

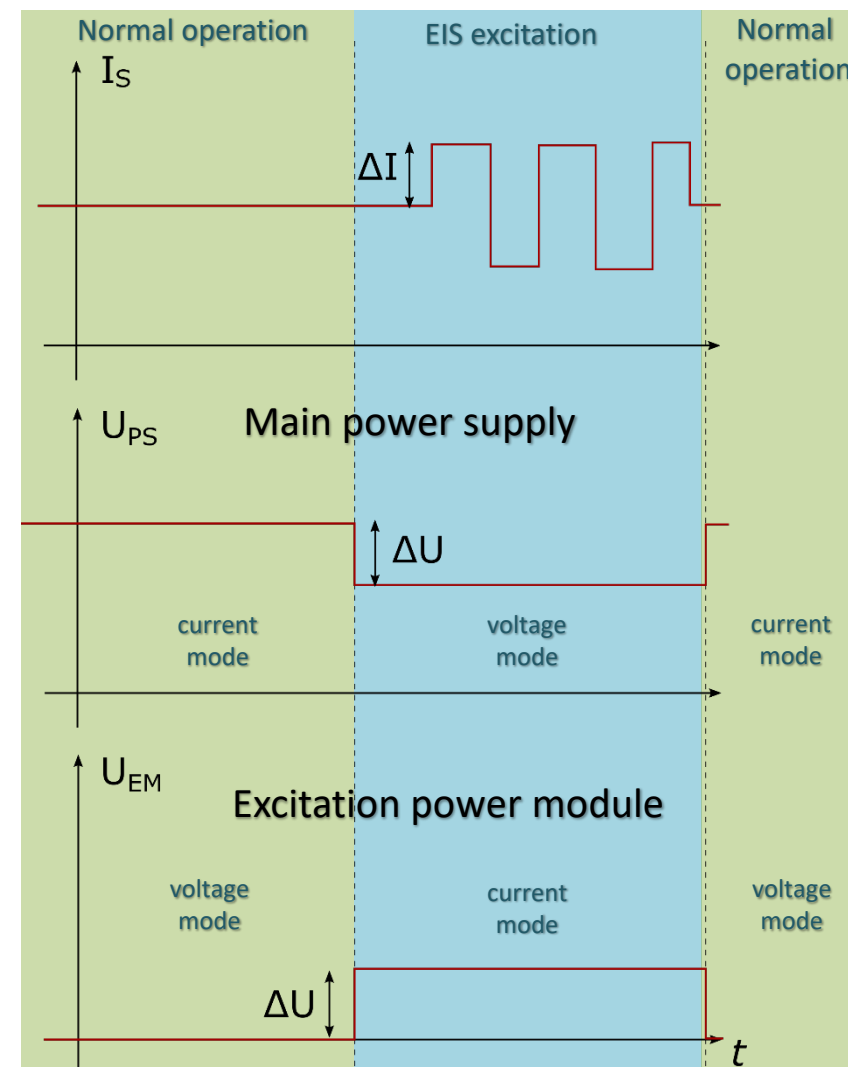
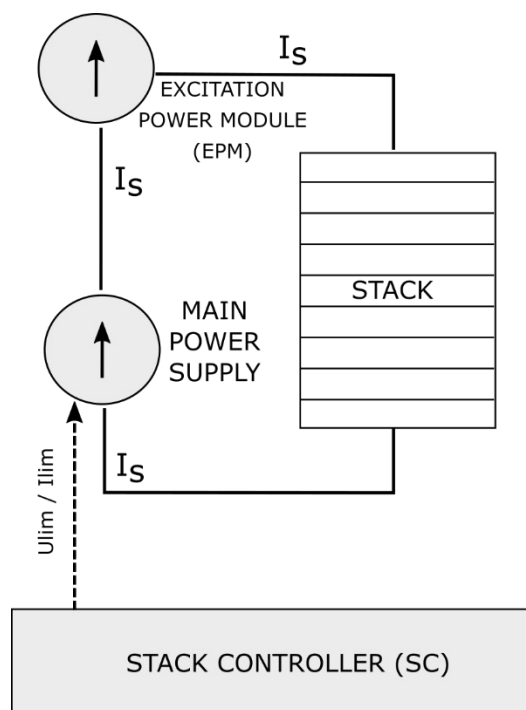
# On excitation of SOEC stacks for impedance spectroscopy in in-field applications

Miha Glavan, IJS ([miha.glavan@ijs.si](mailto:miha.glavan@ijs.si))

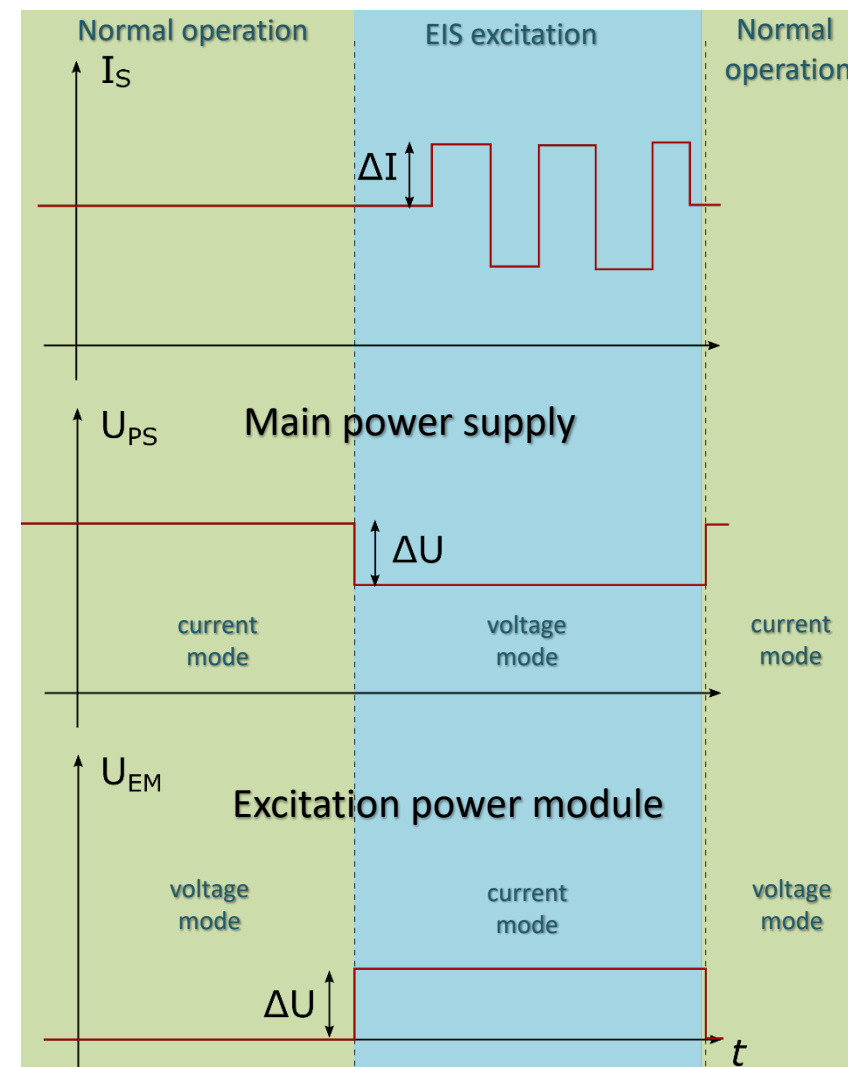
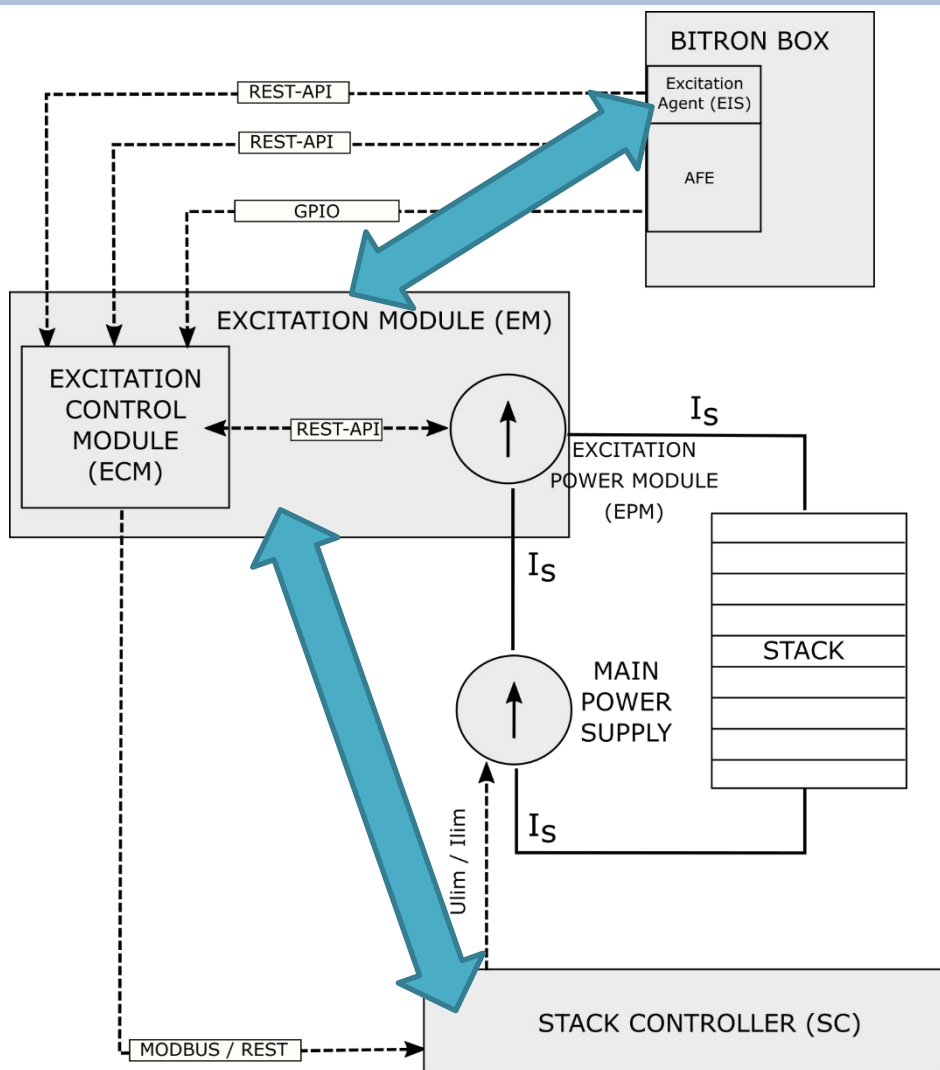
- Electrochemical impedance spectroscopy (EIS) is a powerful tool to characterize electrochemical reaction process
- Typically an expensive laboratory equipment is applied to perform EIS
- REACTT objective
  - Development of affordable (low-cost), reliable and flexible equipment for EIS
  - Equipment 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

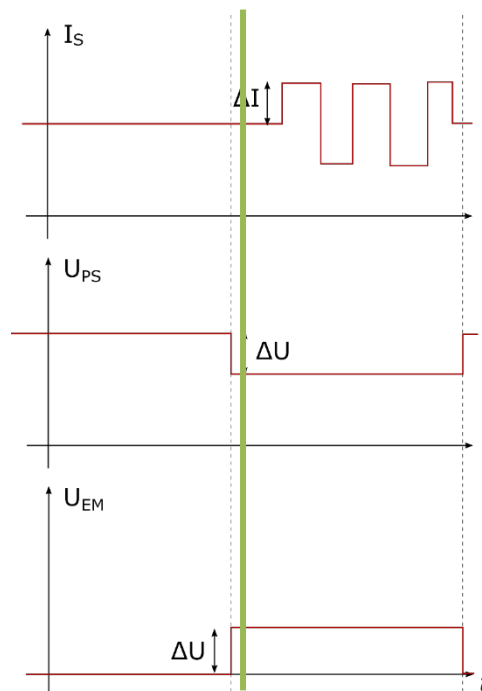


# EIS setup



# EIS procedure steps 1/3

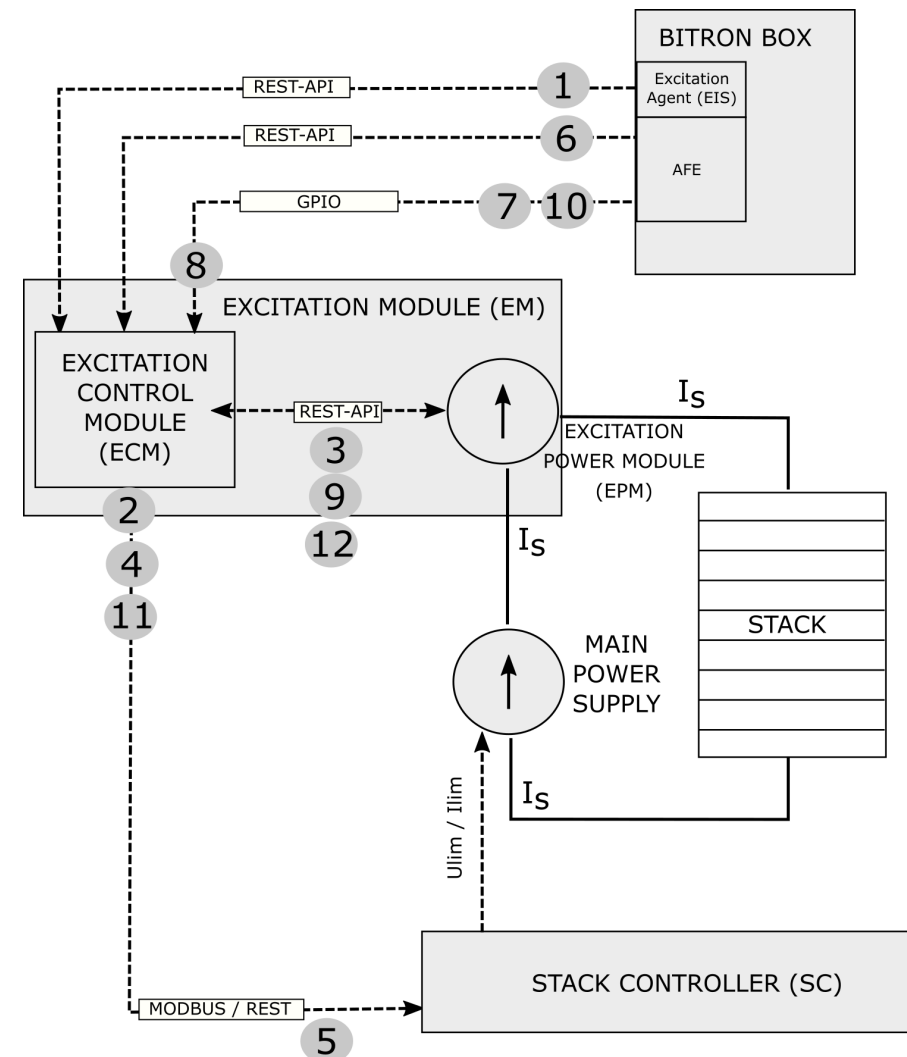
1. BBR -> EM
  - Initialize all EIS signals
  - Obtain measurement details
2. EM -> Stack controller
  - EM to coordinate with Stack controller to manage the current control transition
3. BBR -> EM
  - check if EM is ready for EIS



EM take-over procedure

Stack controller  
 $U_{lim} = U_{stack0} - 2.5 \text{ V}$   
 $I_{lim} > I_{stack0}$

EM  
 $U_{exc} = 2.5 \text{ V}$   
 $I_{exc\_sp} = I_{stack0}$



# EIS procedure steps 2/3

Initialization of EIS

Prep. Of signals and  
UI take-over

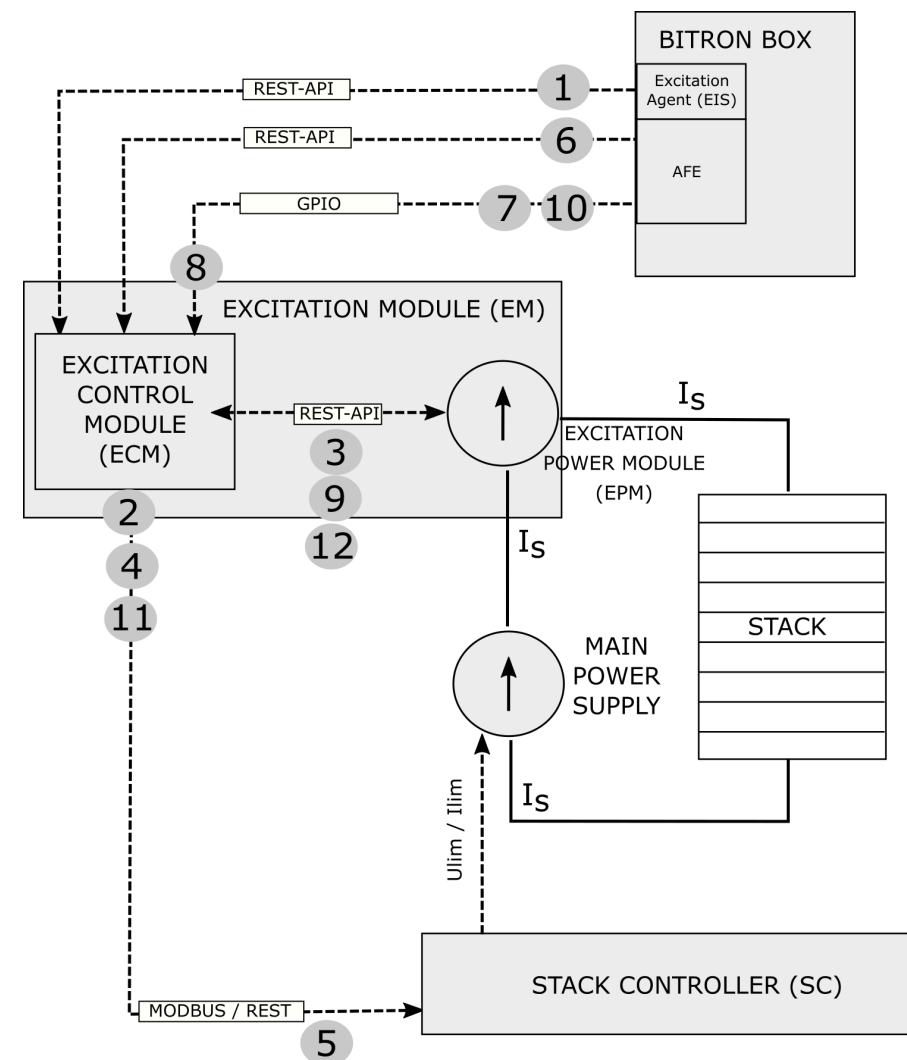
BBR coordination of EIS

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
4. BBR -> EM
  - Get ready specific signal
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 procedure steps 3/3

Initialization of EIS

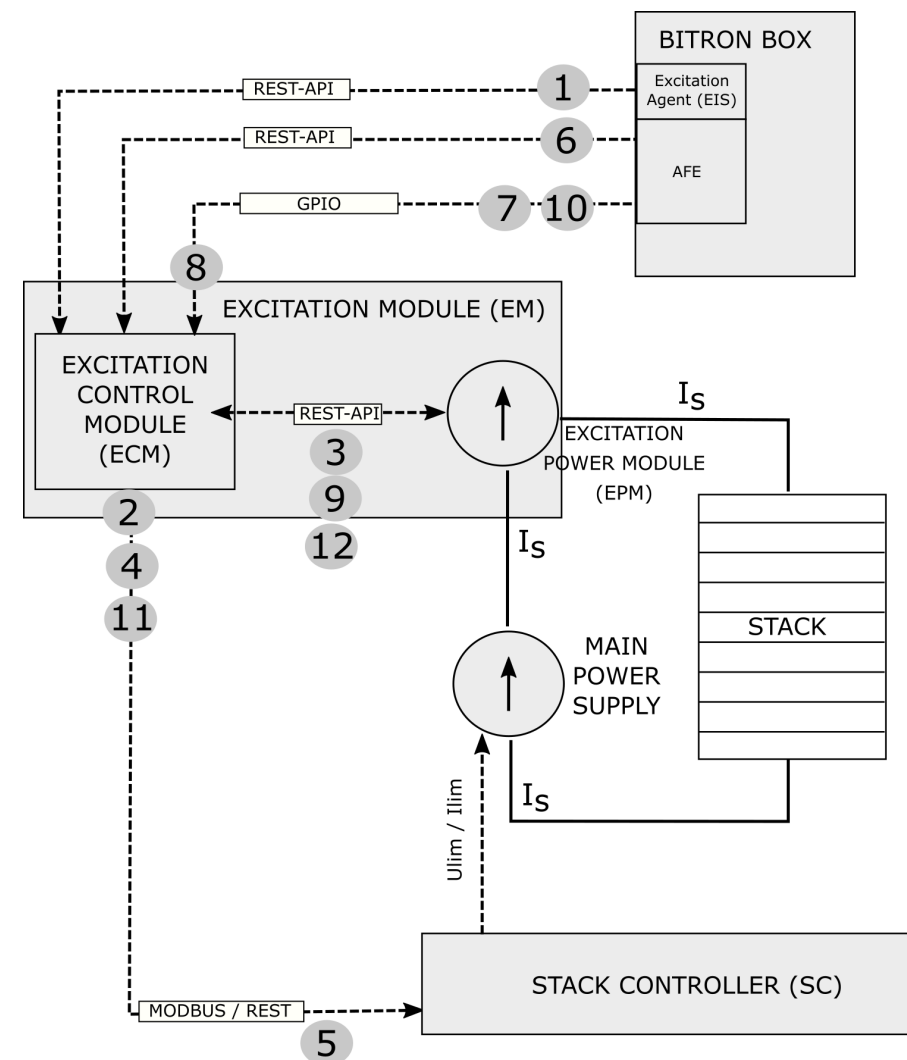
Prep. Of signals and  
UI take-over

BBR coordination of EIS

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  
Experiment initiation  
EIS ending procedure

6. AFE -> EM
    - Start / stop for each experiment (initialized signal)
- <<stop iteration over signals>>
7. BBR -> EM
    - End EIS experimentation
  8. EM -> Stack controller
    - Coordination to switch to normal UI operation



# EIS procedure – communication

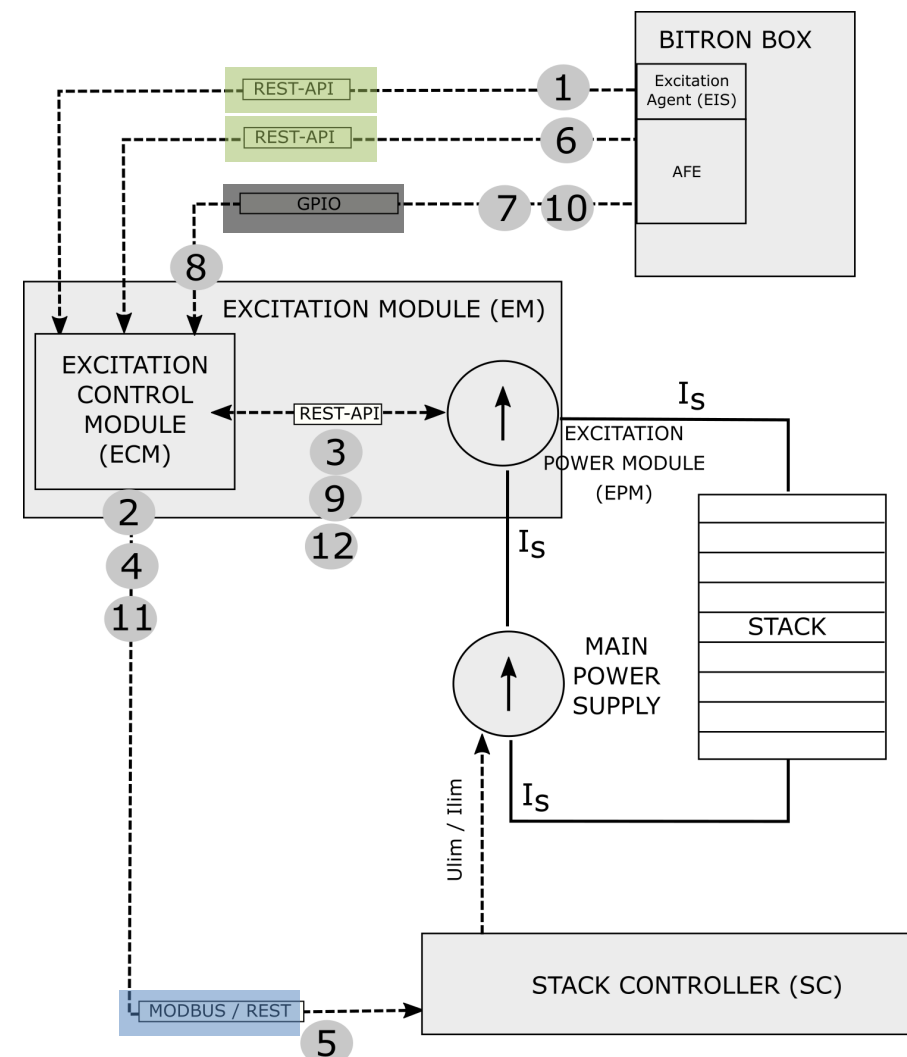
Initialization of EIS  
Prep. Of signals and UI take-over  
BBR coordination of EIS

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  
Experiment initiation  
EIS ending procedure

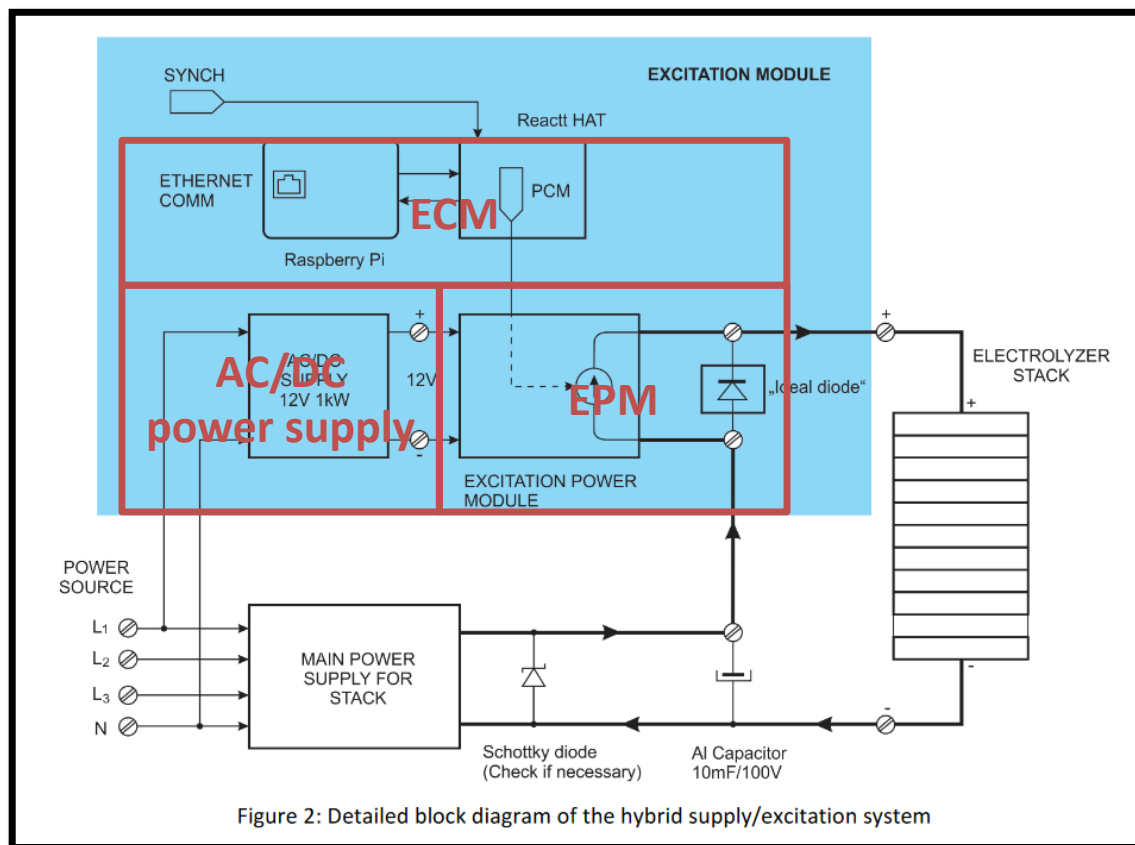
6. **AFE -> EM**
    - Start / stop for each experiment (initialized signal)
- <<stop iteration over signals>>
7. **BBR -> EM**
    - End EIS experimentation
  8. **EM -> Stack controller**
    - Coordination to switch to normal UI operation

HTTP REST communication  
MODBUS TCP or HTTP REST  
Direct GPIO communication

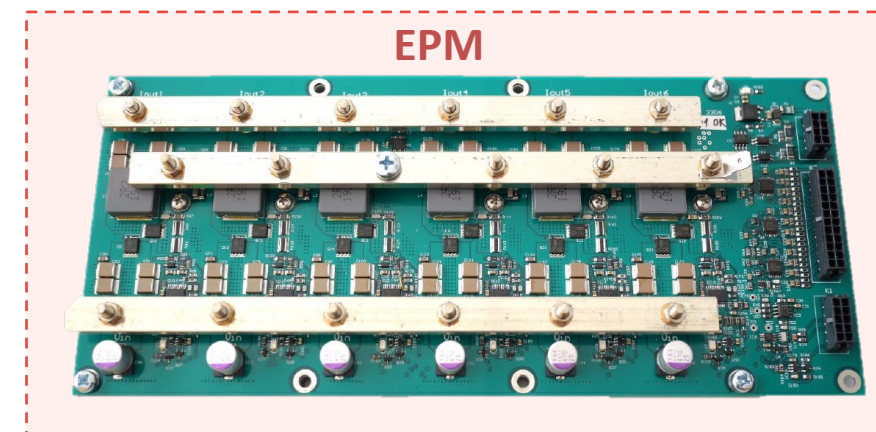
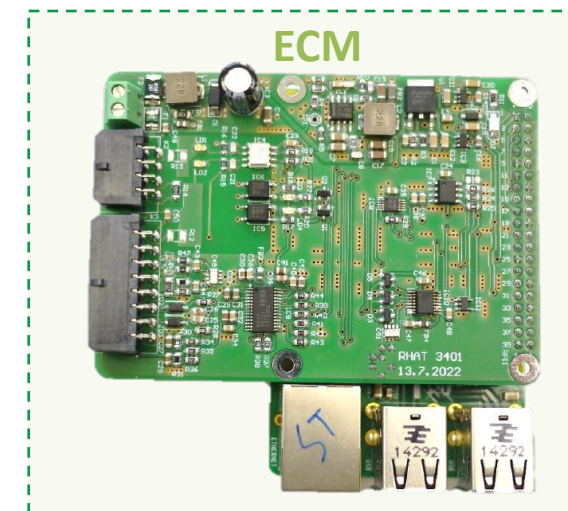
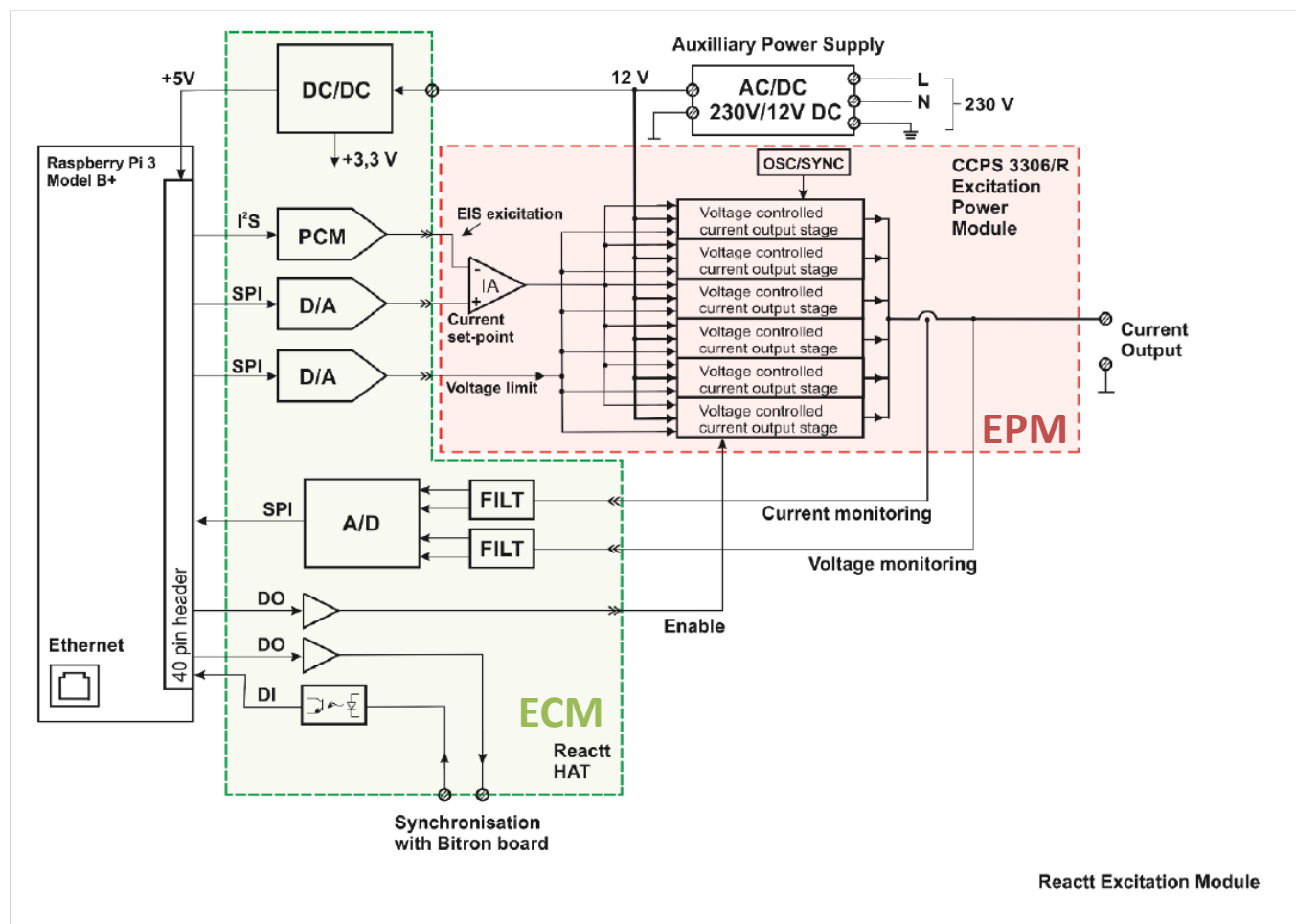


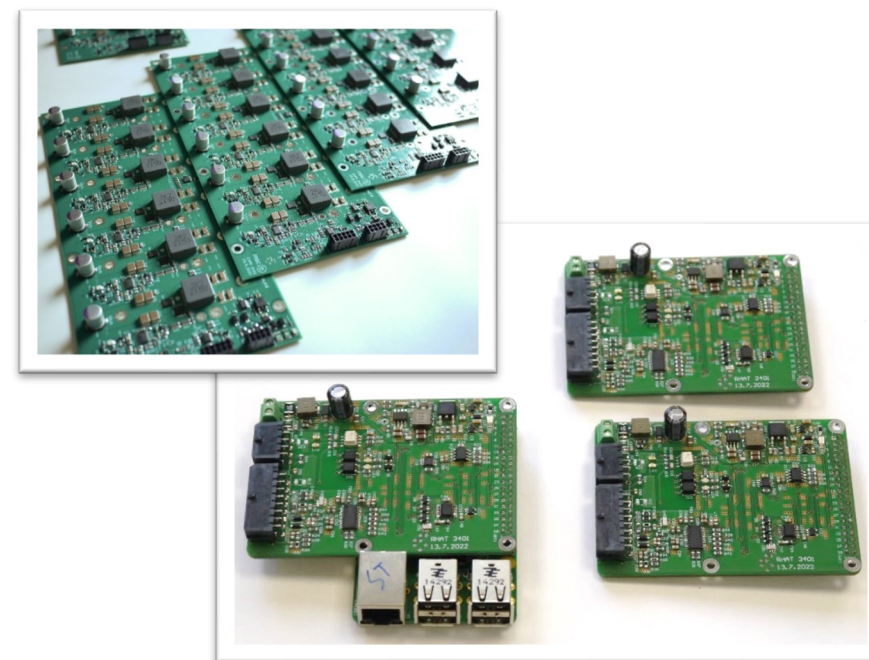
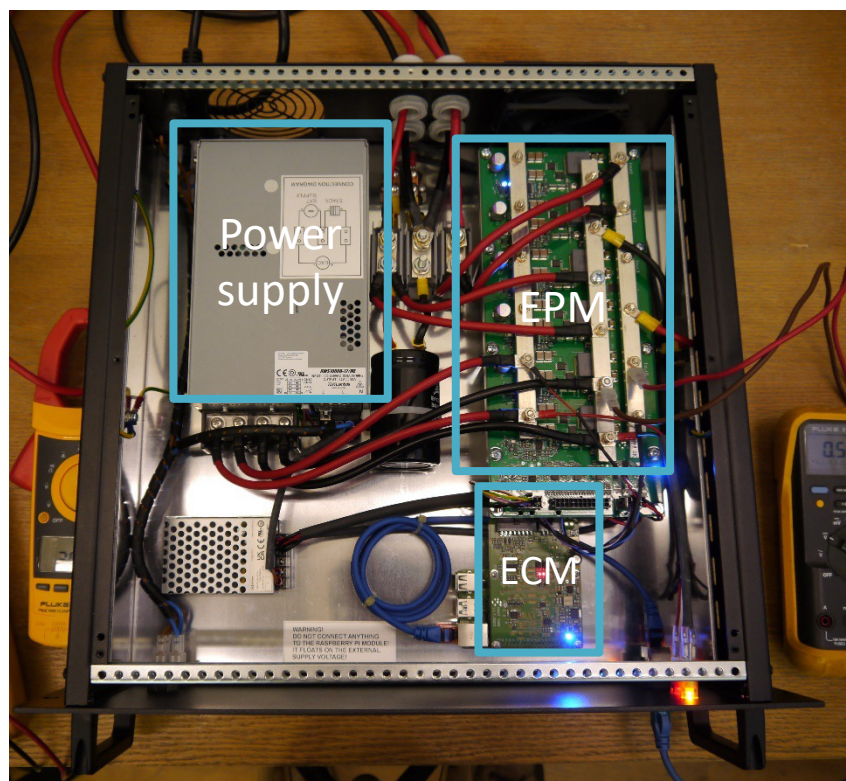
# Hardware

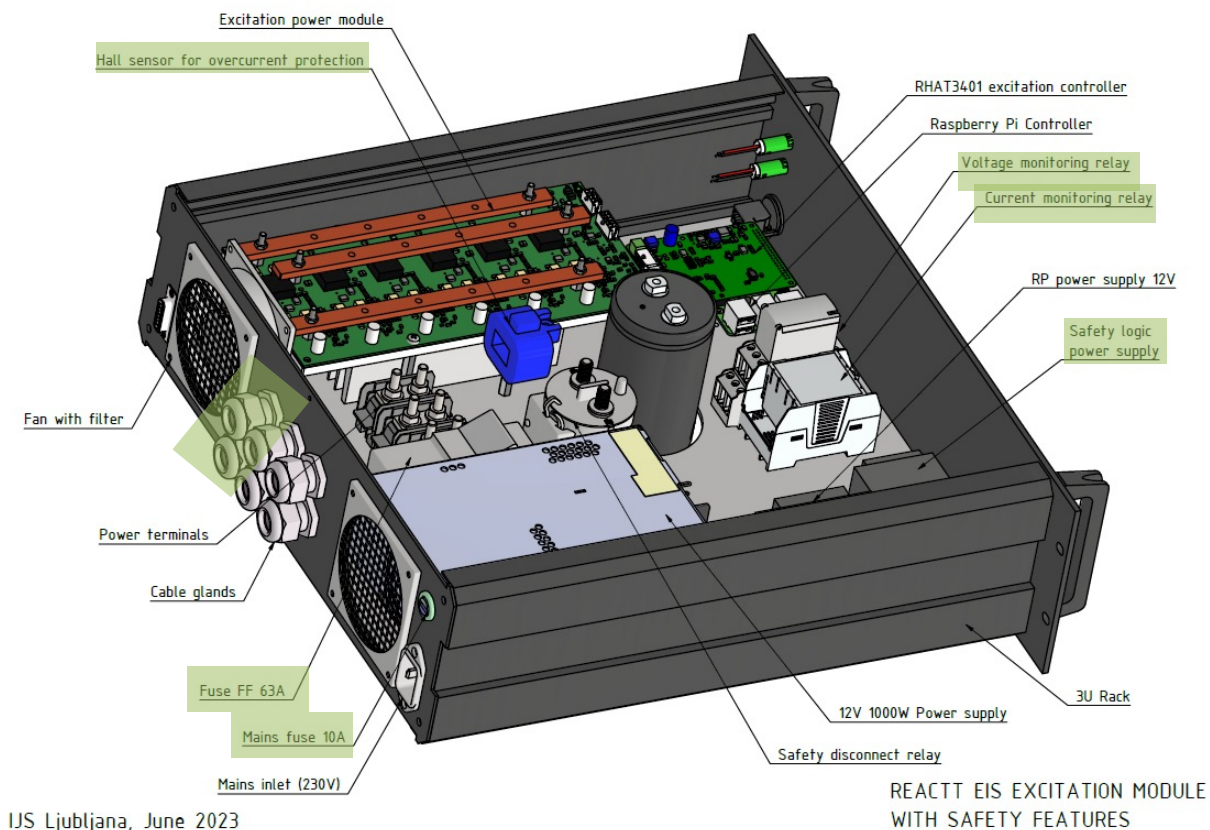
# Excitation module hardware structure



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







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

IJS Ljubljana, June 2023

# Software

## 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

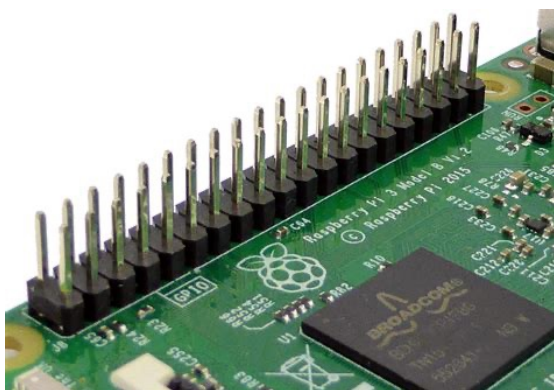
## GUI

Signal creator

Signal upload

Experiment  
management /  
monitoring

Debug



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

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



Signals Signal creation and management	
GET	/signal/{exp_id} Get signal details
POST	/signal/{exp_id} Upload signal wav file
DELETE	/signal/{exp_id} Delete signal
GET	/signals Get list of available signals
DELETE	/signals Delete signals
DELETE	/all_experiments Delete all experiment signals
DELETE	/all_signals Delete all signals
POST	/create/duration/{duration_in_s} Prepare excitation experiment by time duration
POST	/create/repetition/{repetition_no} Prepare excitation experiment by number of repetitions
POST	/create/sine/{repetition_no} Prepare sine excitation experiment by number of repetitions
POST	/create/prbs/{repetition_no} Prepare PRBS excitation experiment by number of repetitions

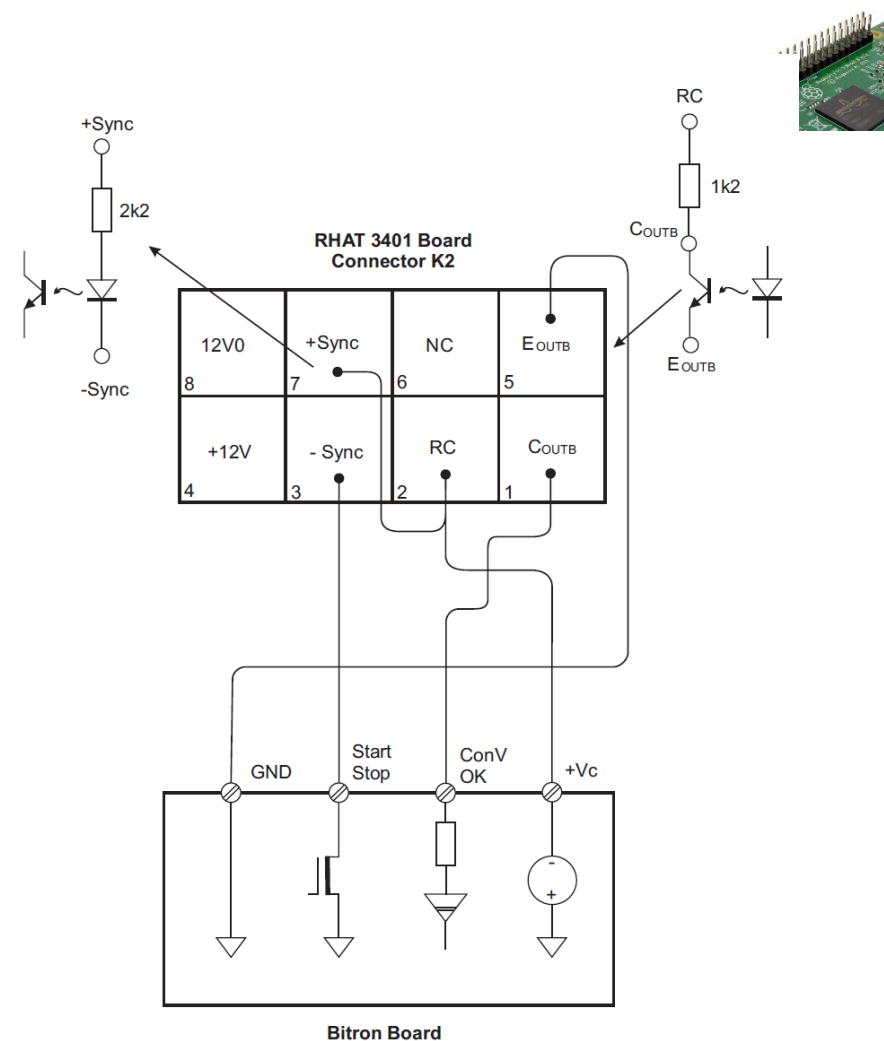
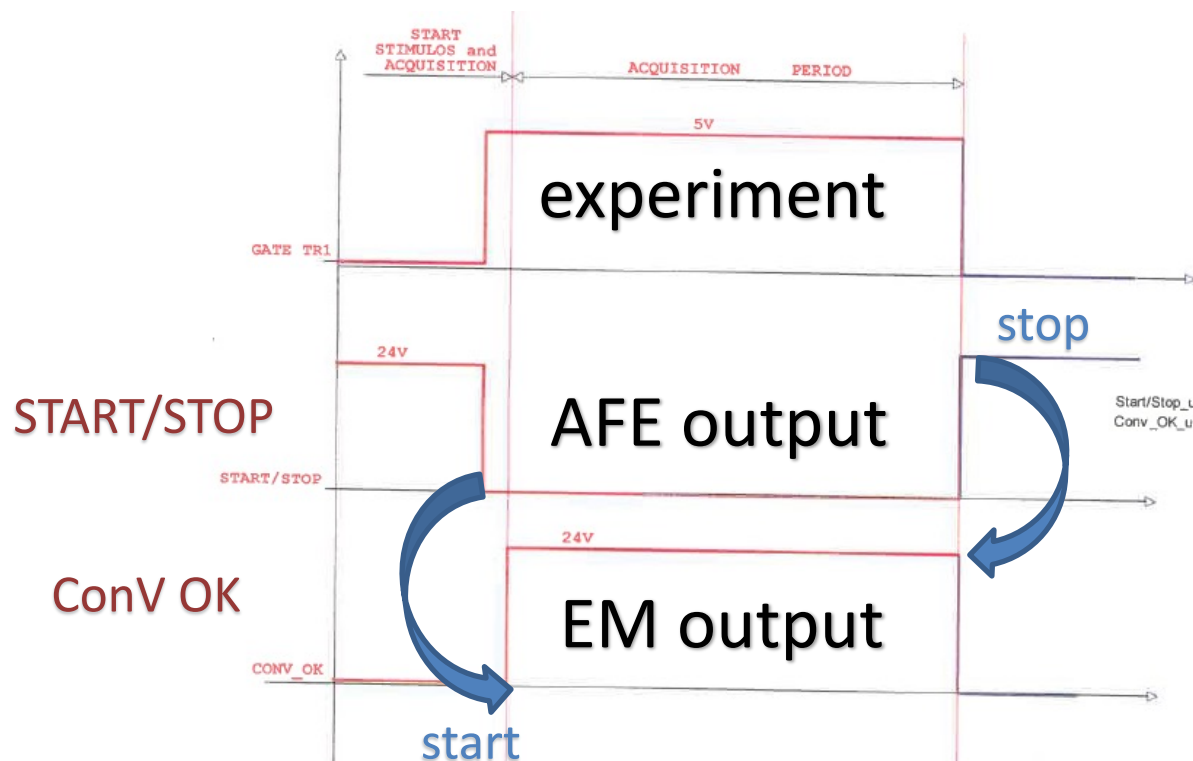
Excitation Excitation control	
GET	/prepare/{exp_id} Prepare excitation experiment
GET	/trigger Trigger excitation experiment
GET	/terminate Terminate current excitation experiment
GET	/measure Get current measurement of voltage and current
GET	/state Get state of excitator
GET	/set_current/{current_value} Set current to new value
GET	/set_dc/{dc_value} Set dc to new value

EIS Communication between EM&BBR to perform EIS experiments	
POST	/init_experimentSIN Initialize EIS experiment consist of several sinusoidal signals
POST	/init_experimentPRBS Initialize PRBS experiment consisting of several sinusoidal signals
GET	/started Check if EM is ready for EIS execution
POST	/set_perturbationSIN Prepare next sinusoidal excitation signal
POST	/set_perturbationPRBS Prepare next PRBS excitation signals
POST	/stop_experiment Stop current EIS experimentation
GET	/stopped Check EIS status

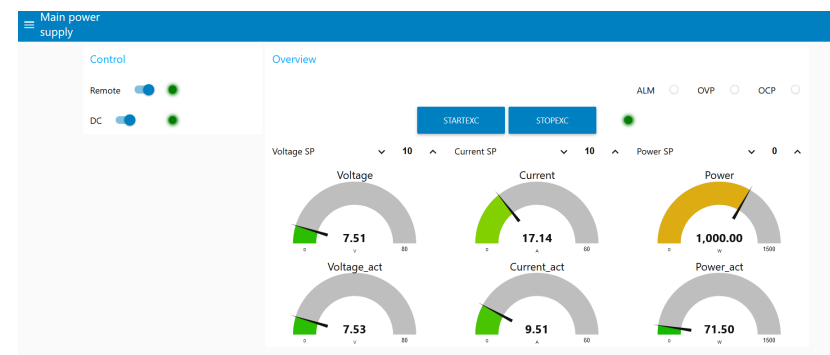
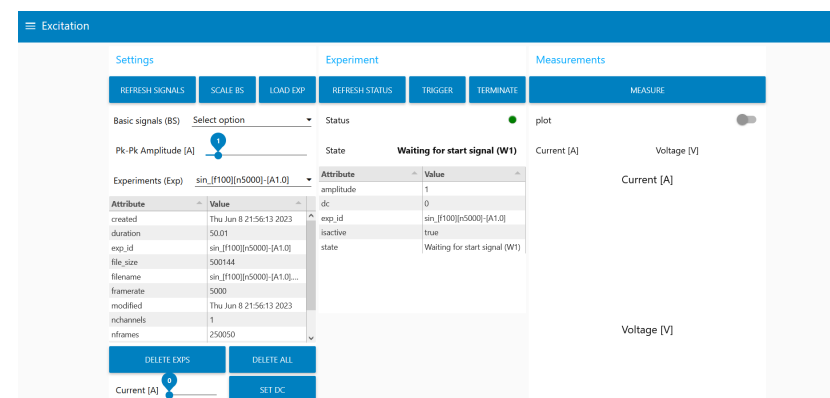
StackPowerSupply Management of Stack Power Supply	
GET	/voltage_mode/ Drive stack power supply to voltage operation mode
GET	/current_mode/ Drive stack power supply to current operation mode
GET	/remote_control/{state} Change remote control mode of Stack Power Supply
GET	/output_control/{state} Enable/Disable output of of Stack Power Supply
GET	/state/ Get current state of the stack power supply
POST	/set_setpoints Set stack power supply setpoints

## Used GPIO signals

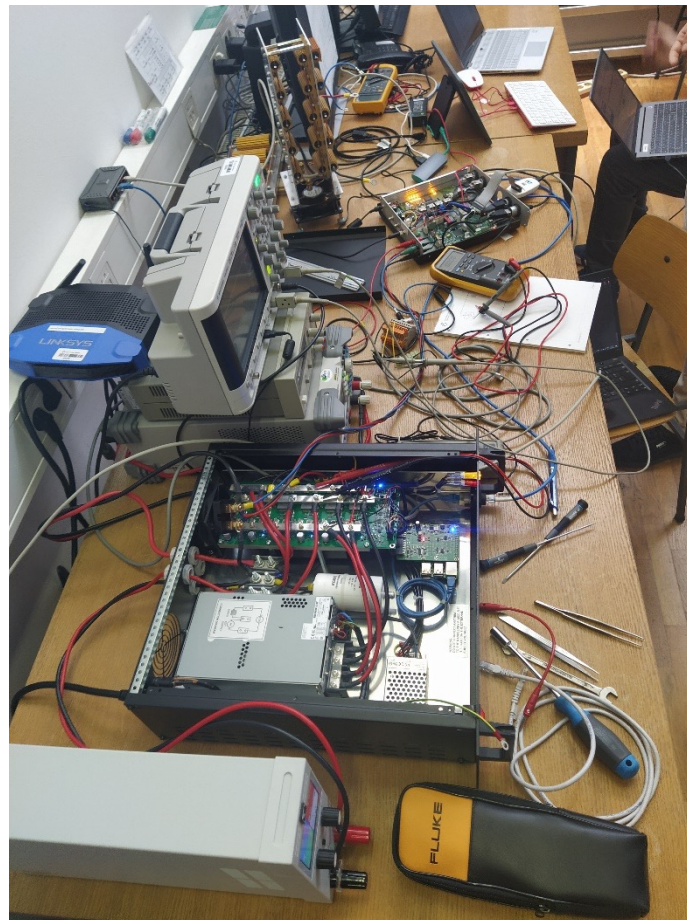
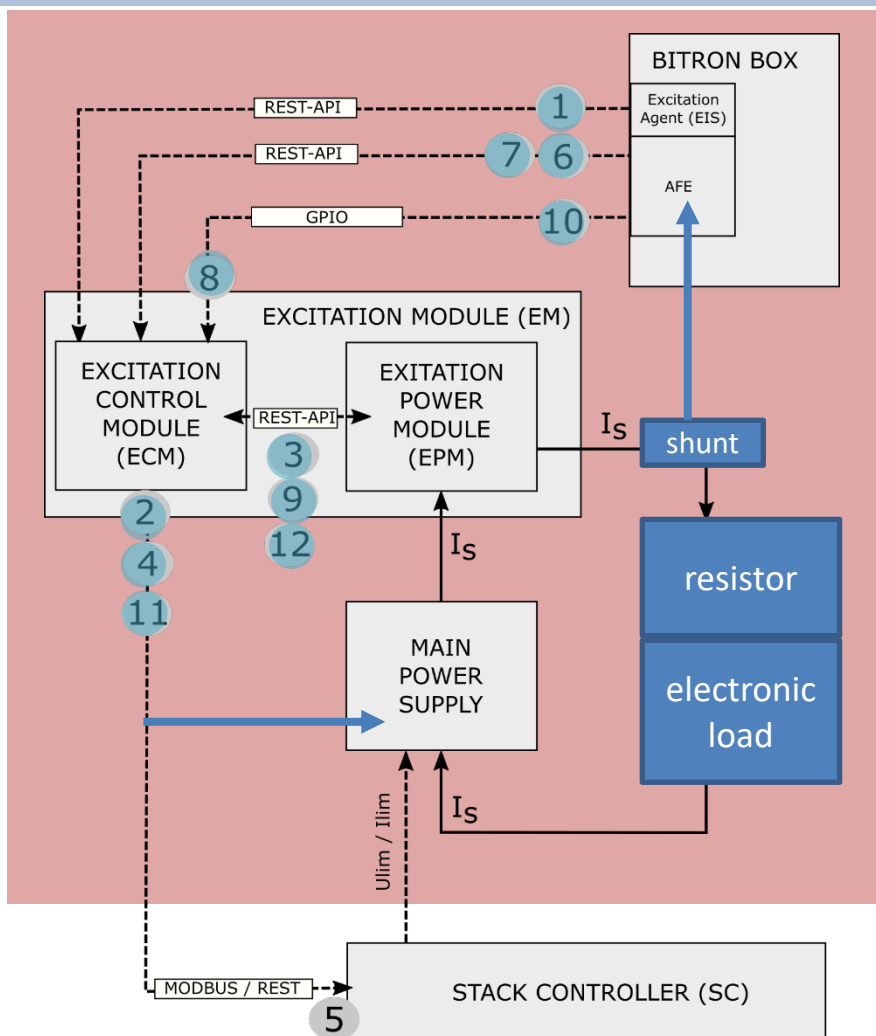
- AFE triggers experiment with START/STOP
- EM responds to confirm with ConV OK



- 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

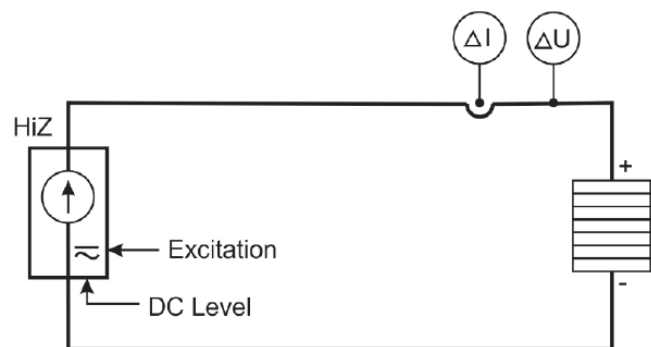


## Lab testing

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

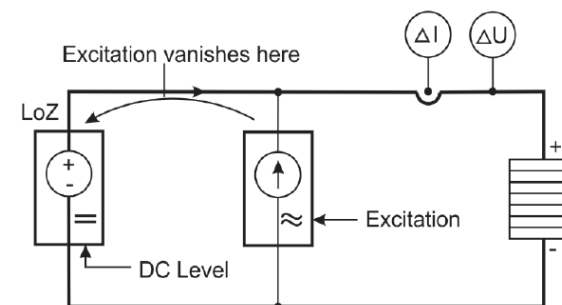
- New hardware in finalization phase
- Software update in progress (Power Supply interface, general update resolving minor bugs)
- Field implementation and testing (EPFL, VTT, CEA)

Thank you



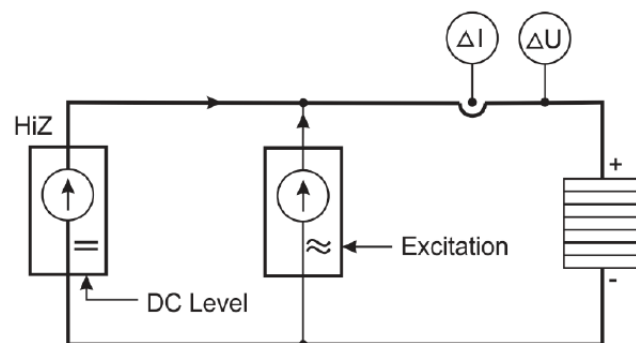
Solution A:

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



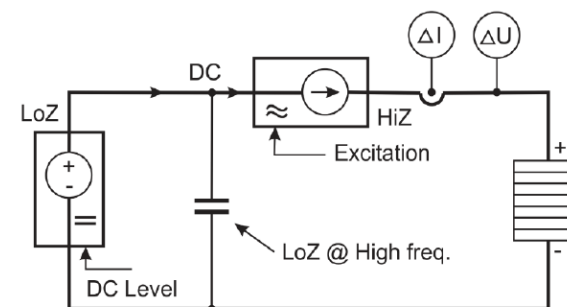
Solution C:

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

