harvestKit® Energy Harvesting Reference Design

Final Hardware Rev 1.3

December 21, 2024

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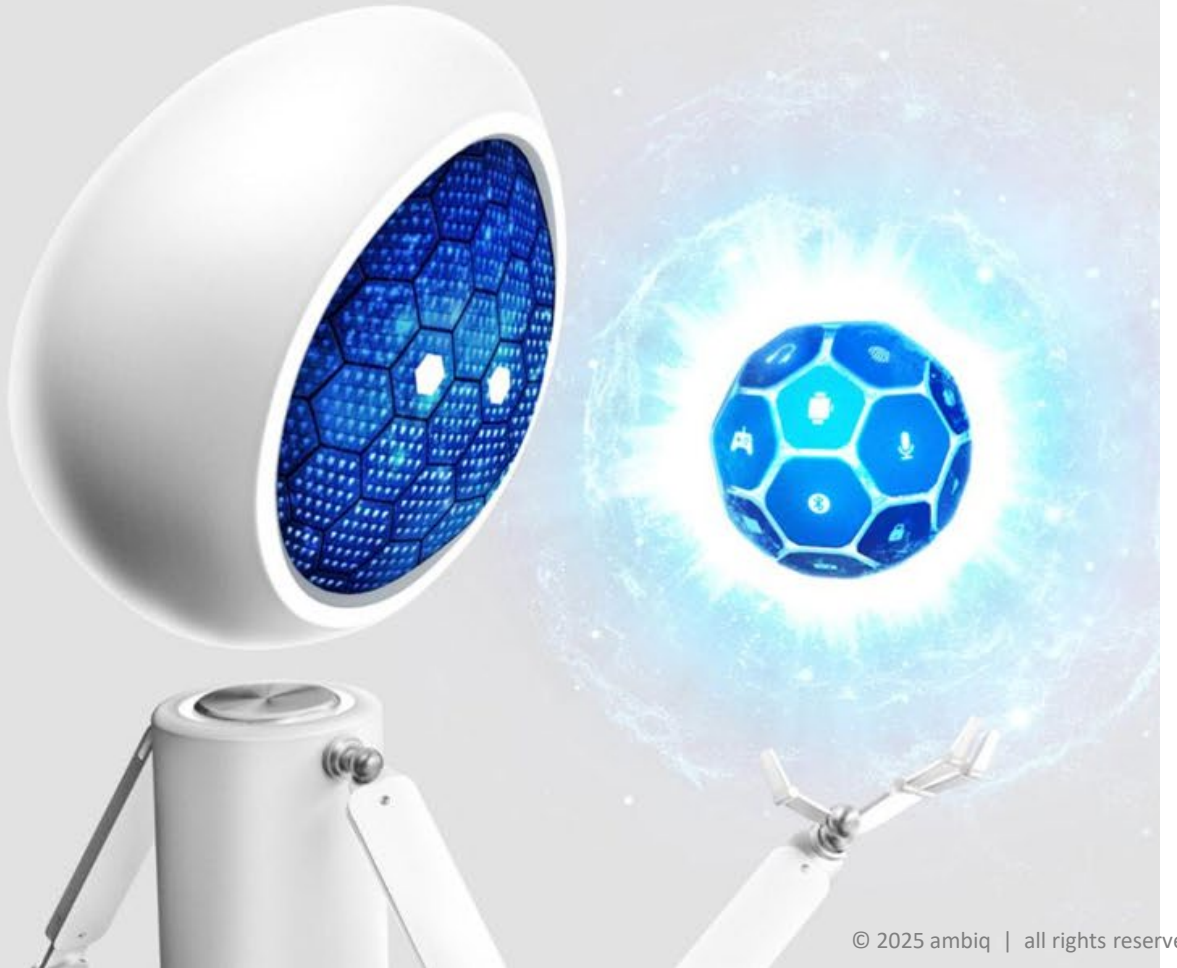
Ambiq's Mission

ambiq → ambient + IQ



Enable intelligent devices everywhere by developing

THE LOWEST-POWER SEMICONDUCTOR SOLUTIONS

to drive a more energy-efficient, sustainable, and data-driven world.

Revolutionizing Ultra-Low Power Processing

Key Facts

Founded: 2010

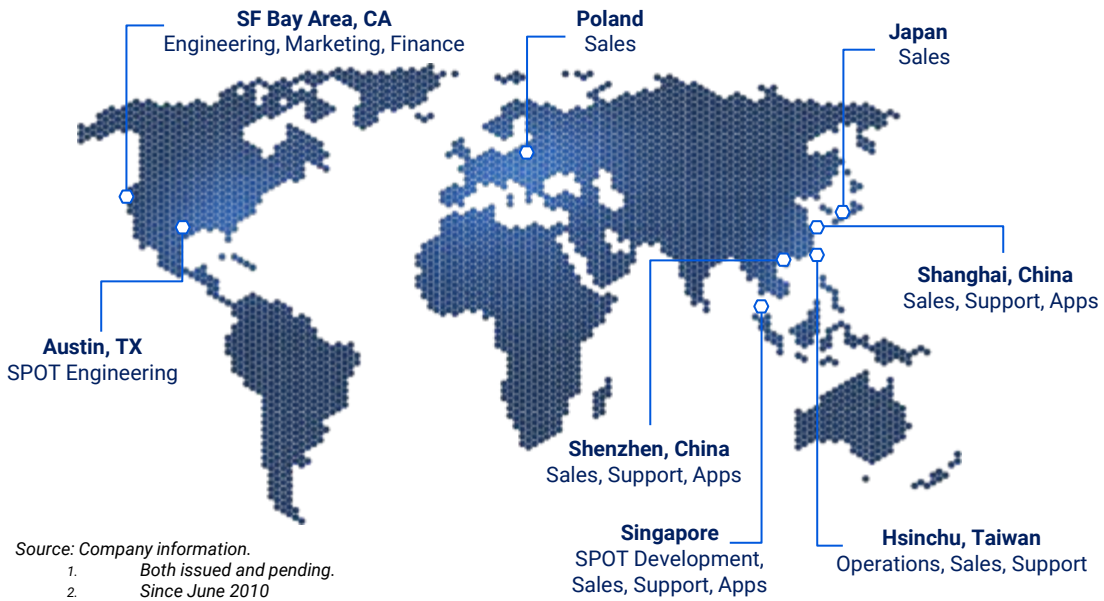
Global HQ: Austin, TX
Other Key Locations: China, Japan, Poland, Singapore, Taiwan

Key Investors: Kleiner Perkins, ARM, Conductive Ventures, Fujitsu Semiconductor Memory Solutions

Key Metrics

Operational Metrics				
	200+ Employees	200+ Customers	75+ (1) Patents	250M+ (2) Units Shipped

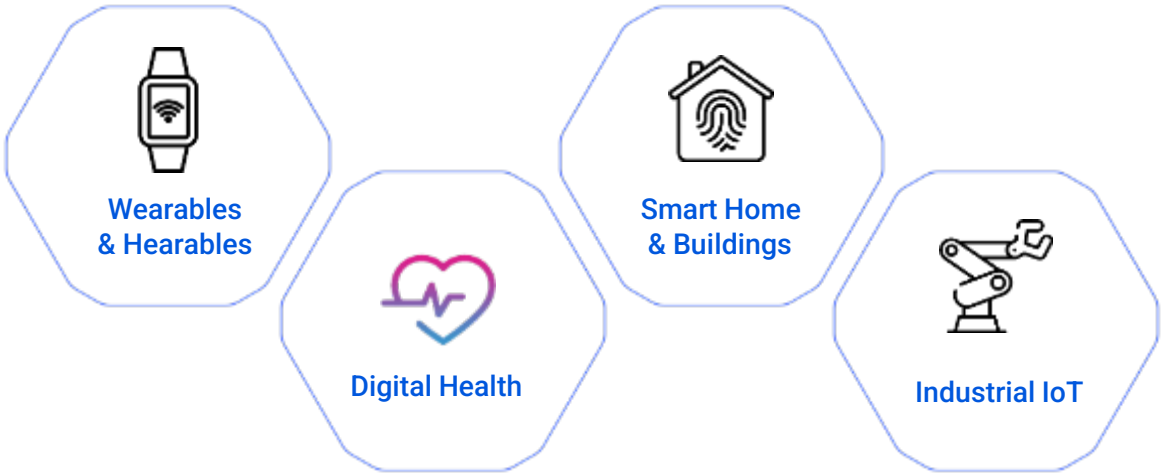
Solutions Experts Globally



Source: Company information.

1. *Both issued and pending.*
2. *Since June 2010*

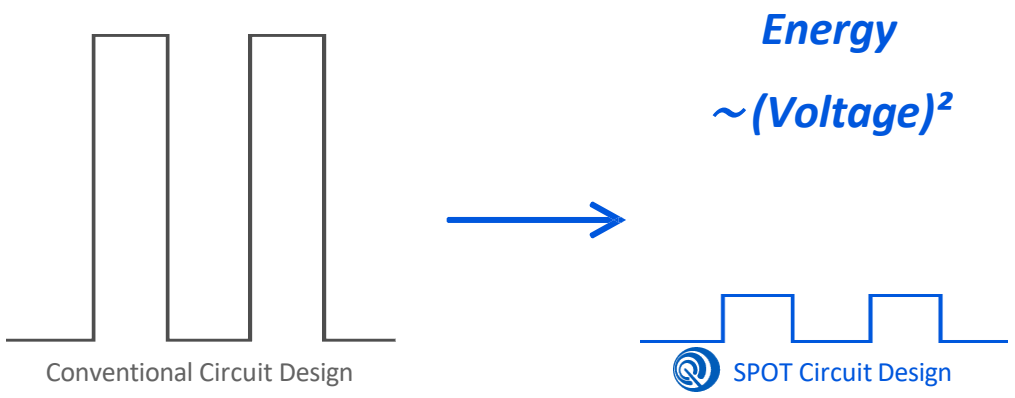
Addressing High-Growth End Markets



Differentiated Subthreshold Power Optimization Technology (SPOT®)

Backed by 75+ issued and pending patents

Unique Subthreshold Power Technology



Extensibility into Several High-Growth Use Cases

Processing	Microcontrollers (MCUs)	Application Processors	Graphics
AI Acceleration	Inference	Training	
Connectivity	Bluetooth	Wi Fi	5G
Sensing	Audio	Biosignals	Imaging

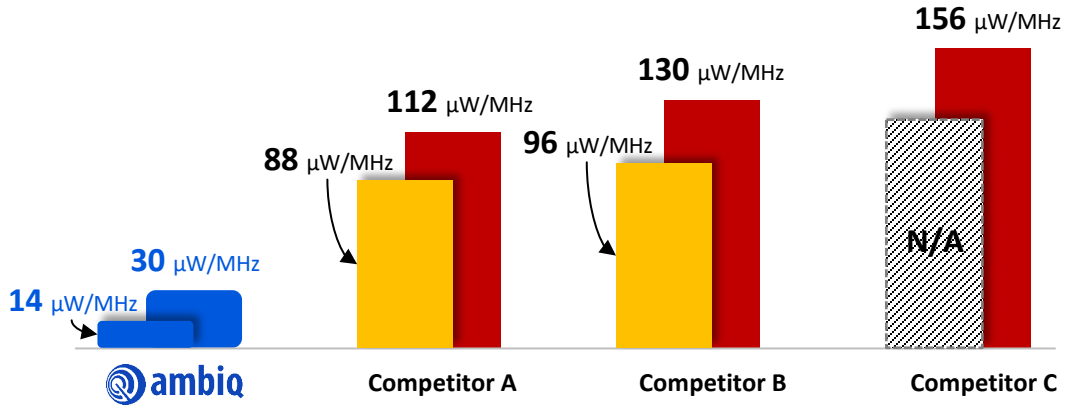
SPOT Overcomes Complex Design & Process Challenges

Process Variations

Voltage Fluctuations

Temperature Fluctuations

Significant Power Advantage Over Competitors



Ambiq vs. Competitors While Loop and CoreMark® Power

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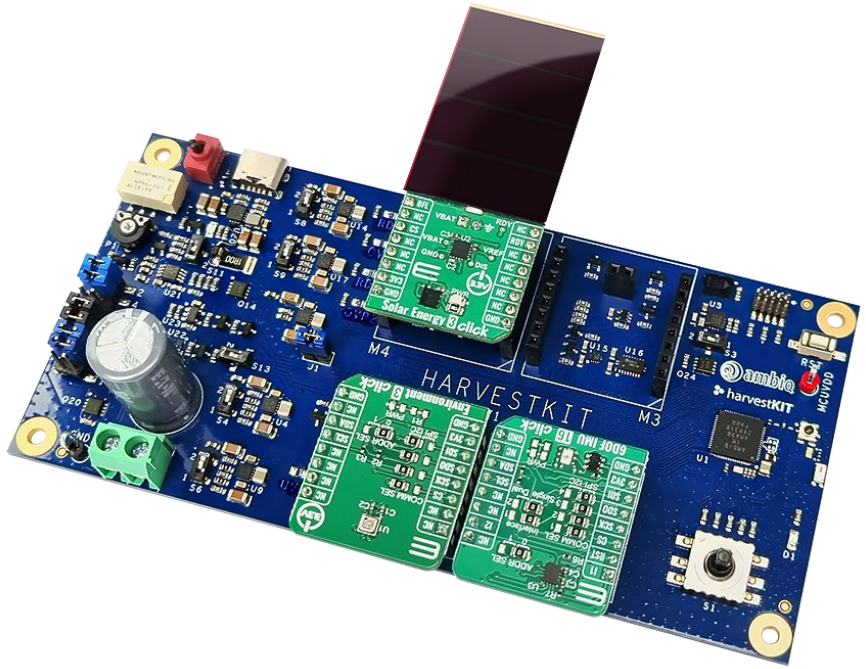
Energy Harvesting Motivation



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Design **GOALS**

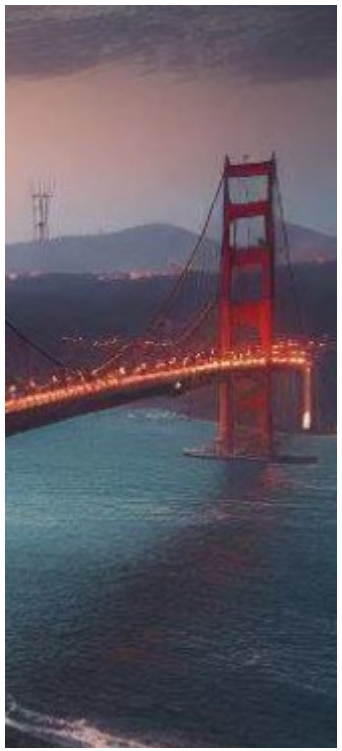
- **Extensible platform** to enabling clients to evaluate multiple **Energy Harvesting** power supplies along with different **Sensors**.
- **Modular** approach facilities rapid hardware prototyping leveraging the **mikroBUS Click interface** from MikroE .
- Base Apollo 3 Blue board optimized for **minimal power drain** and easy **power consumption measurement**.
- Power flexibility: either **Harvesting modules** or **USB-C** (priority).
- Ambiq **10 pin Compact Debug header** added to base board.
- **BLE** is the primary interface to a host phone/tablet/PC application.
- **Chrome browser web app** displays sensor data from BLE connected HarvestKit.
- Additional Click interface available for optional **WiFi, LTE, or other connectivity** options.
- Additional **eInk display Click module interface** available for local display w/o BLE connected PC (enabled, but not officially supported).

Energy Harvesting Applications

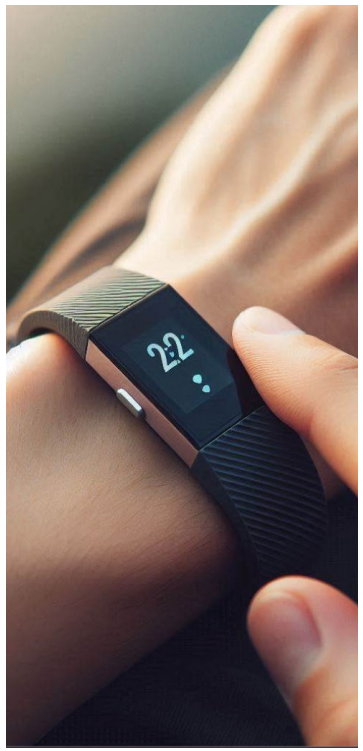
Why Harvest? *Extend* Battery Life or *Eliminate* Battery Entirely!

- Smart Home
- Smart Building
- Access Controls

- Remote Controls
- Video Game Console Controls



Remote Monitoring
- Bridge/highway
- Rail health
- Geology
- Weather Station



Wearable Bands

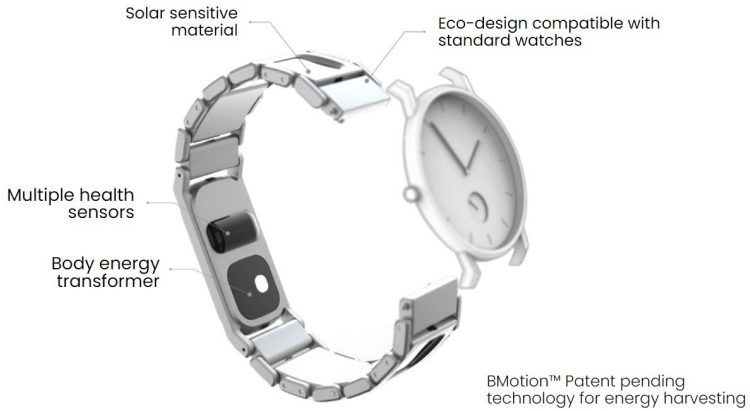
Asset Trackers
- Luggage
- Pets
- Cargo

- Factory Automation
- Predictive/Preventative Maintenance

Ambiq Wearable Band Example

Adding smarts to legacy/classic watches

Energy Harvesting



SONY
Wena 3 Smart Band
1 week battery life (w/o harvesting)
(Apollo 3 Blue Plus)

Baracoda
BHeart Smart Band
Infinite battery life (w/ harvesting)
(Apollo 3 Blue)

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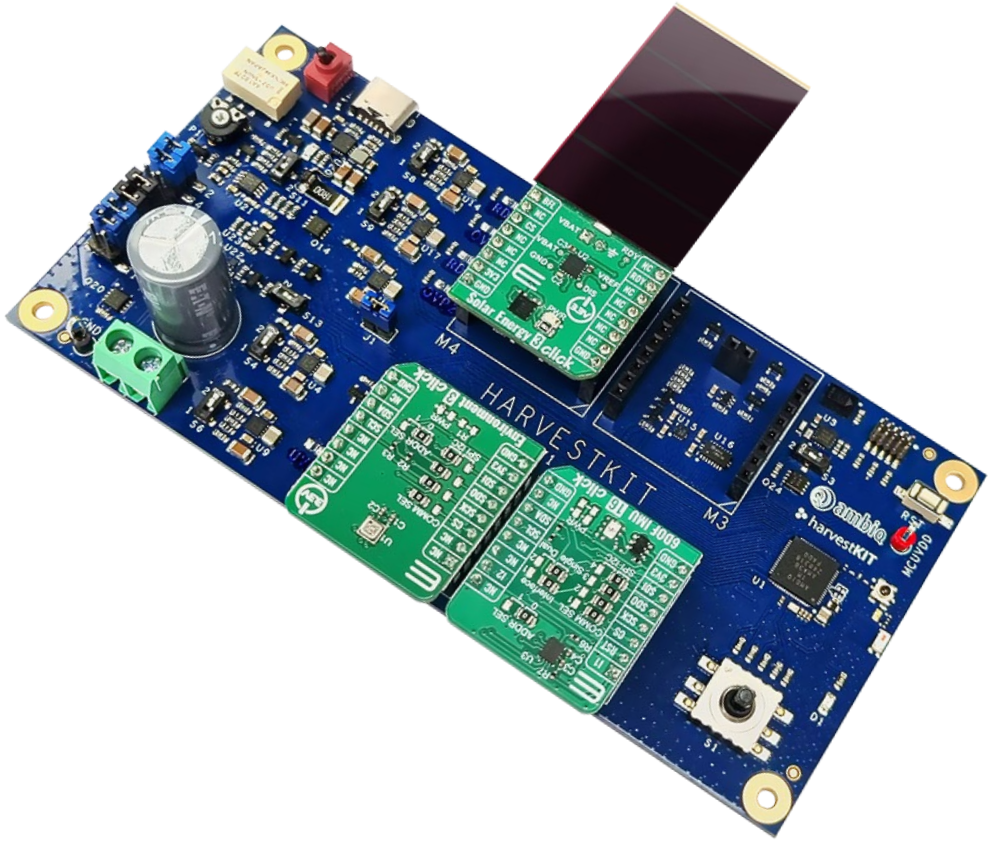
Reference Design Architecture



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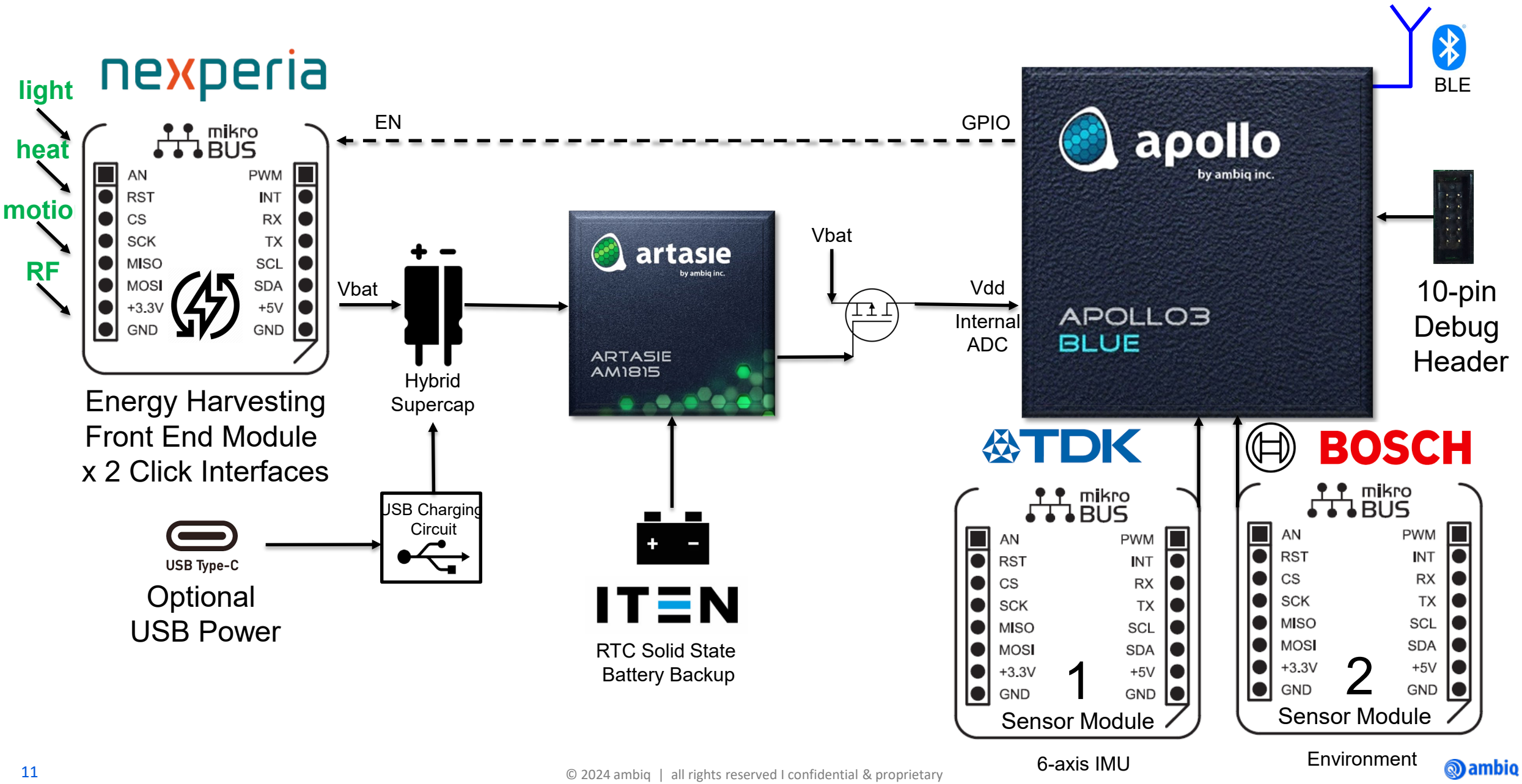
harvestKIT Block Diagram



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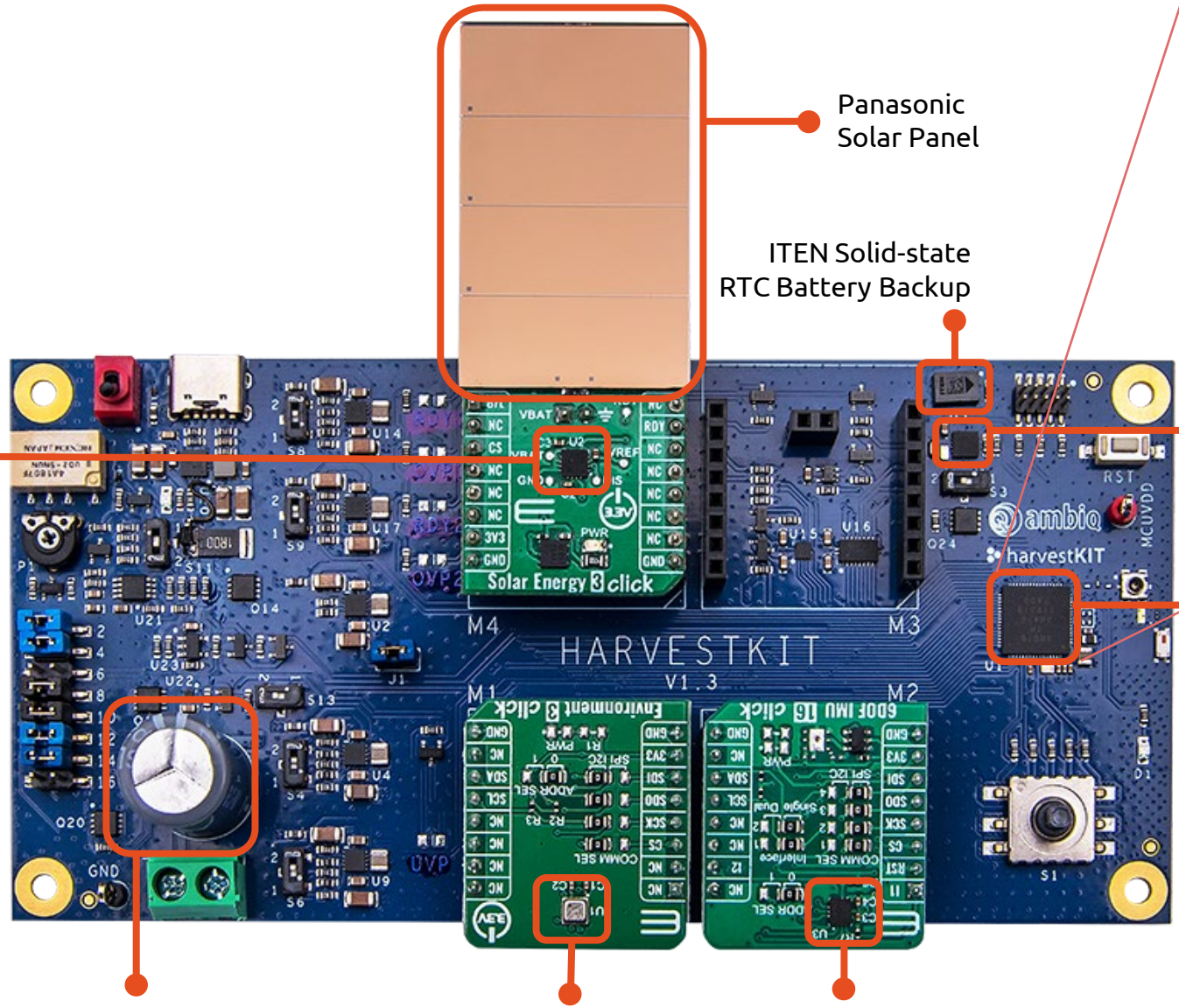
harvestKIT Key Components



Panasonic
Solar Panel

ITEN Solid-state
RTC Battery Backup

Nexperia
NEH2000BY
Energy Harvesting
PMIC

Ambiq Artasie
AM1805 RTC

Ambiq Apollo3
Blue SoC (QFN)

SiTime 32MHz
Resonator

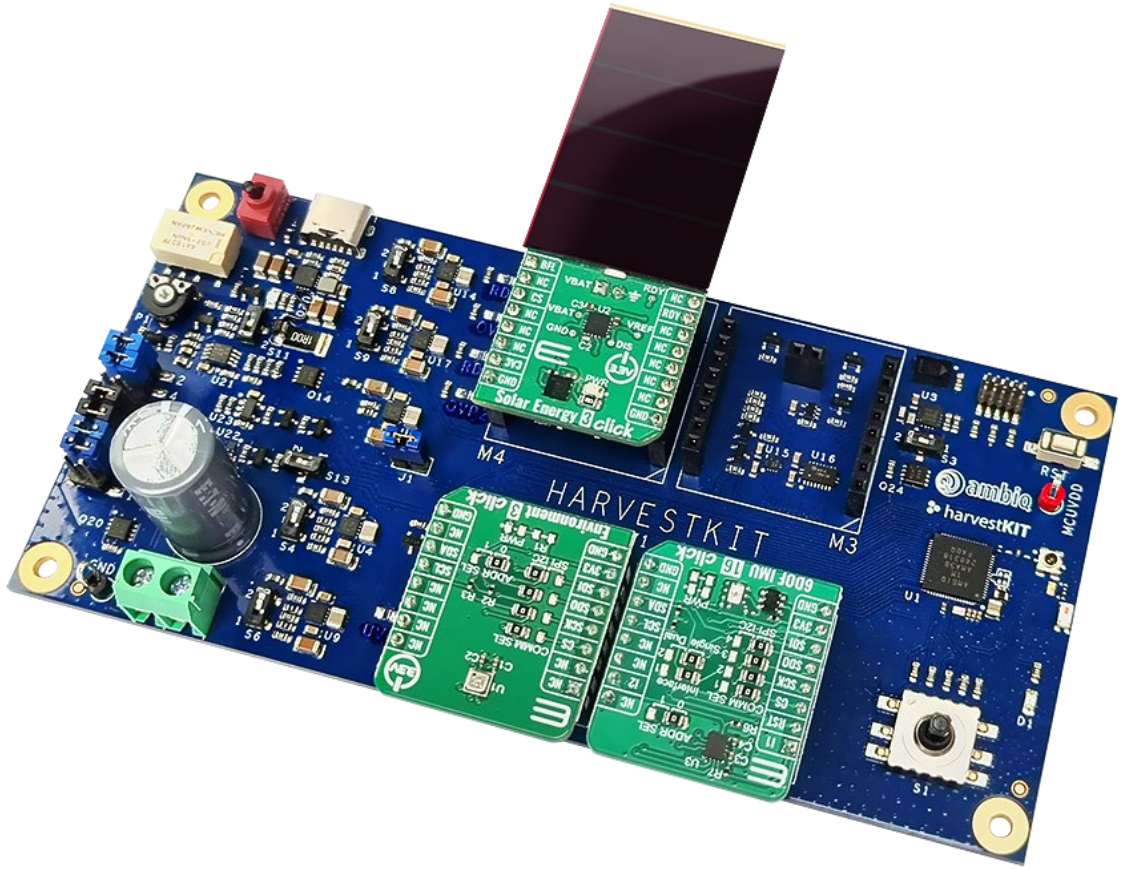
Epson 32KHz
Crystal

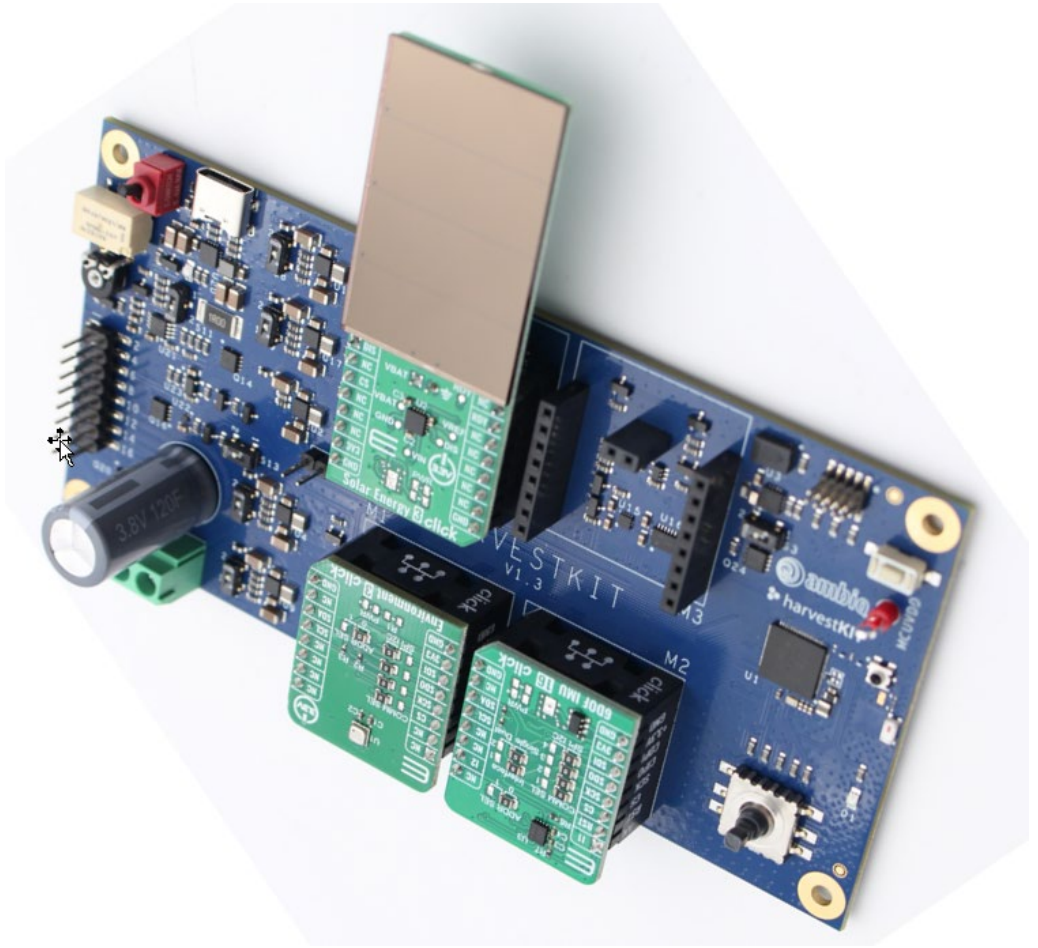
Eaton Hybrid
Supercapacitor

Bosch
BME688

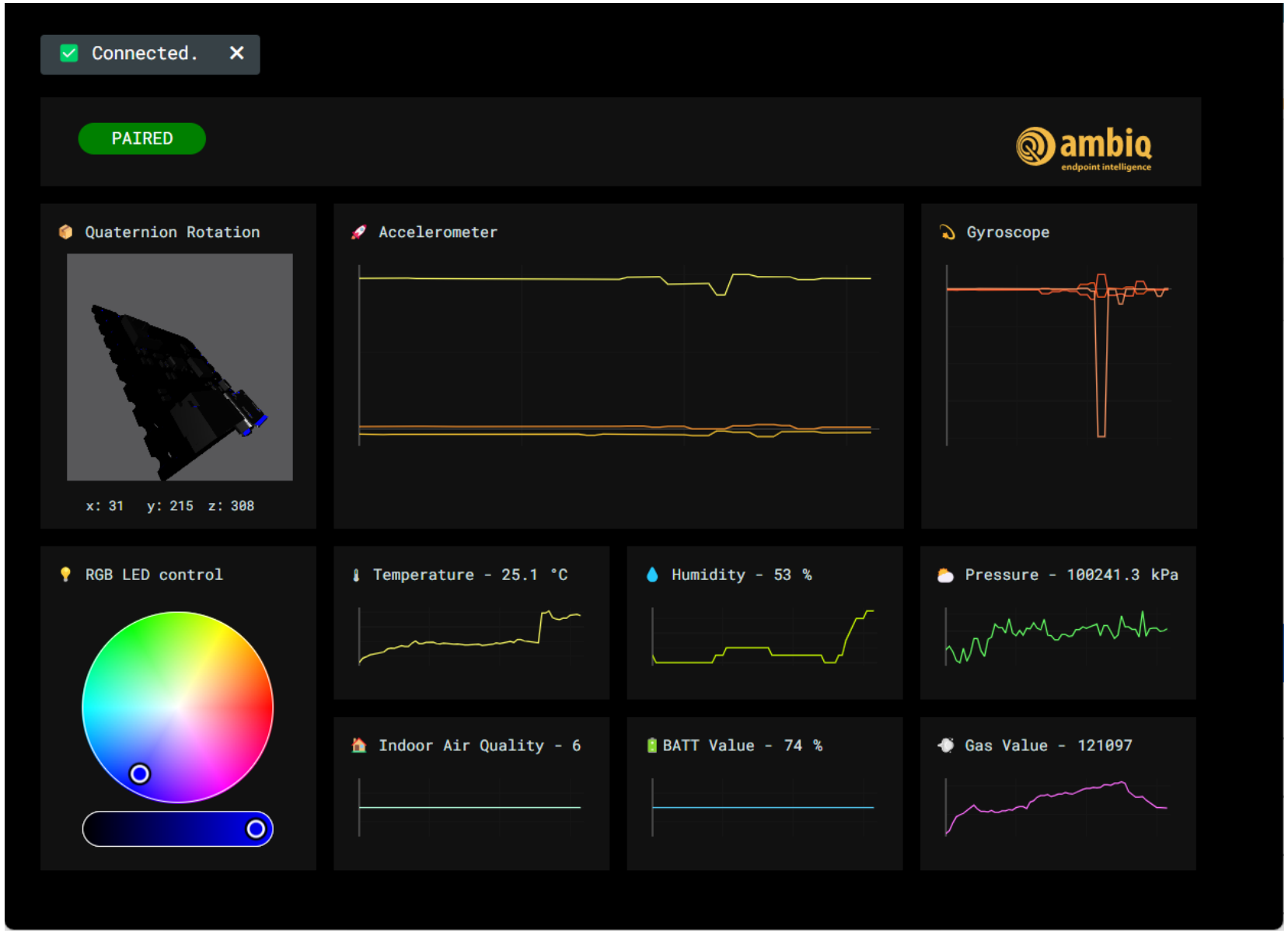
TDK ICM-
45605

HarvestKit Photo (Final Production HW Rev 1.3)





HarvestKit Chrome Web App GUI (Prelim)



- **Nexperia NEH2000BY**
  - Batt Value (cap voltage)
- **TDK ICM-45605 IMU**
  - Quaternion Rotation
  - Accelerometer
  - Gyroscope
- **Bosch BME688**
  - Temperature
  - Humidity
  - Air Pressure
  - Air Quality
  - Gas Value (resistance)
- **RGB LED**
  - To Be Removed
  - Does not exist

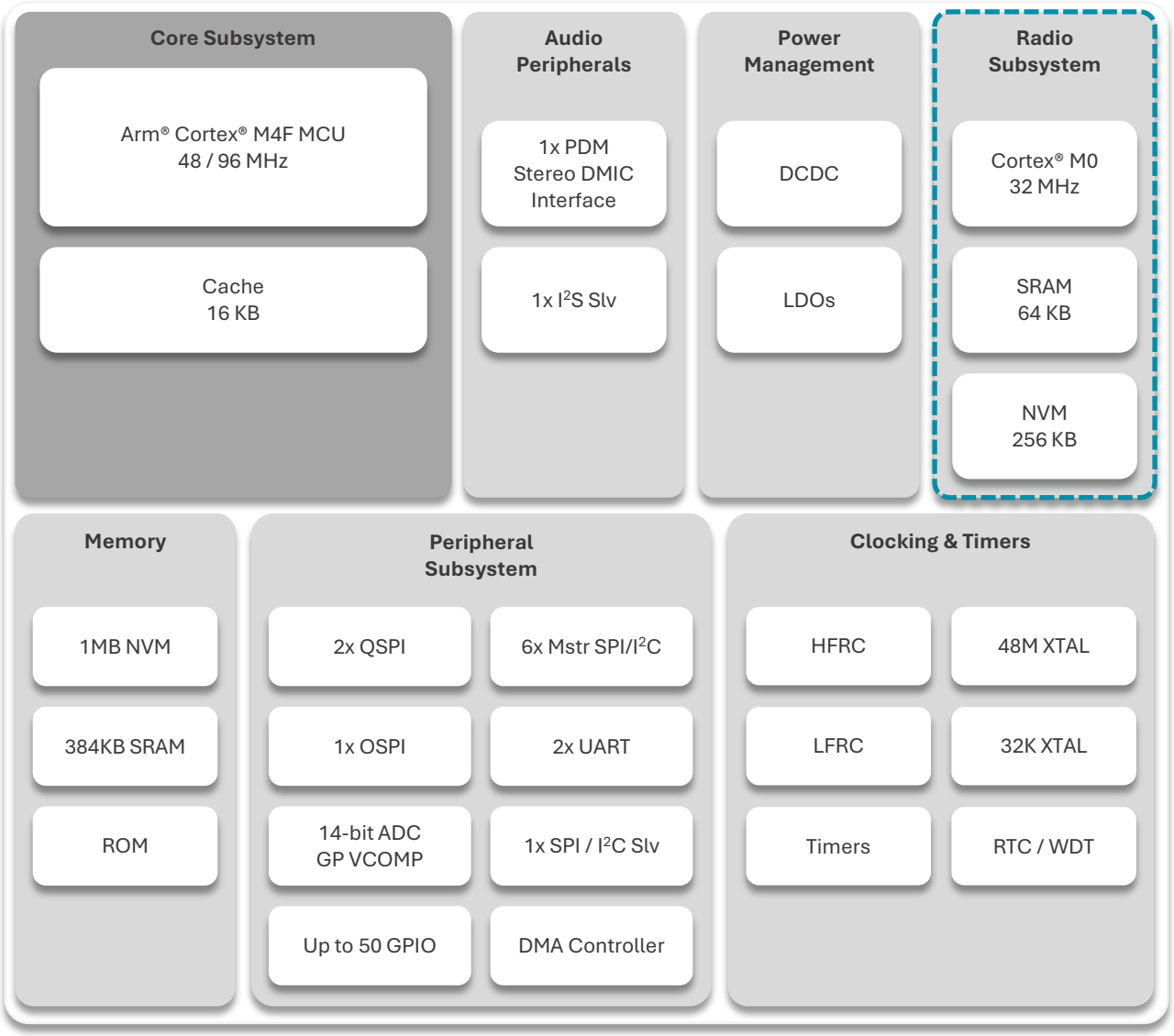
Basic

Apollo3 & Apollo3 Blue

Arm Cortex-M4F core MCU at up to 96 MHz
Dedicated Arm Cortex-M0 network coprocessor
1MB Embedded NVM
384MB Embedded SRAM
16KB 2-way Associative/Direct-Mapped Cache
Bluetooth Low Energy 5 (Apollo3 Blue)
OSPI, PDM stereo DMIC interface

Available now.

Apollo3 & Apollo3 Blue Specifications



Bluetooth® Low Energy 5 connectivity in Apollo3 Blue.

Arm® Cortex® M4F, 48 / 96 MHz

- Executing from flash or RAM @ 1.8V
  - 18 µW/MHz While Loop (10 µA/MHz)
  - 33 µW/MHz CoreMark® (18 µA/MHz)
- 2.9 µW (1.6 µA @ 1.8V) deep sleep mode w/ RTC
  - 25µs deep sleep wake to run mode (buck)
- secureSPOT 2.0 features including Secure Boot and Root of Trust
- 1MB NVM, 384KB SRAM, 16KB 2-way Associative/Direct-Mapped Cache
- Single Floating Point

Peripherals

- 2x UART
- 2x QSPI
- 1x OSPI
- 1x PDM stereo DMIC interface with low-power always-on & HiFi audio modes
- 6x SPI/I2C masters
- 14b ADC (15-ch)
- Up to 50 GPIO (Apollo3 Blue: 38)

Bluetooth® Low Energy 5 (Apollo3 Blue)

- Arm® Cortex® M0, Up to 32 MHz network processor
- Tx Power: Up to +3dBm
- Rx Sensitivity: -93dBm (1Mbps)

Package Options

- Apollo3: 5 mm x 5 mm x 0.8 mm, 81-pin BGA, 50 GPIO
- Apollo3: 3.25 mm x 3.37 mm x 0.51 mm, 66-pin WLCSP, 37 GPIO
- Apollo3 Blue: 3.25 mm x 3.37 mm x 0.34 mm, 66-pin Thin WLCSP, 37 GPIO
- Apollo3 Blue: 8 mm x 8 mm x 0.8 mm, 64-pin QFN, 38 GPIO

Temperature Range

- Commercial: -20 to +60 °C
- Industrial: -40 to +85 °C

Apollo3 Family Packages and EVBs

harvestKIT	Part Number	Part Number	BLE	Package	Dimension [mm]	Temp
	APOLLO3	AMAP31KK-KCR	No	66-pin CSP	3.25 x 3.37 x 0.452	- 40 to +85° C
harvestKIT Proto (Rev 1.2)	**APOLLO3 BLUE**	**AMA3B1KK-KBR-B0**	**Yes**	**81-pin BGA**	**5 x 5 x 0.665**	**- 40 to +85° C**
	APOLLO3 BLUE	AMA3B1KK-KCR-B0	Yes	66-pin CSP	3.25 x 3.37 x 0.452	- 40 to +85° C
harvestKIT Final (Rev 1.3)	**APOLLO3 BLUE**	**AMA3B1KK-KQR-B0**	**Yes**	**64-pin QFN**	**8 x 8 x 0.8**	**- 40 to +85° C**
	APOLLO3 BLUE THIN	AMA3B1KK-KCR-TB	Yes	66-pin WLCSP	3.25 x 3.37 x 0.3	- 40 to +85° C
	APOLLO3 BLUE PLUS	AMA3B2KK-KBR	Yes	108-pin BGA	5.3 x 4.3 x 0.8	- 40 to +85° C

Apollo3 Blue
BGA

Apollo3/Apollo3 Blue
WLCSP

Apollo3 Blue
QFN

Apollo3 Blue Plus
BGA

Apollo3 Blue Plus
AMA3B2EVB

Apollo3 Blue
AMA3BEVB

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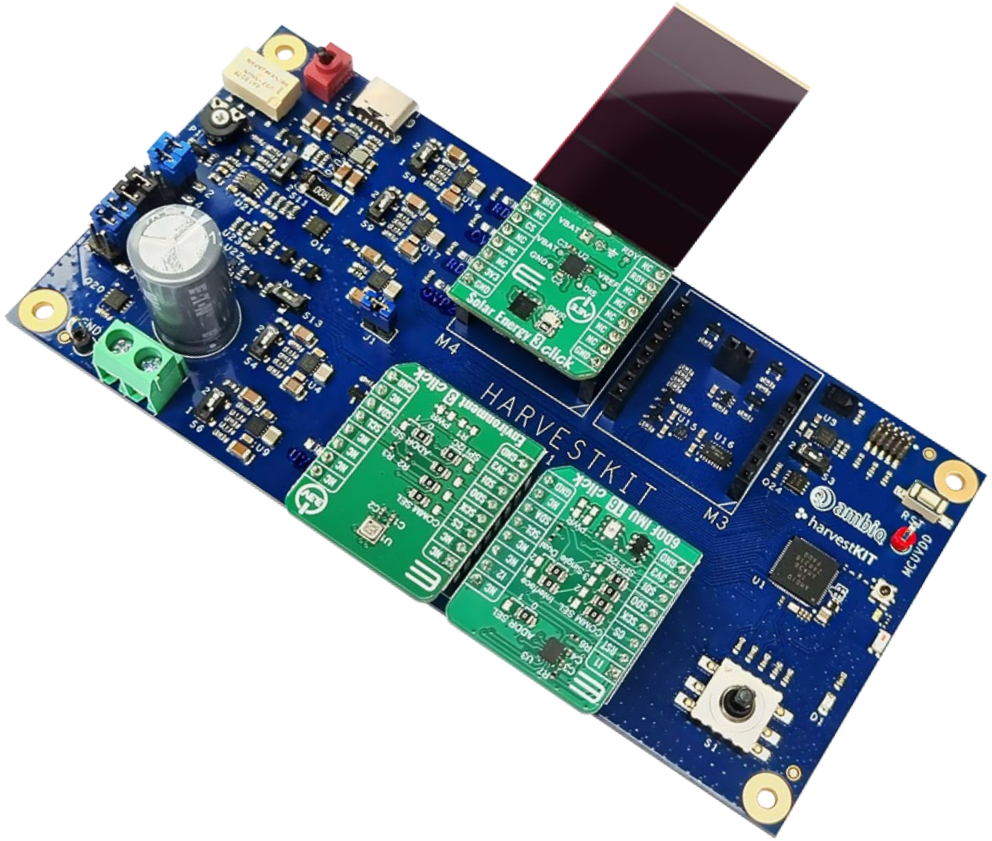
Ref Design HW Guidelines



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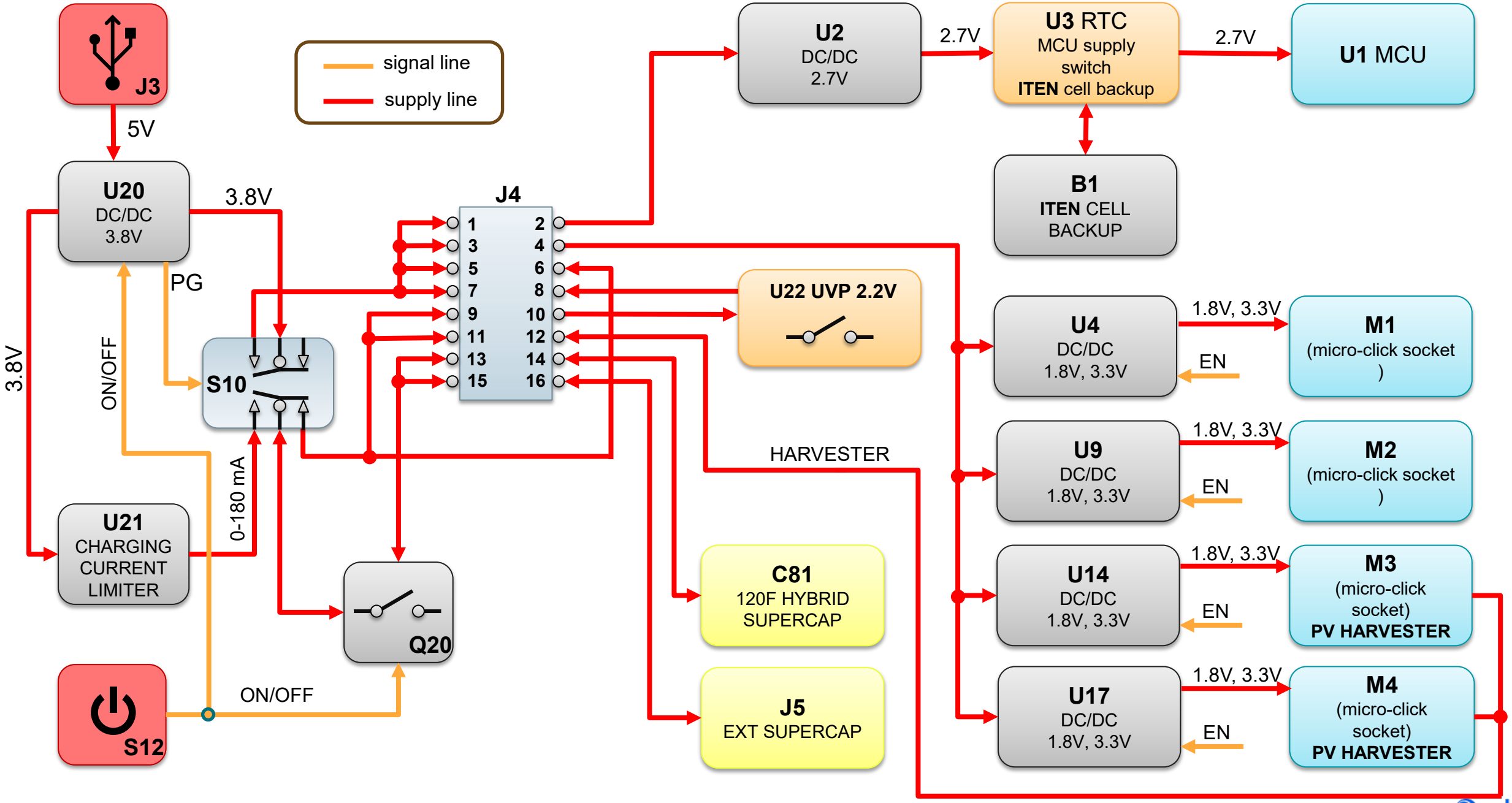
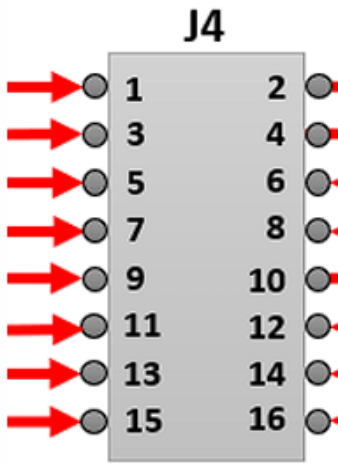
POWER SUPPLY SCHEME



Socket J4 guideline



1-2 : RTC+MCU supply line

3-4 : Micro-click sockets supply line

5-6 : Supercapacitor backup supply line
if UVP switch is not used. Jumpers 7-8 and 9-10 must be removed.

7-8 : UVP switch output for supercapacitor supply line

9-10 : UVP switch input for supercapacitor supply line

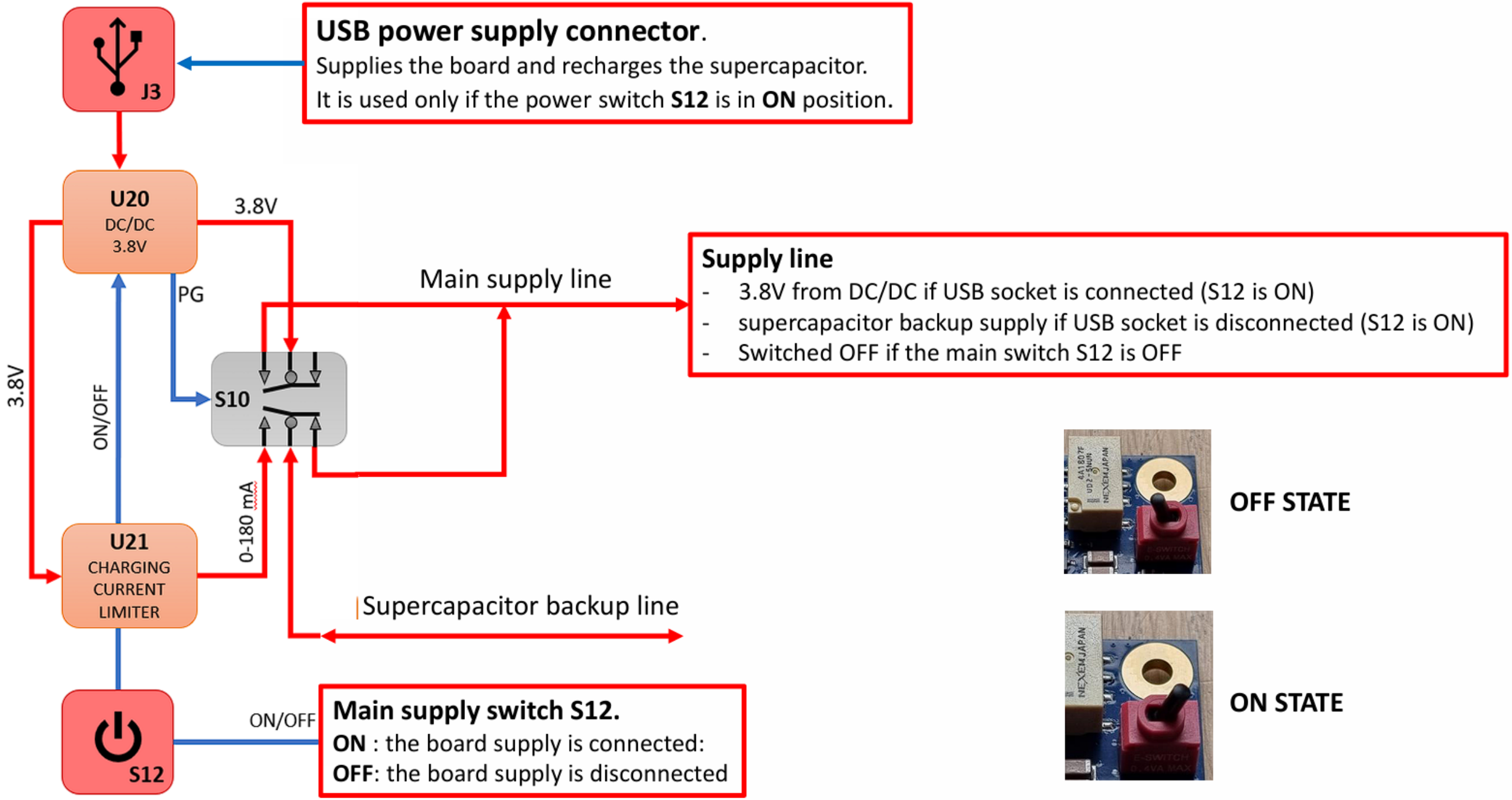
11-12 : Harvester supply line. Used for supercapacitor charging.

13-14 : Supercapacitor C81 connecting jumper.
Remove it if the board will be not used for a long time.

15-16 : External supercapacitor connecting jumper.
Jumper 13-14 should be removed if used

POWER SUPPLY

Main supply ON/OFF switch



USB power supply connector.
Supplies the board and recharges the supercapacitor.
It is used only if the power switch **S12** is in **ON** position.

Supply line
- 3.8V from DC/DC if USB socket is connected (S12 is ON)
- supercapacitor backup supply if USB socket is disconnected (S12 is ON)
- Switched OFF if the main switch S12 is OFF

Main supply switch S12.
ON : the board supply is connected:
OFF: the board supply is disconnected

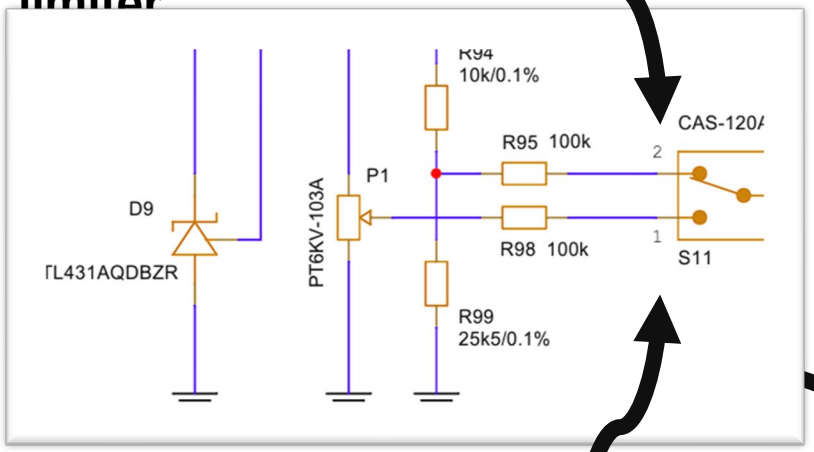
OFF STATE

ON STATE

Supercap charging circuit

Supercap charging circuit

Charging curent limiter



S11-2: -> Imax = 180 mA

S11-1: Imax = 0…180 mA (P1)

signal line
supercap charging path
main board supply line
disconnected

J3

+5V connected

5V

U20
DC/DC
3.8V

3.8V

PG

3.8V

ON/OFF

S10

J4

1 2
3 4
5 6
7 8
9 10
11 12
13 14
15 16

HARVESTER

U21
CHARGING
CURRENT
LIMITER

0-180 mA

Q20

C81
120F HYBRID
SUPERCAP

J5
EXT SUPERCAP

S12

ON/OFF

ON state

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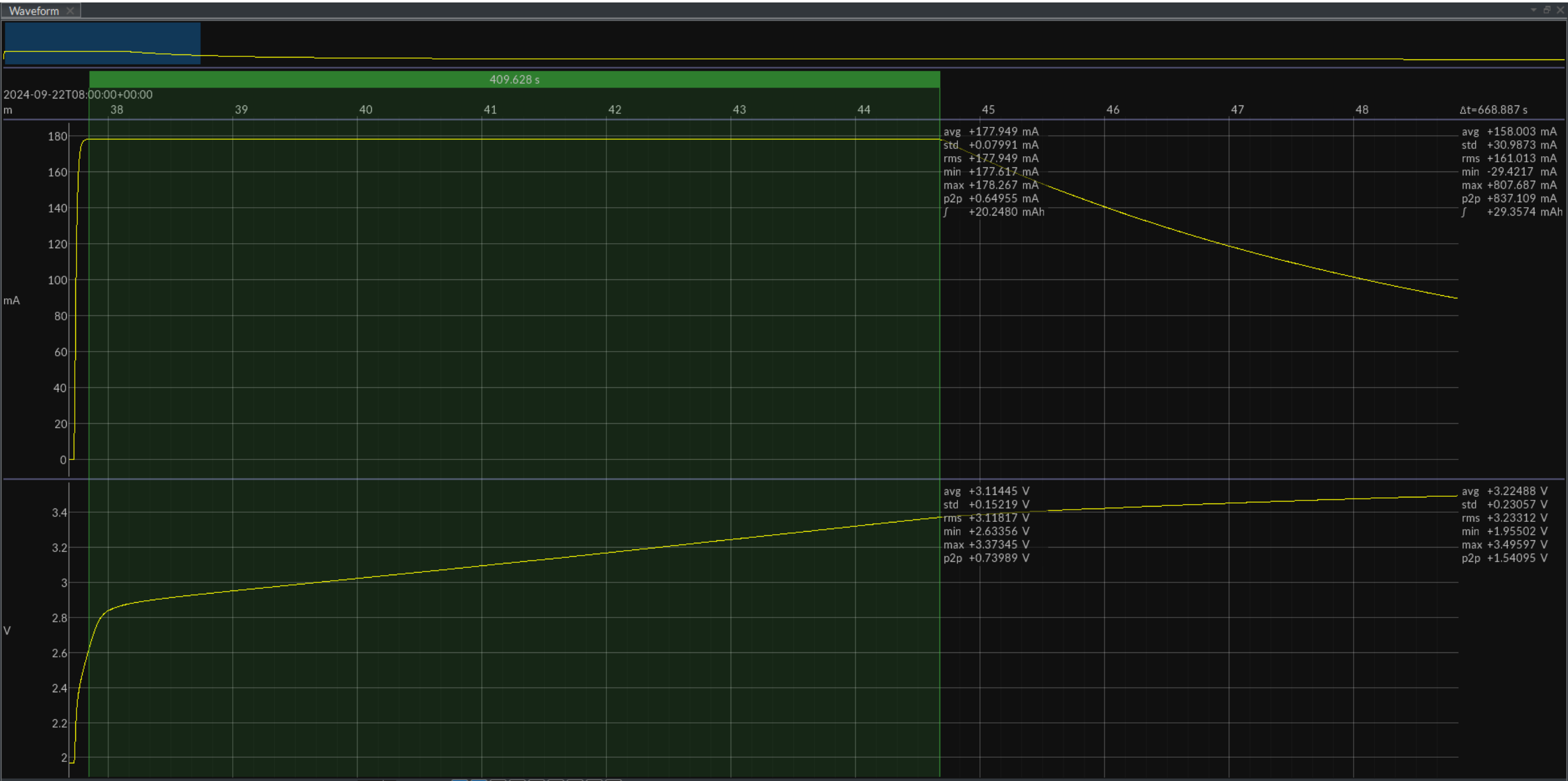
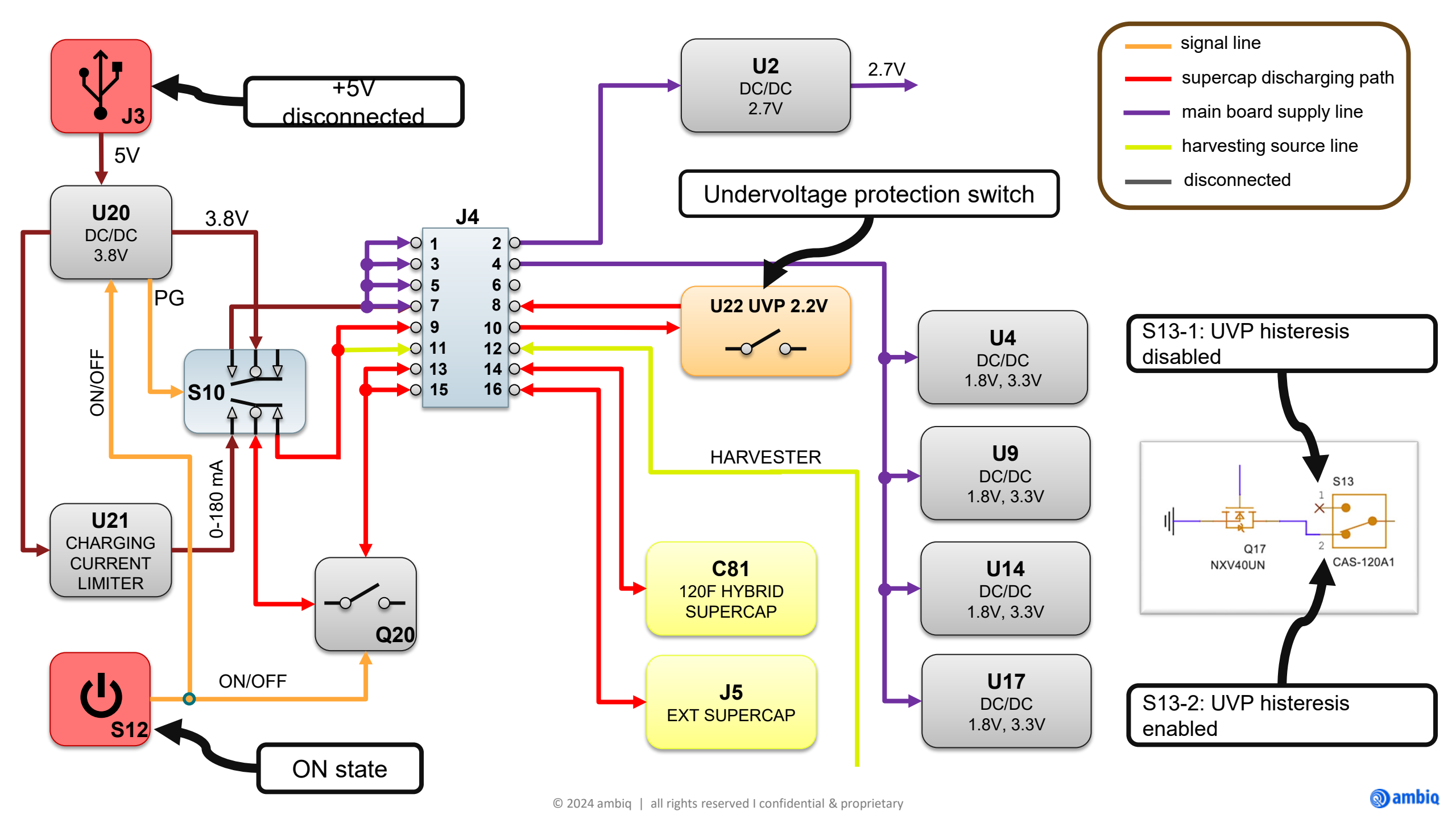
Charging haracteristic, 120 F supercap

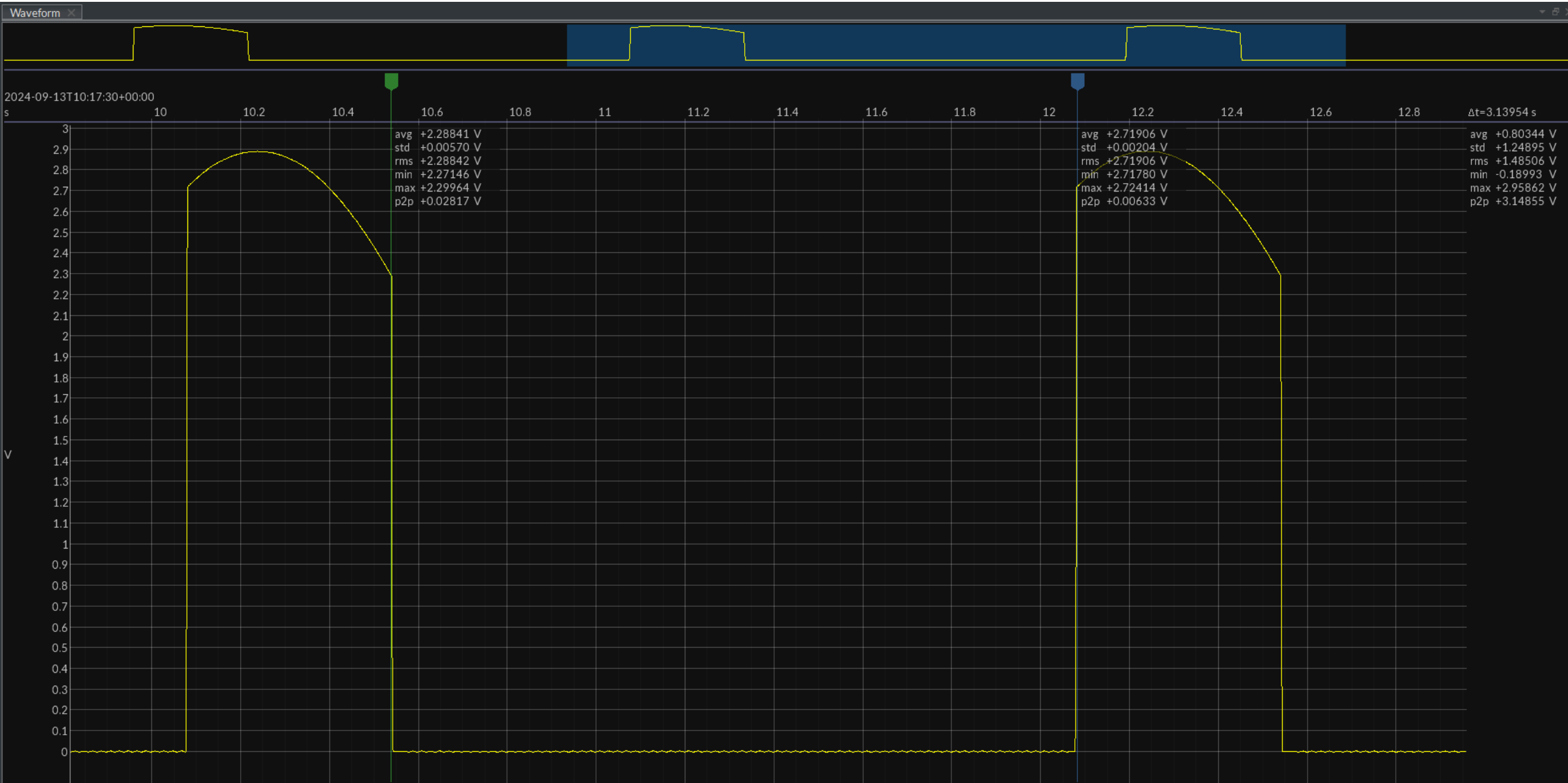


Supercap discharging circuit

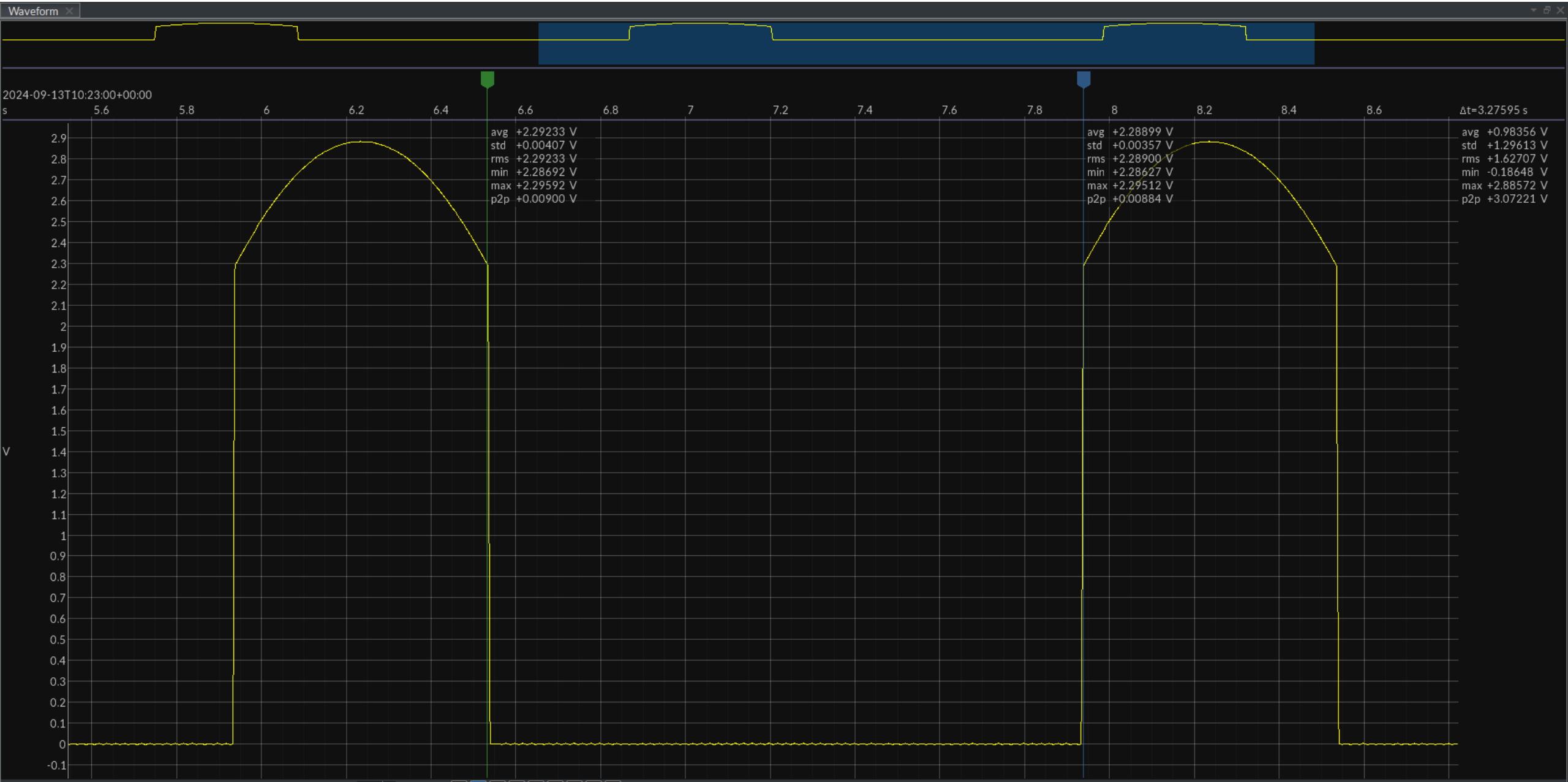
UVP - Undervoltage Protection



UVP haracteristic, hysteresis enabled

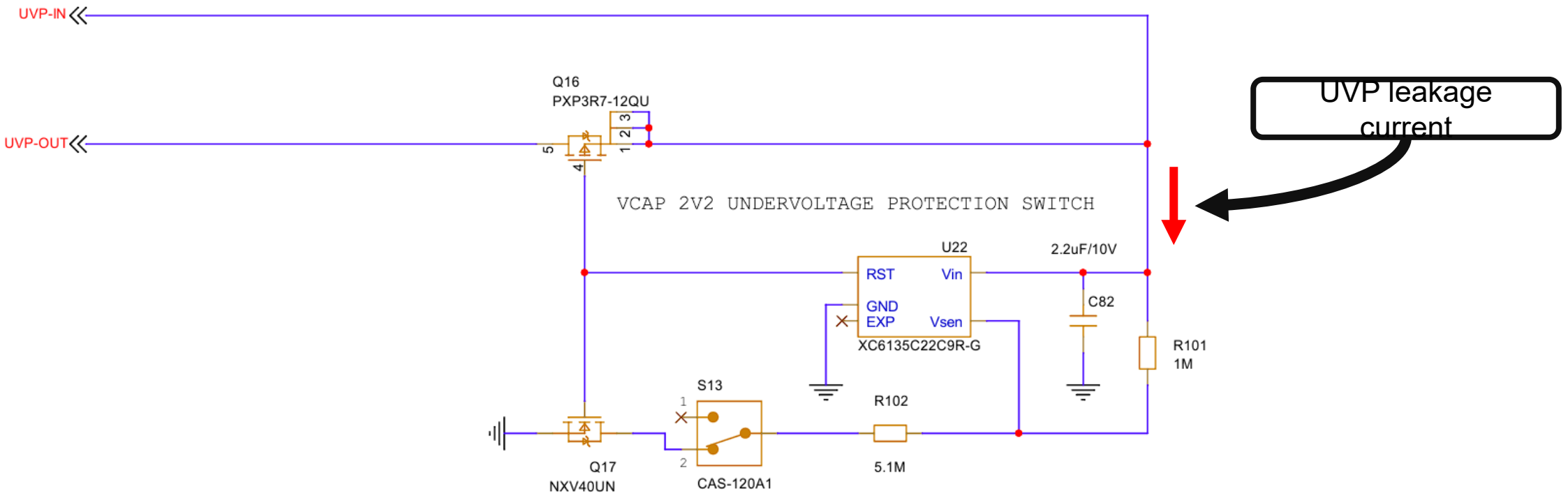


UVP haracteristic, hysteresis disabled



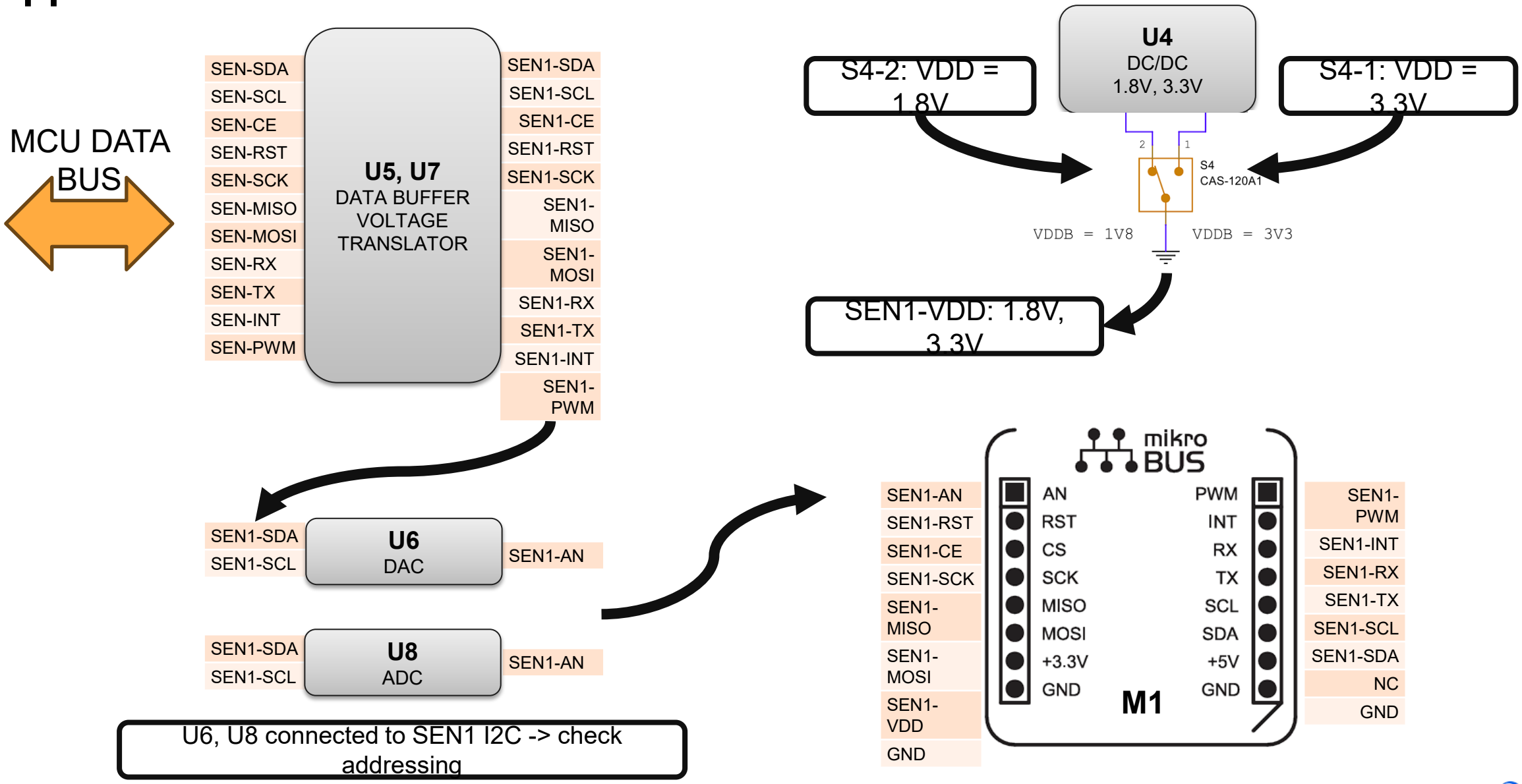
UVP typical leakage current

UVP state	Leakage current
Ucap = 3V, UVP inactive, hysteresis enabled	160 nA
Ucap = 3V, UVP inactive, hysteresis disabled	160 nA
Ucap = 2V, UVP active, hysteresis enabled	438 nA
Ucap = 2V, UVP active, hysteresis disabled	134 nA

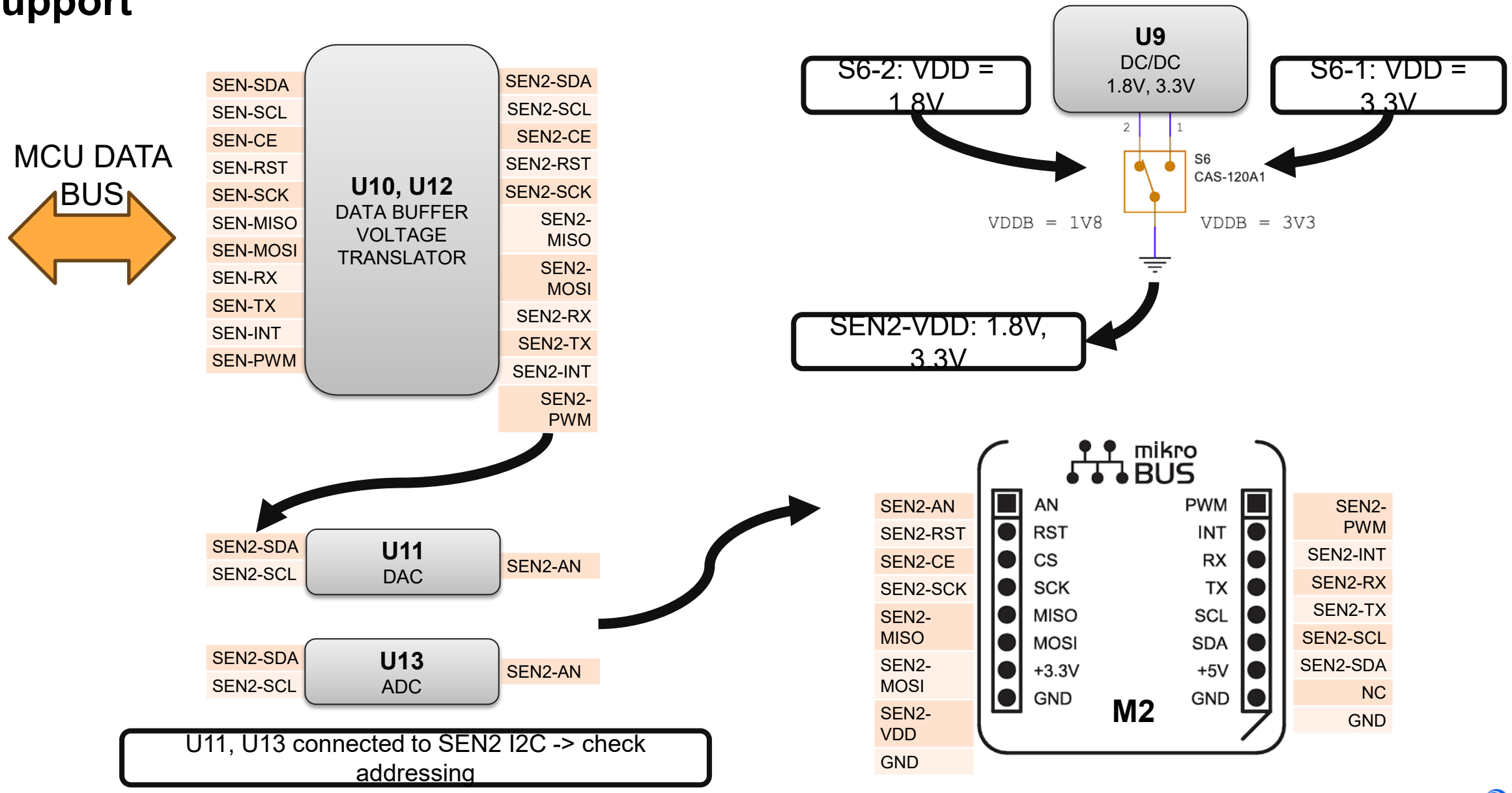


MicroBus sockets

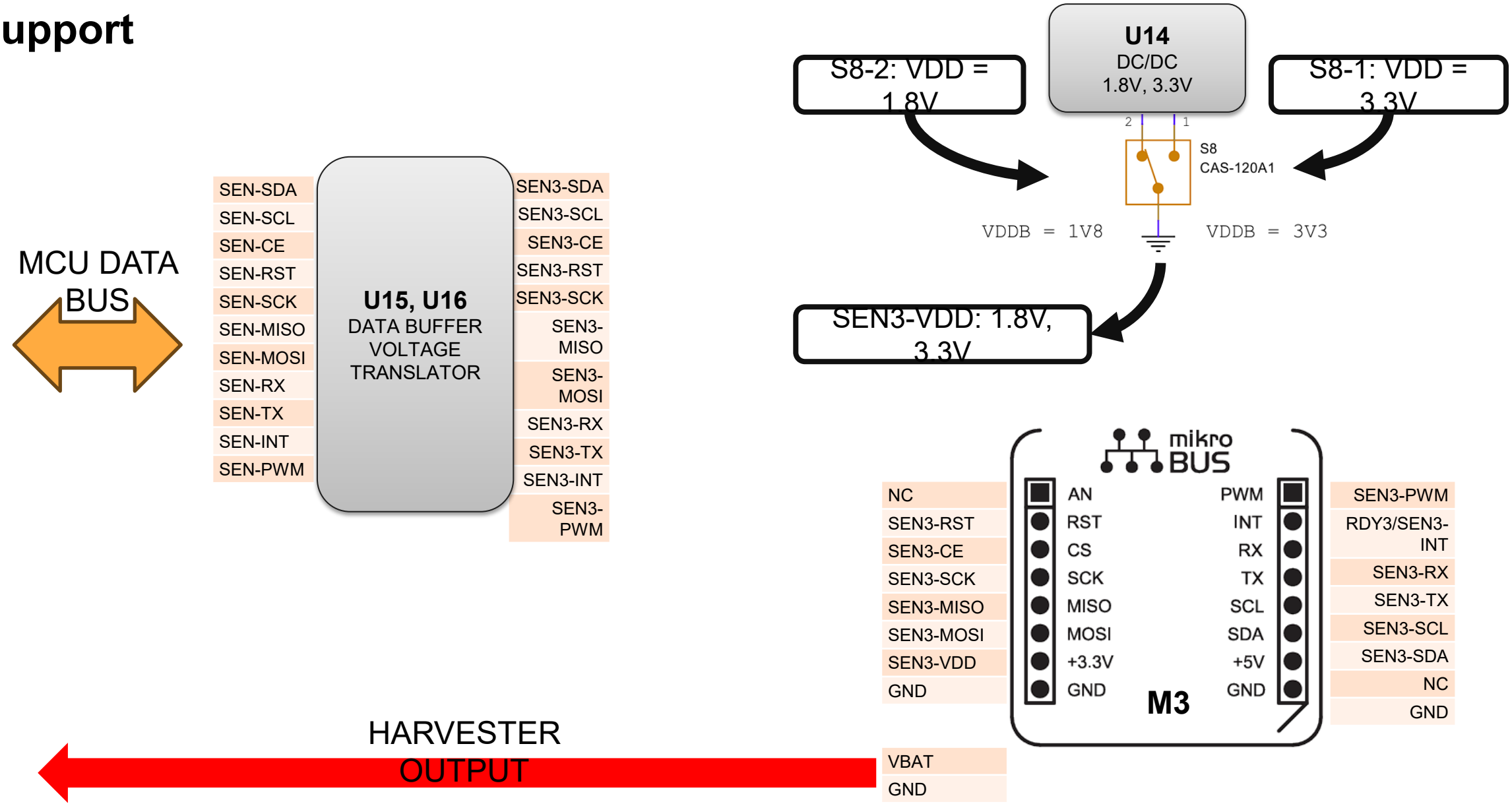
M1: MicroBus socket support



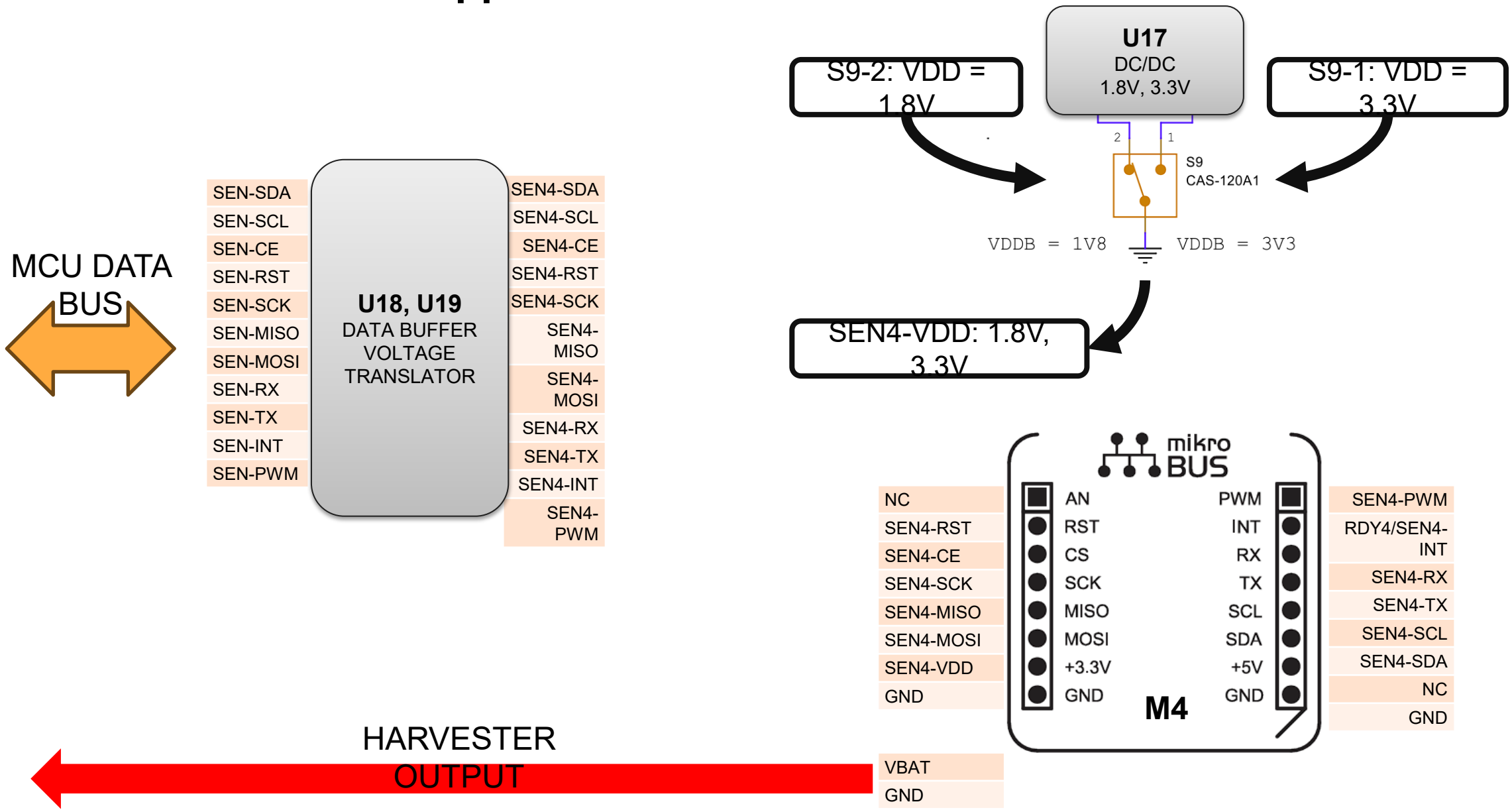
M2: MicroBus socket support



M3: MicroBus socket support

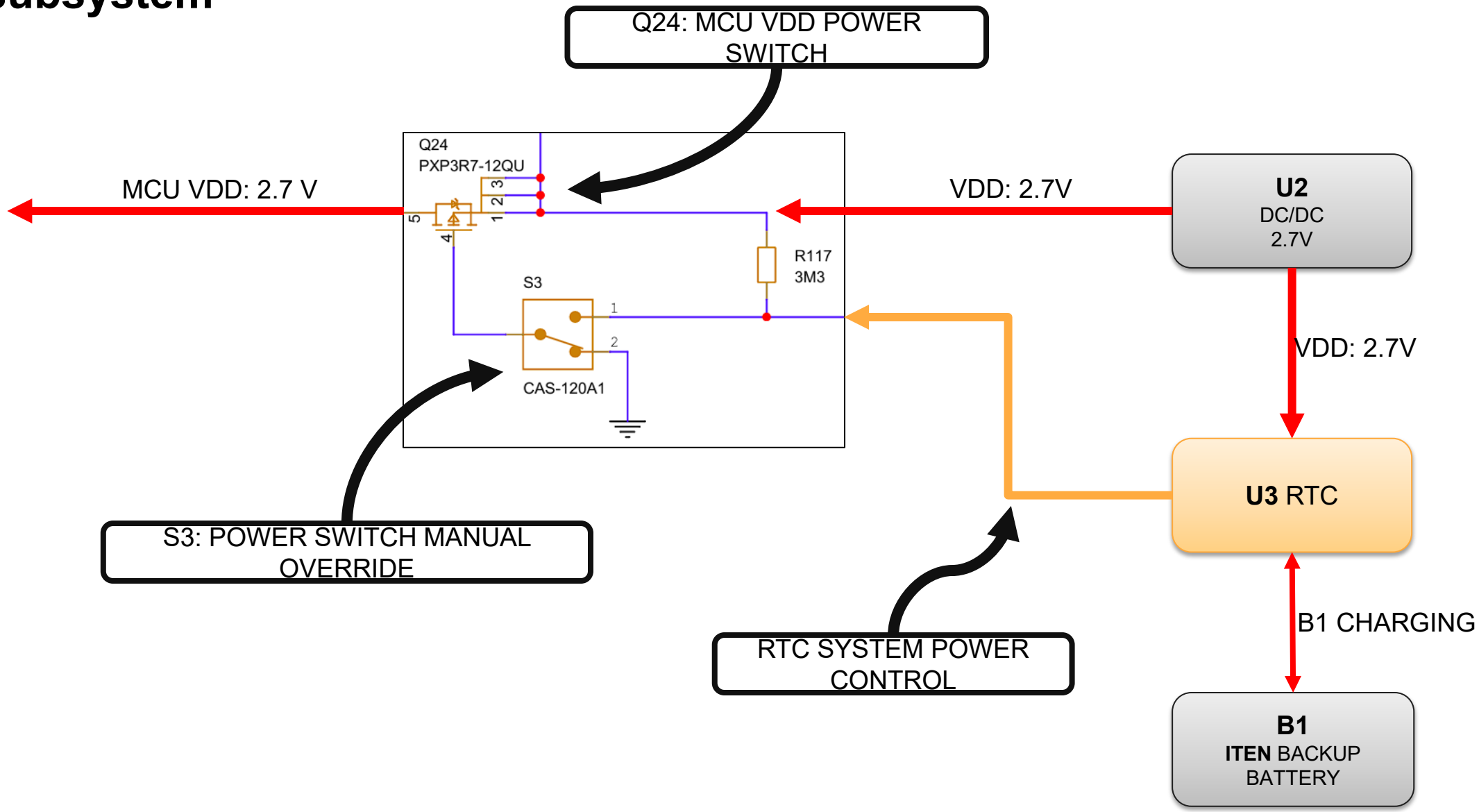


M4: MicroBus socket support



RTC subsystem

RTC subsystem

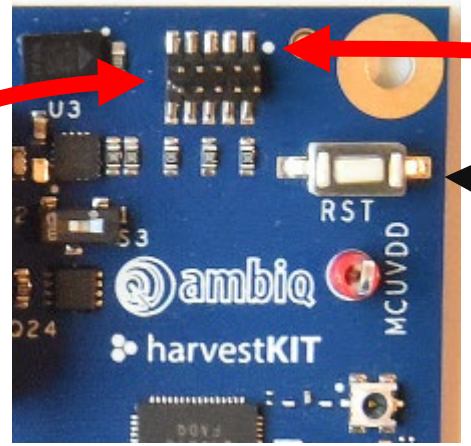


Debug interface

Debug interface

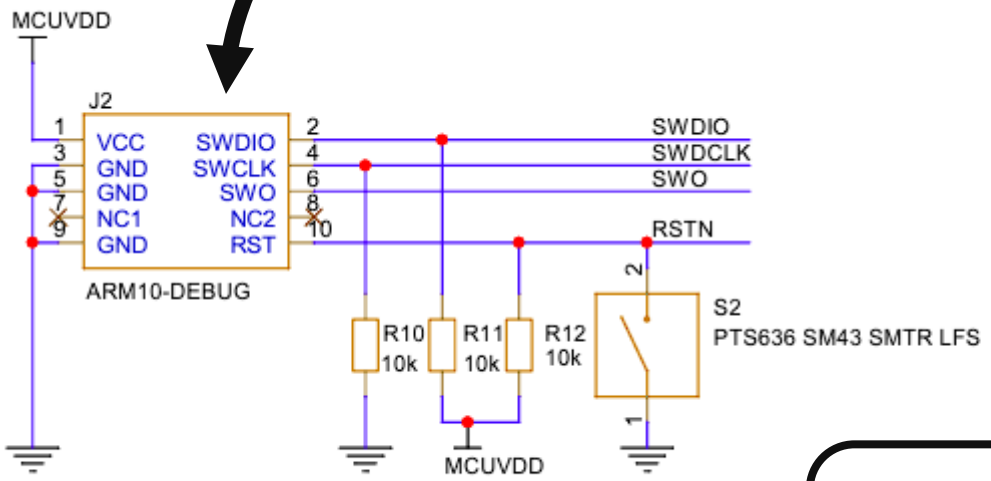
MCUVDD = 2.7V

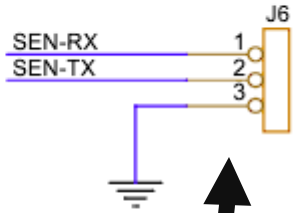
ARM10 - SWD



J2-PIN1

S2: RESET





S2: RESET

J6: UART RX / TX (2.7V logic level)
WARNING: SEN-TX line ONLY for SBL firmware recovery and override.
See „Apollo3-Blue-Plus-Secrity-Getting-Started-Guide.pdf", Chapter 10.
Don't connect SEN-TX in application: possible collisions

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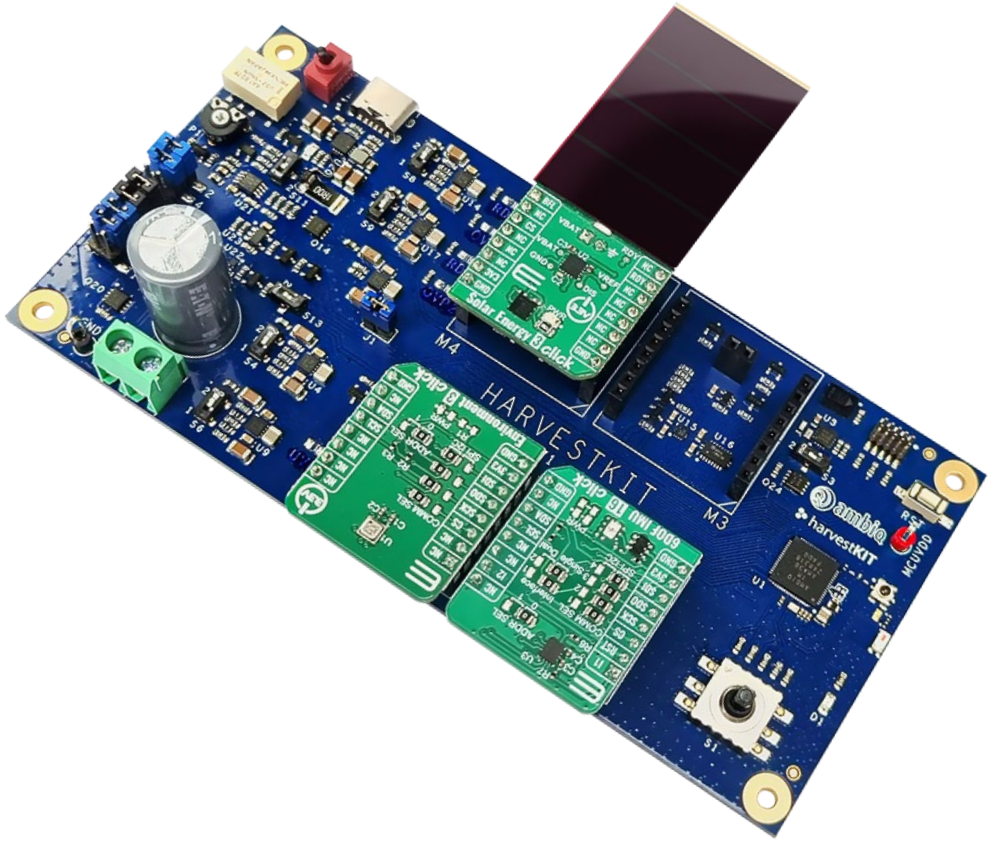
Ref Design SW Guidelines



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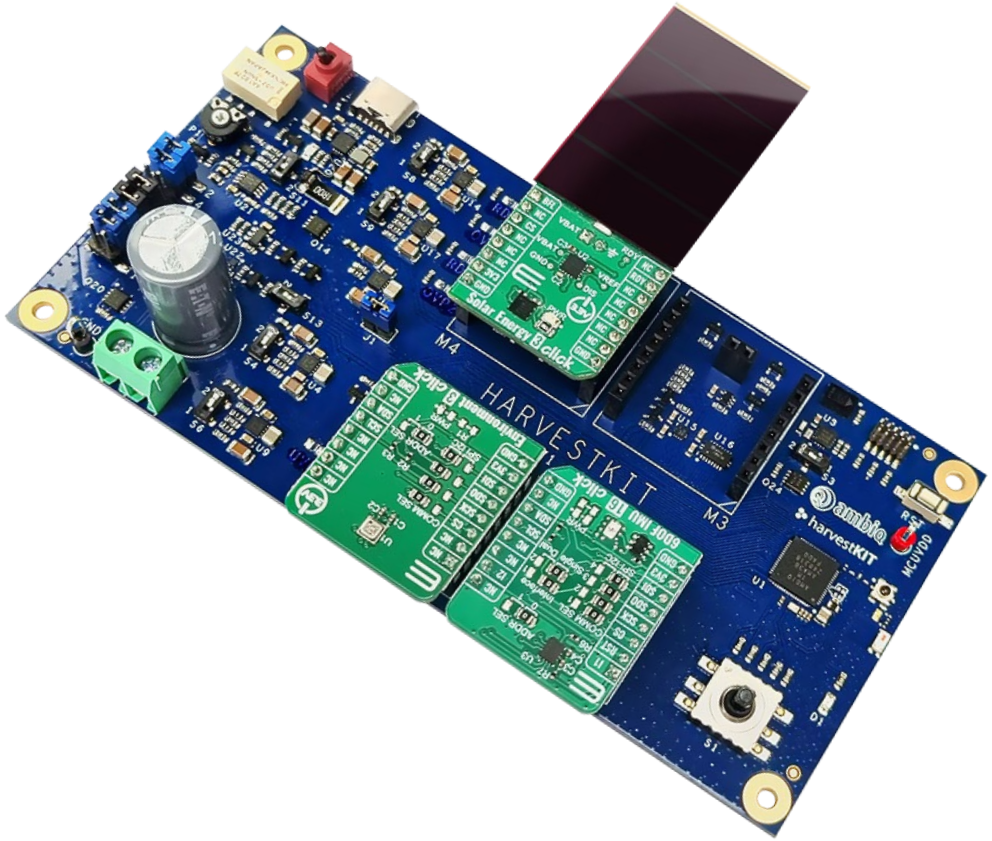
Harvesting Partners



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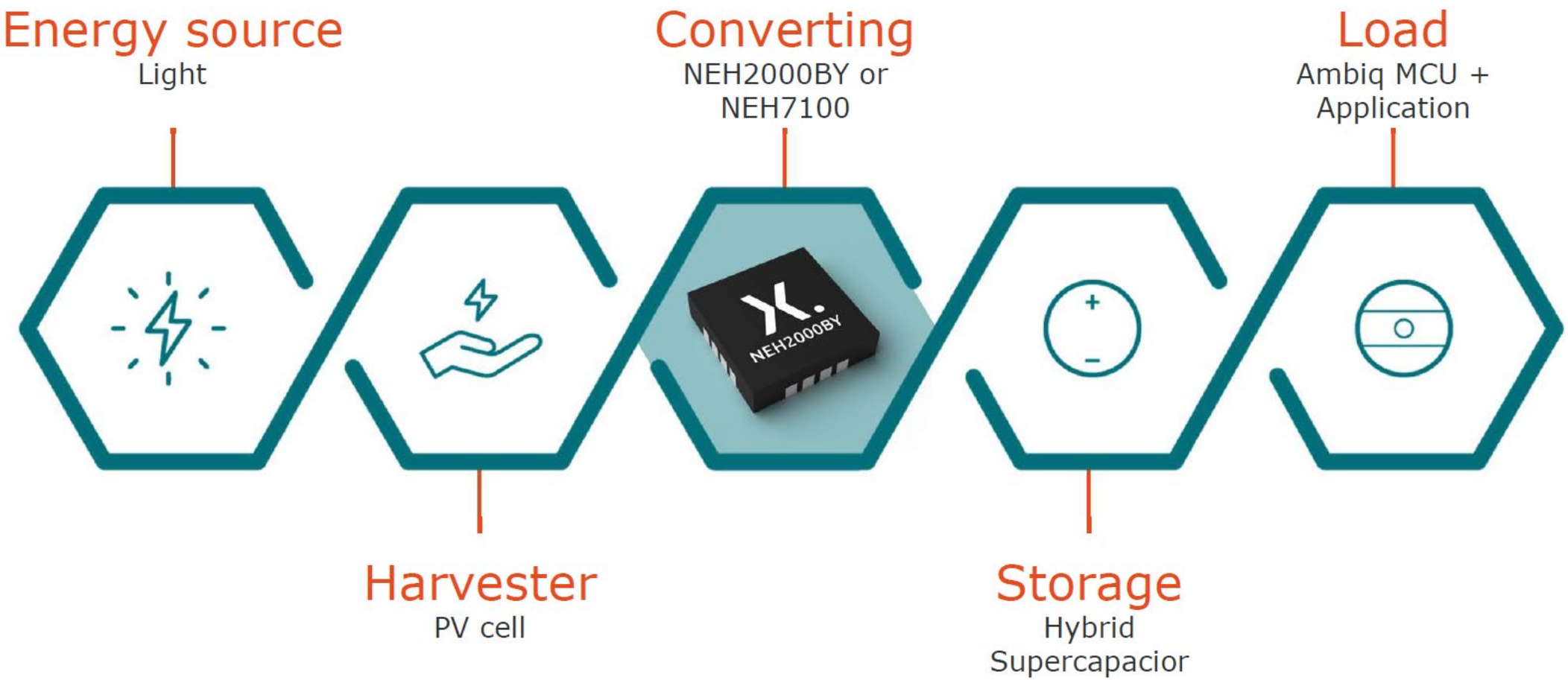
Nexperia PV Harvesting

Energy harvesting | System



NEH2000BY | Product at a Glance

Design benefits

- High-efficiency low-power DC-DC converter designed for light Energy Harvesting
- Embedded ultra-fast Maximum Power Point Tracker – MPPT
- Small BOM with no external inductor required
- Compact QFN16 - package 3x3 mm
- Assembly footprint of ~12mm2

Applications

- Smart home: TV remote controls, smart tags, keyboards, home sensors
- Smart city: beacons, IoT sensor networks, industrial monitoring
- Wearables: smart bands, earbuds, smart shoes, smart glasses, health monitoring
- Retail: Electronic shelf labels, asset trackers

Product Roadmap

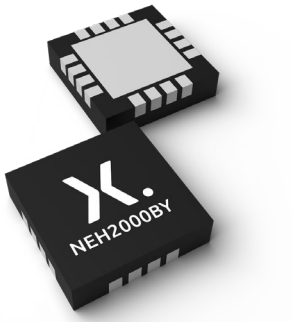
Device Part Number	Power Range	Conversion Efficiency	Boosting Factor	MPPT Interval	LDO, OVP, LVD, USB, Cold Start, I2C	Harvester
NEH2000	35uW to 2mW	Up to 80%	2x	1s	Not Supported	PV-Cells
NEH7100	10uW to 50mW	Up to 90%	2x, 4x, 8x, 16x	0.5s to 64s	Supported	PV-Cells, RF, Piezo, TEG

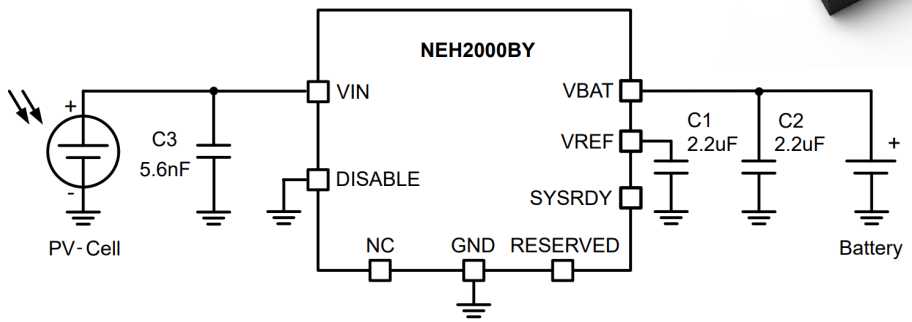
Key technical features

- Harvesting power range from 35uW to 2mW
- Conversion efficiency: up to 80%
- Battery voltage: 2.5V .. 4.5V
- Boosting factor: 2x
- MPPT interval: 0.7s
- Time for MPPT optimization: 10ms
- Standby current: < 625 nA
- Only three external capacitors required
- Temperature range: -40 to 85degC

Engineering support

- Datasheet
- Reference Design
- Evaluation board



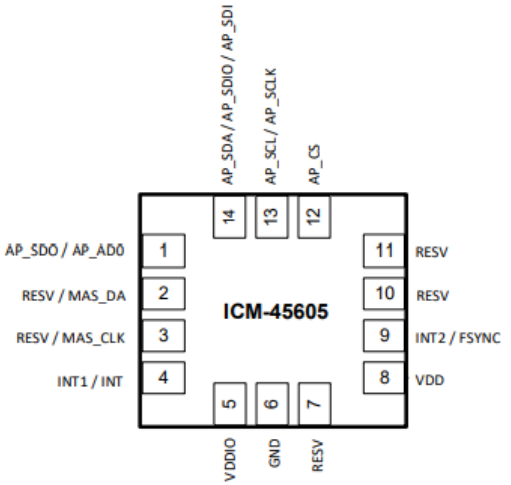


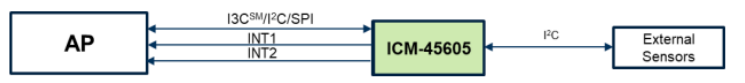
ICM-45605 Industry's Lowest Power 6-Axis IMU

Attracting Tomorrow

Features

- Industry's lowest power 6-axis IMU enables "always on" gyroscope with 40% power reduction
- Superior vibration rejection & temperature stability with BalancedGyro™ technology
- Low noise gyroscope and accelerometer: 3.8mdps/√Hz; 70µg/√Hz
- User-programmable interrupts and digital filters
- Up to 8kB FIFO supports 20-bit data format high resolution sensor data
- Host interface: 12.5 MHz I3C℠, 1 MHz I²C, 24 MHz SPI; 400 kHz I²C master on auxiliary interface
- Supports 1.2V VDDIO; 1.8V -3.3V VDD
- Register based Motion Functions: Wake on Motion, Pedometer, Tilt Detection, Low-g/high-g Detection, Freefall Detection, Significant Motion Detection, Single/double tap
- Small Package size: 2.5 x 3.0 x 0.81 mm (14-pin LGA)





Key Parameters			
Accel Full scale Range	**±2g**		**±16g**
Accel Sensitivity Error		**±0.5%**	
Accel Offset		**±20 mg/°C**	
Accel Offset vs. Temp		**±0.15 mg/°C**	
Accel Noise Density		**70 µg/√Hz**	
Gyro Full scale Range	**±15.625 dps**		**±2000 dps**
Gyro Sensitivity Error		**±0.8%**	
Gyro Offset		**±0.4 dps**	
Gyro Offset vs. Temp		**±0.015 dps/°C**	
Gyro Noise Density		**3.8 mdps/√Hz**	
Output data rate	**1.5625Hz**		**6400Hz**

Power Consumption	
6-Axis LN Mode Current	0.42 mA
6-Axis LP Mode Current@50Hz	0.22 mA
Gyro LN Mode Current	0.36 mA
Accel LN Mode Current	0.12 mA
Accel ULP Mode Current @12.5Hz	4.97 µA, 7.8 µA@25Hz
Sleep Mode Current	2.2 µA

[For more information: SmartMotion® | TDK InvenSense]

BME688 - Bosch Sensortec‘s 4-in-1 Gas Sensor with AI

Product Overview

The **BME688** integrates high-linearity and high-accuracy **pressure**, **humidity**, and **temperature** sensing from the BME680, but adds a “gas scanner”. The product consists of 3 parts:

1. **BME688 Hardware**: Fully backward compatible to BME680, but with a higher gas resistance range enabled in the ASIC.

2. **BSEC Software:** Enables
   a) operating modes (DC/LP/ULP) for air quality (VOCs)
   b) new BME688 gas scanning mode for VSCs (specified by H_2S lab tests) and custom use case detection.

3. **BME AI-Studio:** Enables customer to train the BME688 on his special application (e.g. for several home appliances, IoT products, smart home,…).

Applications and use cases

Target Applications:

- Breath checker
- Connected devices
- Smart home

Use Case Examples:

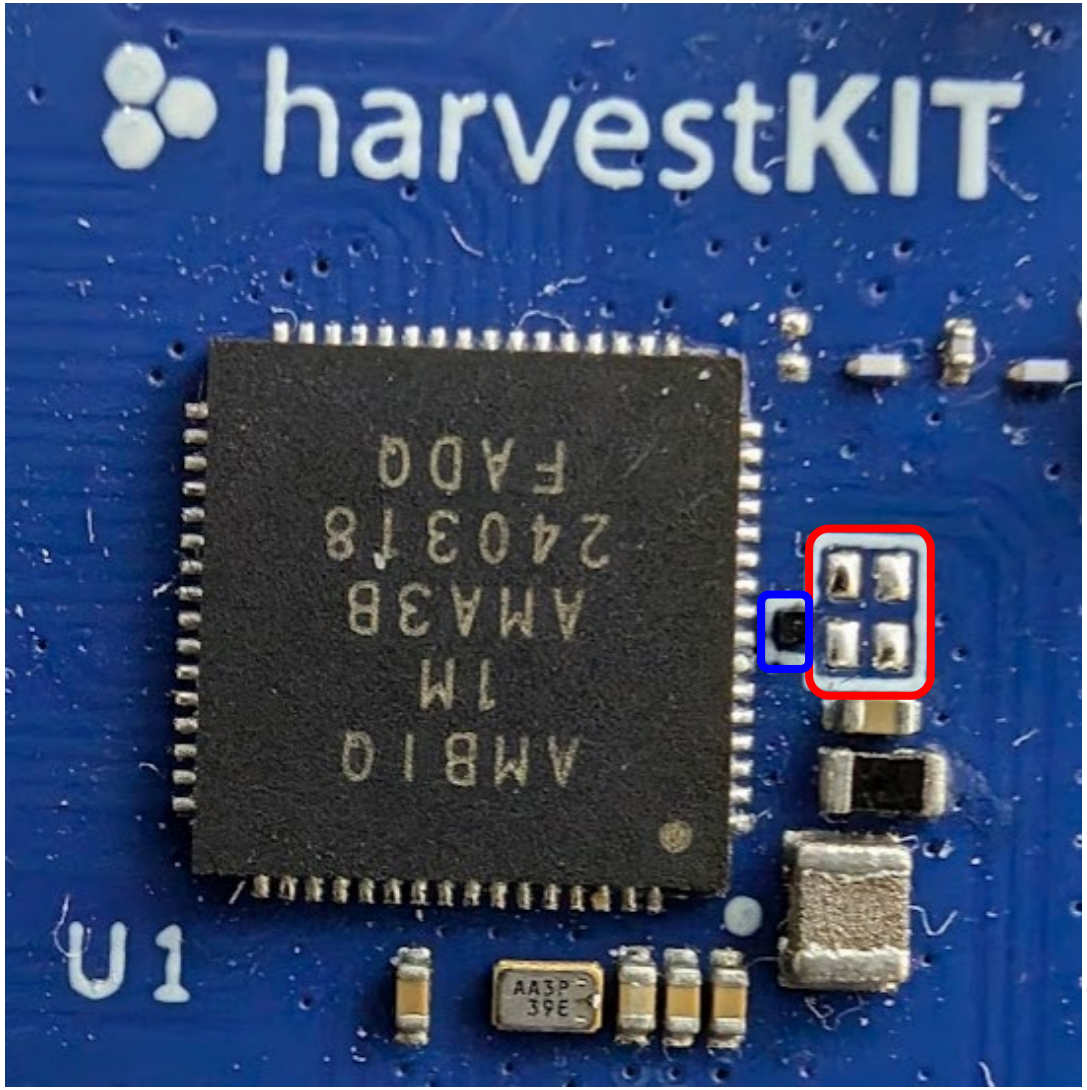
- Detection of bad breath
- Indoor Air
- Diaper state
- Fresh food in fridge

Technical Data

BME688 Technical data	
Package dimensions	8-Pin LGA with metal 3.0 x 3.0 x 0.93 mm³
Operating range	Pressure: 300...1100 hPa Humidity 0...100% Temperature: -40...85°C
Supply voltage V_{DDIO} Supply voltage V_{DD}	1.2 ... 3.6 V 1.71 ... 3.6 V
Interface	I²C (up to 3.4 MHz) and SPI (3 and 4 wire, up to 10 MHz)
Average typical current consumption	2.1 µA at 1 Hz for h/T 3.1 µA at 1 Hz for p/T 3.7 µA at 1 Hz for h/p/T 90 µA at ULP mode for p/h/T/air quality 0.9 mA at LP mode for p/h/T/air quality 3.9 mA in standard gas scan mode (gas scan mode & scan rate can be optimized on applications with BME AI studio)

SiTime 32MHz MEMs Resonator vs Quartz Space Savings

harvestKIT



SiTime

SiTime SiT11100-A8-032.0000

- 0.46 x 0.46 x 0.50mm CSP
- 0505 body size
- **0.21mm² pad area**

ECS INC INTERNATIONAL

ECS Inc ECX-1247

- 1.60 x 1.20 x 0.35mm ceramic
- 1612 body size
- 1.8 x 1.4mm² = **2.52² pad area**
- **12X larger board area**

BOSCH

FC1610BN

EPSON

Small size, Low ESR 32.768kHz Crystal

Features

- Package size: 1.6 x 1.0 mm, t = 0.5 mm Max.
- Nominal frequency range: 32.768 kHz
- Frequency tolerance: ±20 x 10^{-6} (+25 °C)
- Operating temperature: -40 °C to +105 °C
- ESR: 45 kΩ Typ. (+25 °C)
  60 kΩ Max. (-40 °C to +85 °C)
  70 kΩ Max. (-40 °C to +105 °C)

Applications

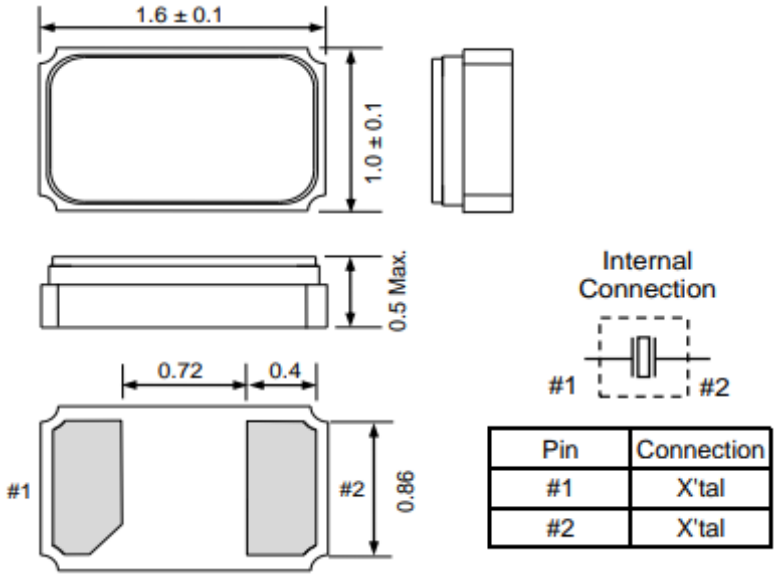
- Wearable products
- MCUs for sub-clock
- Wireless modules for sub-clock
- FA equipment

FC1610BN
(1.6 x 1.0 mm, t = 0.5 mm Max.)

Specifications (characteristics)

Item	Symbol	Specifications	Conditions / Remarks
Nominal frequency range	f_nom	32.768 kHz	
Storage temperature range	T_stg	-55 °C to +125 °C	Storage as single product.
Operating temperature range	T_use	-40 °C to +85 °C -40 °C to +105 °C	
Level of drive	DL	0.1 μW Typ. (0.5 μW Max.)	
Frequency tolerance (standard)	f_tol	±20 x 10^{-6}	+25 °C, DL = 0.1 μW
Turnover temperature	Ti	+25 °C ± 5 °C	
Parabolic coefficient	B	-0.04 x 10^{-6} / °C^2 Max.	
Load capacitance	CL	7 pF, 9 pF, 12.5 pF	Please contact us other CL values
Motional resistance (ESR)	R1	45 kΩ Typ.	+25 °C
		60 kΩ Max.	-40 °C to +85 °C
		70 kΩ Max.	-40 °C to +105 °C
Motional capacitance	C1	7.9 fF Typ.	
Shunt capacitance	C0	1.5 pF Typ.	
Frequency aging	f_age	±3 x 10^{-6} / year Max.	+25 °C, First year

External dimension



Pin	Connection
#1	X'tal
#2	X'tal

ambiq

ambiq
endpoint intelligence

Thank You!