On excitation of SOEC stacks for impedance spectroscopy in in-field applications

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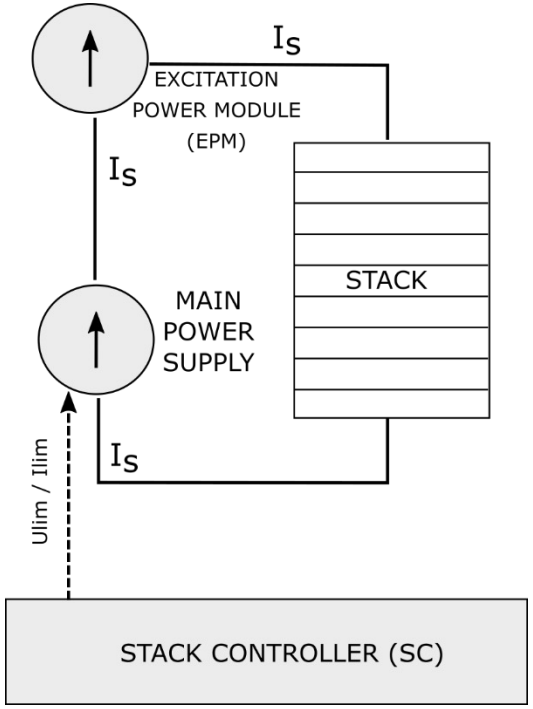
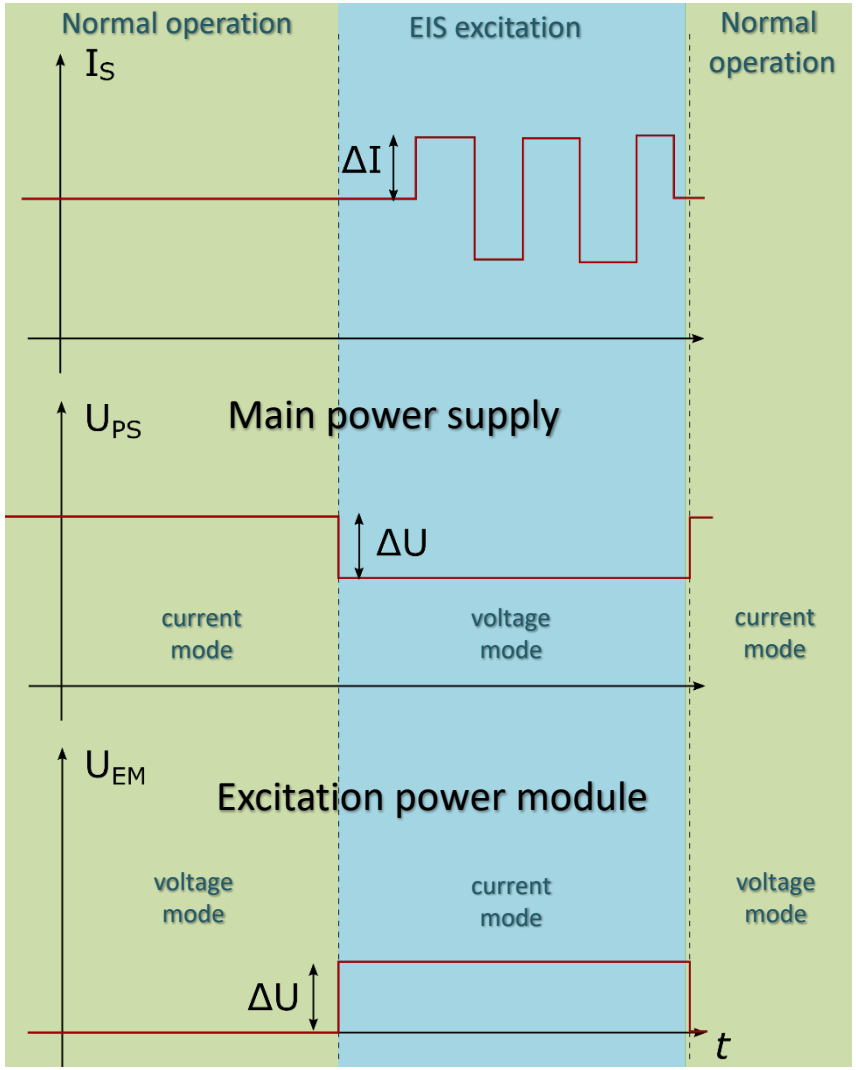
Motivation

- Electrochemical impedance spectroscopy (EIS) is a powerful tool to characterize electrochemical reaction process
- Typically an expensive laboratory equipment is applied to perform EIS
- REACTT objective
  - Development of affordable (low-cost), reliable and flexible equipment for EIS
  - Equipment that could be applied for in-field application of EIS for SOEC
  - In first step as incorporated additional hardware, but eventually it can be designed as a part of stack's power electronics

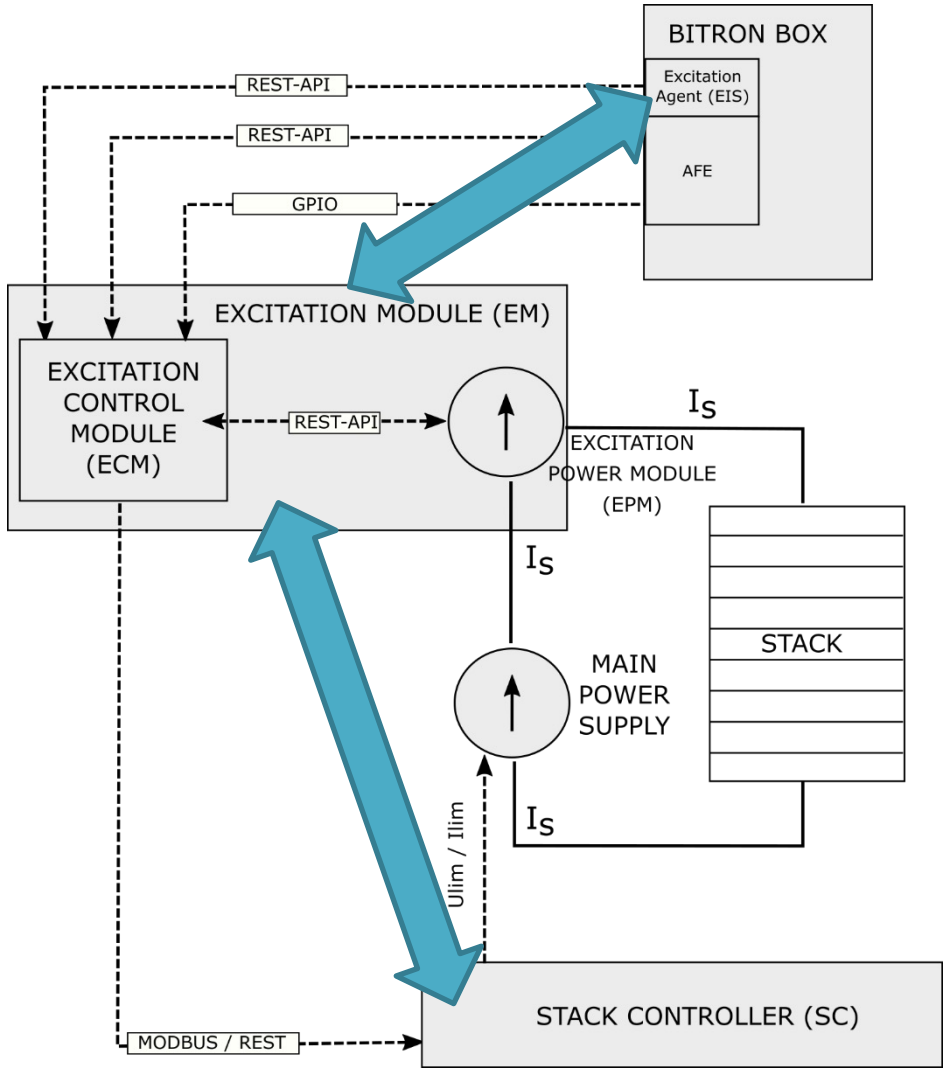
EIS setup and procedure

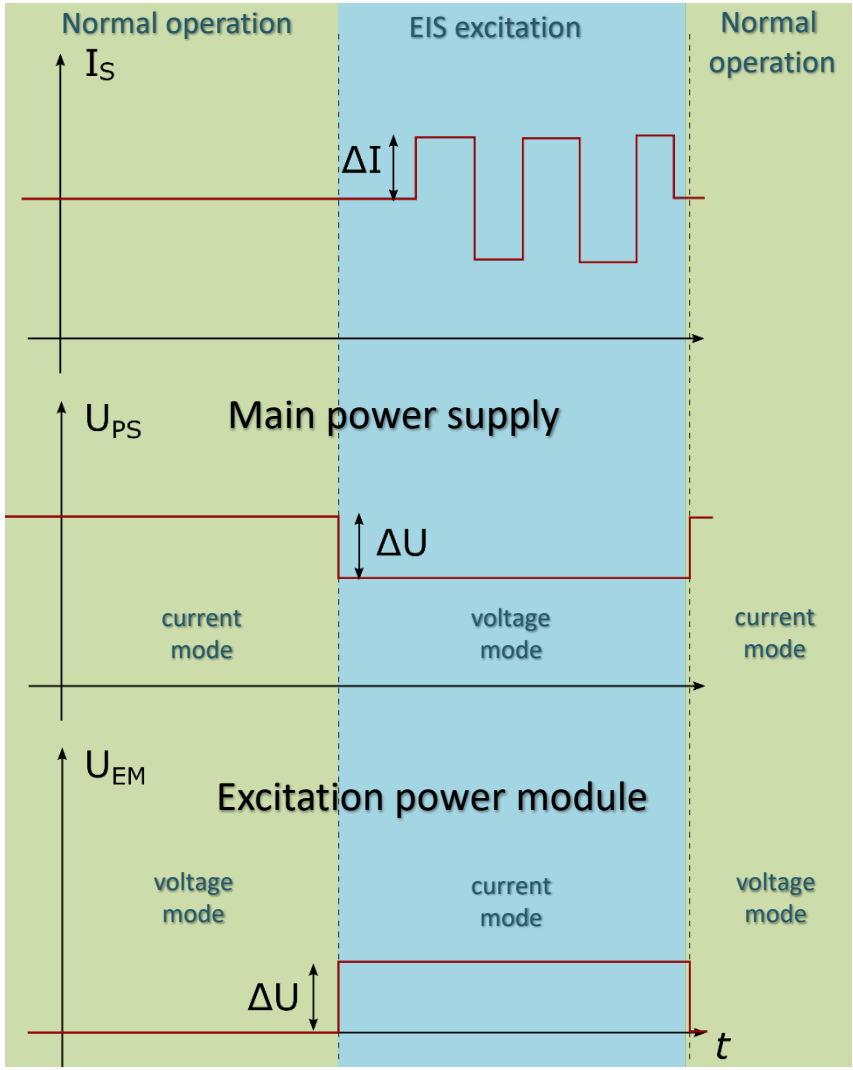
EIS setup





EIS setup



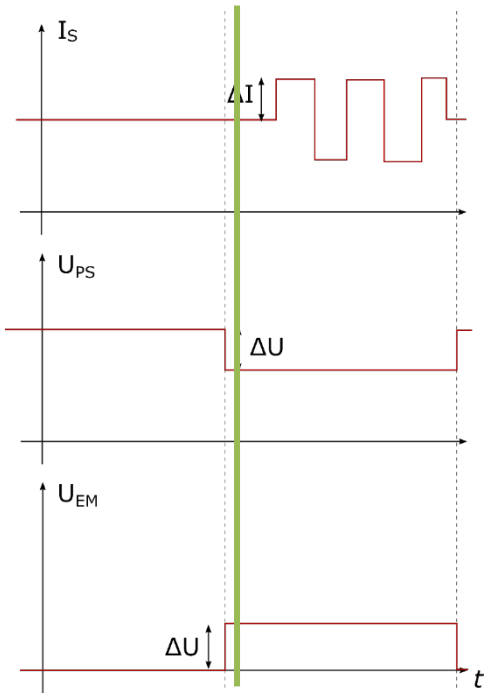


EIS procedure steps 1/3

Initialization of EIS

Prep. Of signals and UI take-over

1. BBR -> EM
   - Initialize all EIS signals
   - Obtain measurement details
2. EM -> Stack controller
   - EM to coordinate with Stack controller to manage the current control transition
3. BBR -> EM
   - check if EM is ready to for EIS



EM take-over procedure

Stack controller

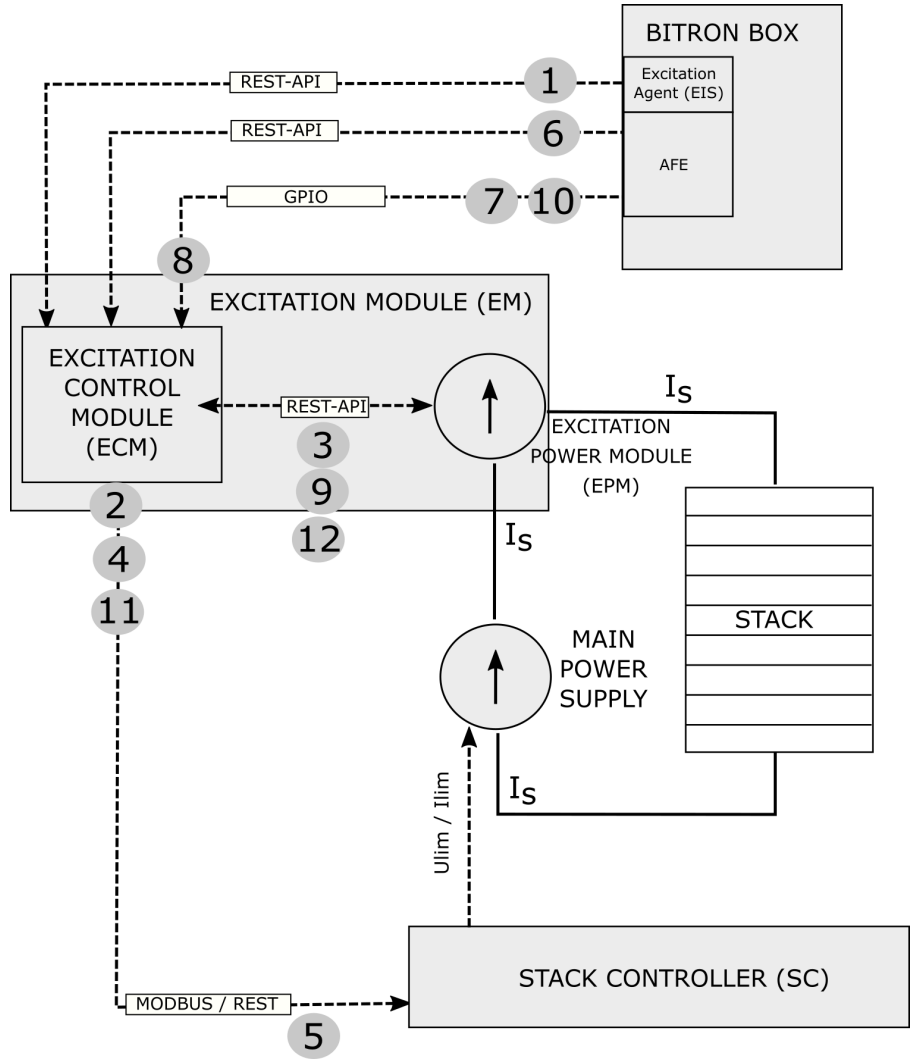
Ulim = Ustack0 – 2.5 V

Ilim > Istack0

EM

Uexc = 2.5 V

Iexc_sp = Istack0



EIS procedure steps 2/3

Initialization of EIS

Prep. Of signals and UI take-over

1. BBR -> EM
   - Initialize all EIS signals
   - Obtain measurement details
2. EM -> Stack controller
   - EM to coordinate with Stack controller to manage the current control transition
3. BBR -> EM
   - check if EM is ready to for EIS

<<Iterate over all signals>>

4. BBR -> EM
   - Get ready specific signal
5. BBR -> AFE
   - Send measurement details for each signal

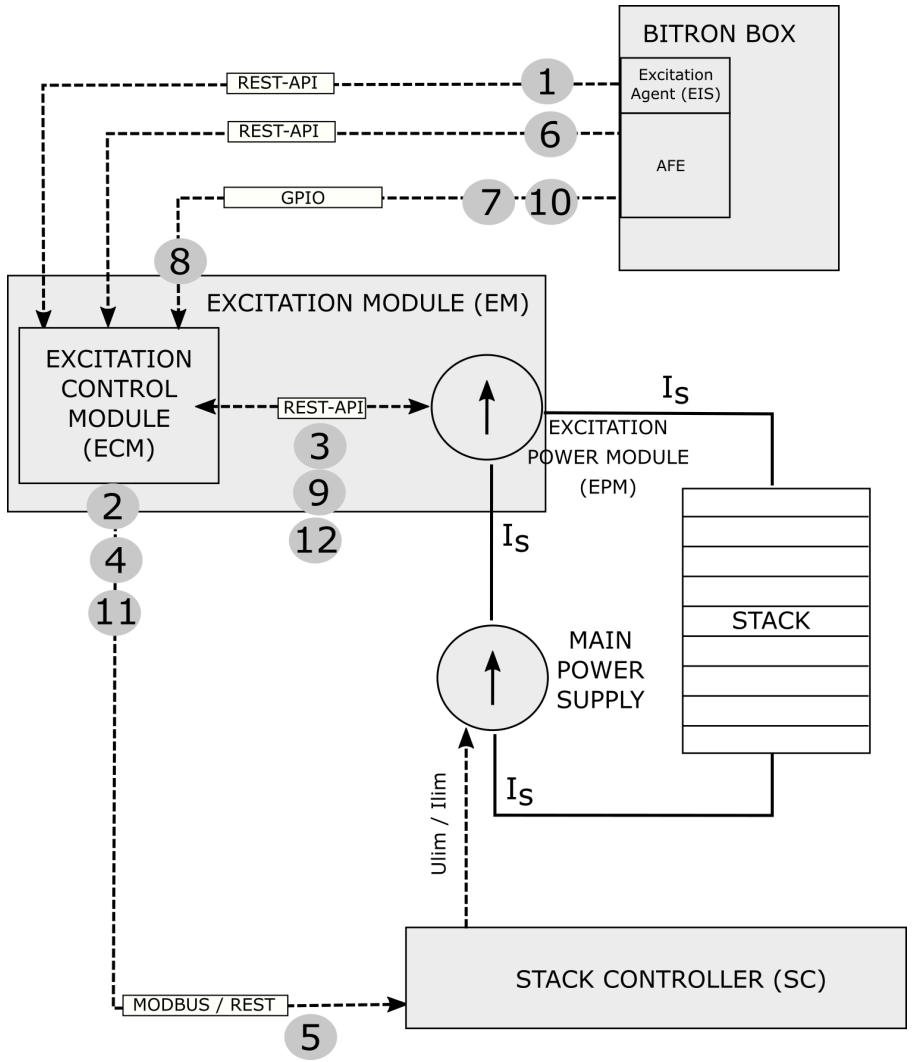
BBR coordination of EIS

BBR coordination of EIS

Experiment initiation

6. AFE -> EM
   - Start / stop for each experiment (initialized signal)

<<stop iteration over signals>>



EIS procedure steps 3/3

Initialization of EIS

Prep. Of signals and UI take-over

BBR coordination of EIS

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2. EM -> Stack controller
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<<Iterate over all signals>>

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BBR coordination of EIS

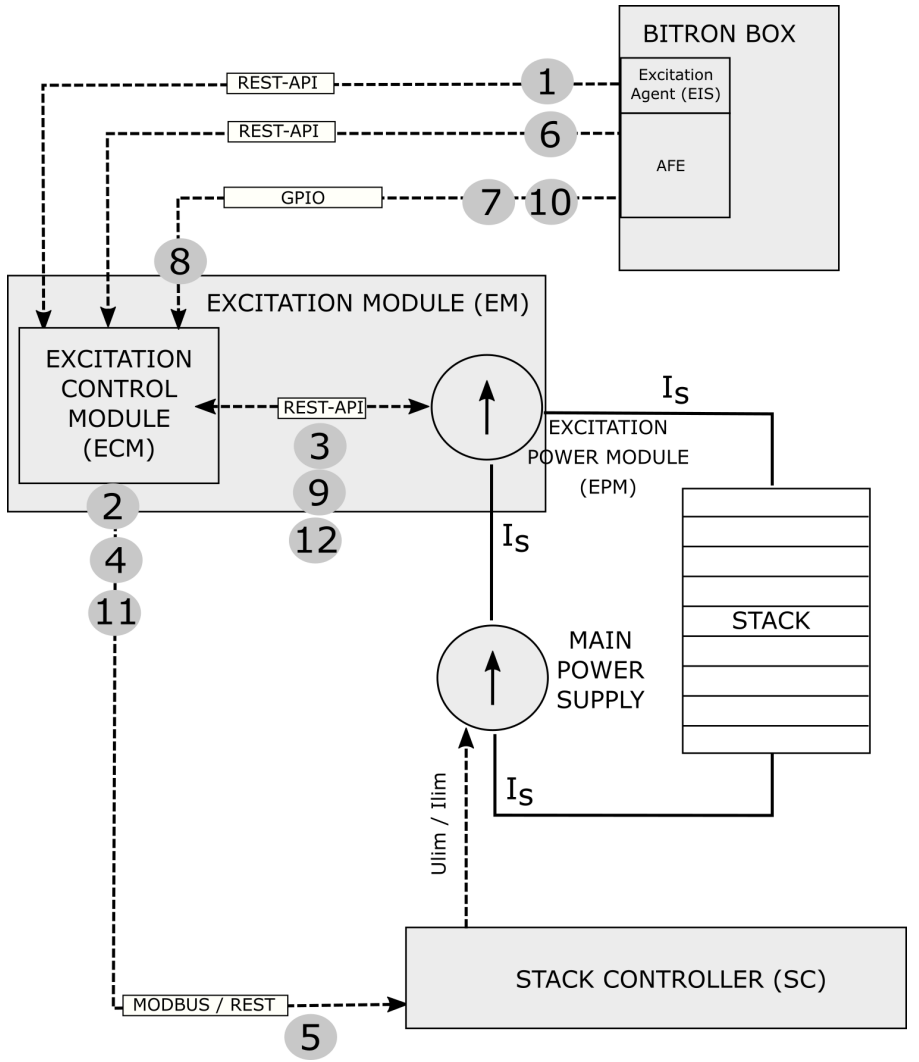
Experiment initiation

6. AFE -> EM
   - Start / stop for each experiment (initialized signal)

<<stop iteration over signals>>

EIS ending procedure

7. BBR -> EM
   - End EIS experimentation
8. EM -> Stack controller
   - Coordination to switch to normal UI operation



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EIS procedure – communication

Initialization of EIS

Prep. Of signals and UI take-over

BBR coordination of EIS

1. BBR -> EM
   - Initialize all EIS signals
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2. EM -> Stack controller
   - EM to coordinate with Stack controller to manage the current control transition
3. BBR -> EM
   - check if EM is ready to for EIS

<<Iterate over all signals>>

4. BBR -> EM
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5. BBR -> AFE
   - Send measurement details for each signal

BBR coordination of EIS

Experiment initiation

6. AFE -> EM
   - Start / stop for each experiment (initialized signal)

<<stop iteration over signals>>

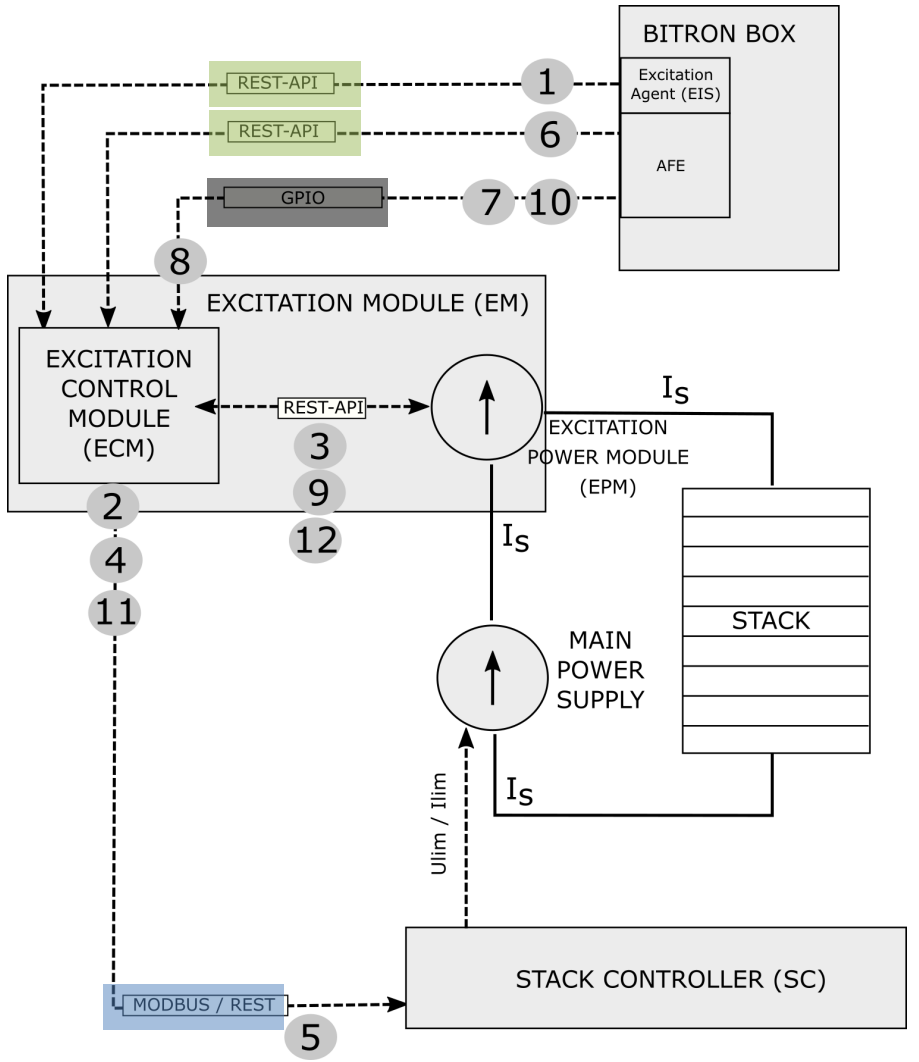
EIS ending procedure

7. BBR -> EM
   - End EIS experimentation
8. EM -> Stack controller
   - Coordination to switch to normal UI operation

HTTP REST communication

MODBUS TCP or HTTP REST

Direct GPIO communication



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Hardware

Excitation module hardware structure

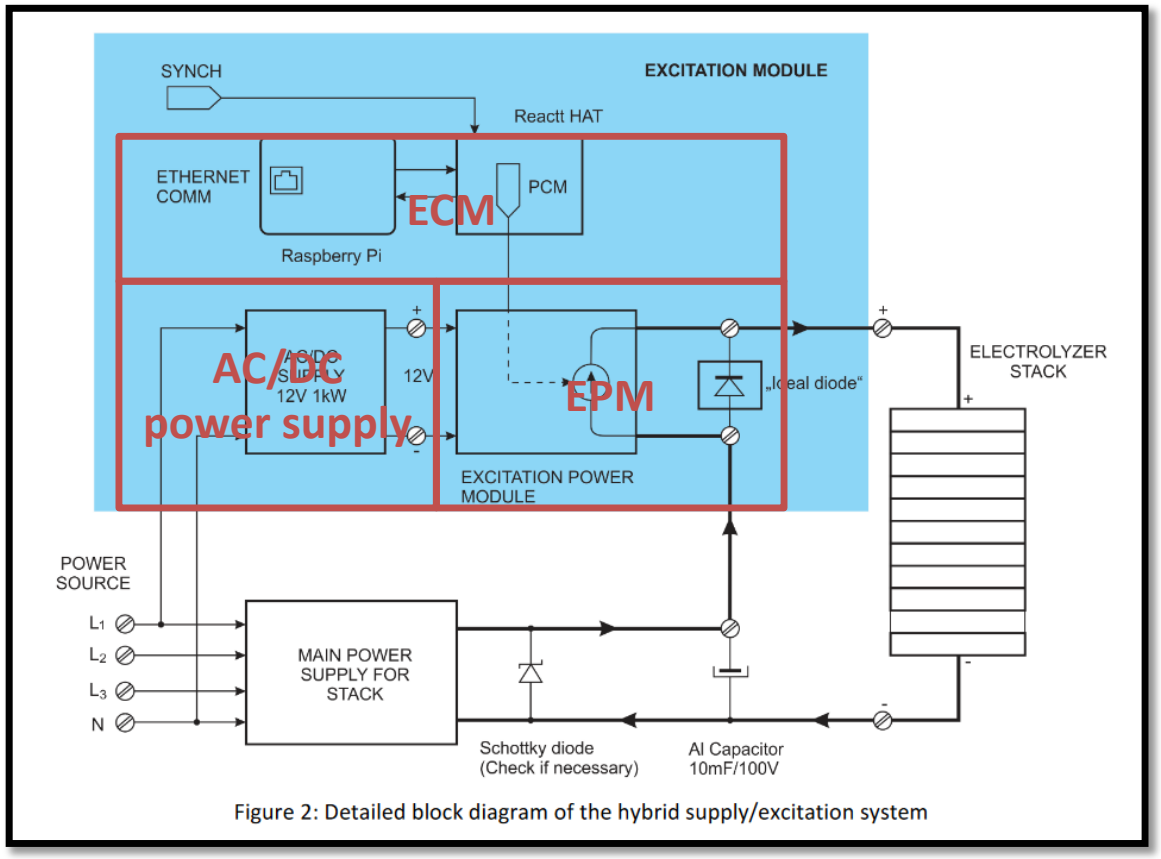

Figure 2: Detailed block diagram of the hybrid supply/excitation system

- Excitation module consists of
  - AC/DC power supply (12V, 1kW)
  - Excitation Power module (EPM)
  - Excitation Control module (ECM)

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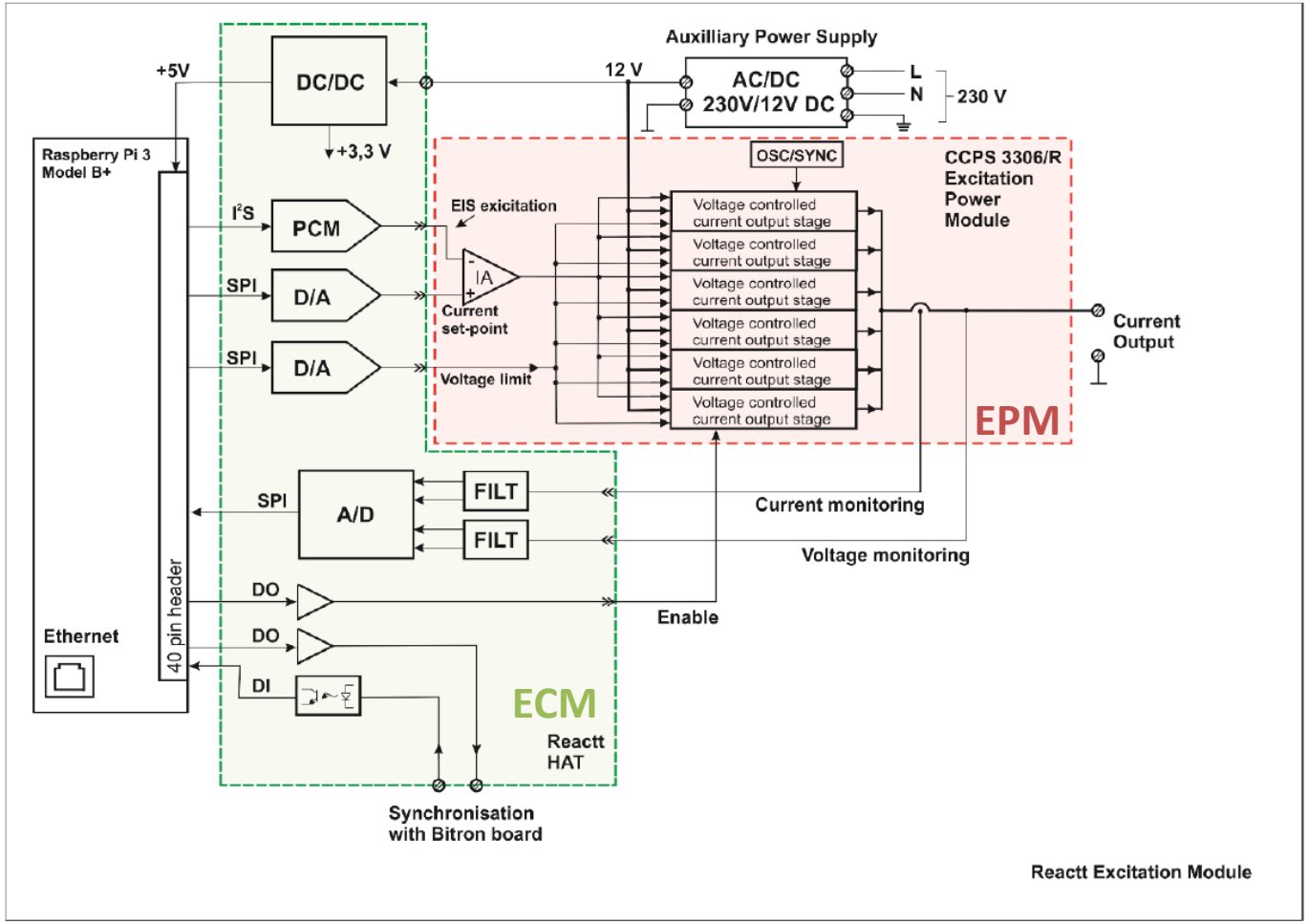
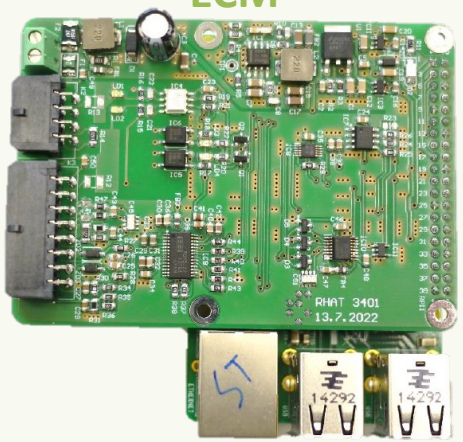
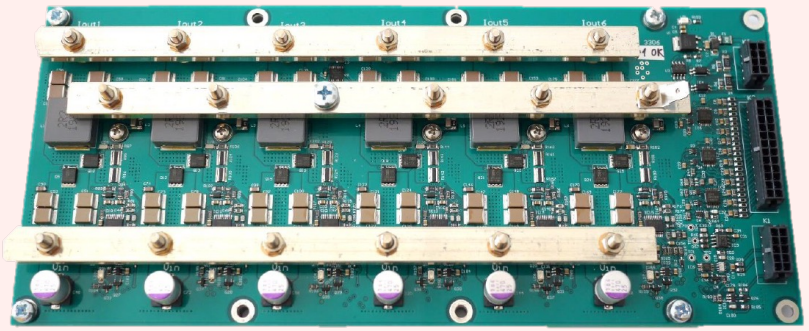
Hardware details



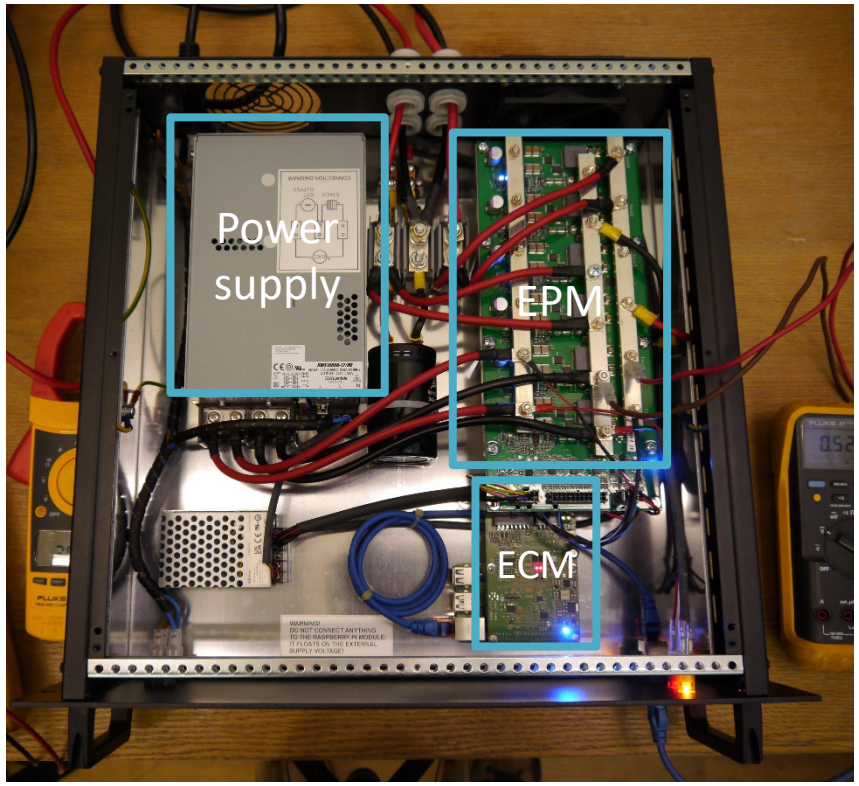
ECM

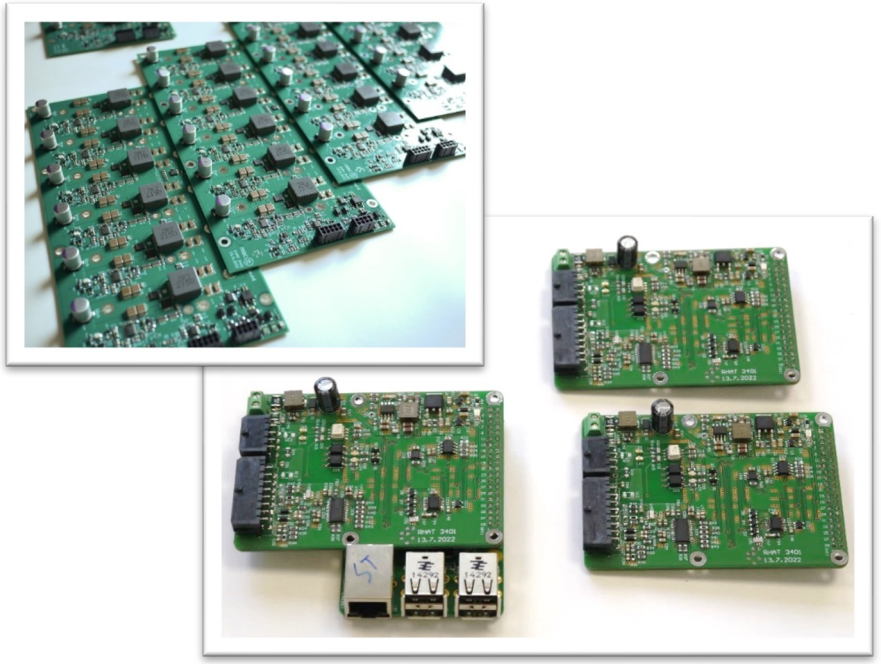


EPM

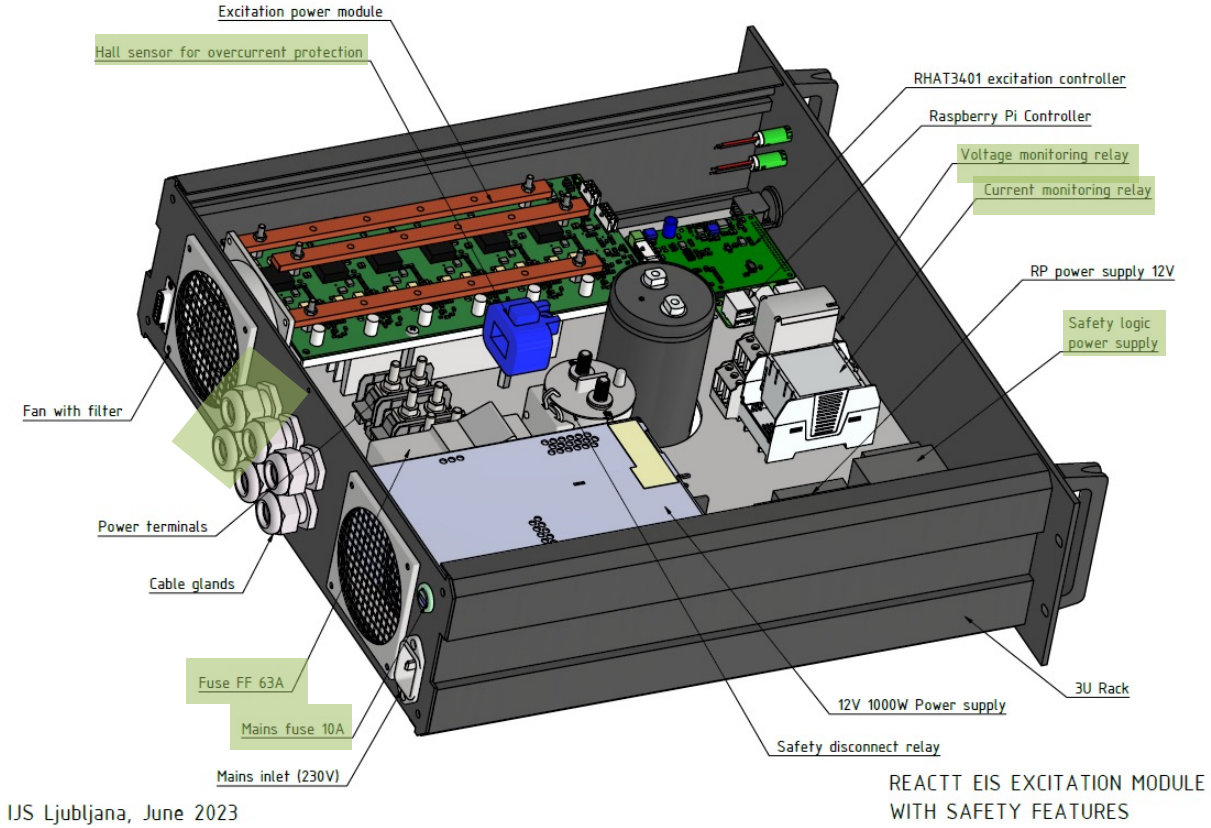


Current implementation of Excitation module





Excitation module – updated version



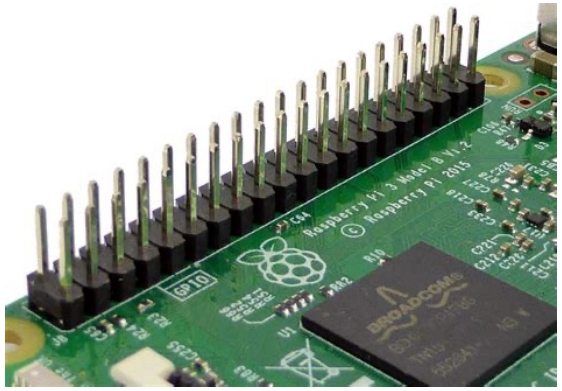
- New version in preparation
- Improved security (over-current protection monitoring and fast cut-off system)
- Possibility to connect two external stack power supplies

Software

Software building blocks of ECM

Signal generator	Sine	PRBS	Signal upload (vector)	Signal upload (wav file)
Excitation control	Experiment preparation	Internal U/I monitoring	Single experiment management	
EIS coordinator	EIS management	Get stack U/I	Voltage/power mode request/control	MODBUS/REST-API communication module with stack power supply
APIs	GPIO	REST API	MQTT	
GUI	Signal creator	Signal upload	Experiment management / monitoring	Debug

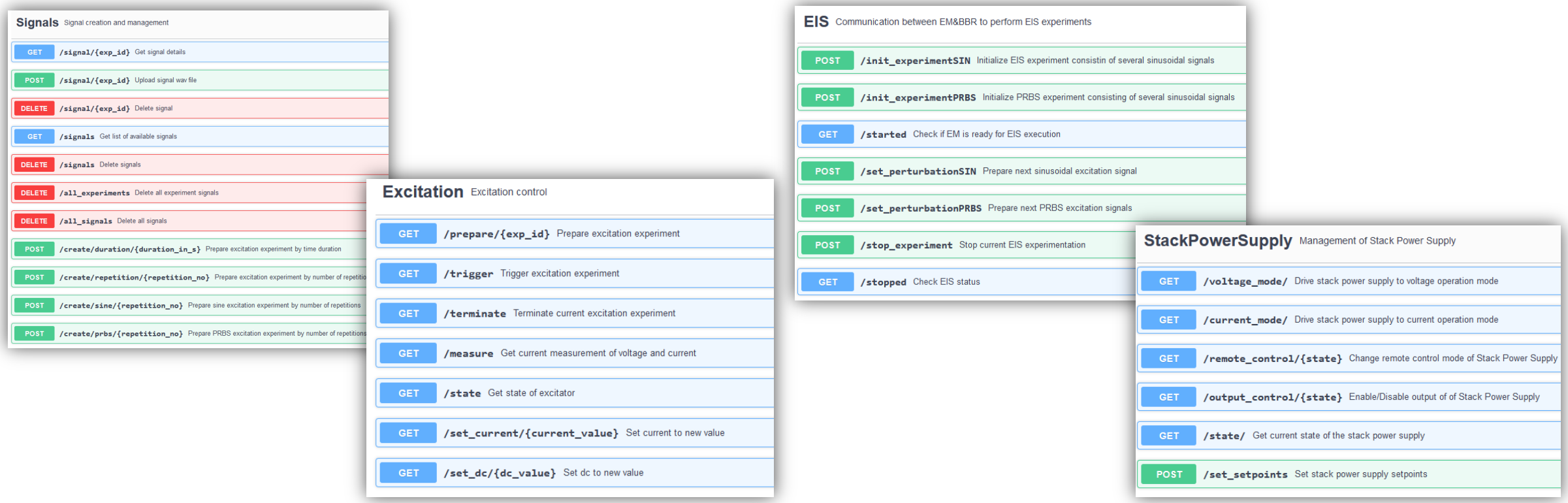
APIs



- *Web-Service (WS) interface*
  - Generate new signal
  - Take over control
  - Manage experiment (trigger, terminate, status)
- *GPIO interface*
  - Trigger excitation
  - Terminate excitation

Web-service API

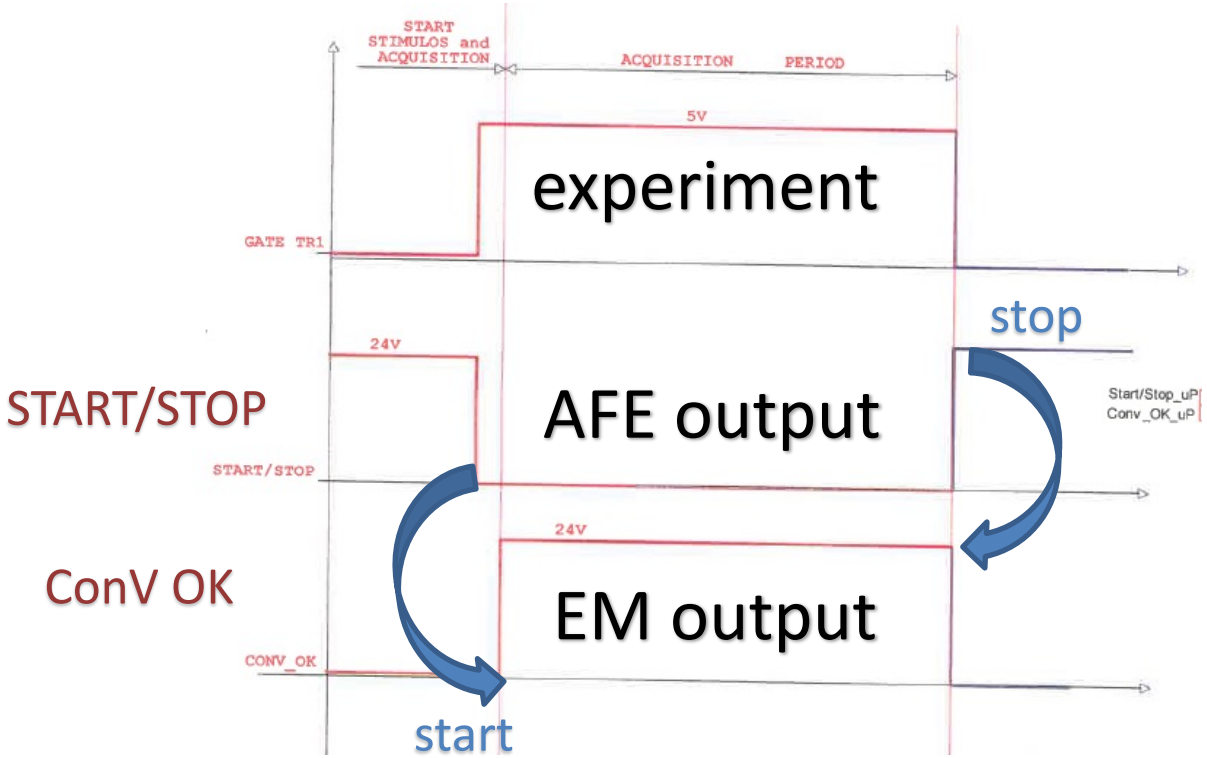
- HTTP request-response communication (REST API)
- Swagger/OpenAPI standard definition of API is available at
  https://repo.ijs.si/mglavan/reactt-excitator-api/

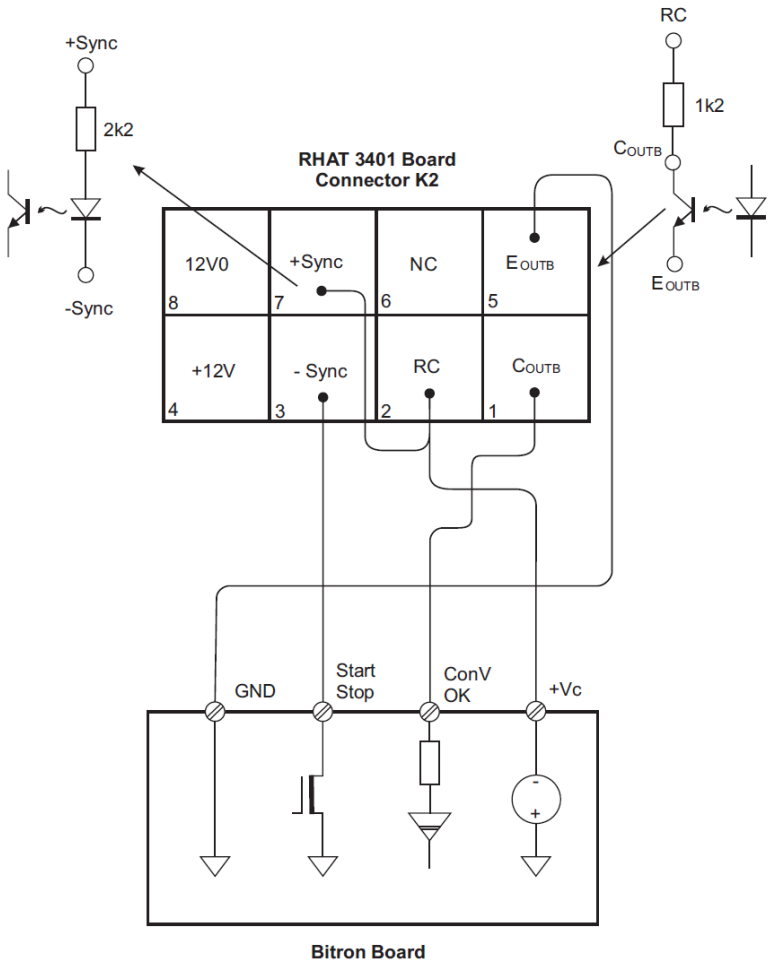


GPIO interface

Used GPIO signals

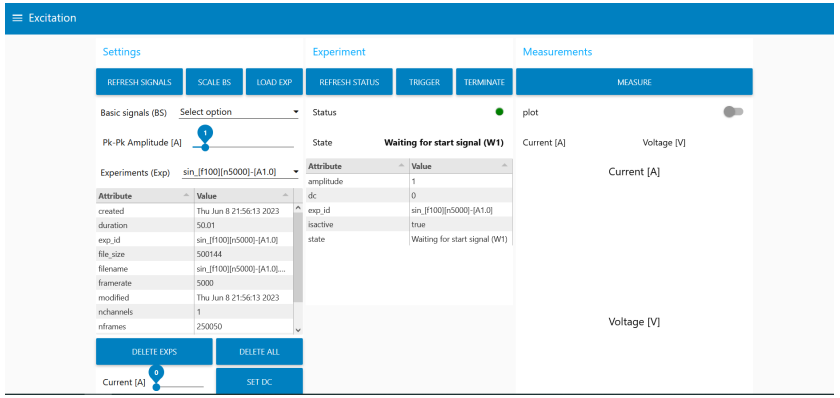
- AFE triggers experiment with START/STOP
- EM responds to confirm with ConV OK

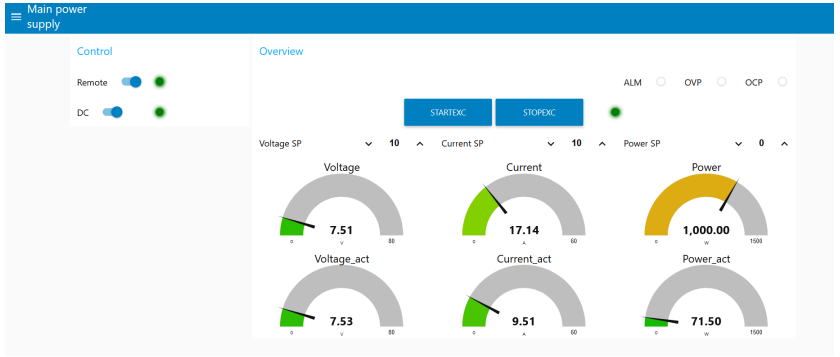




GUI

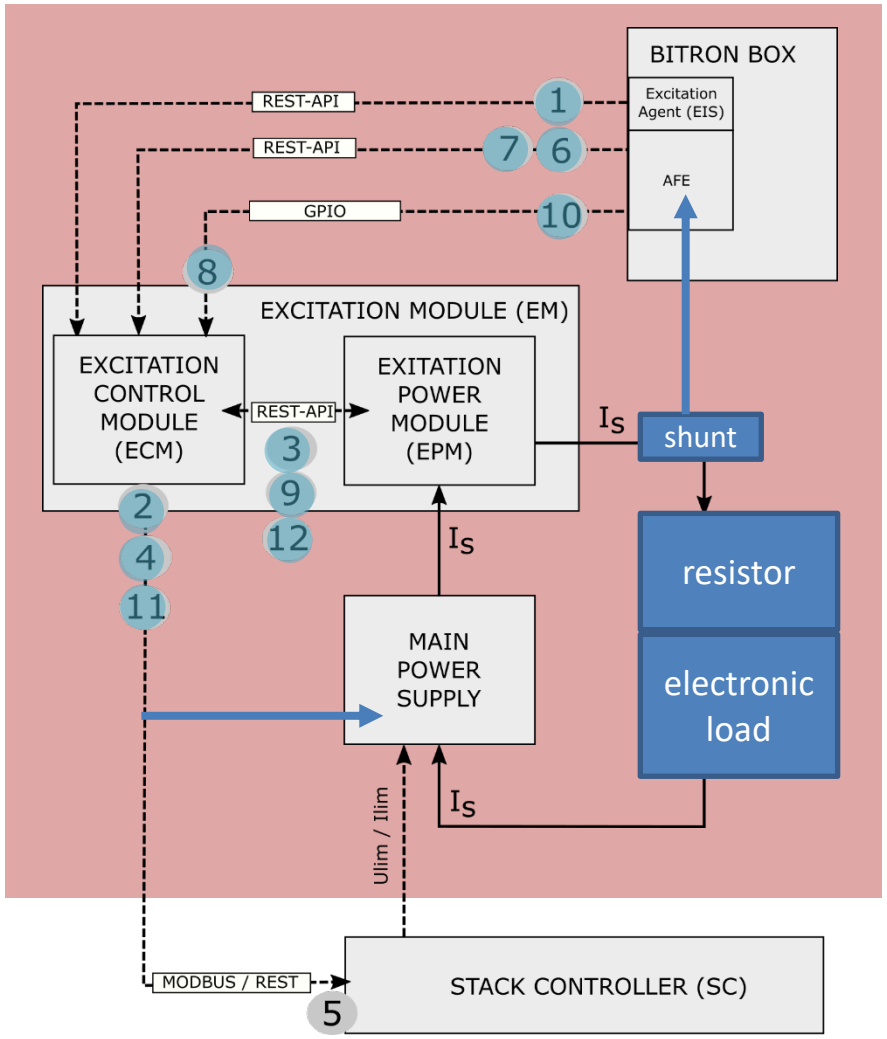
- NodeRed based Web application as GUI
- Use of REST-API to fully control the excitator
  - View 1: Excitation signal upload window
  - View 2: Excitation signal generator
  - View 3: Experiment control window
    - Prepare experiment
    - Trigger/Terminate experiment
    - MQTT for on-line visualization of the current conditions
  - View 4: Console for debugging
  - View 5: Power source control

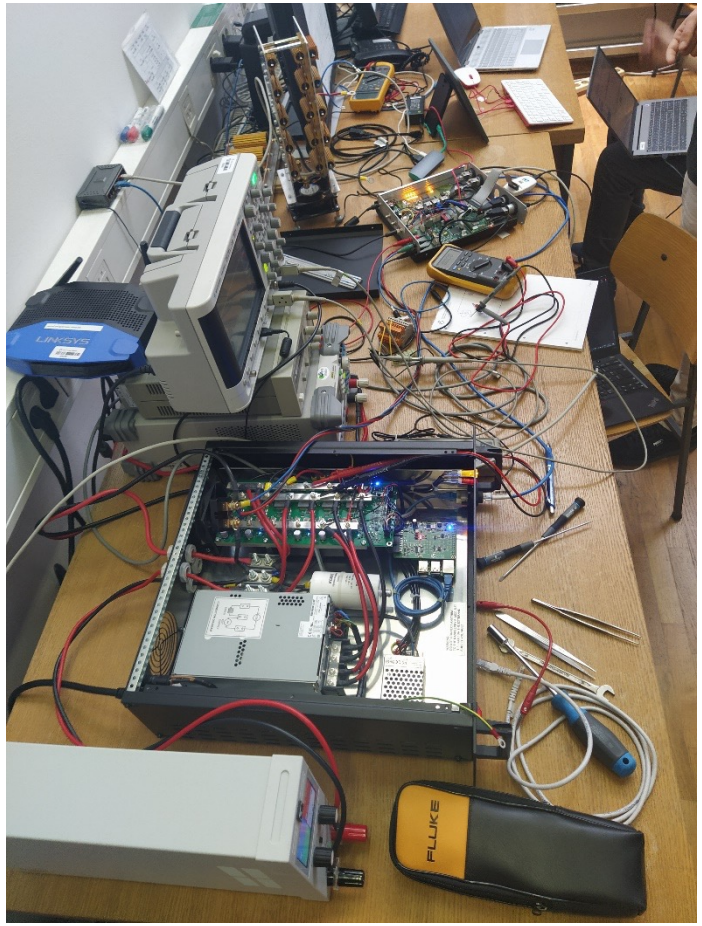




Current status and next steps

EIS component testing





Lab testing

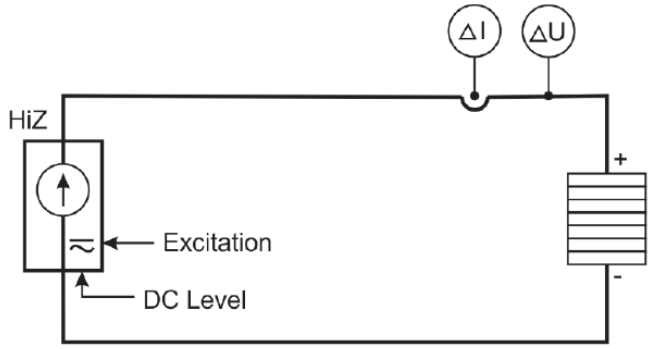
- ½ of 2023 -> manual mode testing (EM + SC)
- 12.6-13.6.2023 -> testing together with BBR and AFE performed together with UNISA & Bitron

Next steps…

- New hardware in finalization phase
- Software update in progress (Power Supply interface, general update resolving minor bugs)
- Field implementation and testing (EPFL, VTT, CEA)

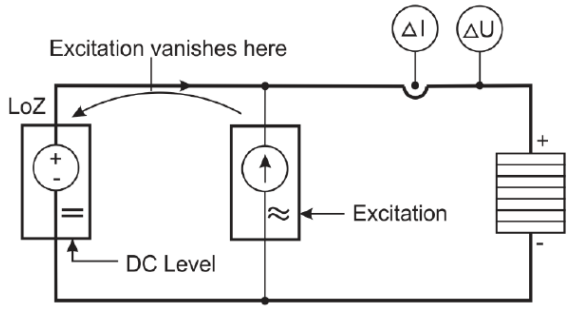
Thank you

SELECTION OF HYBRID POWER SUPPLY SCHEME



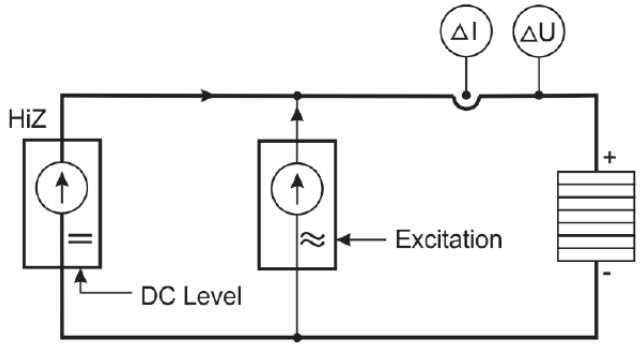
Solution A:

Current-mode power supply provides main supply to the stack and performs also the excitation.



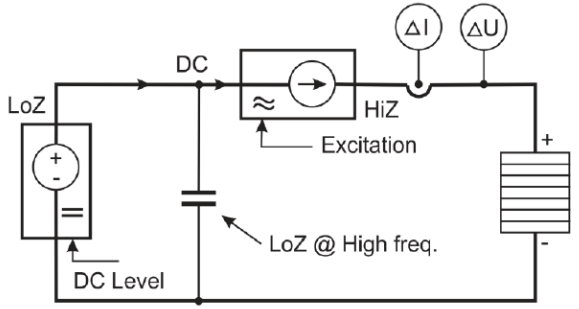
Solution C:

Standard power supply provides main supply to the stack. Excitation module is connected in parallel. Most of excitation current vanishes on output capacitors of the main supply.



Solution B:

Current-mode power supply and excitation module are connected in parallel. Both have high output impedance.



Solution D:

Standard power supply provides main supply to the stack. The excitation module adds the excitation and provides high output impedance.

EIS procedure - example

- Example of power conditions for Main power supply and EM through the EIS experiment routine