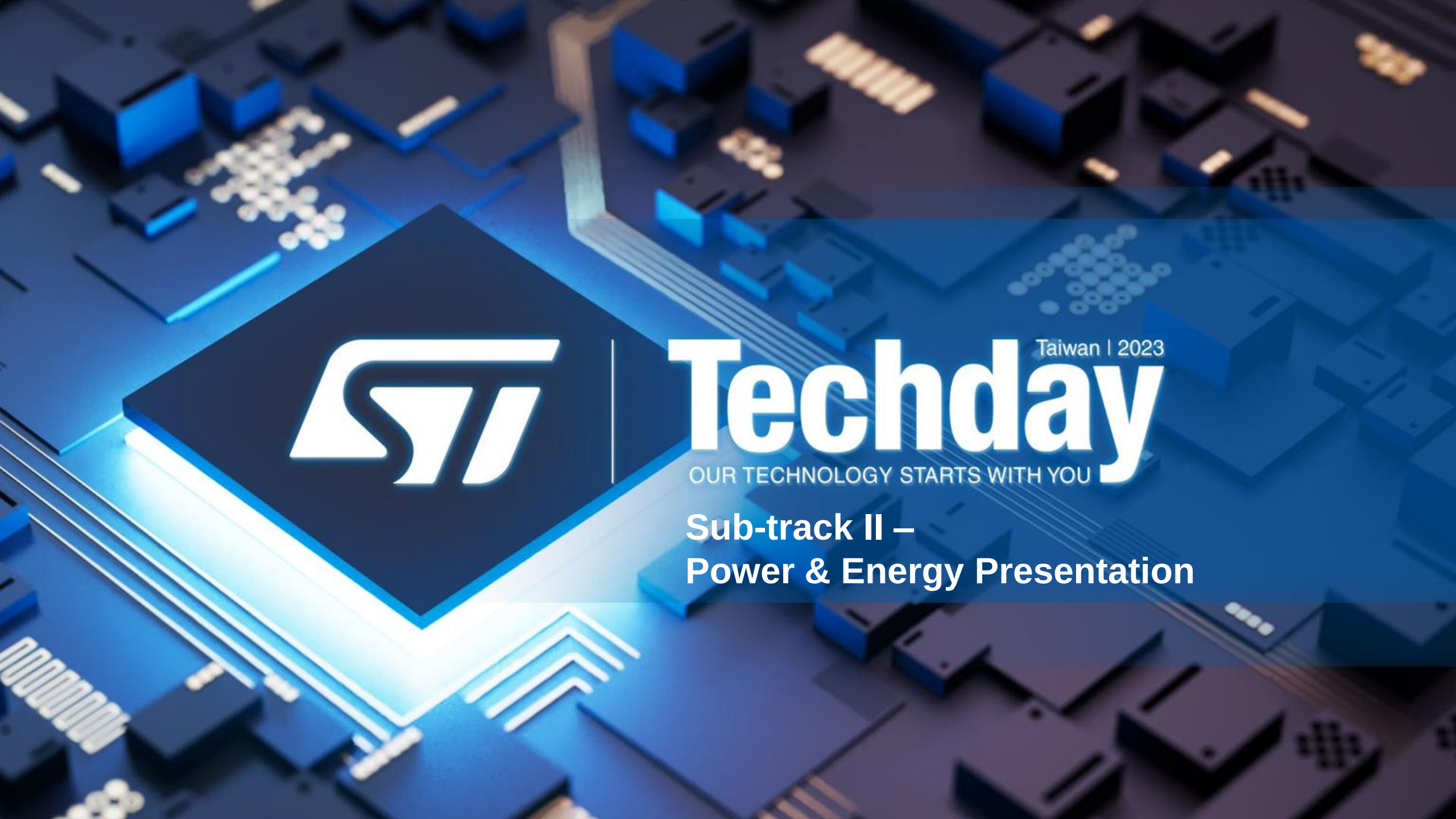

Sub-track II –
Power & Energy Presentation

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AI based smart solar arc-fault circuit interrupter solution

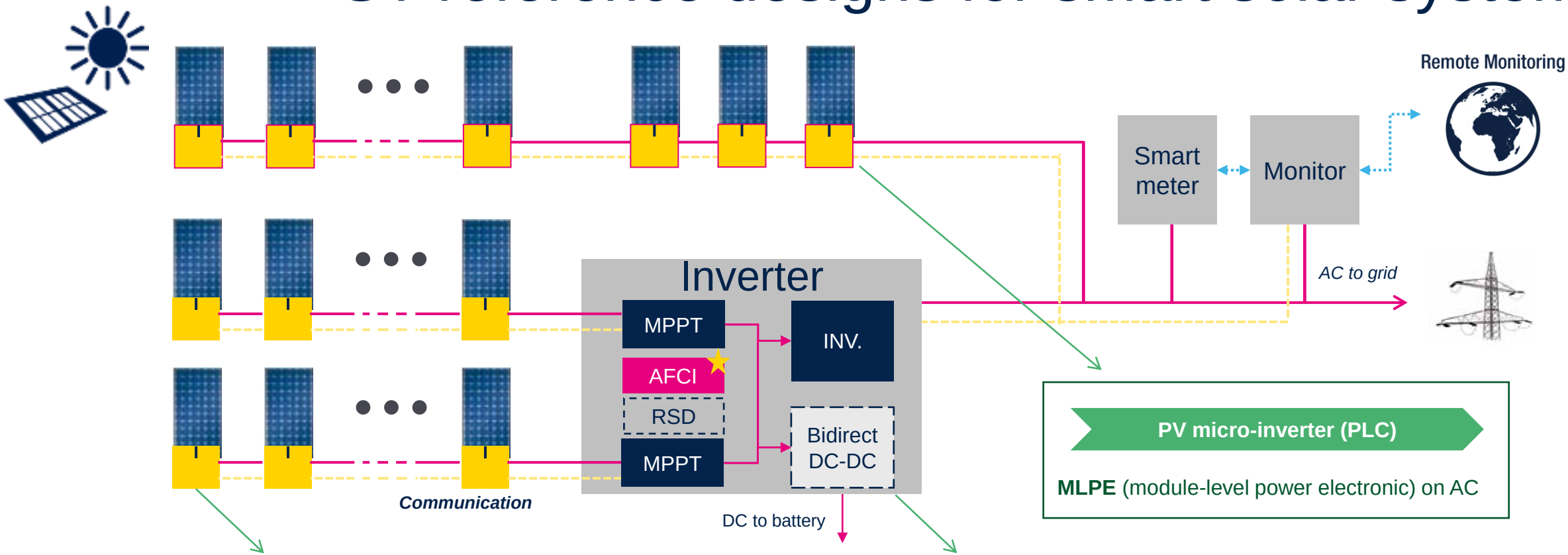
Matteo MARAVITA

STMicroelectronics

Power & Energy Competence Center

AI Competence Center

ST reference designs for smart solar systems



PV micro-inverter (PLC)

MLPE (module-level power electronic) on AC

PV monitor (PLC)

PV optimizer (PLC)

PV rapid shutdown (PLC)

MLPE (module-level power electronics) on DC

Inverter string optimizer (MPPT)

Inverter arc-fault circuit interrupter (AFCI)

Inverter DC-AC converter

Inverter rapid shutdown (DC PLC)

Inverter bidirectional DC-DC

Inverter monitor (AC PLC)

Inverter side modules (**string-inverter** as example)

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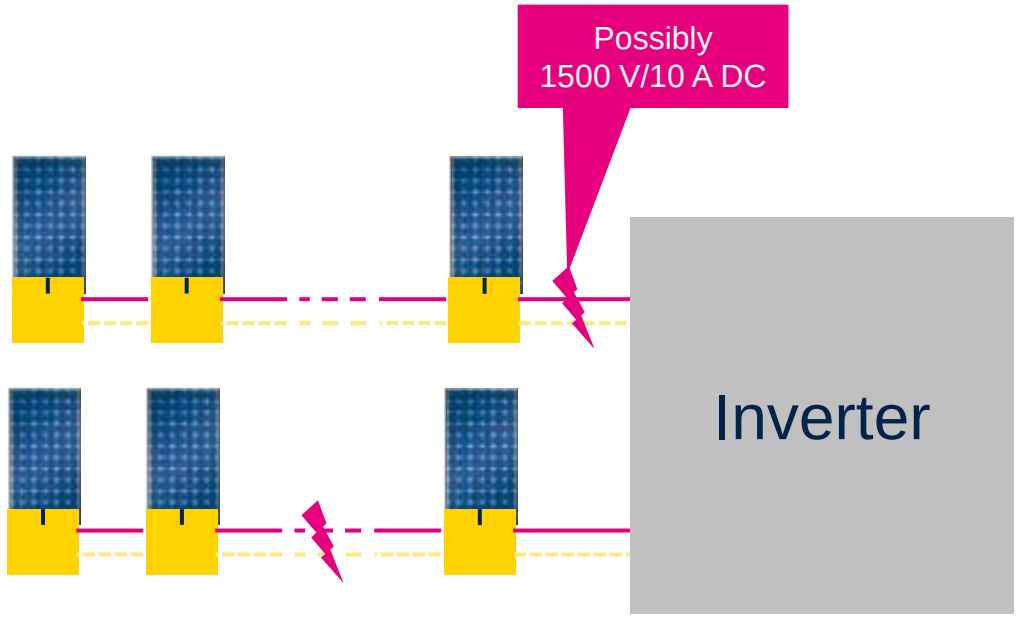
The risks of arc-fault

Factors that may cause arcs

- Aging
- Weather variation
- Harsh environment
- Human factors



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Arc-fault detection standard–UL1699B

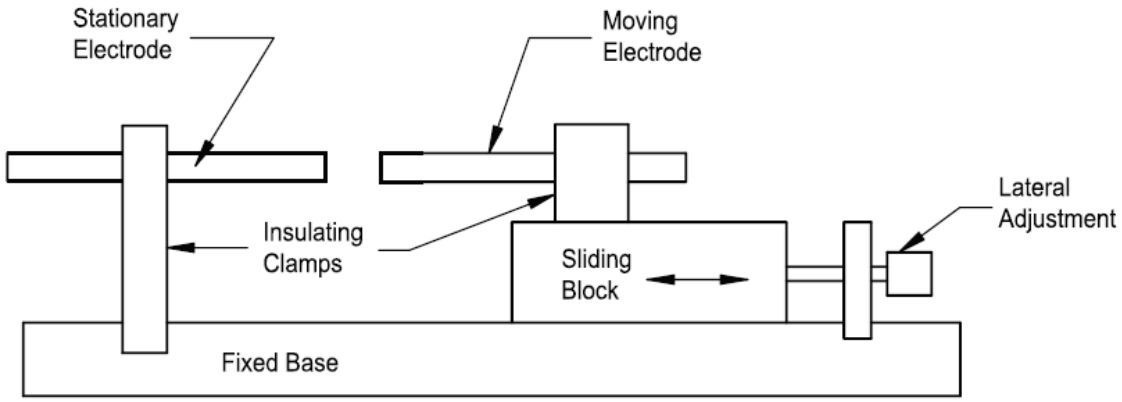
ANSI/UL1699B-2021

Standard for safety

- Photovoltaic (PV) DC arc-fault circuit protection

Figure 29.10

Arc generator



Arcing test conditions

Test no.	Minimum I_{arc} (A)[a]	Impp (A)	Sep. rate (mm/s)	Vmpp (V)[b]	Voc (V)[b]	R_{tot}(ohms)[b]	Gap (mm)
1	2.5	3.0	2.5	312.0	480.0	56.0	0.8
2	7.0	8.0	5.0	318.0	490.0	21.0	0.8
3[c]	14.0	16.0	5.0	318.0	490.0	11.0	1.1
4	7.0	8.5	5.0	607.0	810.0	24.0	2.5
Single module							
5	2.5	3.0	2.5	31.2	48.0	5.6	0.8
6	7.0	8.0	5.0	31.8	49.0	2.1	0.8

[a] I_{arc} values in Table 29.2 are representative of realistic arc events with one or two strings at full and low irradiance. It is expected that the AFCI shall meet compliance criteria below at intermediate current levels also.

[b] These values are approximate.

[c] Required for arcs in series with two parallel strings.

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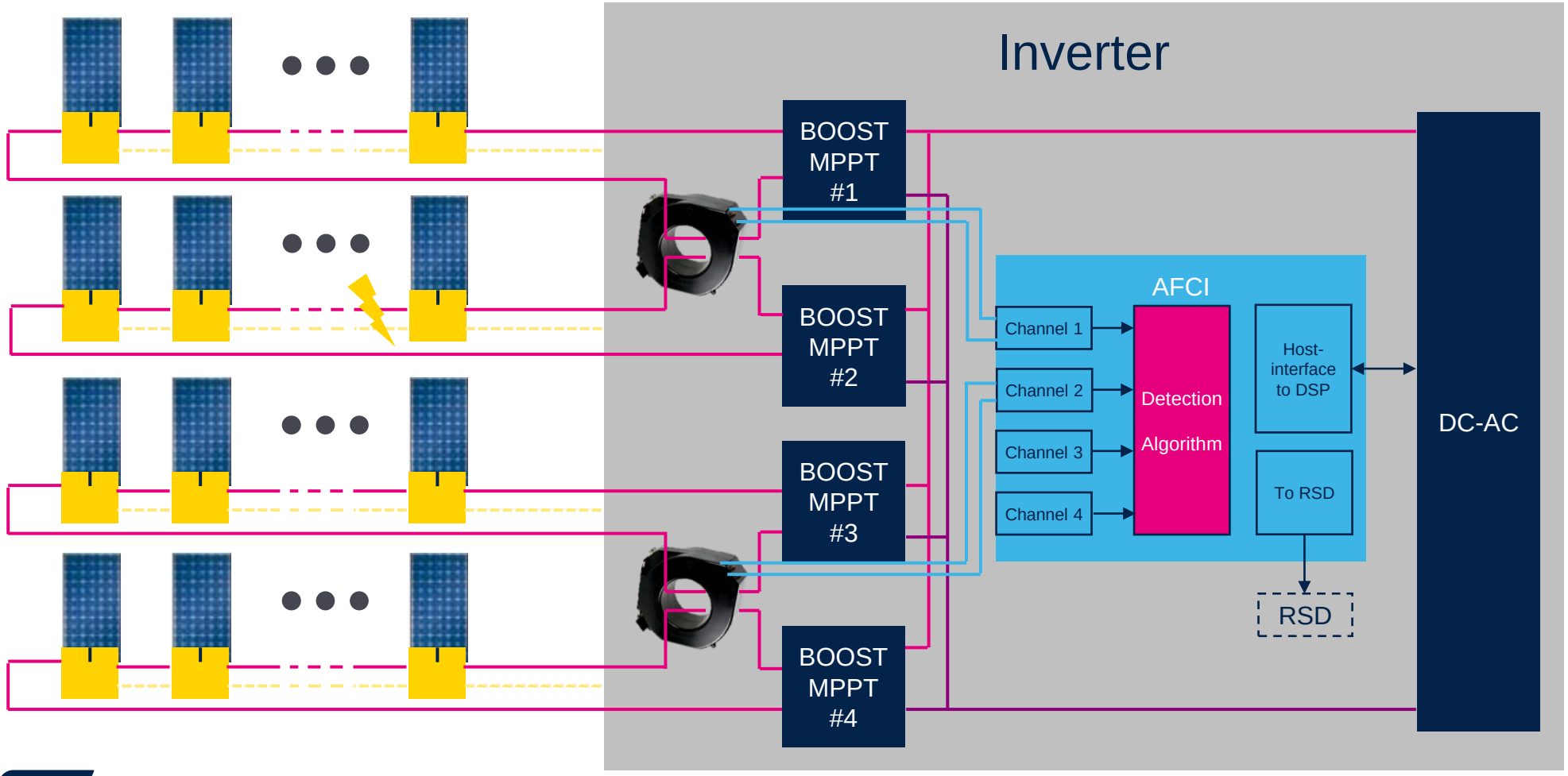
STM32 + AI detector
Field proven and future oriented system for AFCI

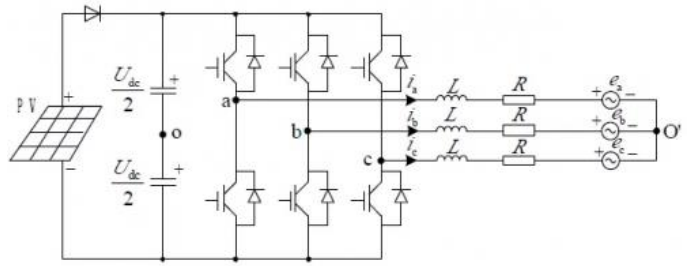


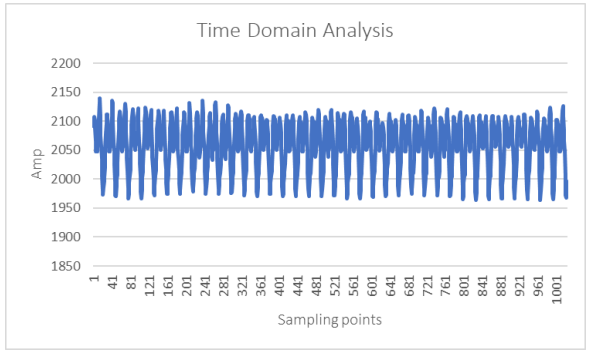
Neural network

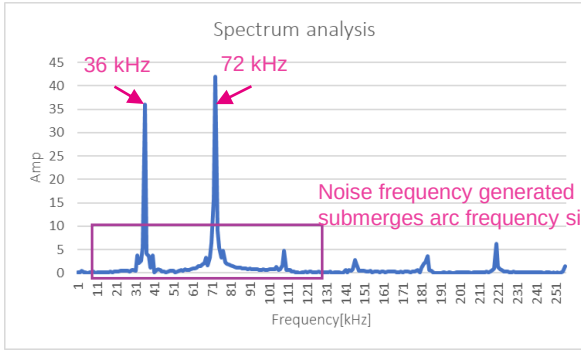
STM32 Cube.AI

Challenges in AFCI system design

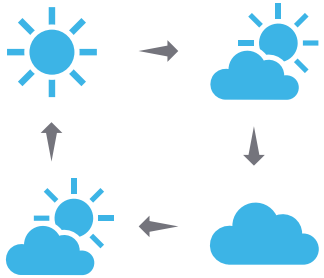
Inverter noise

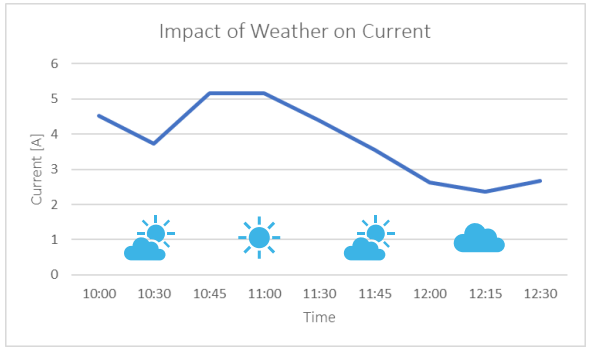






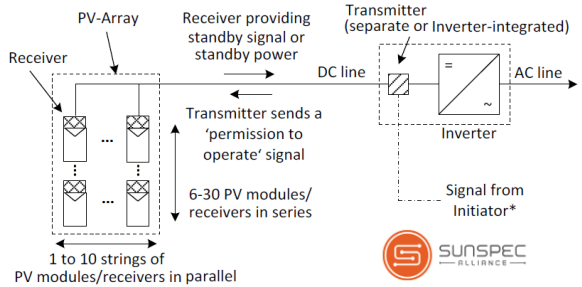
Weather impact





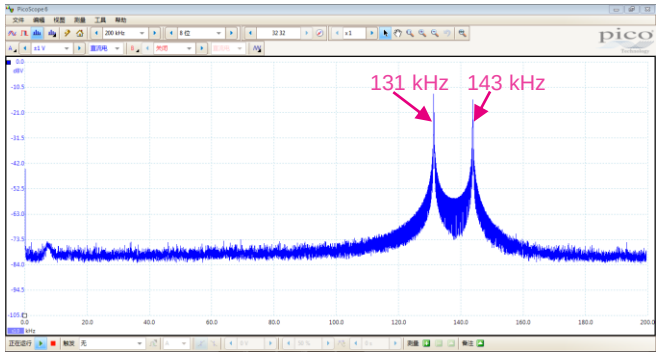
Date	Time	Weather	Voltage [V]	Current [A]	Power [KW]
15/07/2023	10.00	Nice, little cloudy	315	4.52	1.42
	10.30	Nice, little cloudy	277	3.74	1.04
	10.45	Nice, little cloudy	301	5.16	1.56
	11.00	Nice, little cloudy	300	5.16	1.55
	11.30	Nice, little cloudy	300	4.39	1.26
	11.45	Nice, little cloudy	320	3.55	1.10
	12.00	Cloudy	317	2.62	0.83
	12.15	Cloudy	334	2.36	0.79
	12.30	Cloudy	331	2.67	0.87

Rapid shutdown



Requirements of the Power Line Communication

Symbol	Transmitter Specification	Min.	Nom.	Max.	Unit	Remark
W_1	Logic 1 Code Word	{{-1, -1, -1, +1, +1, +1, -1, +1, +1, -1, +1}				+1 = mark, -1=space
W_0	Logic 0 Code Word	{+1, +1, +1, -1, -1, -1, +1, -1, -1, +1, -1}				+1 = mark, -1=space
F_M	Mark Frequency	131.236875	131.25	131.263125	kHz	6.25kHz × 21
F_S	Space Frequency	143.735625	143.75	143.764375	kHz	6.25kHz × 23
T_S	Average Bit Period	5.119488	5.12	5.120512	ms	(Time to complete one full duty cycle)/219
T_T	Transmission Period	168.943104	168.96	168.976896	ms	3 Words
T_Q	Quiet Period	901.029888	901.12	901.210112	ms	16 Words
T_C	Cycle Period	1069.972992	1070.08	1070.187008	ms	19 Words



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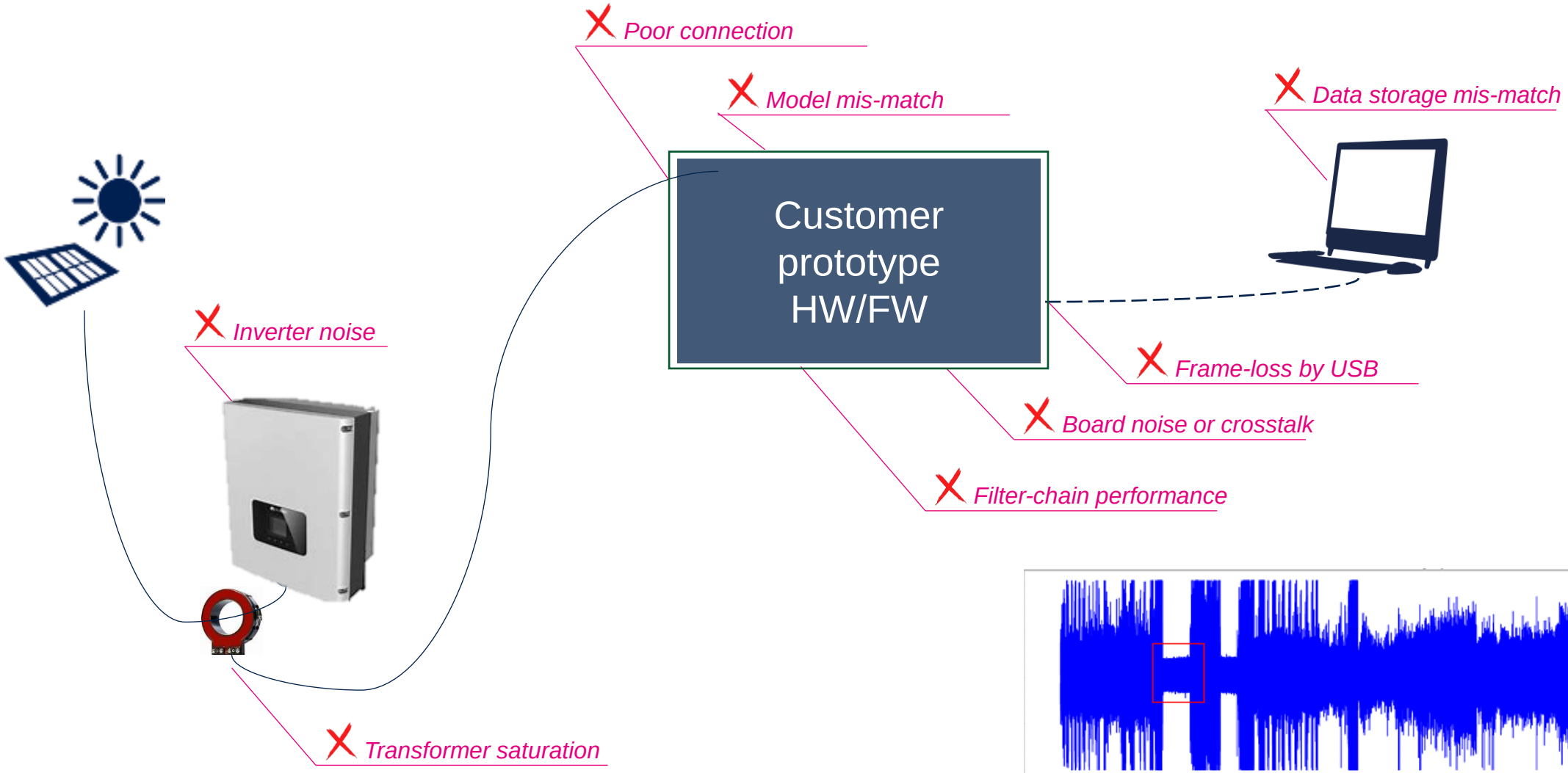
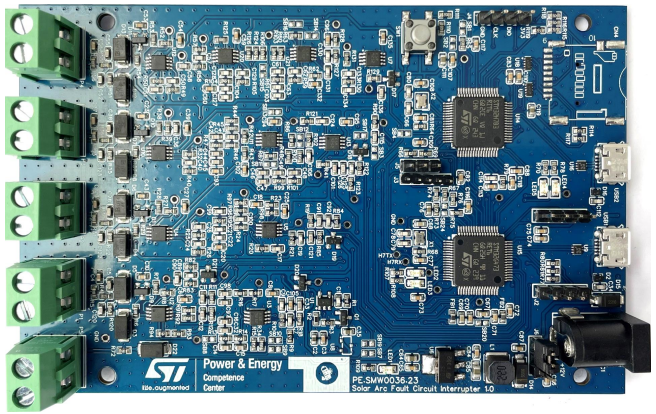
Possible issues in AFCI data processing

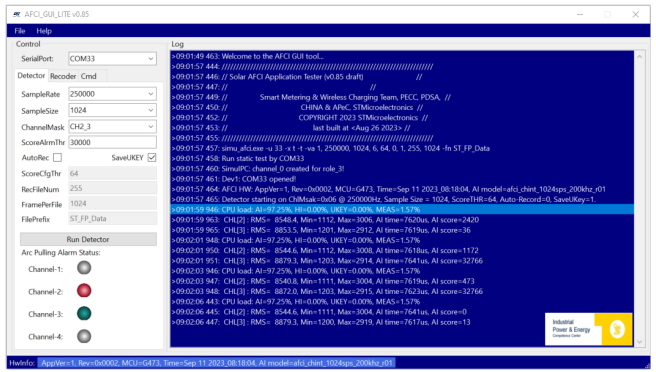


Field recording issue example

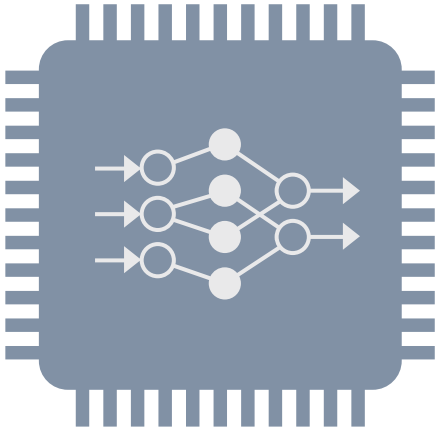
ST reference design for AFCI

Turnkey HW/SW reference design





Turnkey STM32 embedded AI



NANOEDGE AI STUDIO

STM32 Cube.AI

STM32

All STM32 MCUs

AFCI HW/FW reference design

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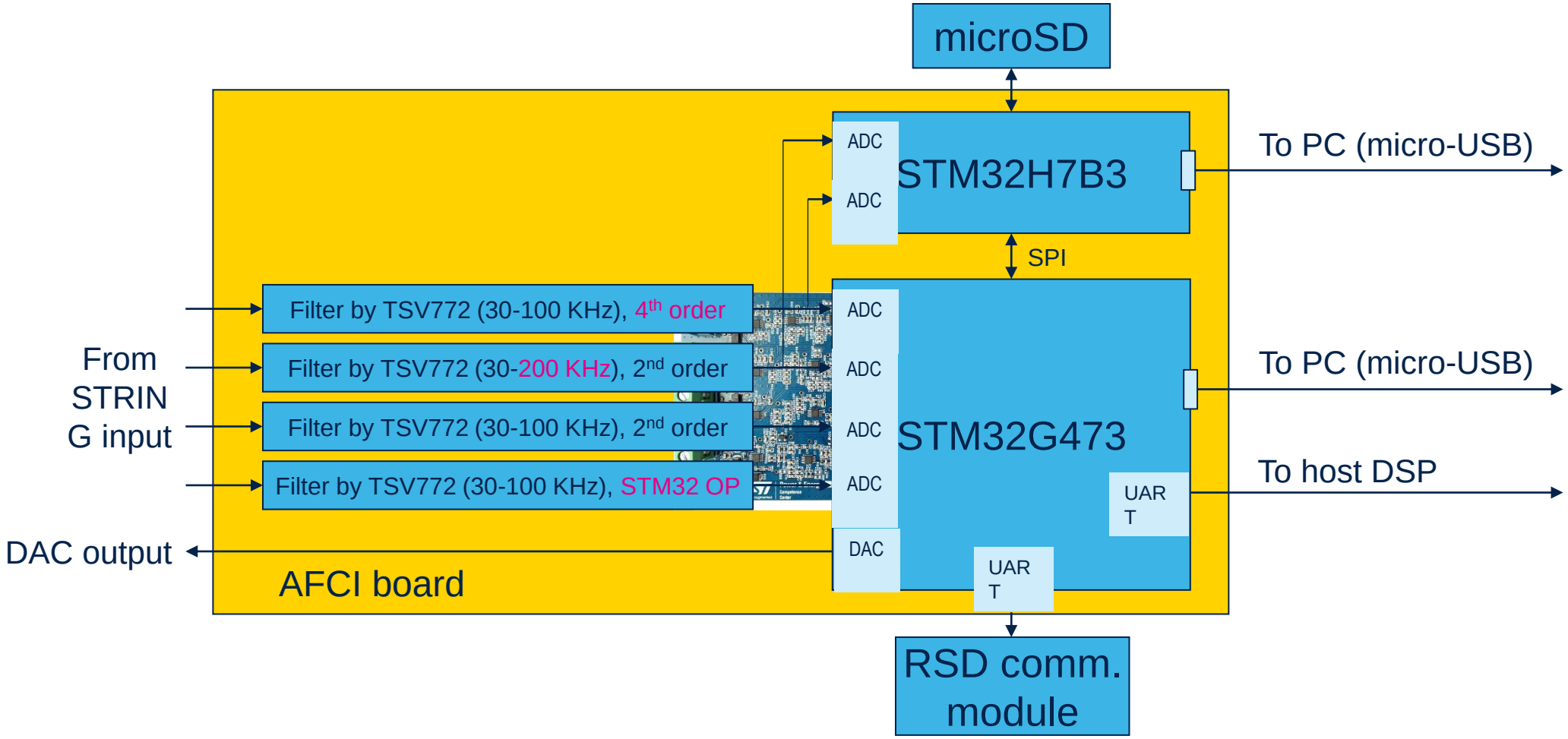
AFCI board hardware block diagram



- The primary target of STM32H7B3 is to drive microSD card.
- STM32G473 or STM32H7B3 should be sufficient for customer AFCI product.

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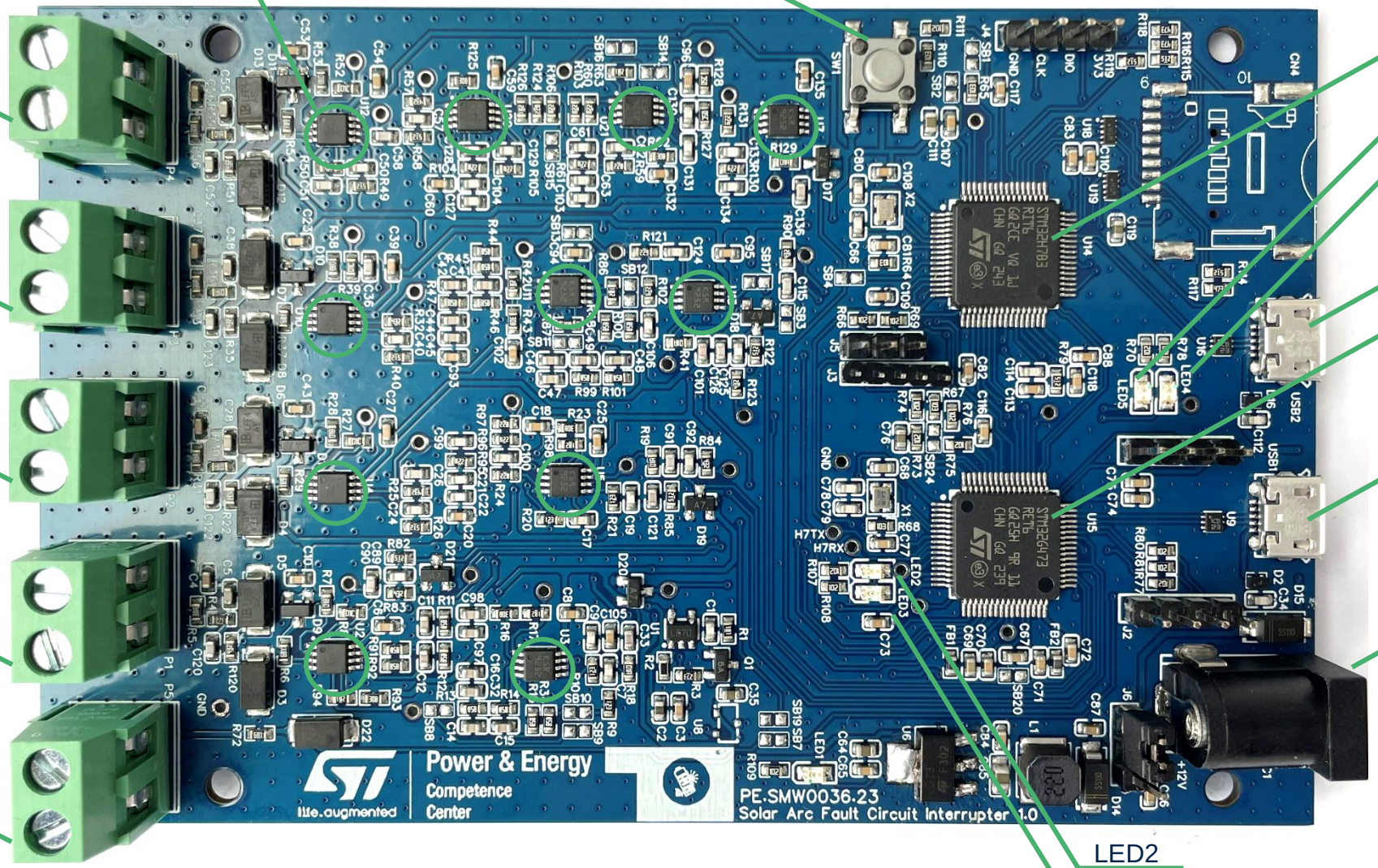
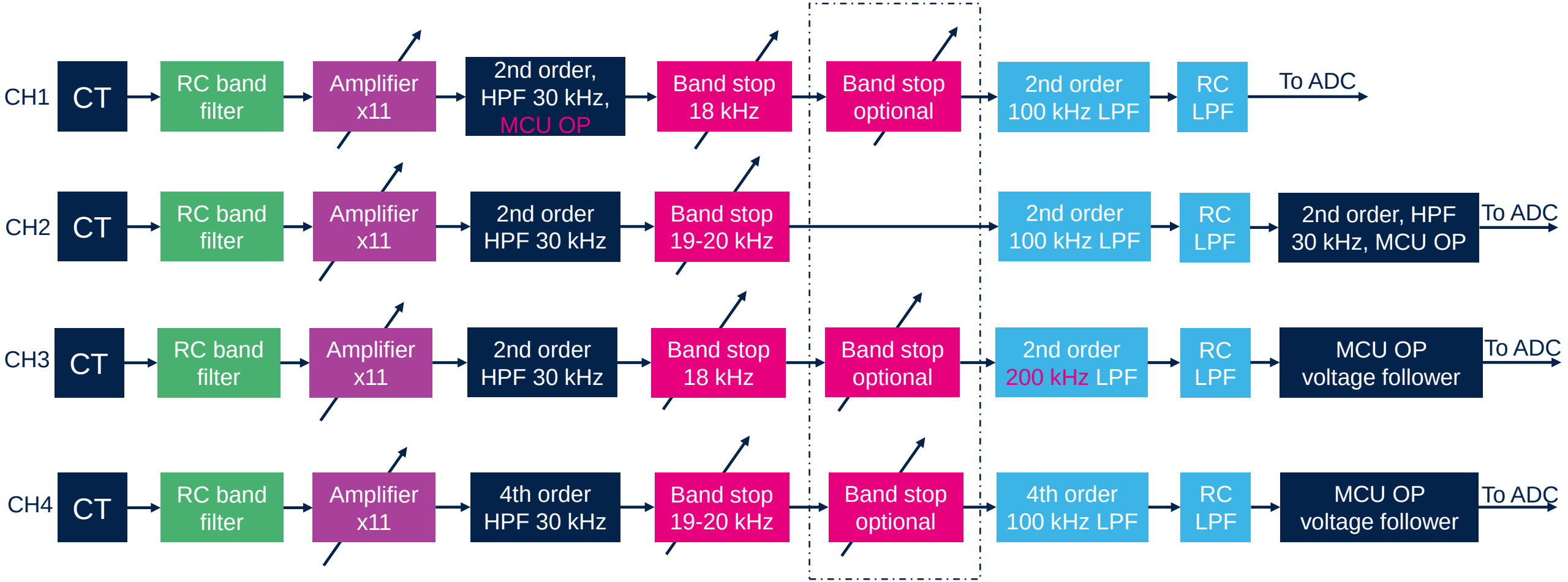
AFCI hardware board v1.0



AFCI filter design

The 2nd band stop filters are bypassed in current board by jumpers



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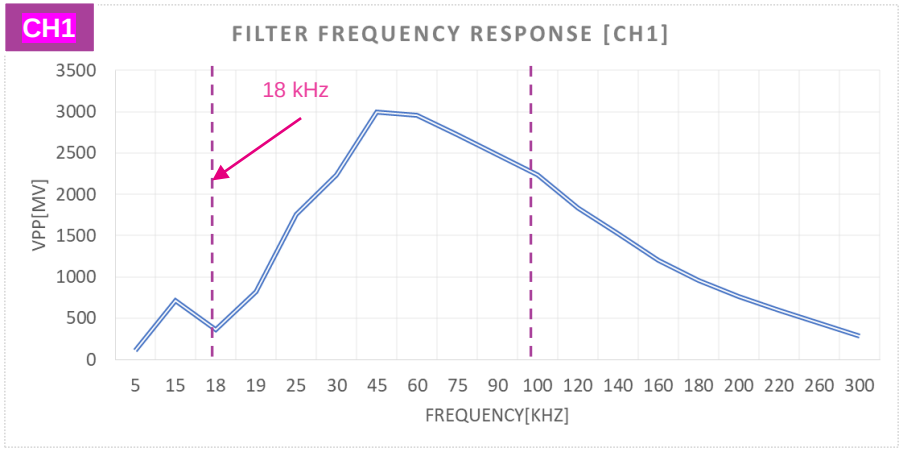
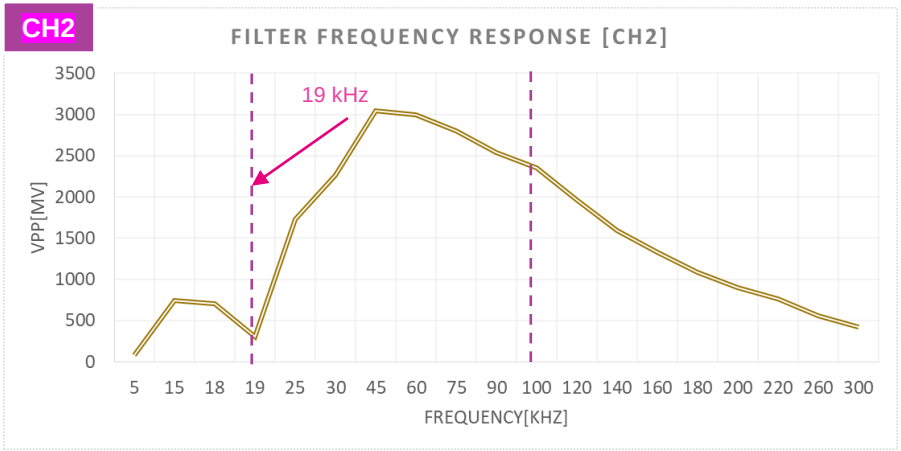
AFCI filter design

Frequency response of hardware filters

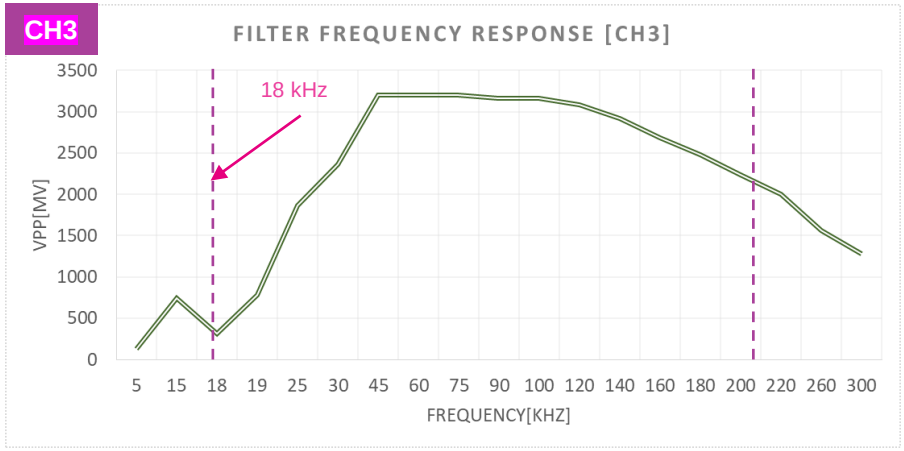
CH1



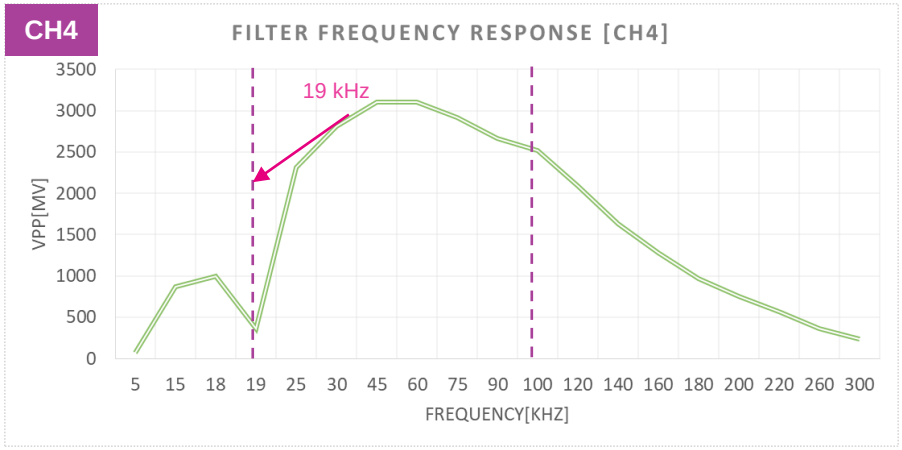
CH2



CH3



CH4



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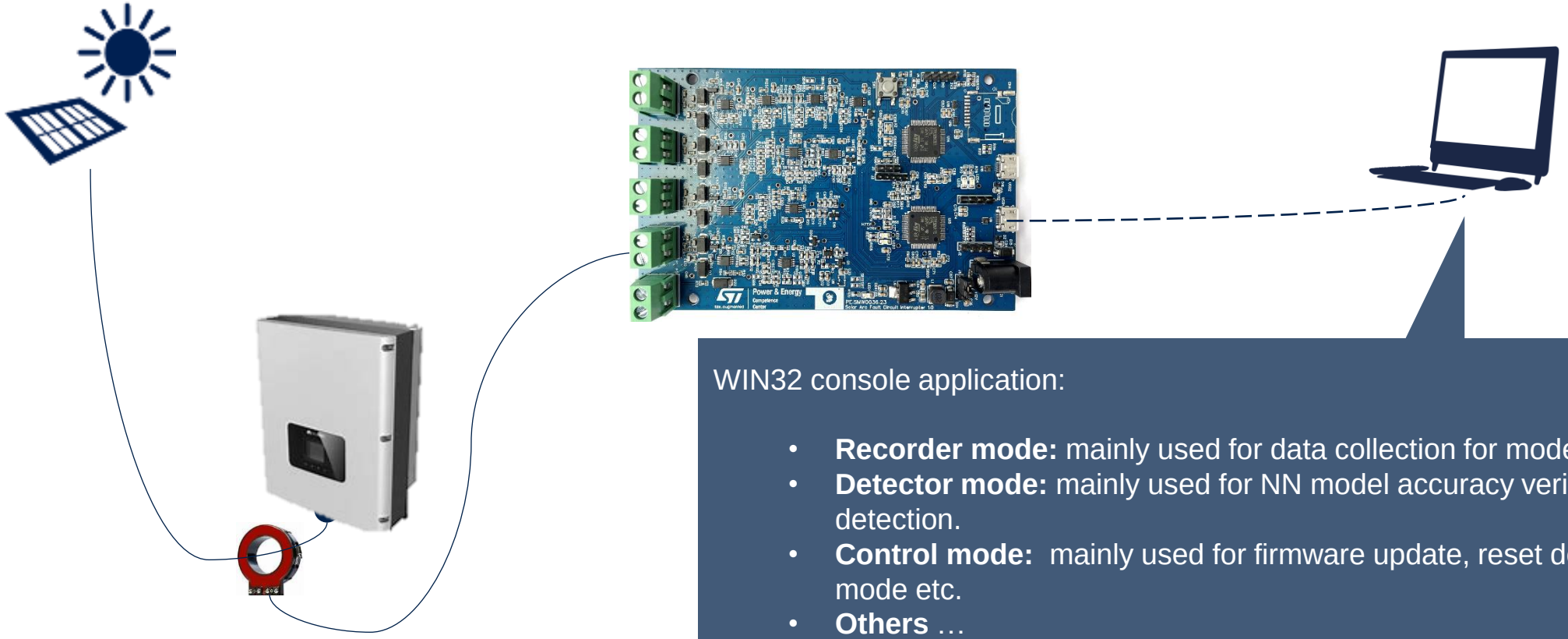
Connection in system



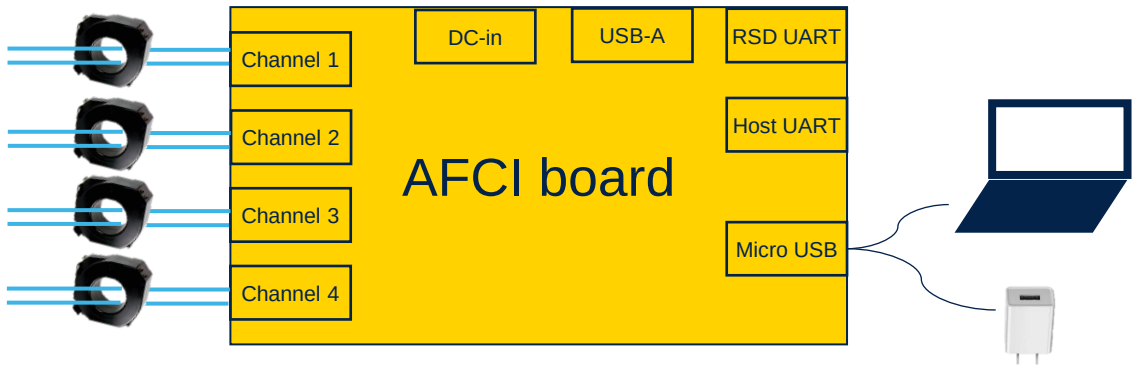
WIN32 console application:

- **Recorder mode:** mainly used for data collection for model training.
- **Detector mode:** mainly used for NN model accuracy verification or ARC detection.
- **Control mode:** mainly used for firmware update, reset device, stop current mode etc.
- **Others** …

AFCI GUI tool

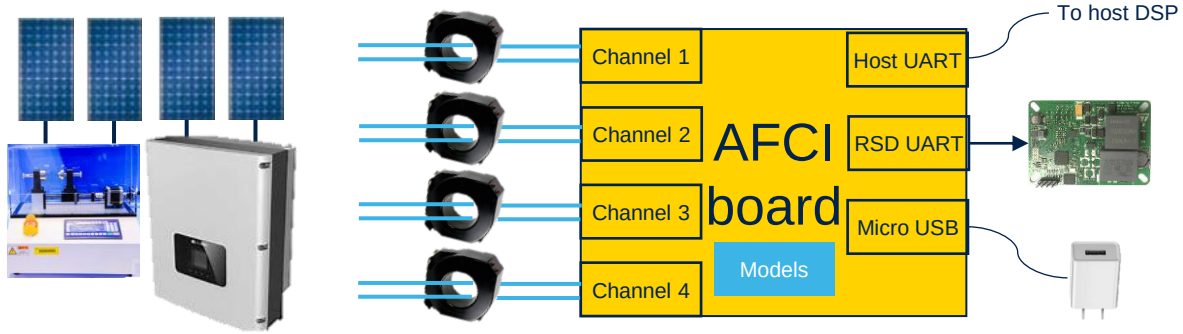
AFCI solution use-cases

Solution function bock:



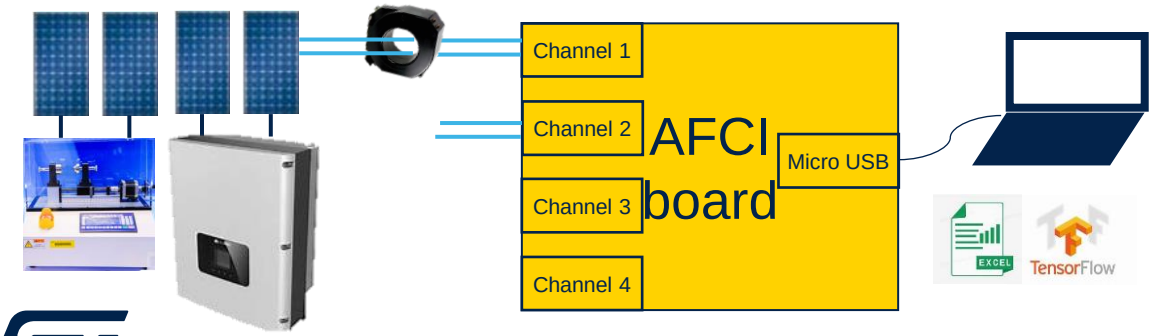
In-lab evaluation mode:

- Install in customer system for evaluation and competitor comparison.
- Enable parallel mode (4 channels), enable rapid shutdown (RSD) on arc-fault detected.



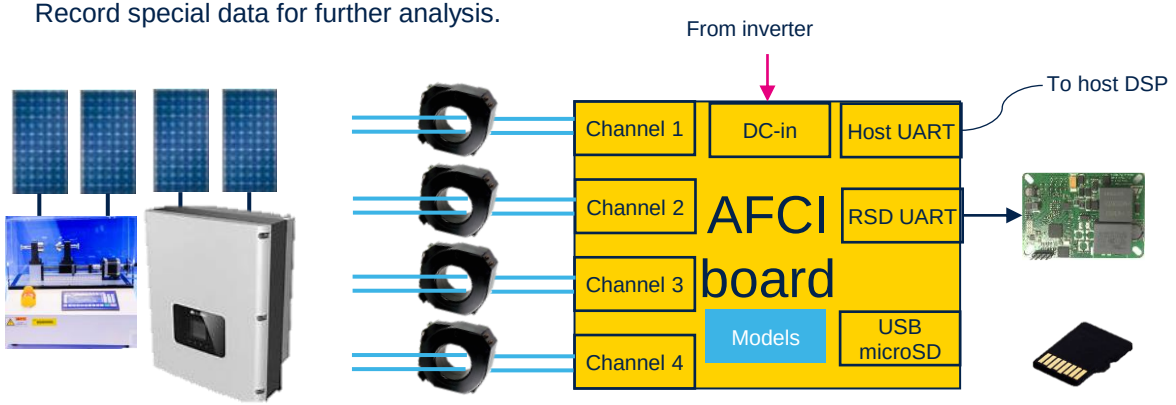
Data gathering mode:

- Read current, and possible voltage, and send to PC through USB.
- AFCI board powered by PC USB.



In-field evaluation mode:

- Support customer field-trial.
- Record special data for further analysis.



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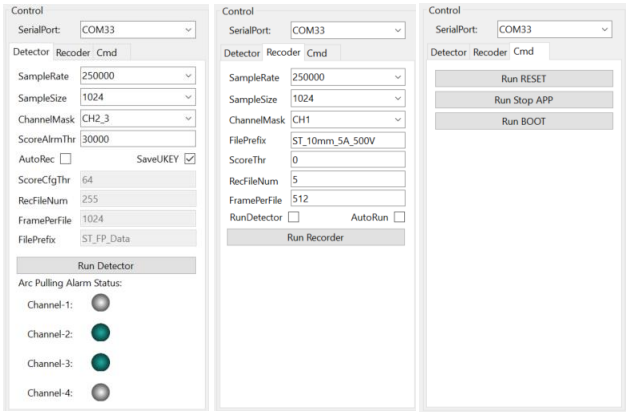
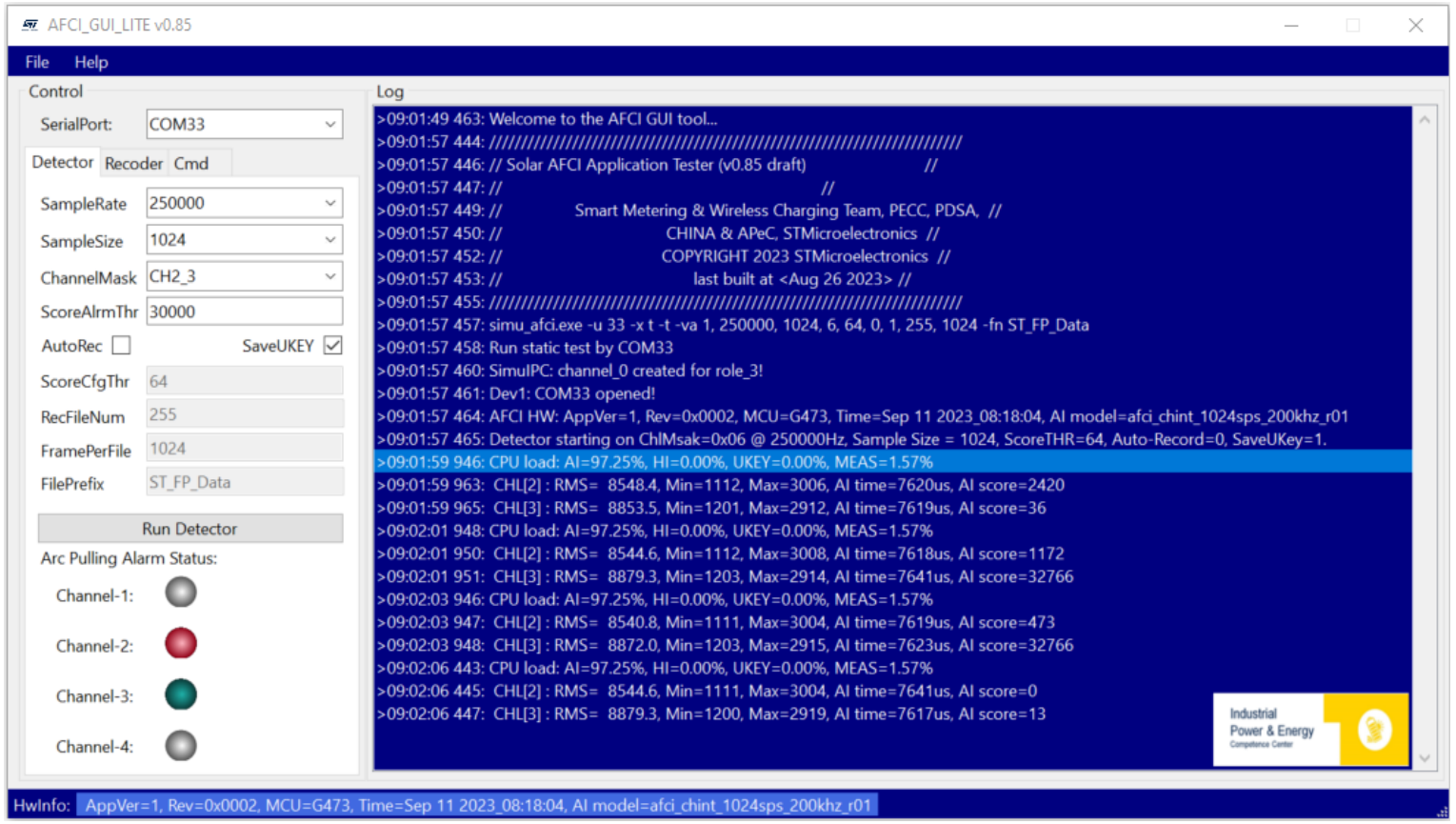
AFCI GUI tool makes development easier

- Support detector mode
- Support recorder mode
- Support control command
- Support NVM configuration
- Support logging





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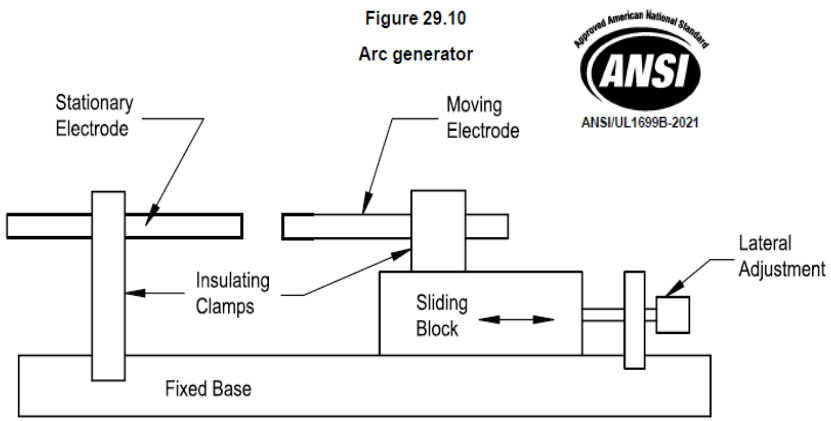
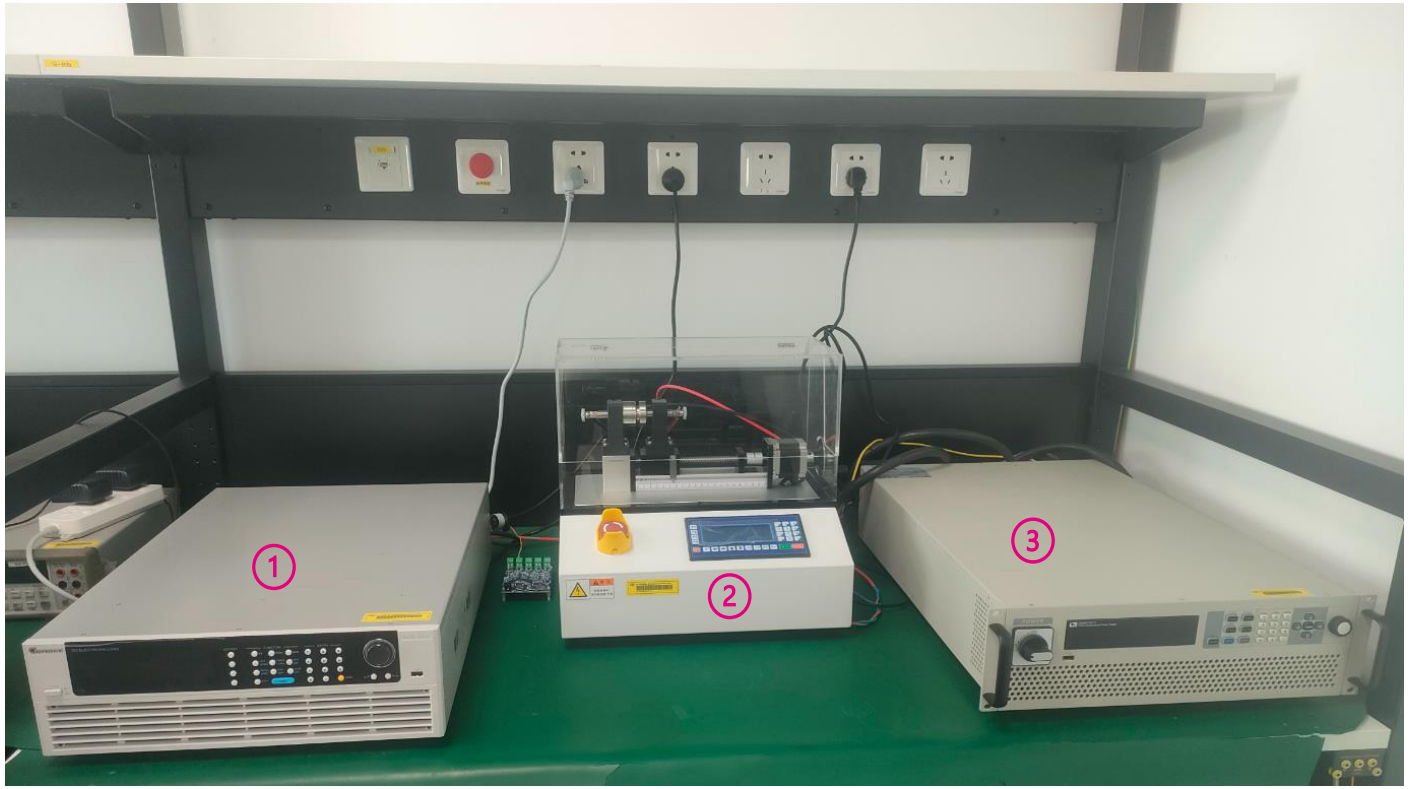
ST arc fault detection lab

Main instruments in AFCI lab

1. DC electronic load.
2. Arc generator
3. DC power supply





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AI reference design

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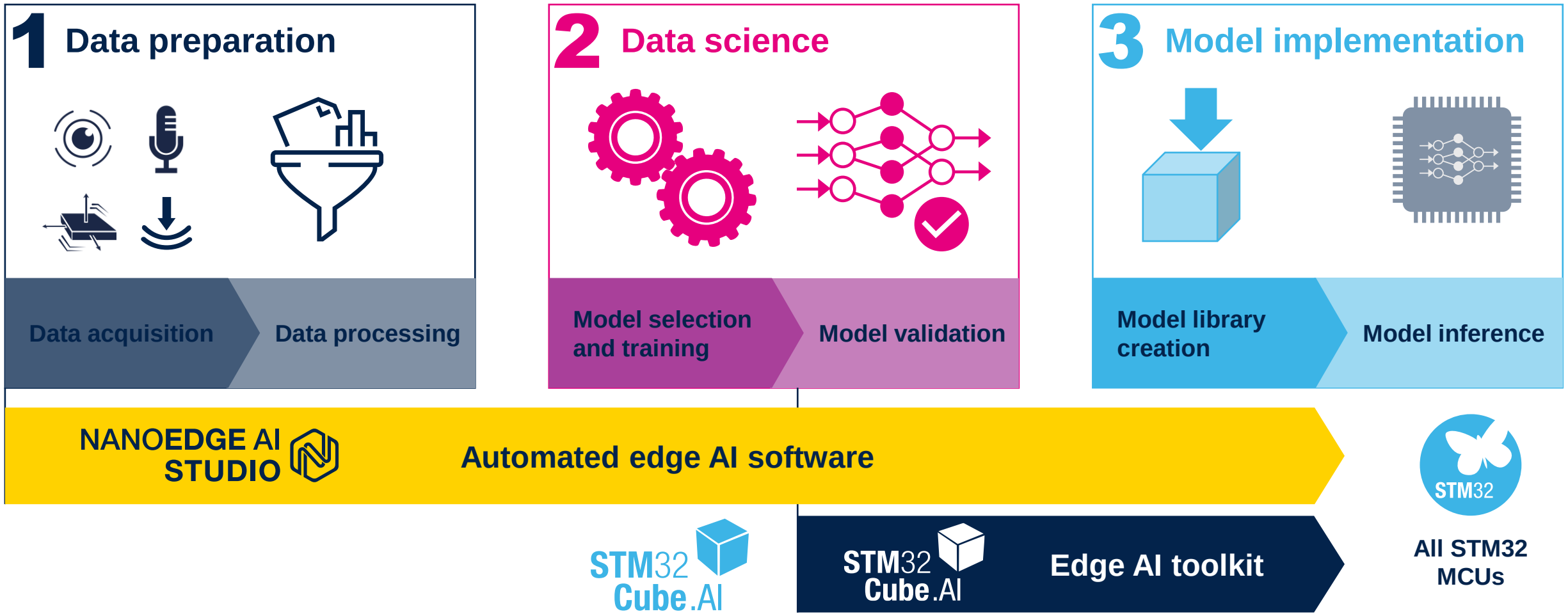
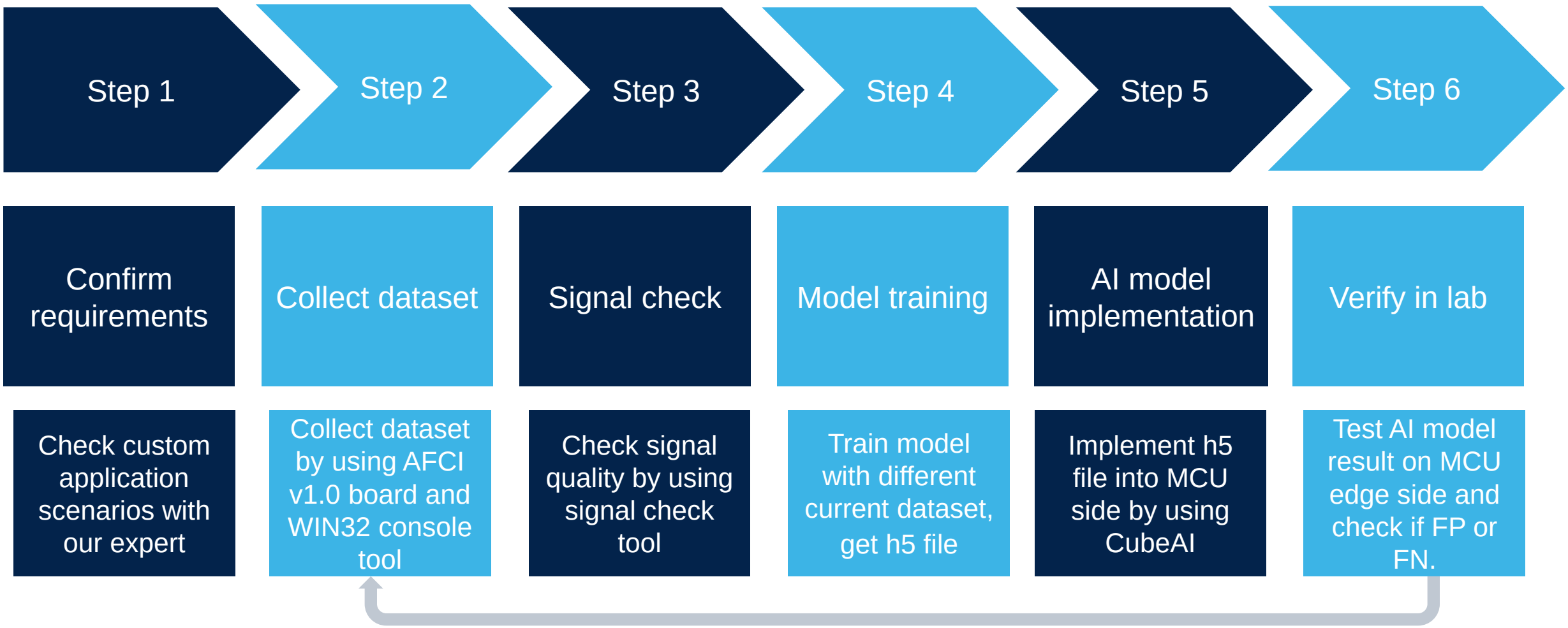
Overall AI development workflow



Step by step for AFCI project



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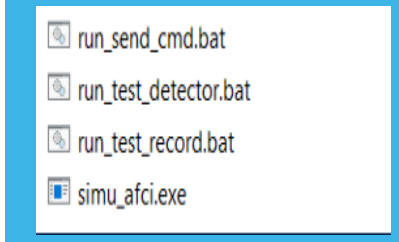
ST packages for AFCI

AFCI HW v1.0 board

Board including STM32G4 and STM32H7 for data collection and testing.

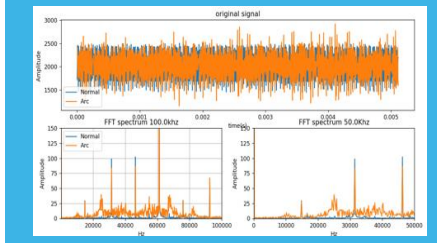
WIN32 console application

- Recorder
- Detector
- FW update



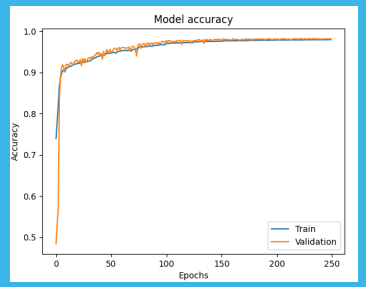
Signal check tool (exe file)

For analyzing signal quality.



AFCI AI model training (exe file)

For training the dataset for AI model.



AFCI FW project for STM32

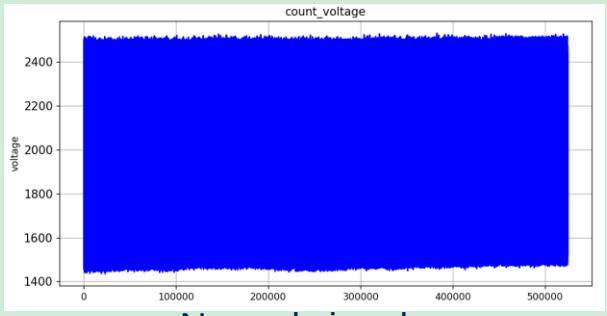
- Datalogging
- AI model real time processing
- Post-processing

User manual and guidelines

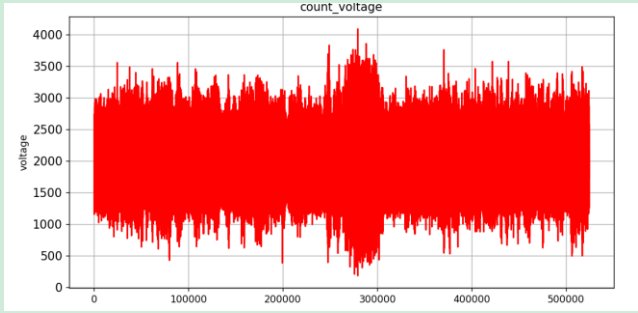
Signal checking

- Checking signal with signal check tool is very important before training neural network.

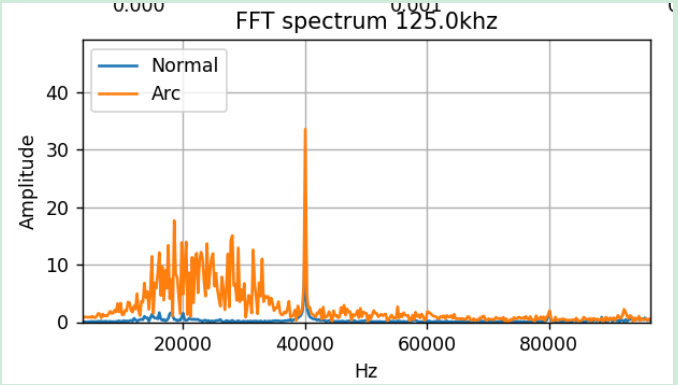
Good examples



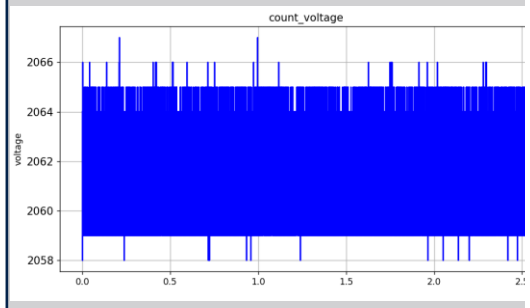
Normal signal

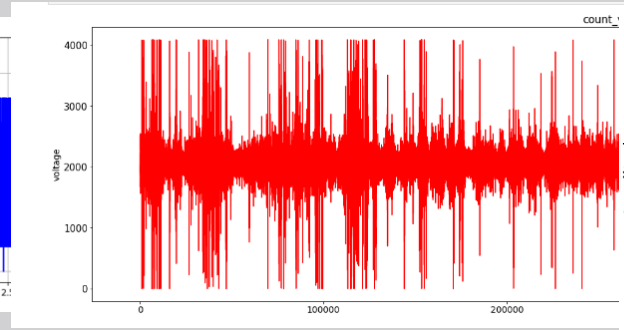


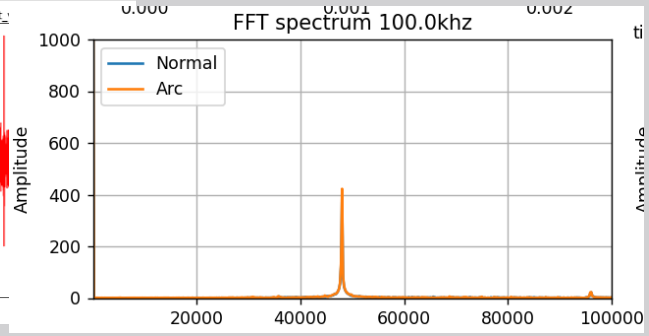
Arc signal

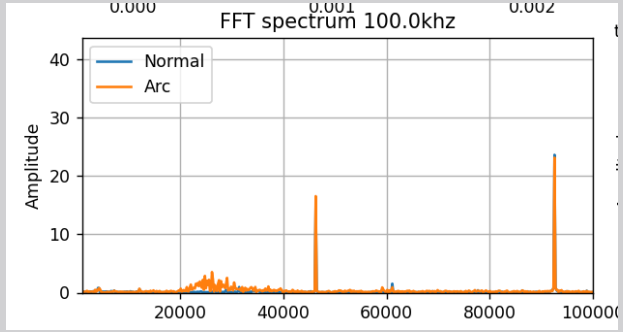


Bad examples









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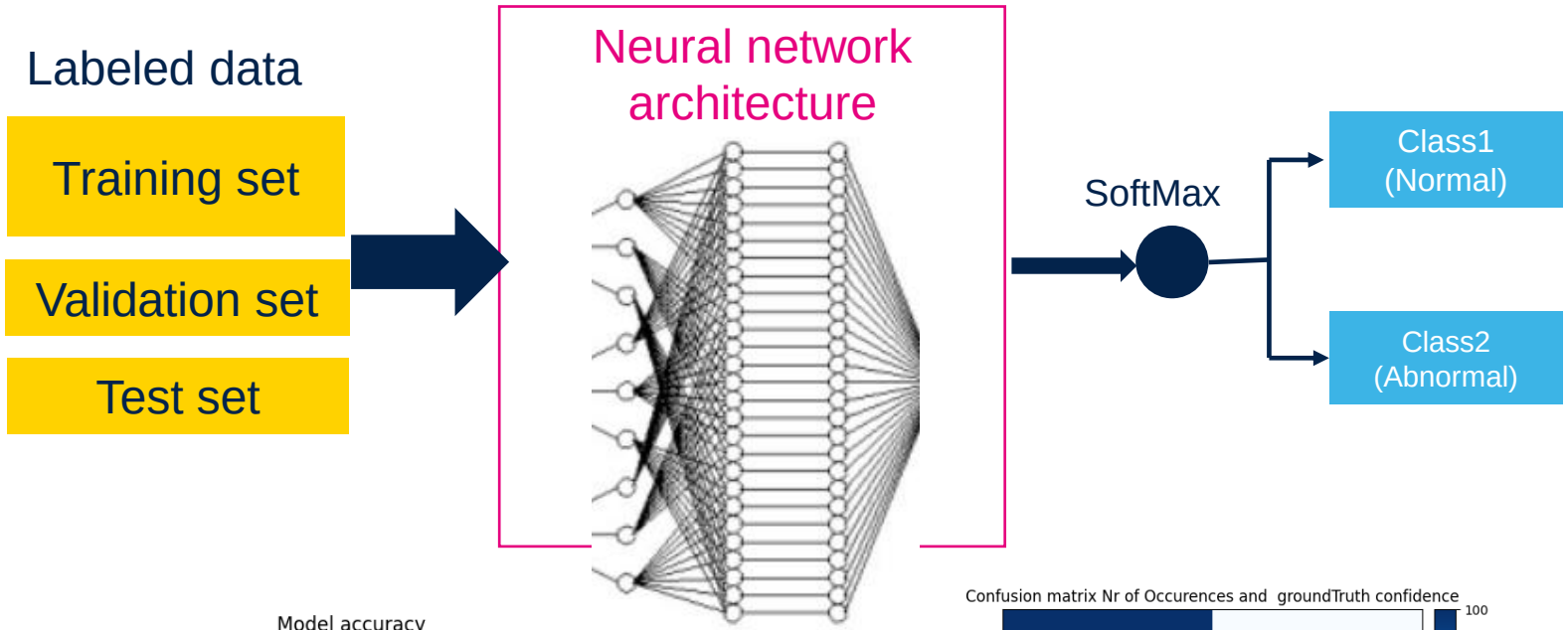
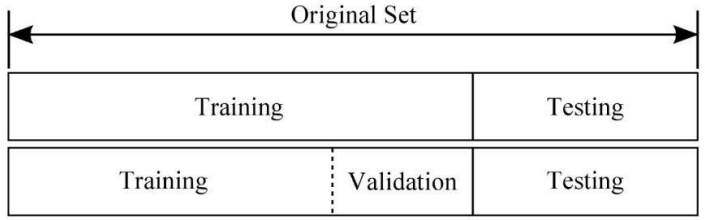
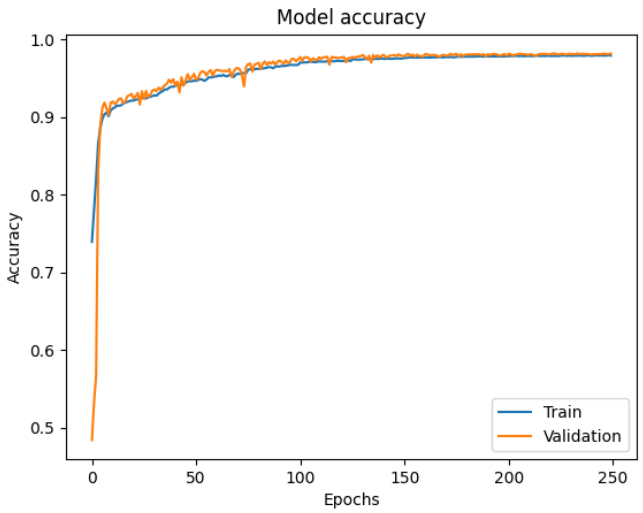
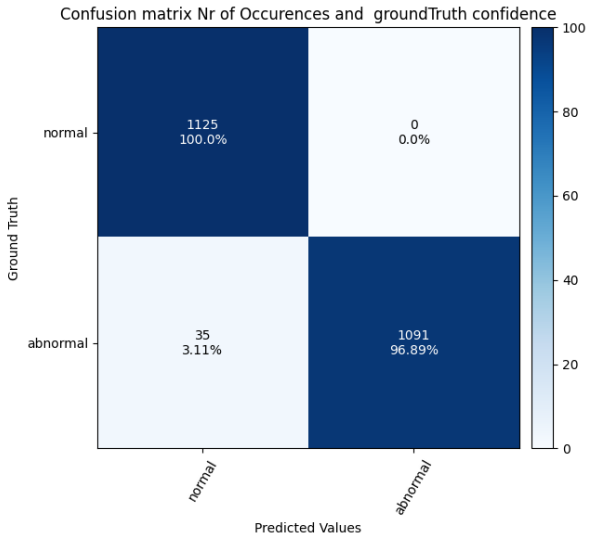
AI model training

- Collecting dataset by using AFCI GUI with two classes.
  - Normal status
  - Arc status
- Split dataset
  - Training set
  - Validation set
  - Test set

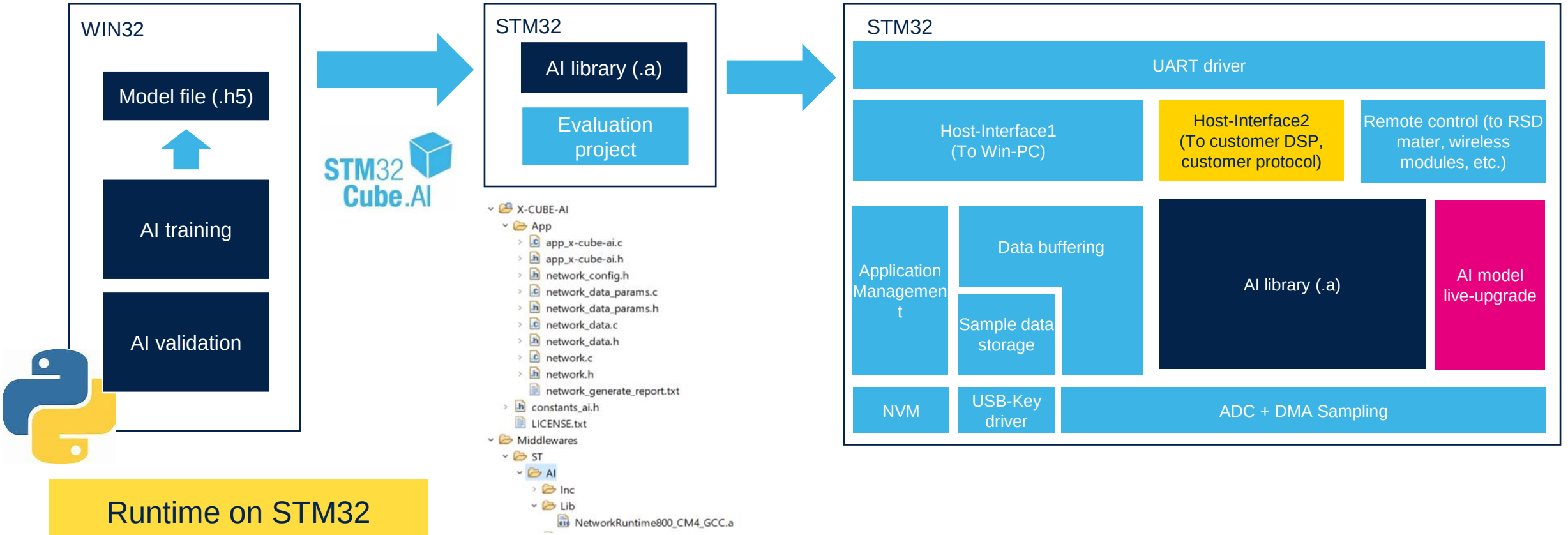








AI model implementation



Runtime on STM32

Input data from CT sensor → AI model result → Postprocessing → Arc detection result

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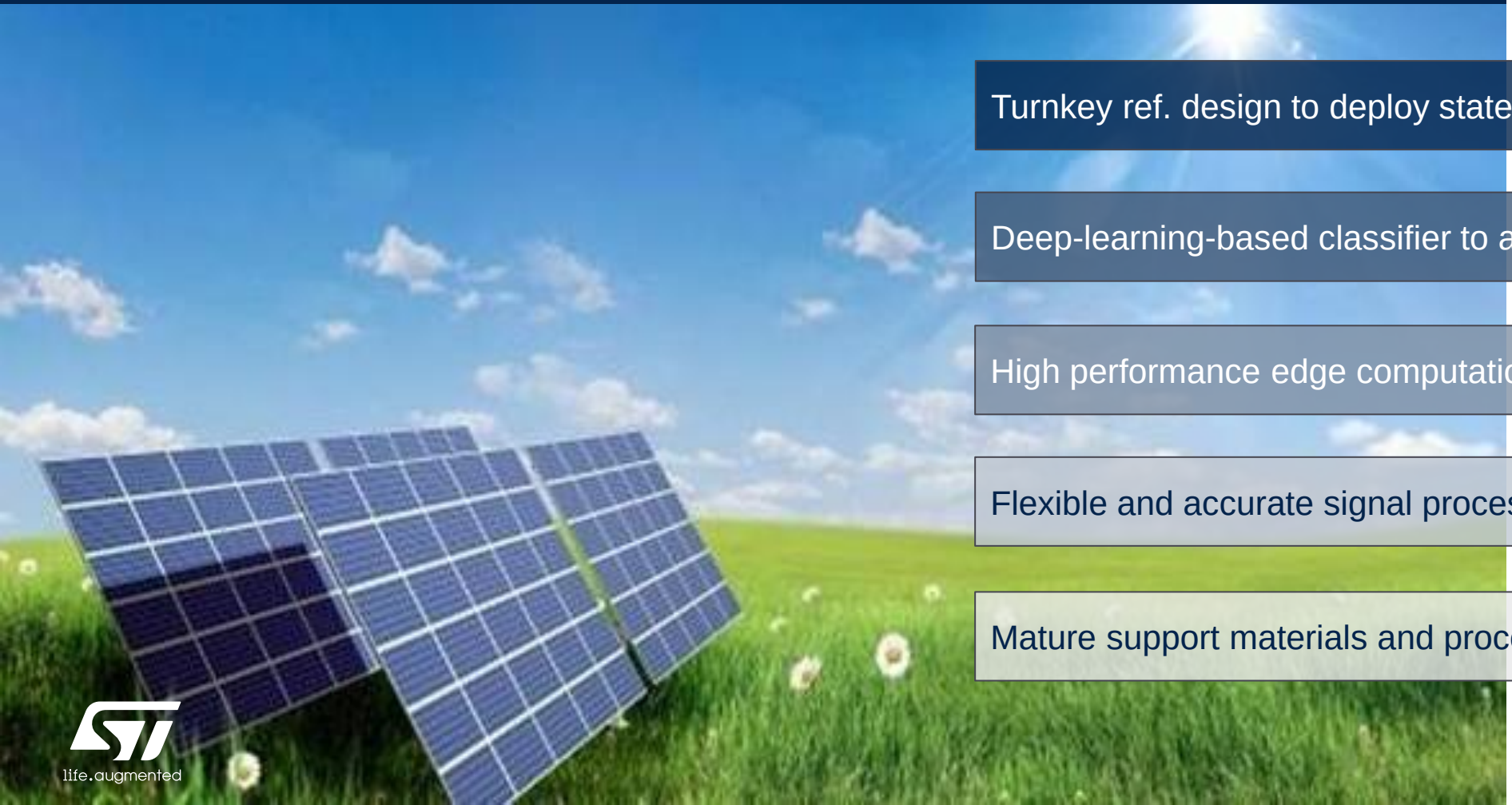
Takeaways

The AI based arc fault circuit interrupter (AFCI) contributes the safe and sustainable development



- Turnkey ref. design to deploy state-of-art AFCI solution efficiently
- Deep-learning-based classifier to address high detection accuracy
- High performance edge computation with STM32G4 or STM32H7
- Flexible and accurate signal processing with TSV7xx amplifiers
- Mature support materials and process with experienced team

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