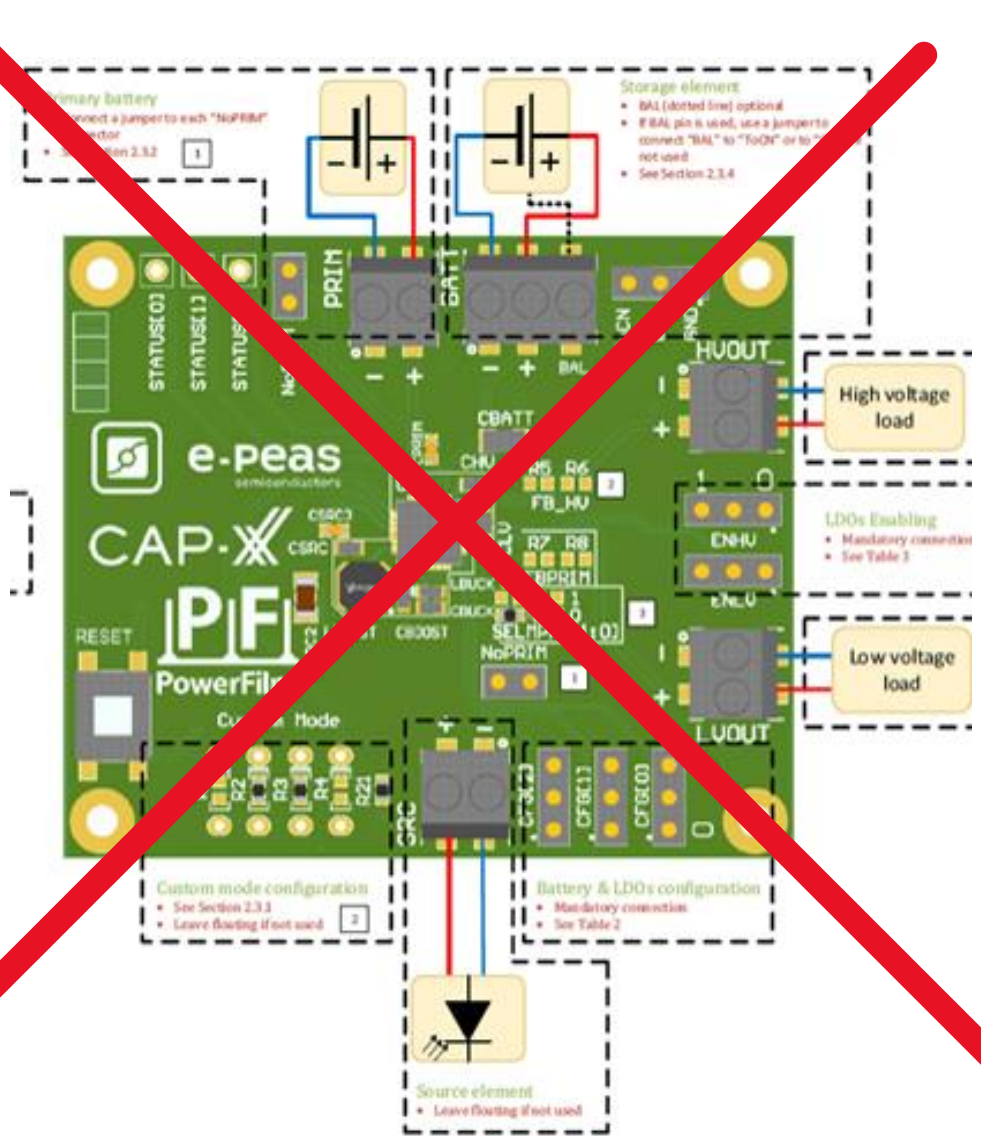
Energy Harvesting

Energy Harvesting

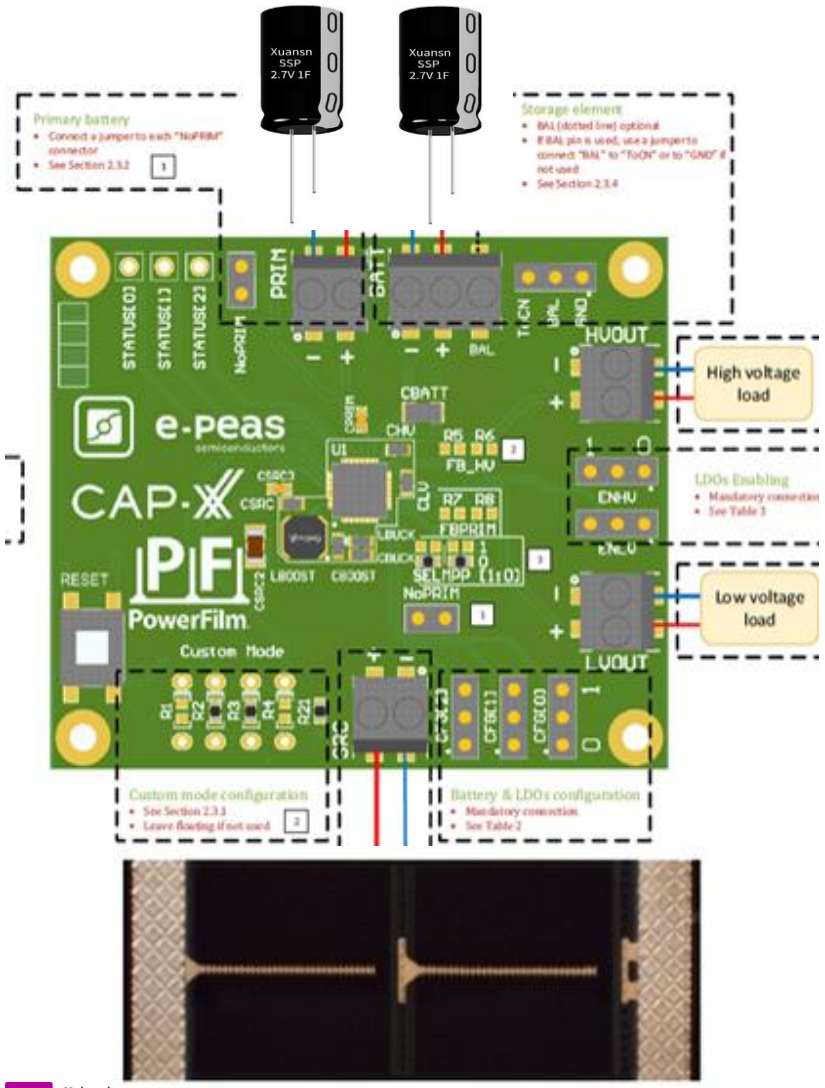
- I2C _HAL_ libary
- PRogRaMinG ....

Energy harvesting so far and expectations

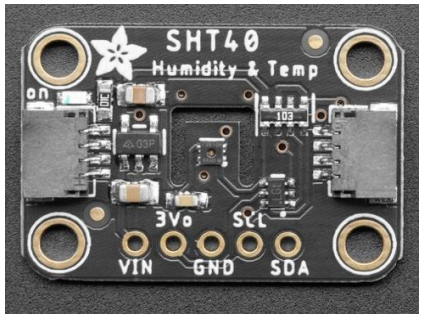




The goal



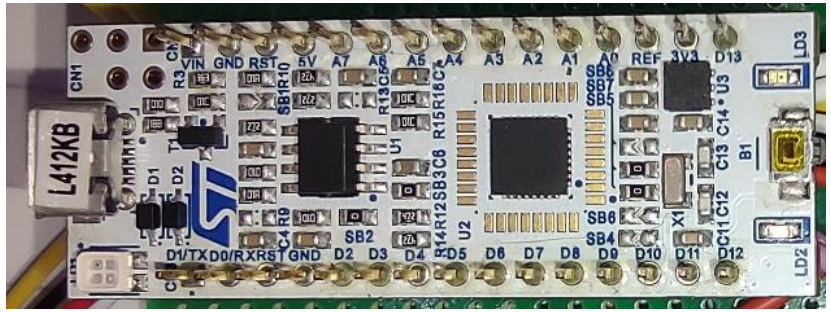
SHT40(1.08 - 3.6)V



LTR-329(2.4 - 3.6)V

BLE(1.7 - 3.3)V

STM(3 - 3.6)V



Do we even have enough power ??? ^^

Configuration pins			Storage element threshold voltages			LDOs output voltages		Typical use
CFG[2]	CFG[1]	CFG[0]	V_{OVCH}	V_{CHRDY}	V_{OVDIS}	V_{HV}	V_{LV}	
H	H	H	4.12 V	3.67 V	3.60 V	3.3 V	1.8 V	Li-ion battery
H	H	L	4.12 V	4.04 V	3.60 V	3.3 V	1.8 V	Solid state battery
H	L	H	4.12 V	3.67 V	3.01 V	2.5 V	1.8 V	Li-ion/NiMH battery
H	L	L	2.70 V	2.30 V	2.20 V	1.8 V	1.2 V	Single-cell (super) capacitor
L	H	H	4.50 V	3.67 V	2.80 V	2.5 V	1.8 V	Dual-cell supercapacitor
L	H	L	4.50 V	3.92 V	3.60 V	3.3 V	1.8 V	Dual-cell supercapacitor
L	L	H	3.63 V	3.10 V	2.80 V	2.5 V	1.8 V	LiFePO4 battery
L	L	L	Custom mode - see Section 2.3.1				1.8 V	

Energy harvesting so far and expectations

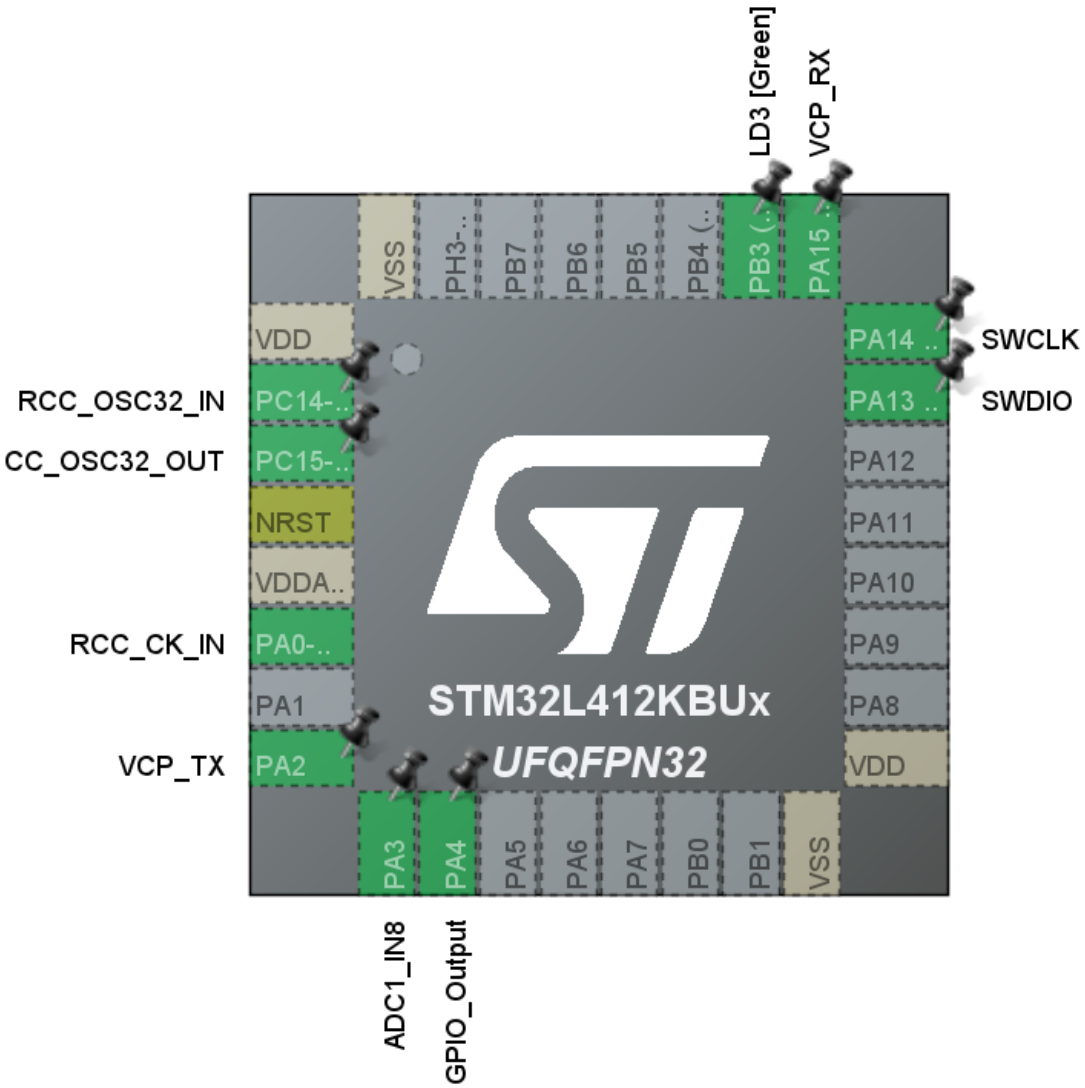
Table 5. External power sources

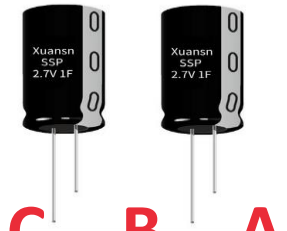
Input power name	Connector pin	Voltage range	Max current	Limitation
VIN	CN4 pin 1	7 V to 12 V	800 mA	From 7 V to 12 V only and input current capability is linked to input voltage: 800 mA input current when VIN=7 V 450 mA input current when 7 V< VIN <9 V 300 mA input current when 10 V> VIN >9 V less than 300 mA input current when VIN>10 V
+5 V	CN4 pin 4	4.75 V to 5.25 V	500 mA	ST-LINK not powered
+3V3	CN4 pin 14	3 V to 3.6 V	-	ST-LINK not powered and SB14 and SB9 must be off.

+3V3 power supply

Using the +3V3 (CN4 pin 14) directly as power input, can be interesting, for instance, in case the 3.3 V is provided by a shield board. In this case the ST-LINK is not powered, thus programming and debugging features are not available. When the board is powered by +3V3 (CN4 pin 14), the solder bridge SB14 and SB9 (NRST) must be off.

Decision making

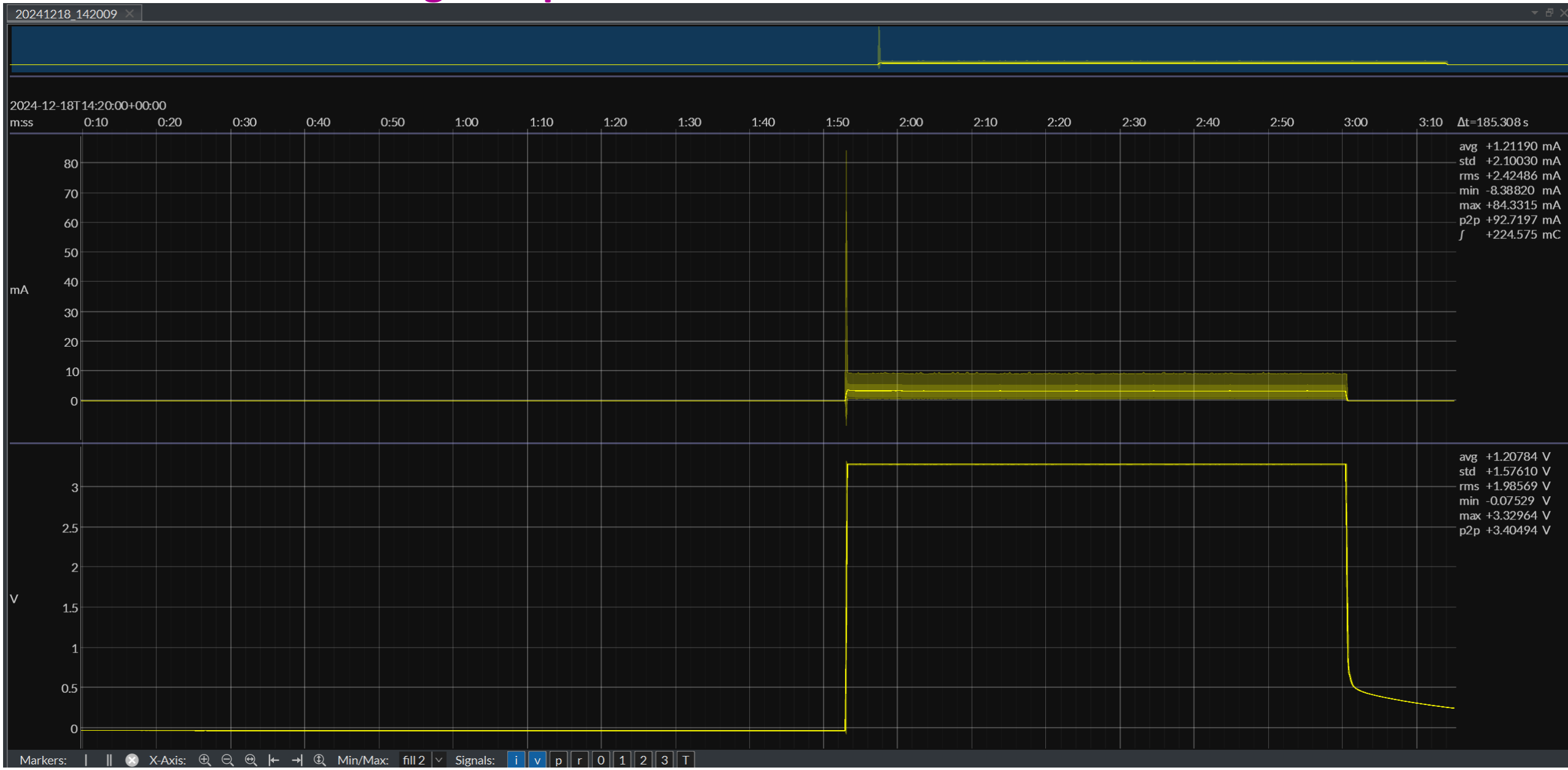




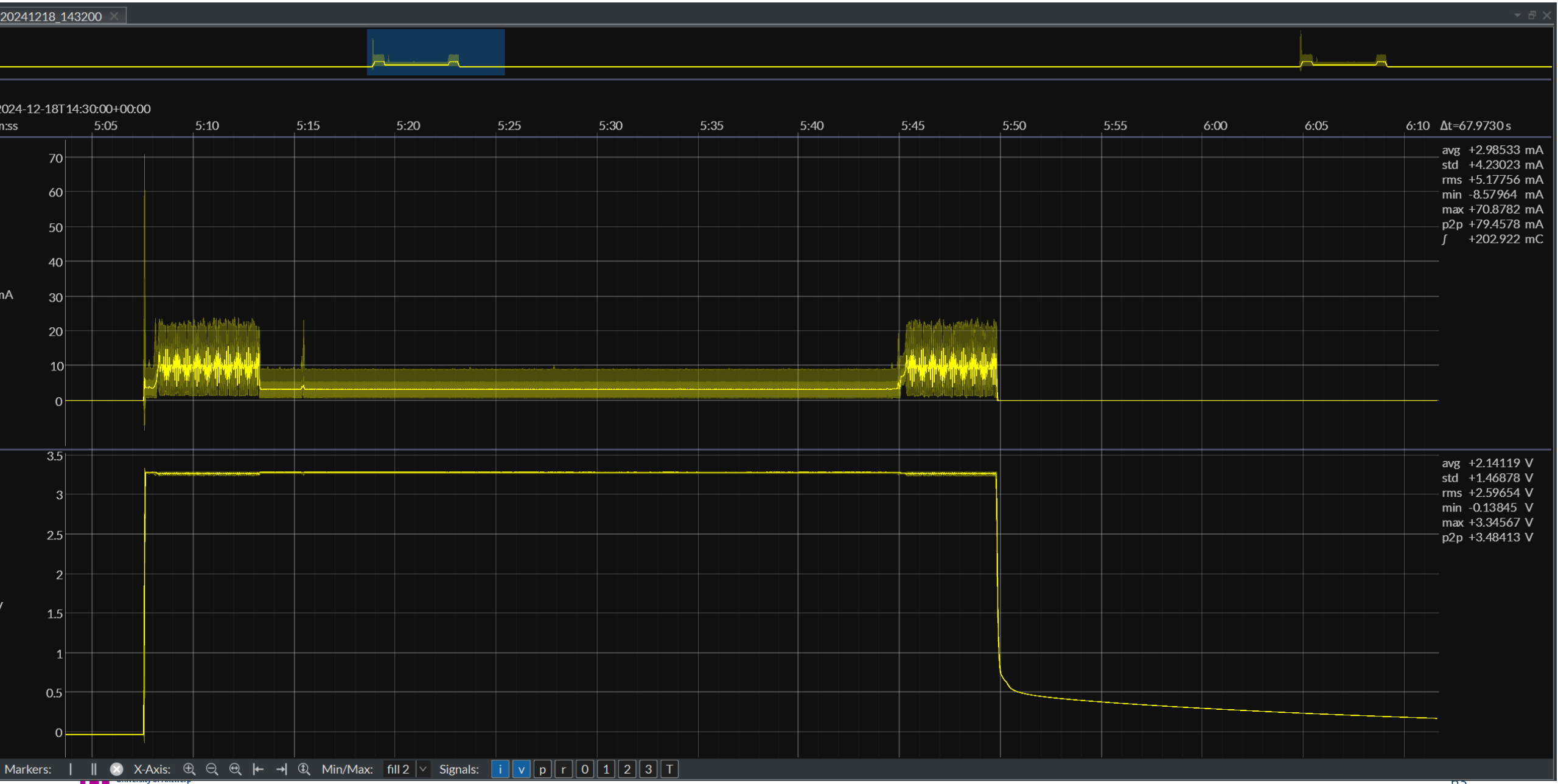
C B A

ADC

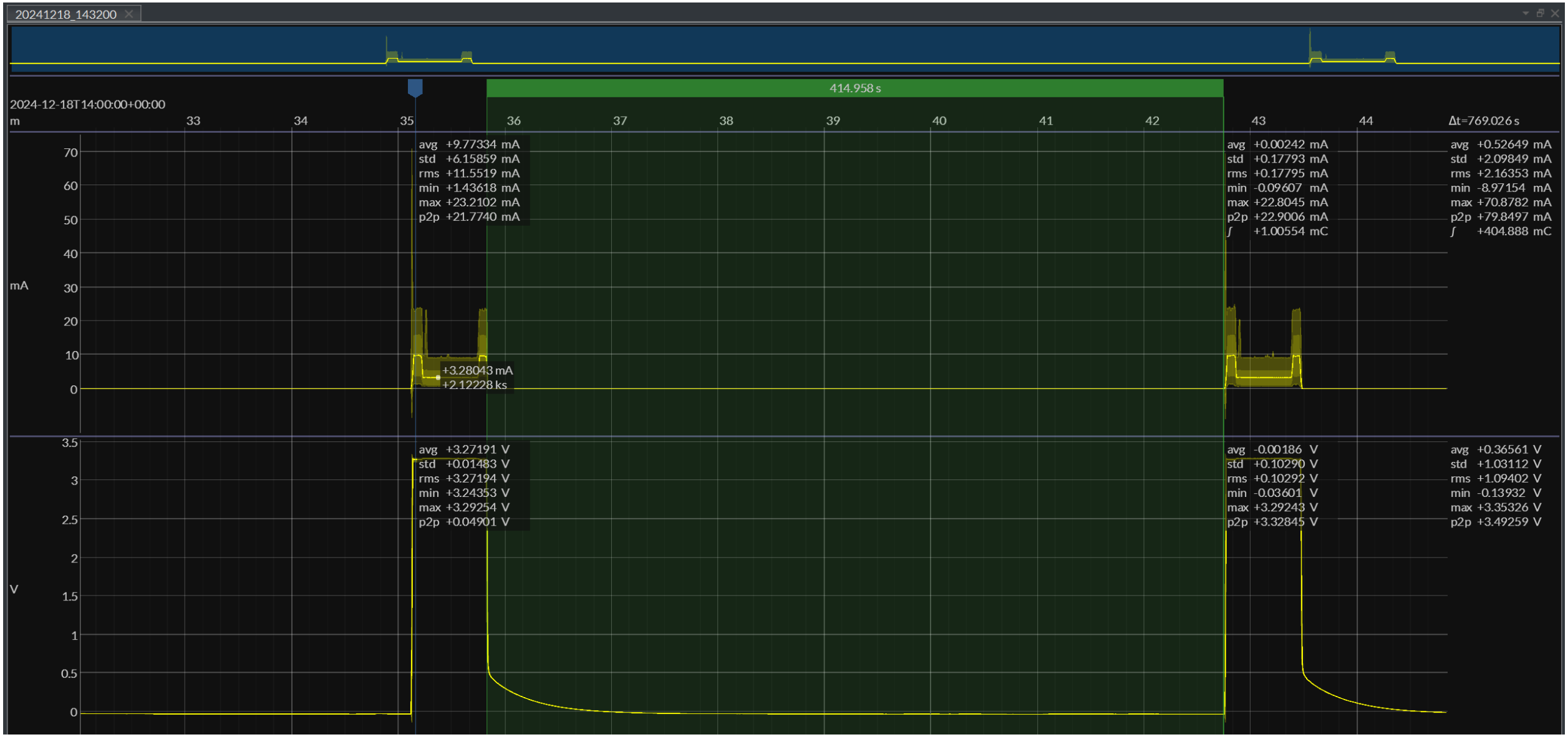
Voltage output measurement



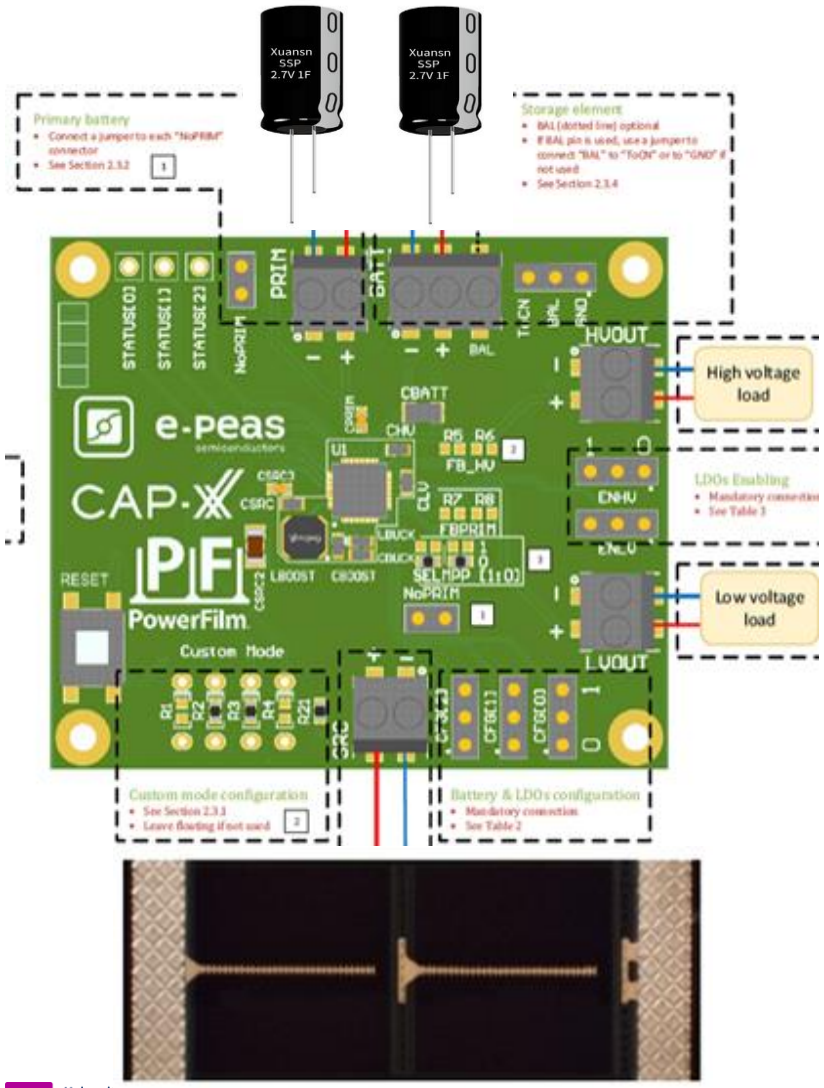
Voltage output measurement



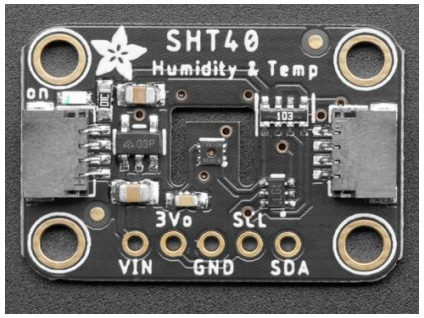
Voltage output measurement



The goal



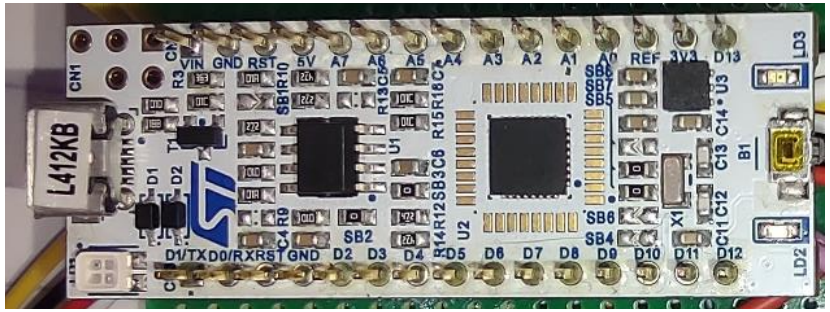
SHT40(1.08 - 3.6)V



LTR-329(2.4 - 3.6)V

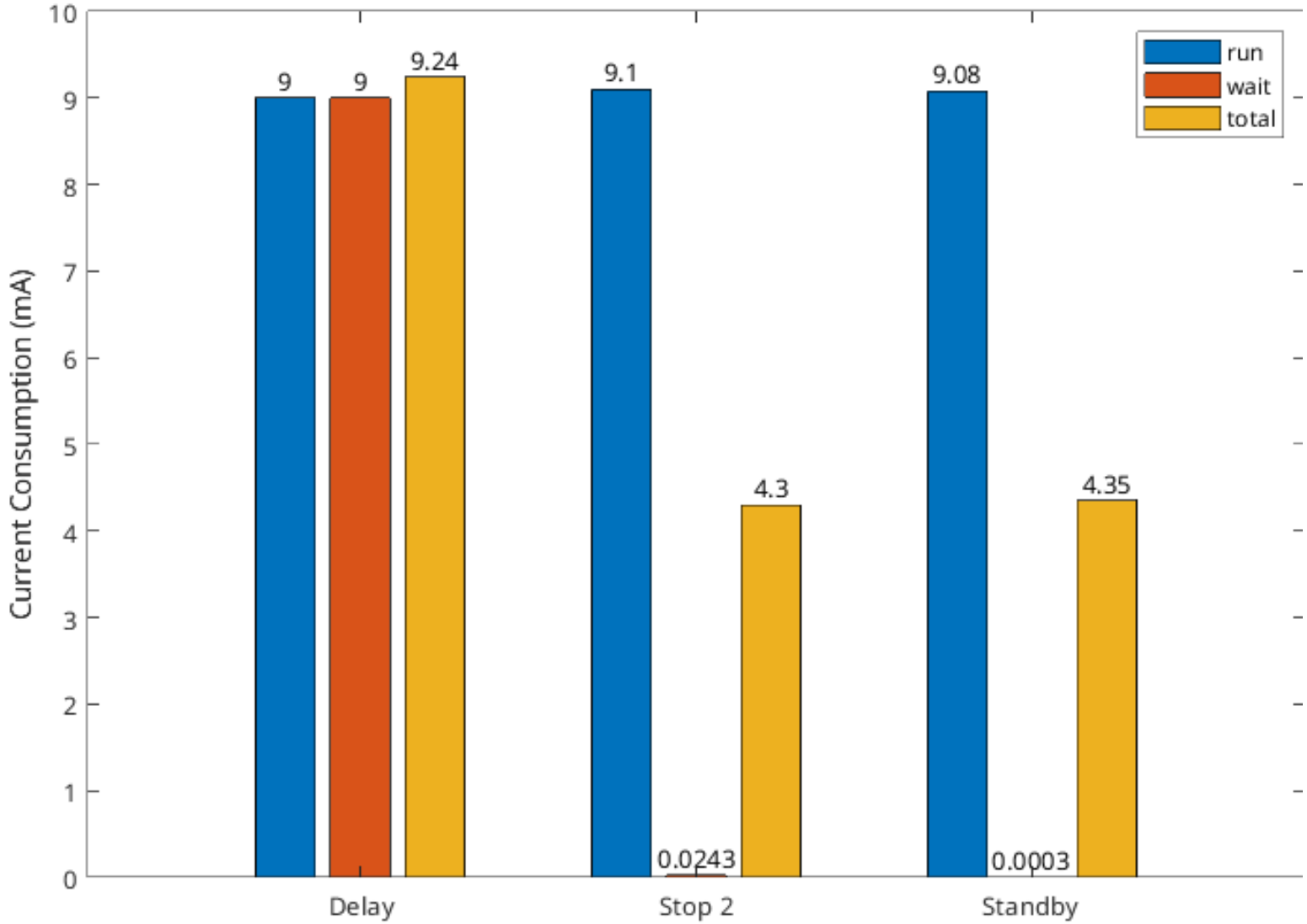
BLE(1.7 - 3.3)V

STM(3 - 3.6)V

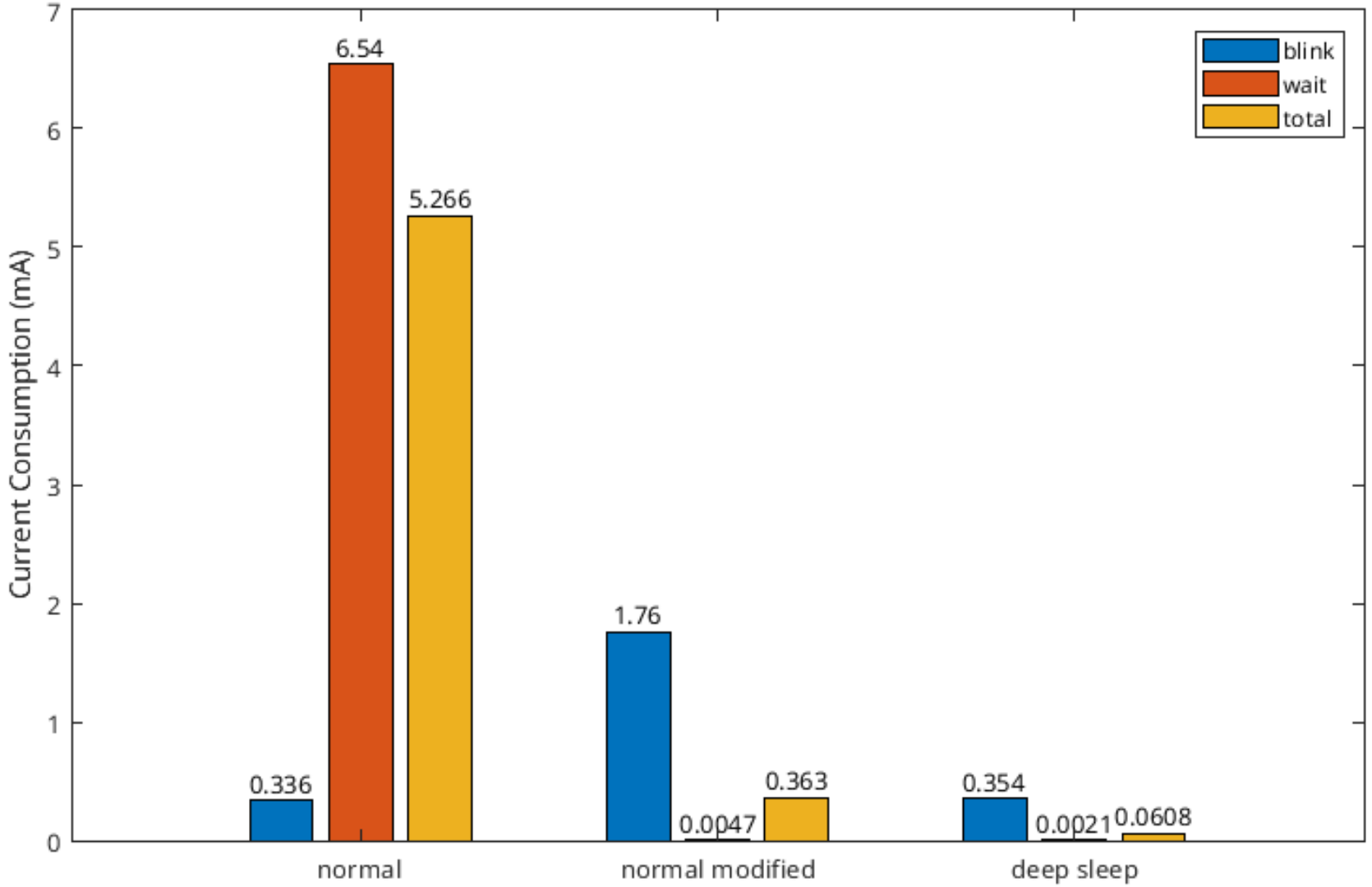


Power Profile

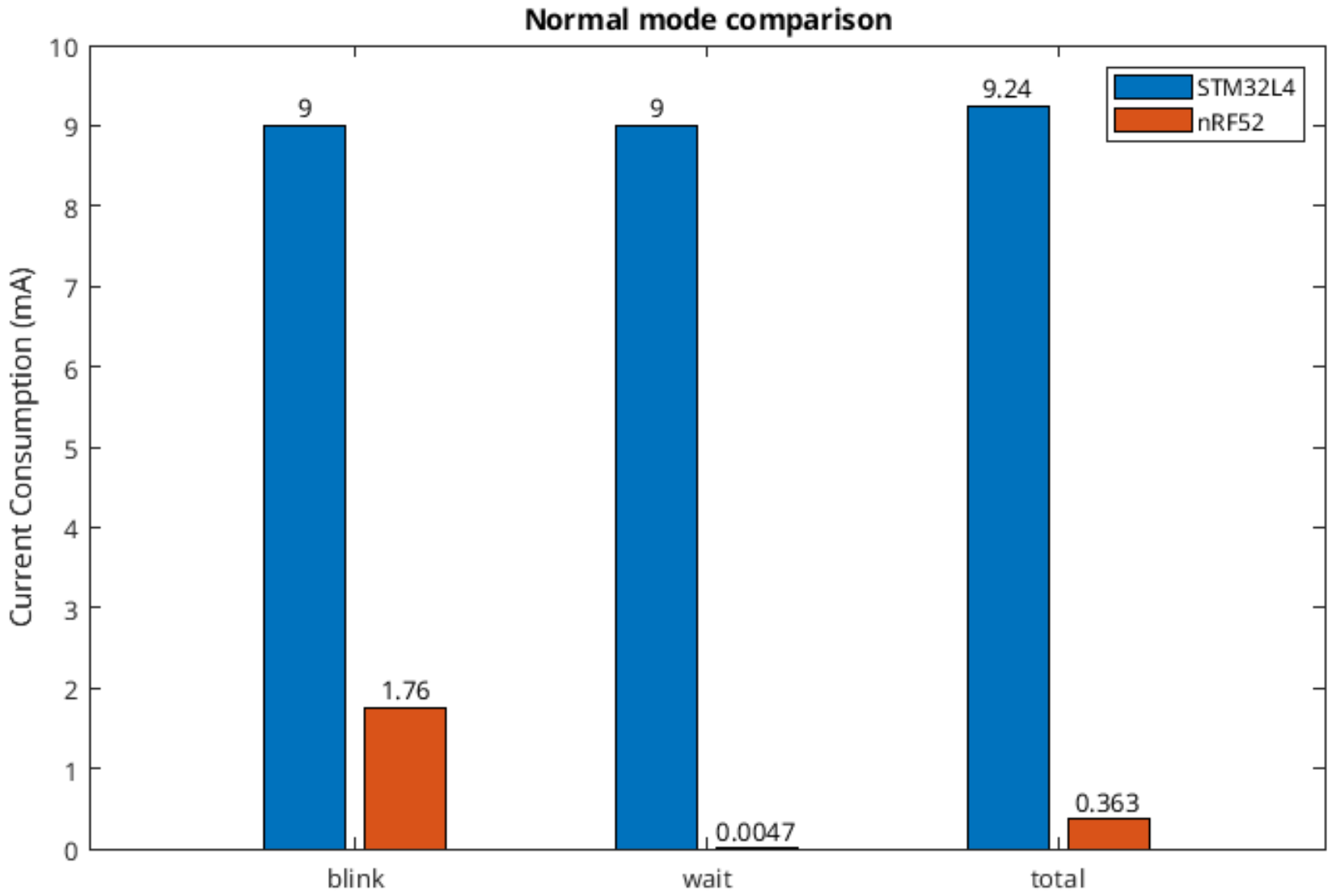
Power Profiling STM32



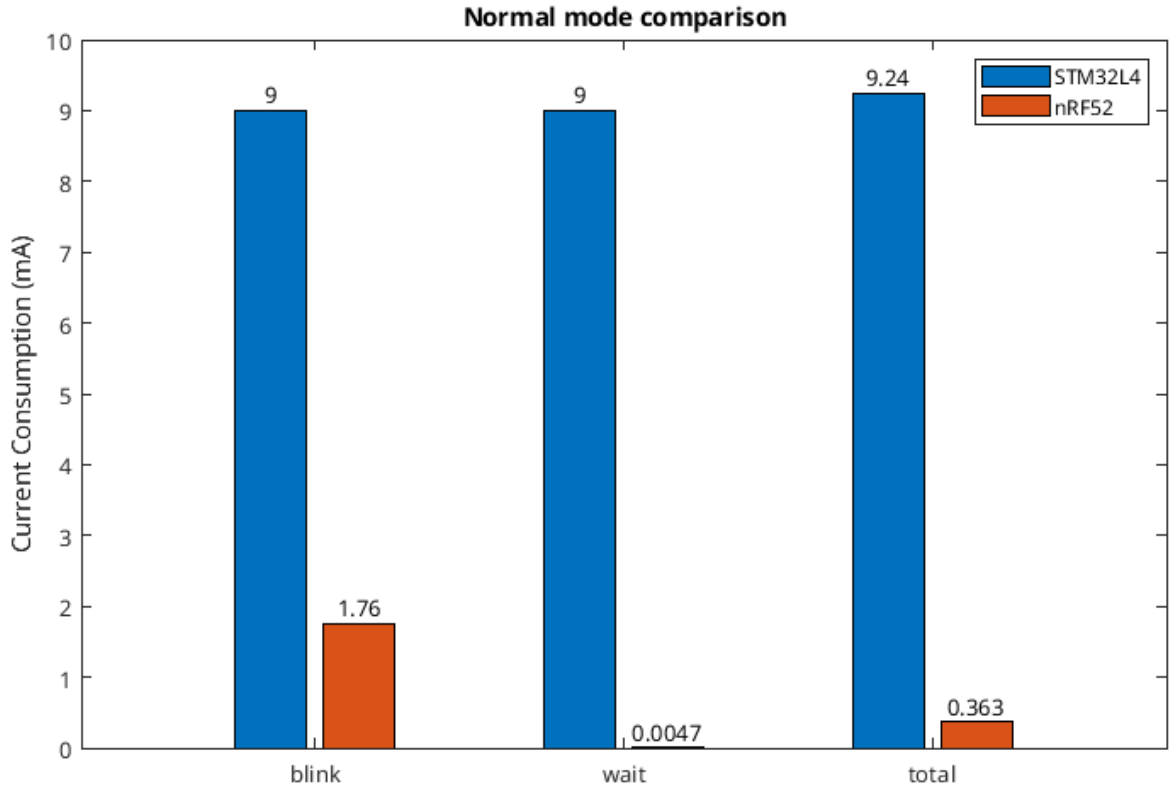
Power Profiling nRF52



STM32L4 VS NRF52

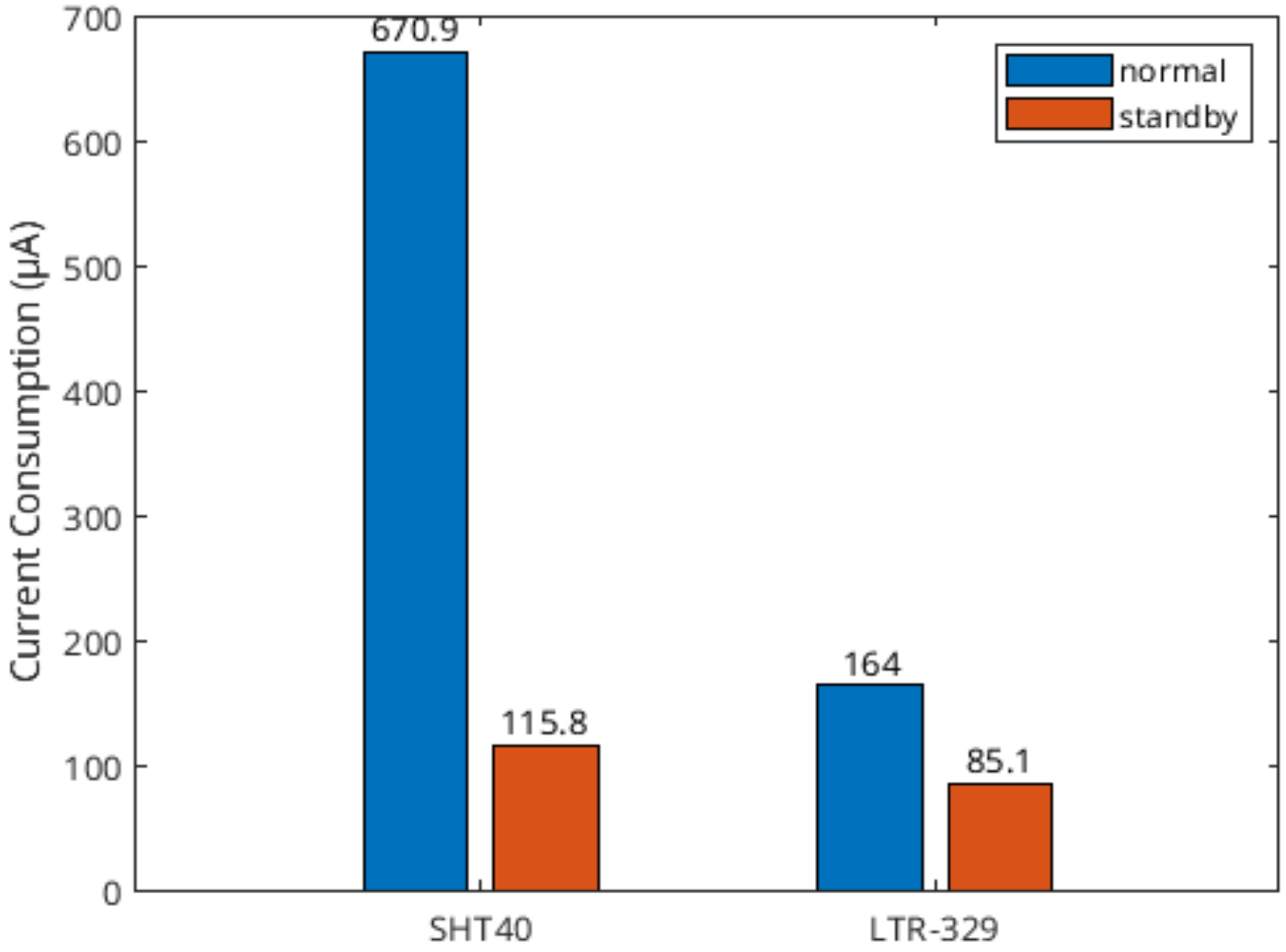


NRF52 VS STM32L4



NRF52 better/ easier than STM32L4?

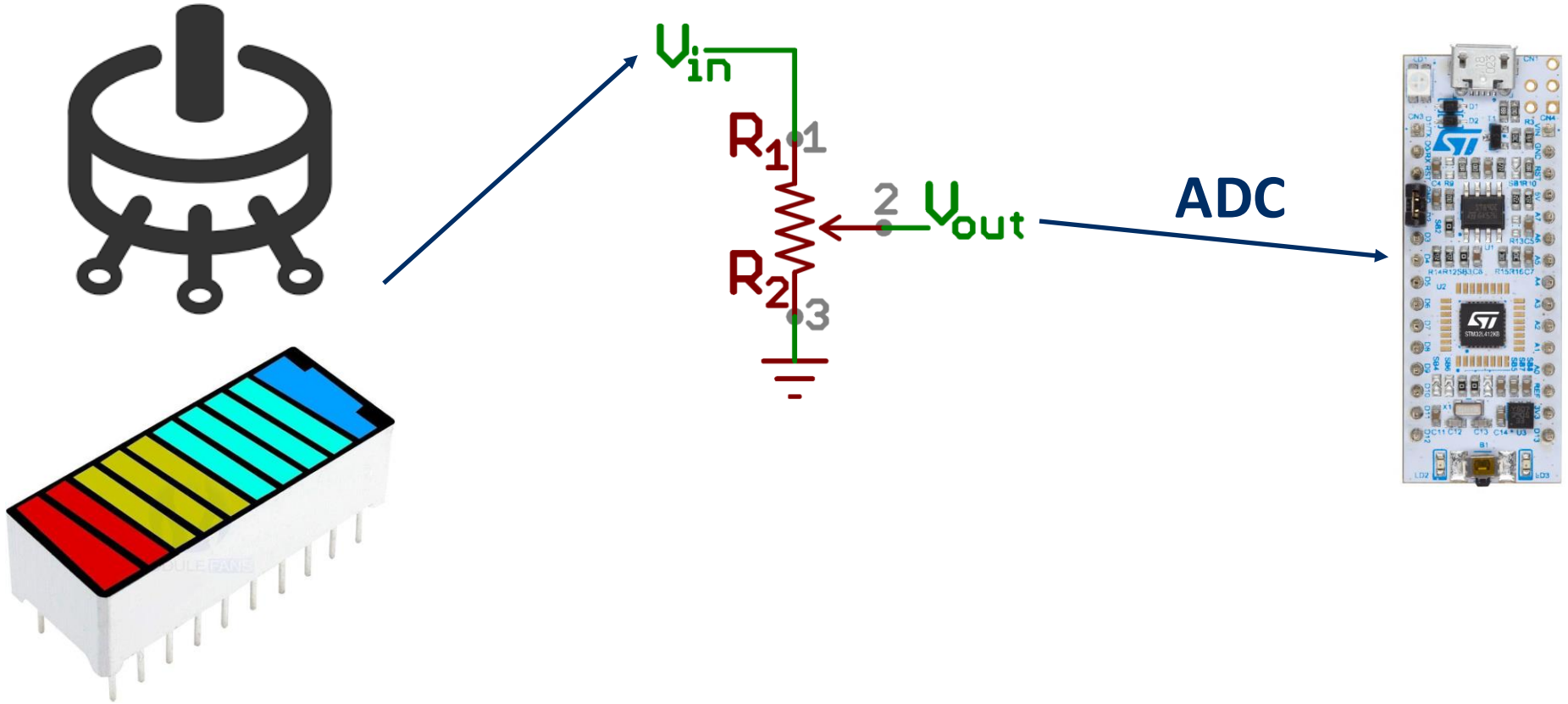
Power Profiling Sensor



Energy Awareness

Energy Awareness

Simulation PMIC



Optimal Task Schedule

Energy Awareness

Energy Awareness

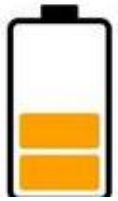
Sens | Store | Scan | Beacon | LoRa | Drive | Sleep

Sens | Store | Beacon | LoRa | Sleep

Energy Awareness

Sens | Store | Scan | Beacon | LoRa | Drive | Sleep

Sens | Store | Beacon | LoRa | Sleep

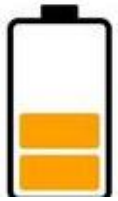


Sens | Store | Beacon | Sleep

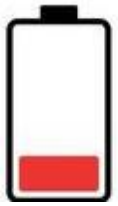
Energy Awareness

Sens | Store | Scan | Beacon | LoRa | Drive | Sleep

Sens | Store | Beacon | LoRa | Sleep



Sens | Store | Beacon | Sleep

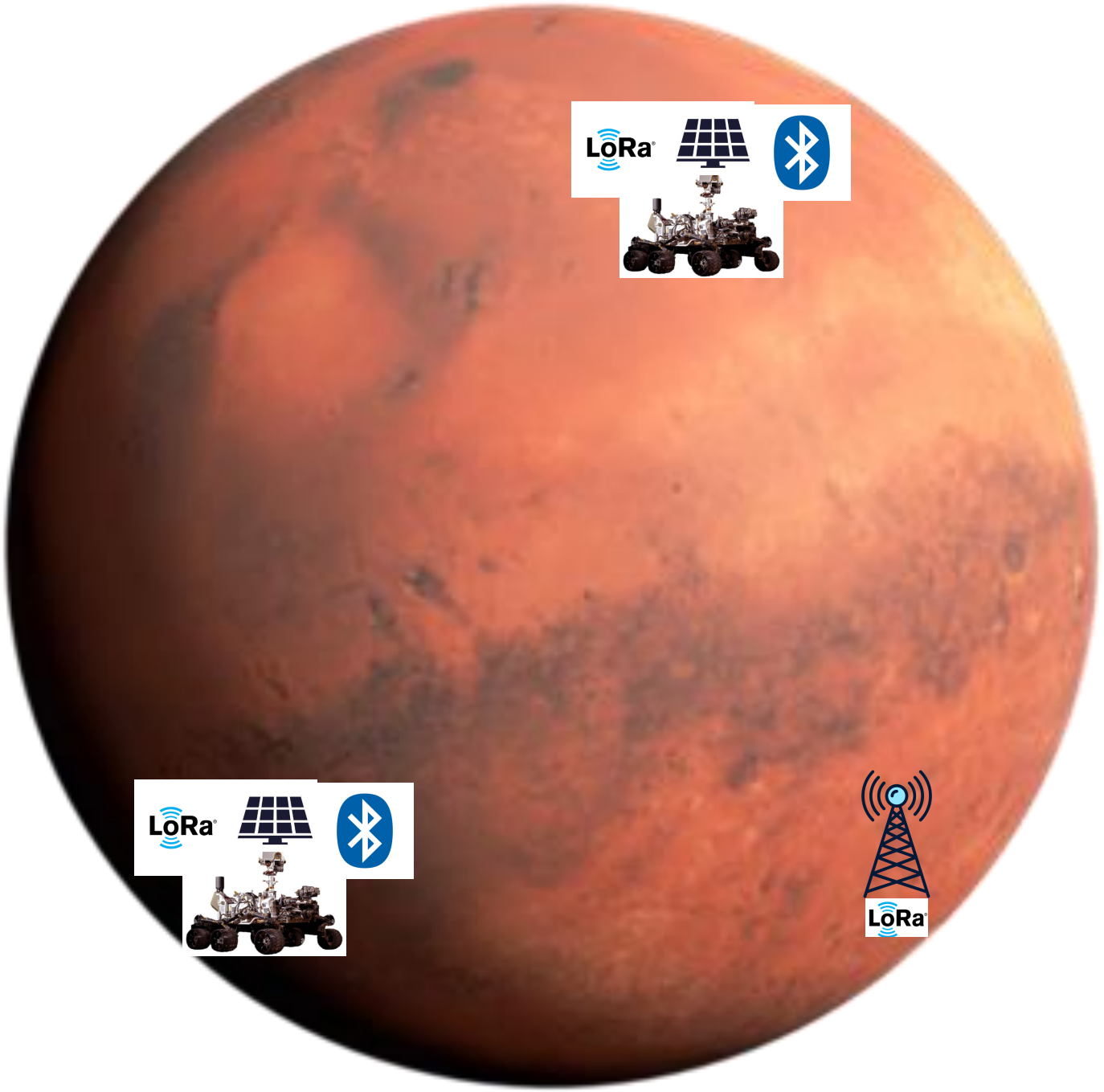


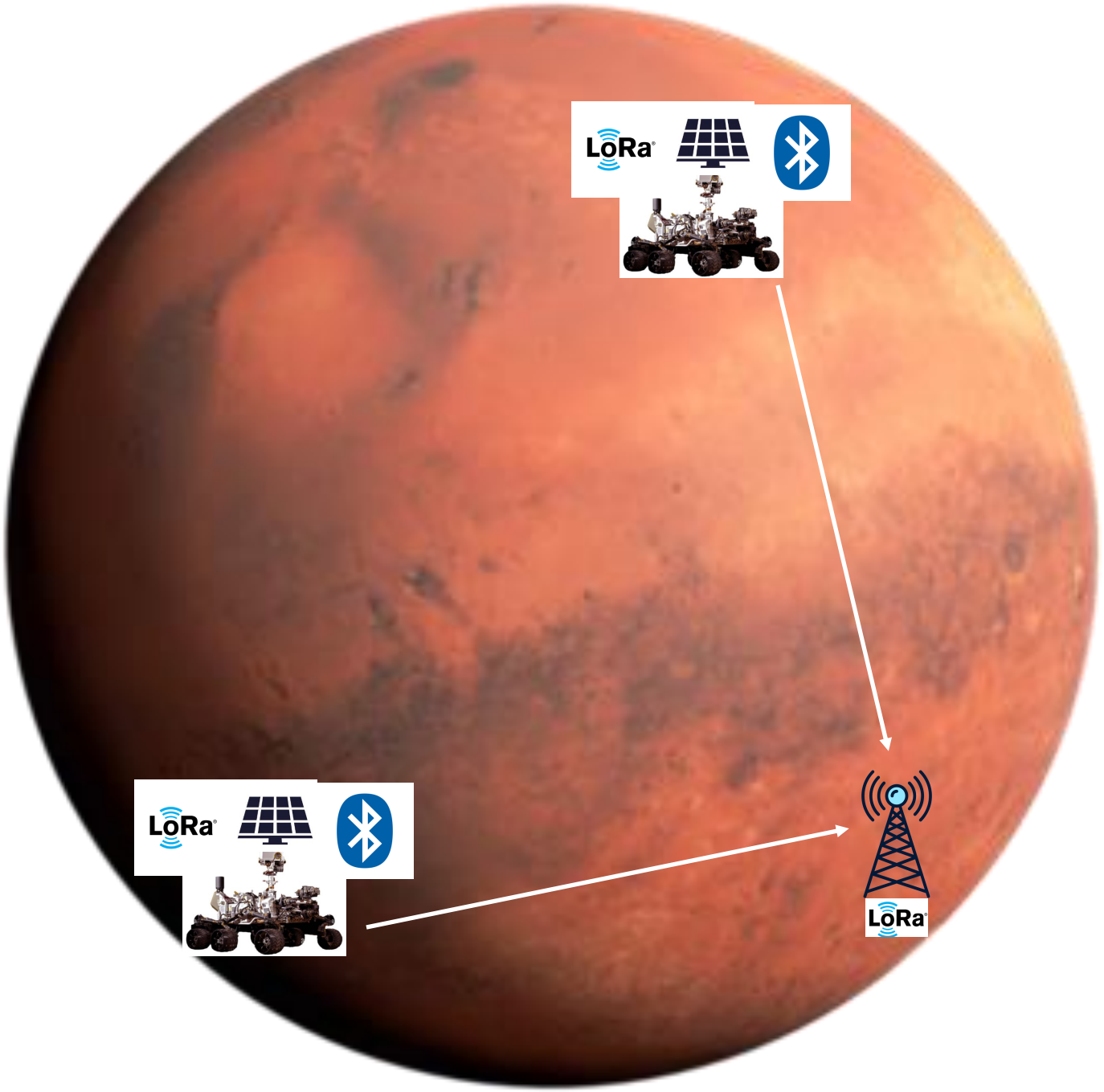
Beacon | Sleep

Optimal Transmission


Mars


LoRa


LoRa
LoRa
LoRa


LoRa
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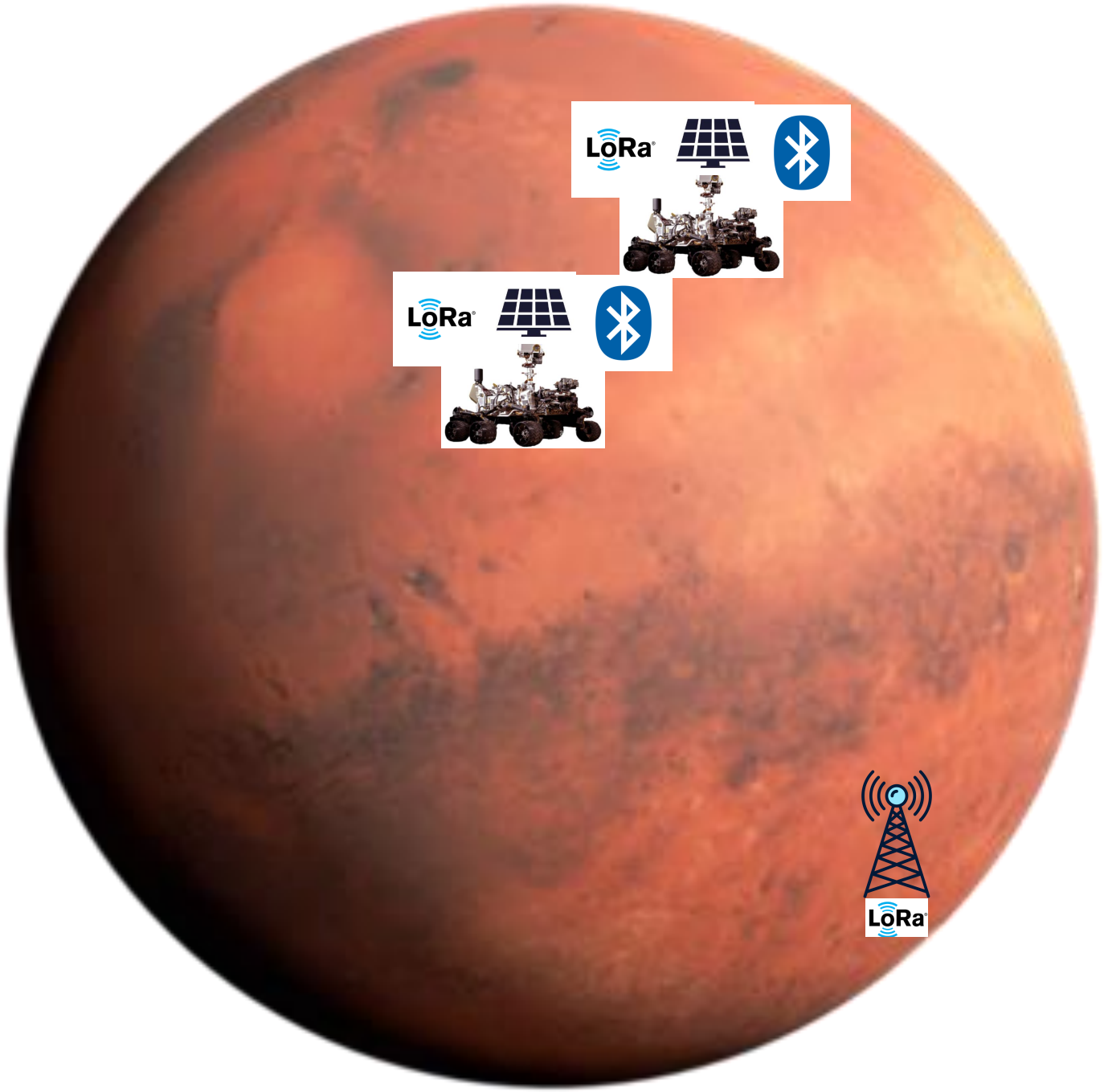
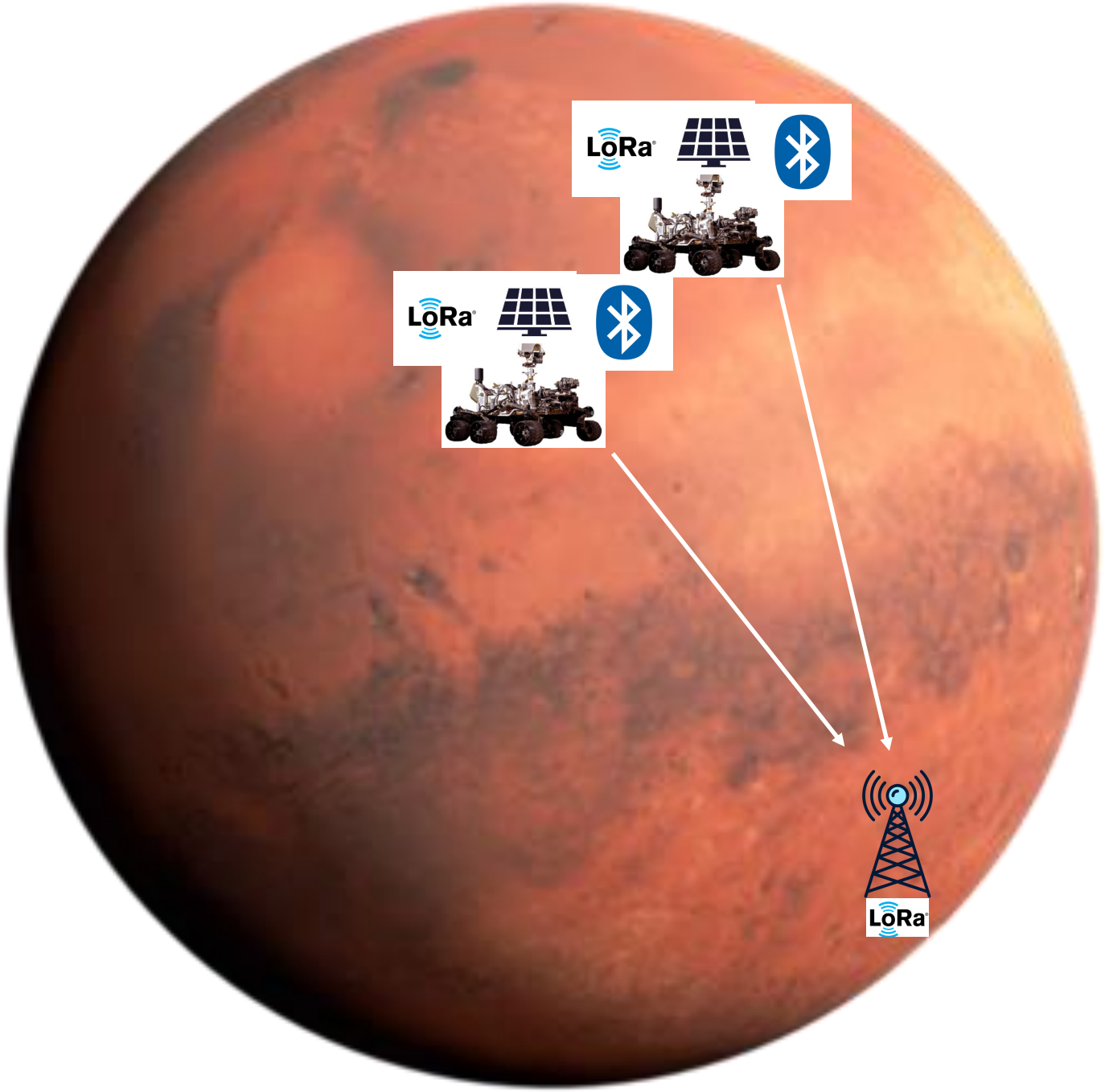
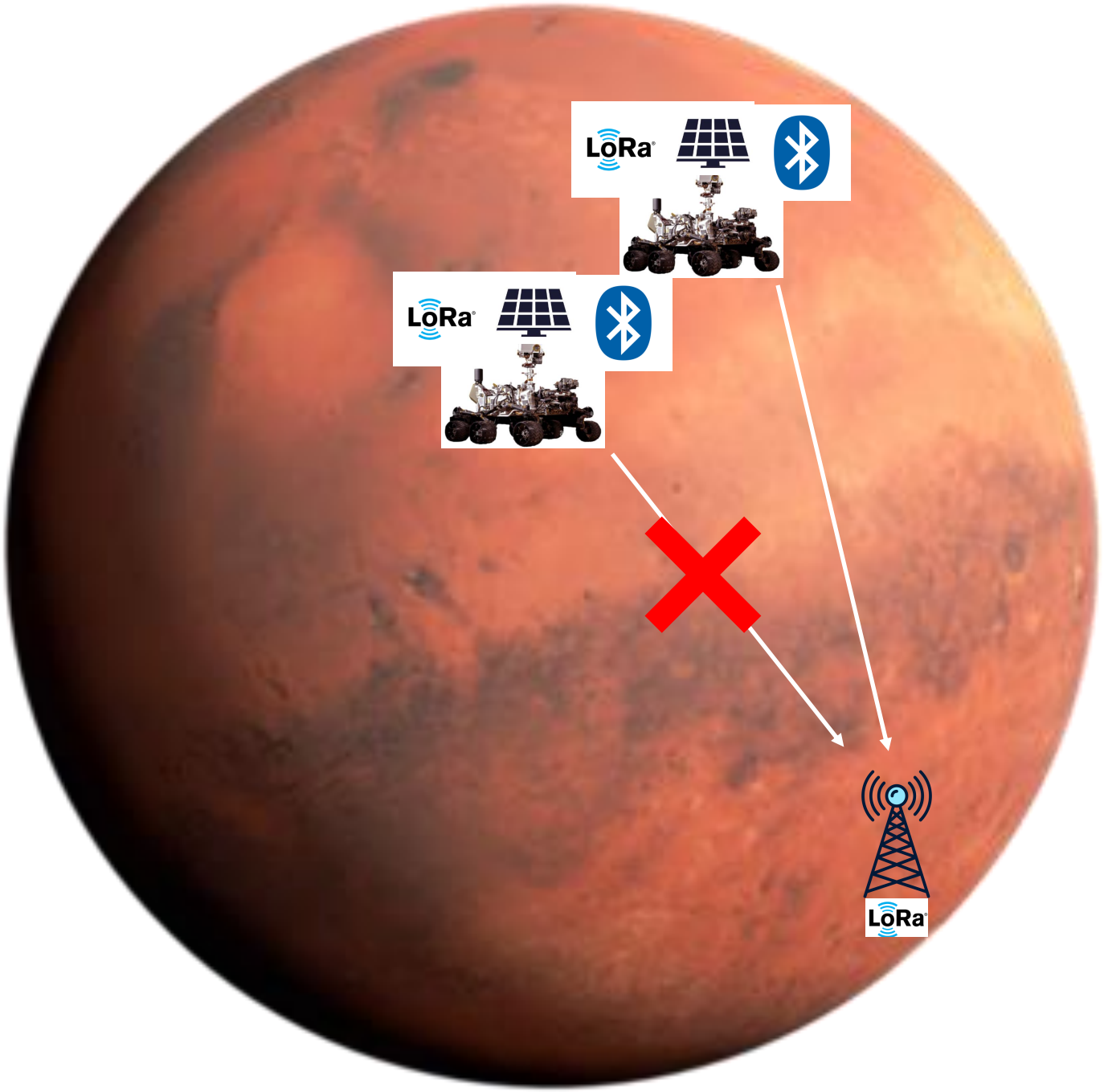
LoRa


LoRa
LoRa
LoRa


LoRa
LoRa
LoRa


LoRa
LoRa
LoRa

Challenges

Adam Hejduk

- I2C protocol with sensors, HAL library and programming in general
- This course has been a new experience !
- Feels like I literally learned how to solder here
- Reading

Robbe Elsermans

- (human) communication
- NRF SDK documentation
- Tools
- Defining propper objectives
- Reading the docs takes time

Thomas Kramp

- Applying I2C support
  - Linebot (GPIO)
  - LoRaWAN (UART)
- Keeping the LoRa module connected
- MPU6050 power measurents

Learns

For all

- mA is high current in LP environment
- STM32 has powerful processor catalogue
- STM32 has extensive examples
- (Personally) STM32 outperforms Nordic Semiconductor documentations
- Power Profiling is fun (with the right equipment)
- Set a stable development environment up before coding
- Have spares to test faults
- ...

Further Development

- Further optimize STM32 power usage
- Use nRF SDK directly
- Further optimize nRF52 power usage
- Reprogram SEEED LoRa module (is STM32 based)
  - Use its build-in EEPROM
- Orientation V2
- Optimal Transmission algorithm
- Find a replacement for the gyroscope measurements
- 4.5V to 5.7V custom E.H.M. configuration
- Supercap equal voltage distribution

Demo

Demo

https://www.youtube.com/watch?v=zGMOyNRa958&ab_channel=RobbeElsermans

Appendix

Orientation V2

Antenna relative placement

References

- https://www.istockphoto.com/fr/vectoriel/ic%C3%B4ne-noire-d%C3%A9nergie-solaire-gm1272457034-374723493
- https://www.flaticon.com/free-icon/antenna_7021857
- https://icon-icons.com/icon/potentiometer/4907
- https://www.alamy.com/mars-rover-isolated-on-white-background-elements-of-this-image-were-furnished-by-nasa-high-quality-photo-image425822621.html
- https://www.amazon.ca/Segment-Battery-Display-Indicator-Multi-Color/dp/B07S3NJCML
- https://www.digikey.be/en/products/detail/stmicroelectronics/NUCLEO-L412KB/9656229
- https://www.ram-center.com/blog/bluetooth-low-energy-interface-ble
- https://www.mouser.be/new/powerfilm/powerfilm-solar-dev-kit-e-peas-cap-xx/
- https://befr.rs-online.com/web/p/development-tool-accessories/2821454
- https://nodered.org/about/resources/
- https://www.thethingsnetwork.org/brand-assets/
- https://learn.sparkfun.com/tutorials/voltage-dividers/all
- https://www.vecteezy.com/free-vector/battery-icon
- https://en.m.wikipedia.org/wiki/File:Mars.png
- https://www.vecteezy.com/free-png/mars

BLE Communication system

Advertise -> IBeacon

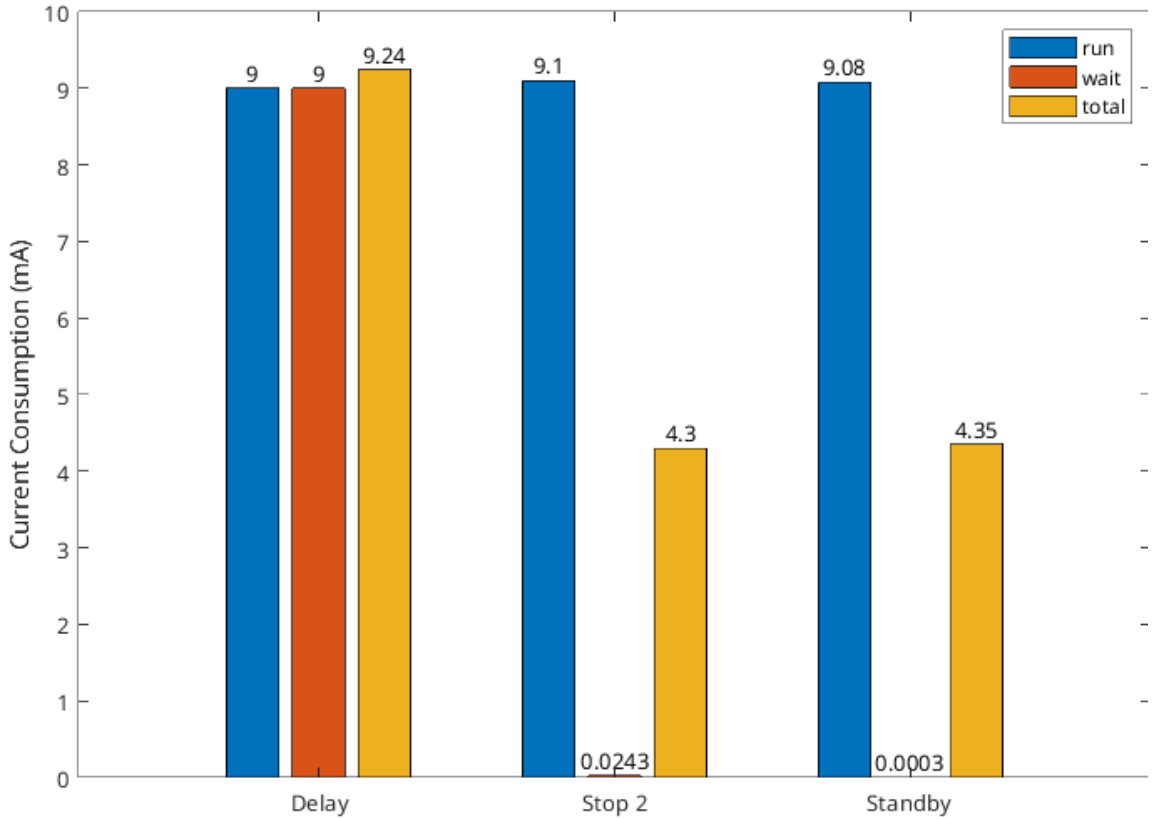
- UUID
- MAJOR
- TX Power @ 1m

```
[0] ->  Temperature MSB(yte)
[1] ->  Temperature LSB(yte)
[2] ->  Humidity
[3] ->  Lux MSB(yte)
[4] ->  Lux LSB(yte)
[5] ->  Device Supercap Voltage MSB(yte)
[6] ->  Device Supercap Voltage LSB(yte)
[7] ->  gyro-x
[8] ->  gyro-y
[9] ->  gyro-z
[10] -> /0xFF
[11] -> /0xFF
[12] -> /0xFF
[13] -> /0xFF
[14] -> /0xFF
[15] -> /0xFF
```

```
beacon.setMajorMinor((BEACON_SSR_ID << 8 |i2c_data.ssr_id), 0x0000);
```

Power Profiling STM32

Current Usage



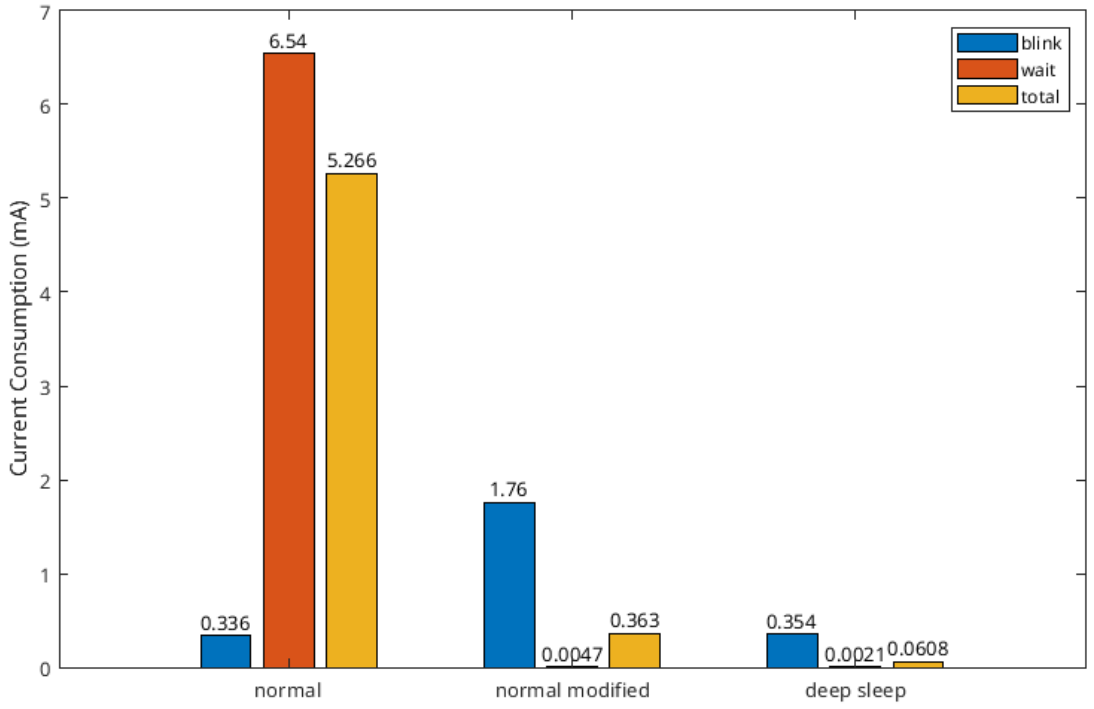
Pseudo code

```
init();
while(1)
{
    // Blinky blinky
    blink_led(1000);
    HAL_Delay(2000);

    // Change these accordingly to the mode we want
    // half_sleep(5000); // Stop Mode 2
    // deep_sleep(5000); // Standby Mode
    // HAL_Delay(5000); // Plain waiting
}
```

Power Profiling nRF52

Current Usage



Pseudo code

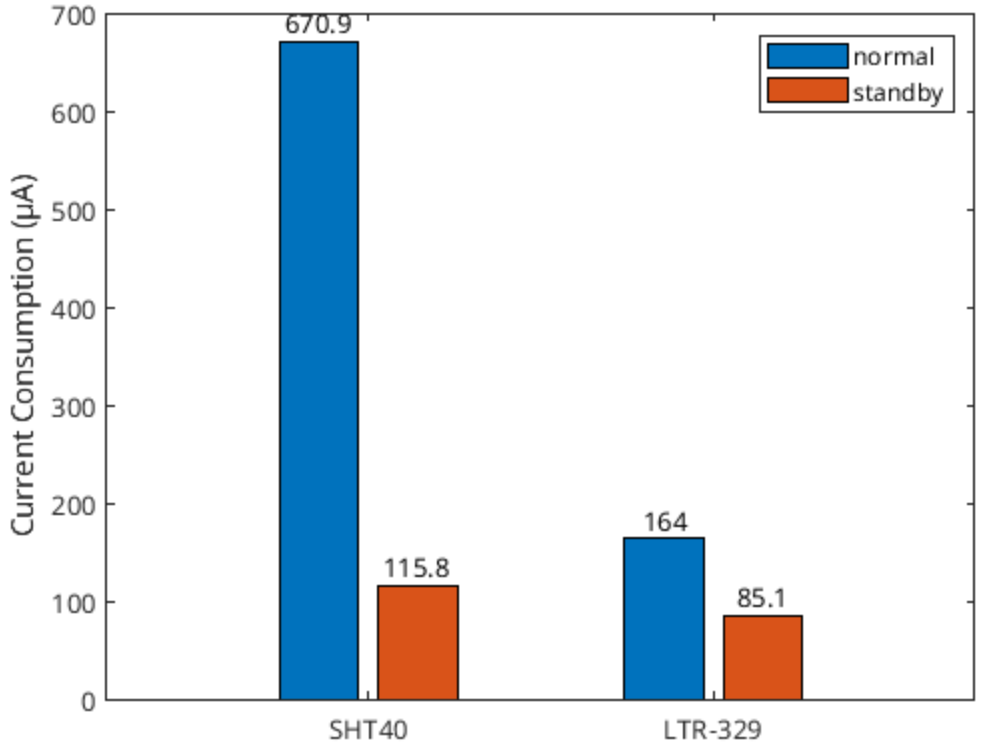
```
init();
while(1)
{
    digitalWrite(LED_BUILTIN, LOW);
    delay(1000);
    digitalWrite(LED_BUILTIN, HIGH);
    delay(1000);

    // Normal mode
    while(!digitalRead(2)) //Wait for pin change
    {
        //normal
        //delay(1000); //normal modified
    }
    // End normal mode

    // deep sleep mode
    // deep_sleep(); //Wake-up based on external pin change
    // End deep sleep mode
}
```

Power Profiling Sensor

Current Usage



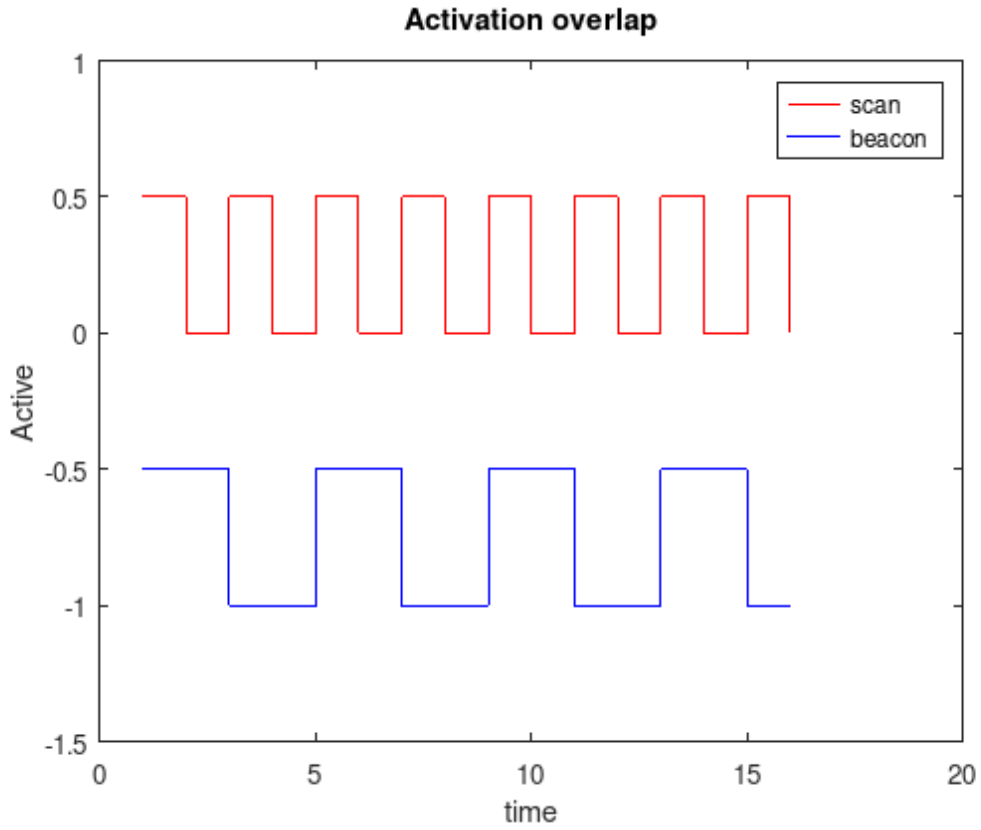
Pseudo code

```
init();
while(1)
{
    // Normal mode
    while(1) //Wait for pin change
    {
        read_sensor();
        wait 10 sec
    }
}
```

BLE Communication system

Intercommunication

- Overlap needed
- 2^n time differences
- Guaranteed delivery
- Test: 7% dropout (100)

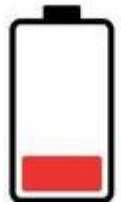


Energy Awareness

Sens | Store | LoRa | Scan | Beacon | Drive | Sleep

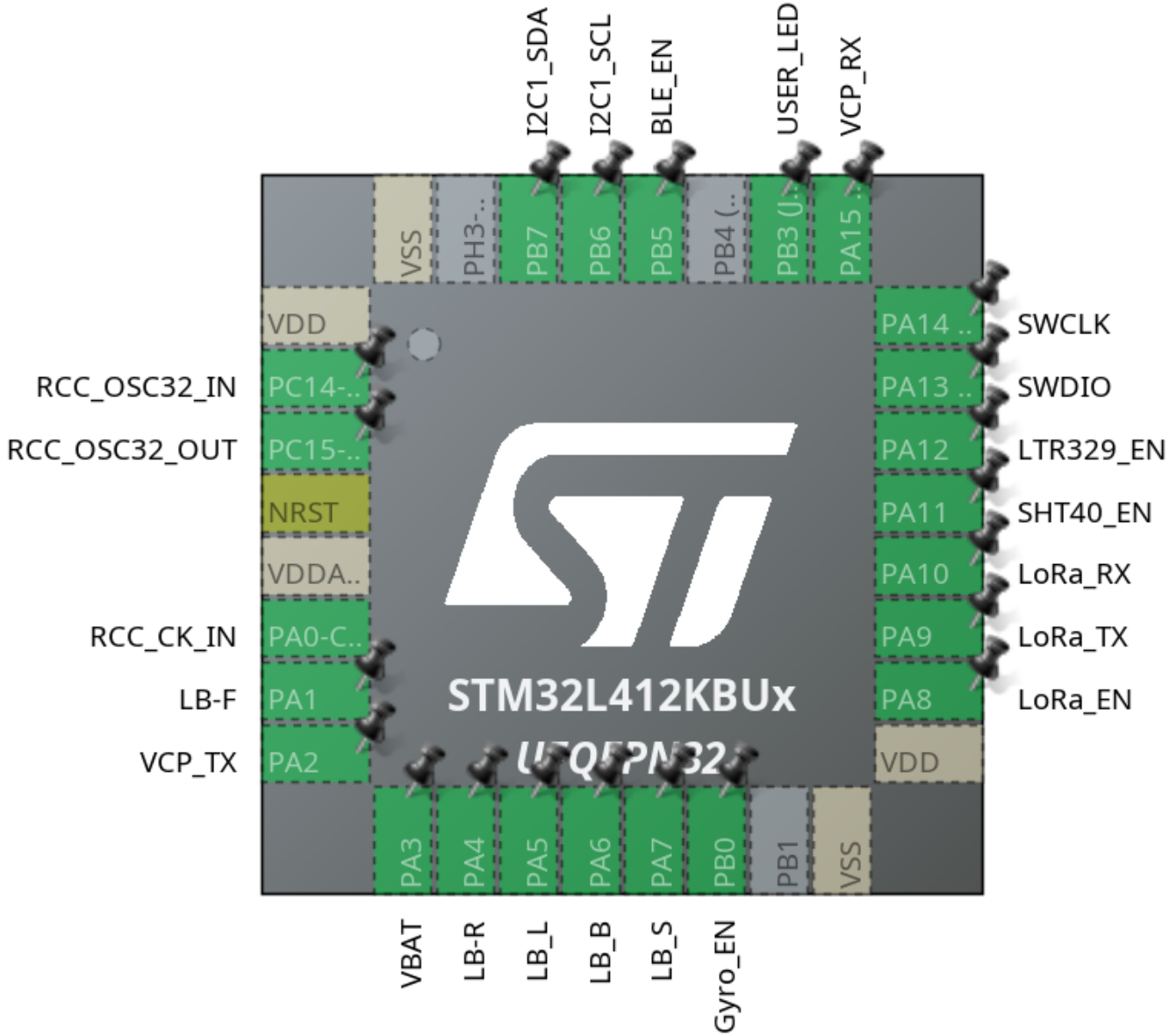
Sens | Store | LoRa | Beacon | Sleep

Sens | Store | Beacon | Sleep



Sleep

MCU Pinout

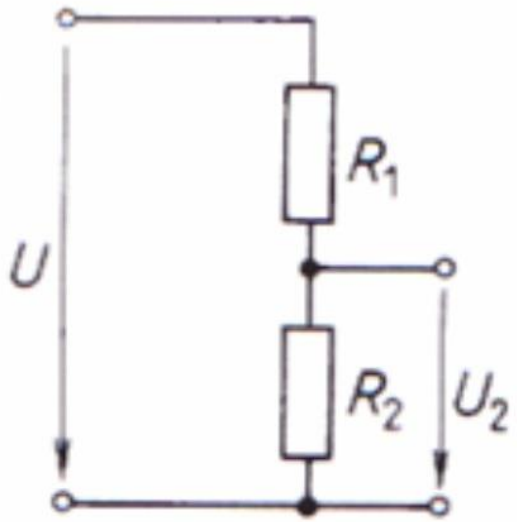

I2C1_SDA
I2C1_SCL
BLE_EN
USER_LED
VCP_RX
VSS
PH3-..
PB7
PB6
PB5
PB4 (..
PB3 (..
PA15 ..
VDD
PA14 ..
SWCLK
RCC_OSC32_IN
PC14-..
PA13 ..
SWDIO
RCC_OSC32_OUT
PC15-..
PA12
LTR329_EN
NRST
PA11
SHT40_EN
VDDA..
PA10
LoRa_RX
RCC_CK_IN
PA0-C..
PA9
LoRa_TX
LB-F
PA1
PA8
LoRa_EN
VCP_TX
PA2
VDD
STM32L412KBUx
PA3
PA4
PA5
PA6
PA7
PB0
PB1
VSS
VBAT
LB-R
LB_L
LB_B
LB_S
Gyro_EN

Demonstration plan

- Powering the STM with reliable source but have a potentiometer to shift the voltage of the circuit to simulate power levels of solar harvesting...
- Depending on the levels of volatege available rover would/could do specific nubmer of tasks (task desicion making)

- Therefore we are optimising a solution

to energy related decision making



Energy Harvesting Simulation

- **Simulation PMIC**