Many thanks to the GSI team for the help and for providing the data!

2nd STEAM Workshop 11-15 October 2021

Analysis of fast discharge of the SIS100 dipole circuit using a SING-generated PSPICE circuit

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indico link: https://indico.cern.ch/event/1060073

STEAM homepage: https://espace.cern.ch/steam

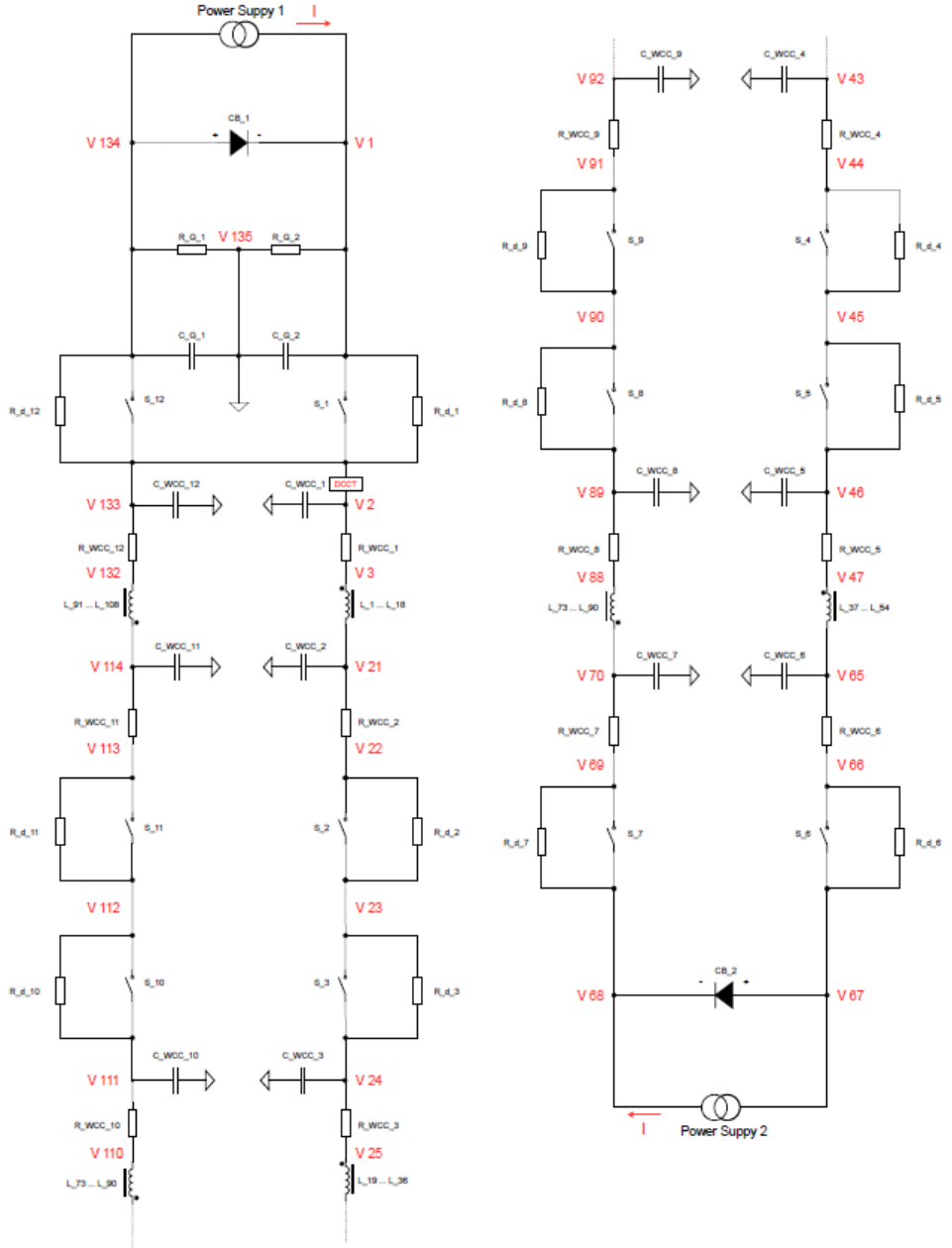
FAIR Accelerator in Darmstadt (Germany)

Aim of the project: Investigation of the transient effects in the SIS100 dipole circuit

The SIS100 dipole circuit contains:

- 12 x energy-extraction-systems
- 108 x dipole magnets
- 2 x power supplies
- 12 x water cooled cables
- 2 x grounding resistors
- 2 x grounding capacitors

Parameters	Value	Unit
Current I_n	13.2	kA
Grounding Resistor R_g	10	kΩ
Inductance of one Magnet L_m	0.55	mH
Resistor EE R_d	67	mΩ
Resistor WCC1	0.425	mΩ
Resistor WCC2	0.3	mΩ
Capacitor WCC1	42.4	μF
Capacitor WCC2	30	μF
Grounding Capacitor C_g	5	μF
Capacitance Magnet C_m	3.5	nF



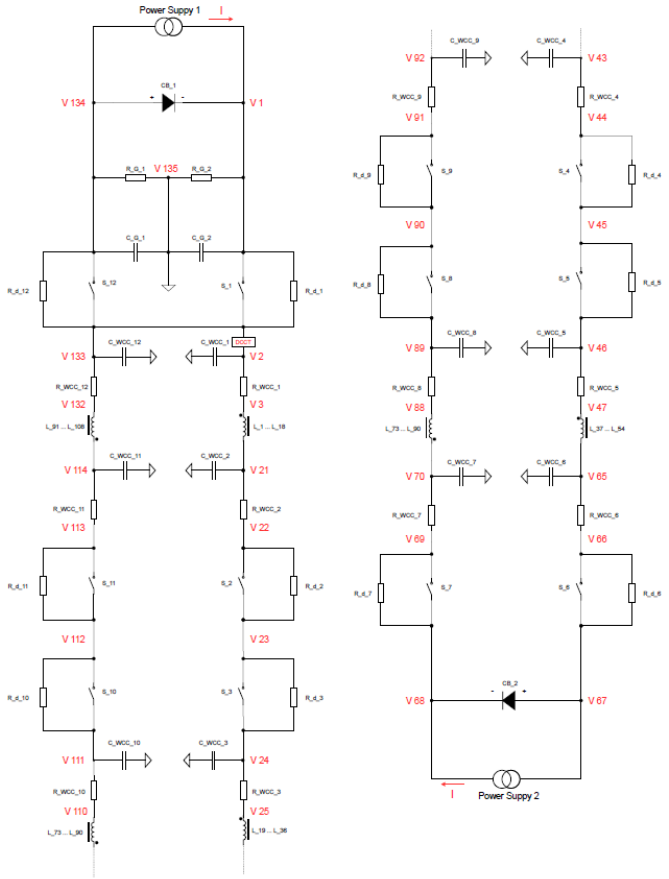
FAIR Accelerator in Darmstadt (Germany)

Motivation to use SWAN-SING for this project

- Re-use PSpice components form the STEAM library
- Have schematic and code to generate netlist in the same place (the notebook)
- Re-use one notebook for another similar circuit
- SIS100 dipole is a large circuit, to do it by hand is very time consuming

SWAN (Service for Web based ANalysis) was used to generate SIS100 dipole electrical circuit

Electrical circuit



SWAN notebook (phyton based)

Grounding Resistors and Capacitors

```
In [8]: # Grounding Resistors

netlist.add(GeneralElement("R_g_1b", a.create_string_array(gateway, ("134", "135")), "50000"))
netlist.add(GeneralElement("R_g_2b", a.create_string_array(gateway, ("135", "1")), "50000"))

# Grounding Capacitors

netlist.add(GeneralElement("C_g_1", a.create_string_array(gateway, ("134", "135")), "{C_GROUND}"))
netlist.add(GeneralElement("C_g_2", a.create_string_array(gateway, ("135", "1")), "{C_GROUND}"))

# Ground

netlist.add(CommentElement("* Earthing circuit"))
ecNodes = a.create_string_array(gateway, ( "135", "0"))
ecAttribute = "earthingCircuit"
ecParameters = a.create_string_array(gateway, ["R_fuse"])
ecValues = a.create_string_array(gateway, ["1.000"])
netlist.add(ParameterizedElement("X_EC", ecNodes, ecAttribute, ecParameters, ecValues))
netlist.add(CommentElement("*"))
```

Current Sensor (I_DDCT)

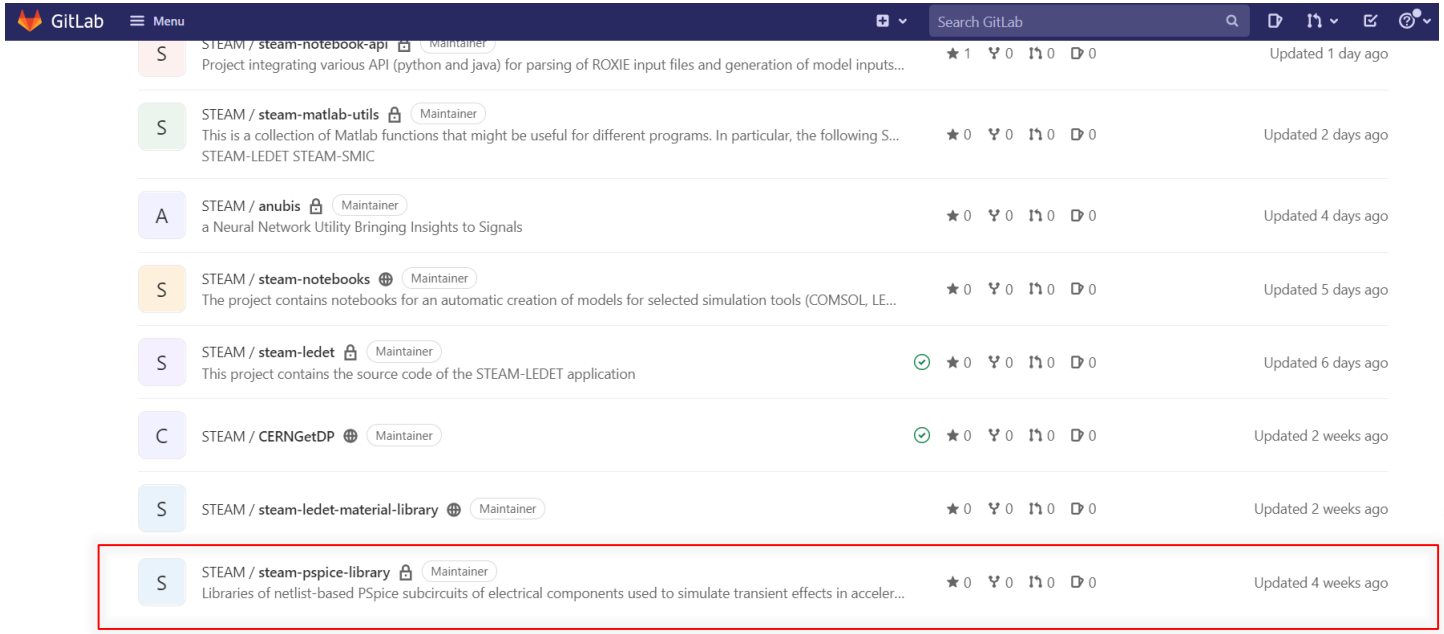
```
In [9]: netlist.add(GeneralElement("V_S", a.create_string_array(gateway, ("1", "1d")), "0"))
netlist.add(GeneralElement("R_S", a.create_string_array(gateway, ("1d", "0")), "1MEG"))
netlist.add(GeneralElement("E_SC", a.create_string_array(gateway, ("1e", "0")), "VALUE = {I(V_S)}"))
netlist.add(GeneralElement("R_SC", a.create_string_array(gateway, ("1e", "0")), "1MEG"))
```

STEAM-SING -> .jar file which is loaded at the beginning of the notebook has various functions that are called to write the netlist.

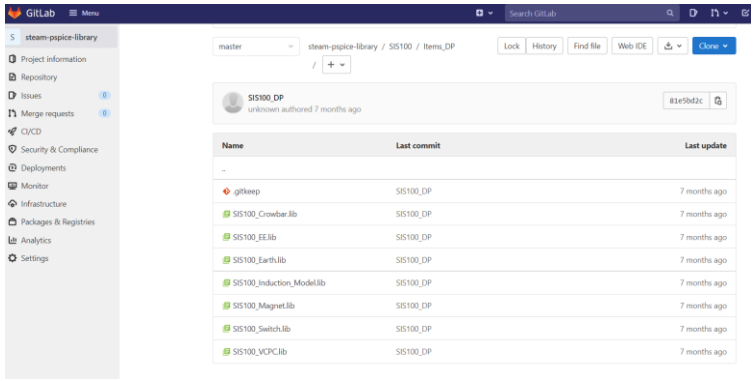
PSpice model (cir. file)

SWAN (Service for Web based ANalysis) was used to generate SIS100 dipole electrical circuit

Pspice library

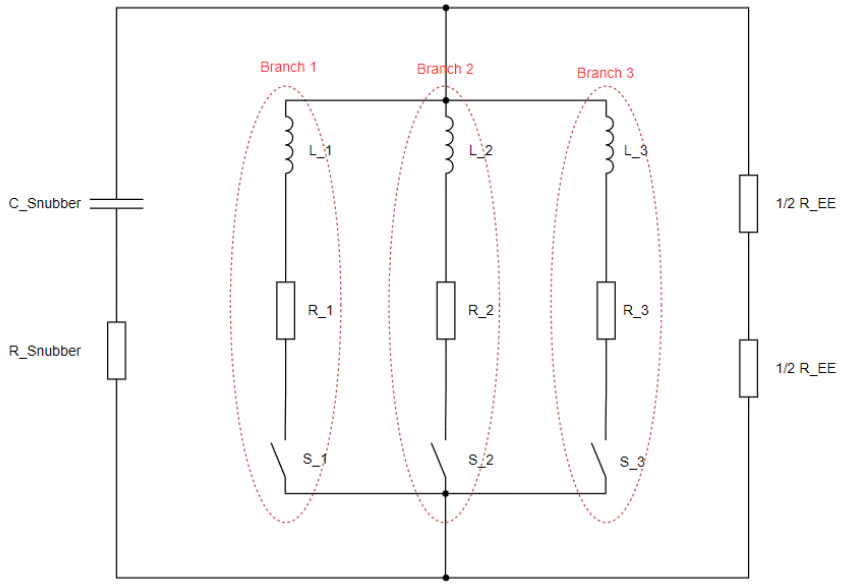


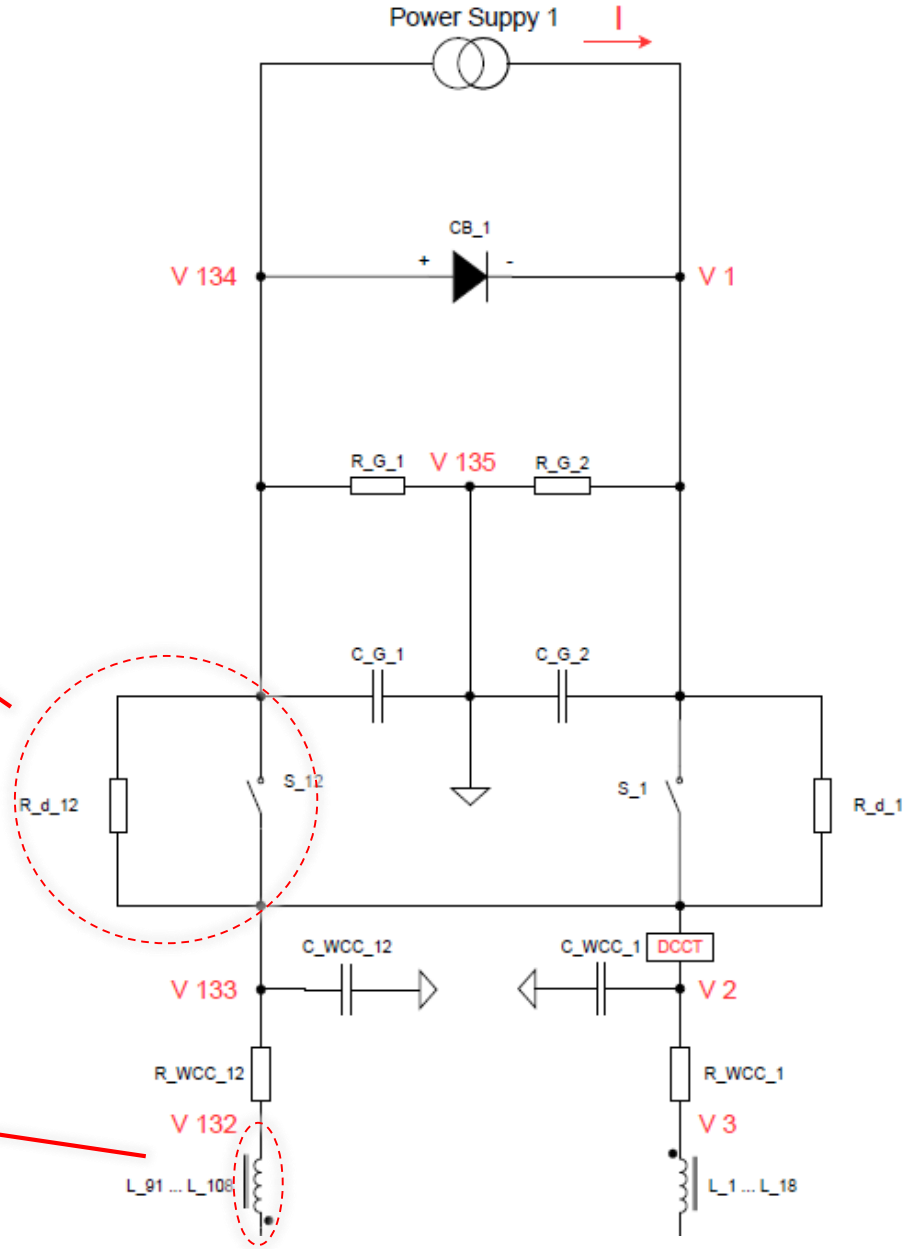
Predefined circuits like EE system,…



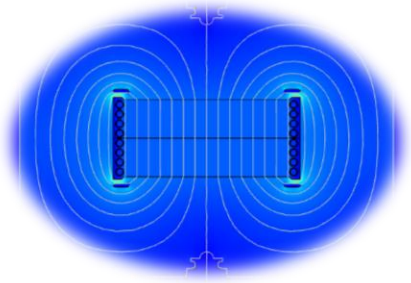
SIS100 dipole circuit

Energy-Extraction-System





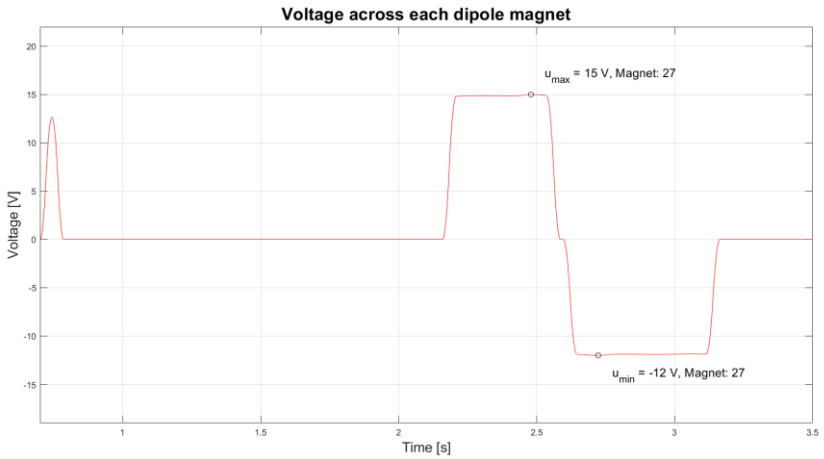
Dipole magnet model



Predefined subcircuits are used from Gitlab.

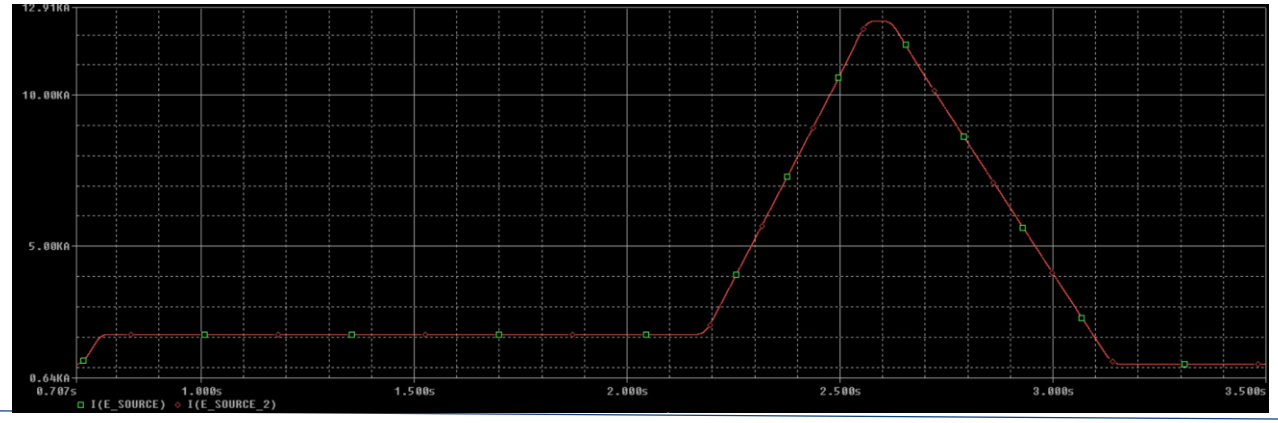
1. Visualization with STEAM PSpice-Manager (Matlab based)

```
% % % This test starts as a copy of the Main.m file in the steam-pspice-manager downloaded
% from Gitlab on 18 November 2019
% E. Ravaioli, TE-MPE-PE, CERN
%% Initialization

tic
close all force
clear
format compact
clc
%% Import useful functions
pathMainFolder='C:\Users\ddelkov\SIS100\SIS100_DP\reference_case\steam-pspice-manager-master';

addpath(genpath([pathMainFolder]))
addpath(genpath([pathMainFolder '\MainFolderSimulations\Useful functions']))
%% Define project folders and desired signals
flag_copyOriginalSimulation=1;

pathWorkingFolder=['C:\Users\ddelkov\SIS100\SIS100_DP\reference_case\SIS100_forTest'];

if flag_copyOriginalSimulation==1
    pathOriginalSimulationPSpice='C:\Users\ddelkov\SIS100\SIS100_DP\reference_case\SIS100';
    nameOriginalSimulationPSpice='SIS100_DP.cir';

    copyfile( pathOriginalSimulationPSpice, pathWorkingFolder);
    display(['Copied folder from ' pathOriginalSimulationPSpice ' to ' pathWorkingFolder])
end
```



Convenient for big circuits

2. Visualization in PSpice



Convenient for small circuits or fast visualization

Current dependent inductance model in PSpice

There is now function in PSpice to simulation a current dependent inductance
- this effect not be neglected in the SIS100 dipole circuit
- a new subcircuit was created to consider the saturation effect of the iron yoke

Measurements from GSI

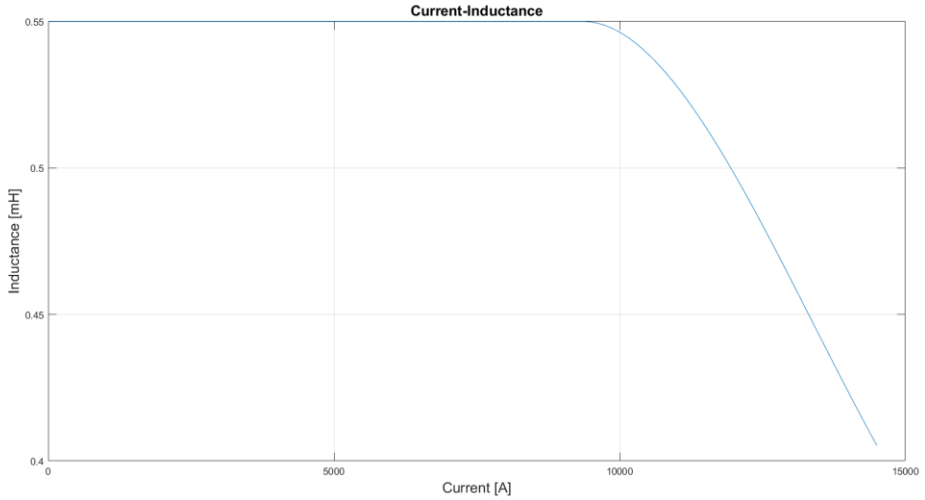


Table in PSpice (ETABLE or GTABLE)

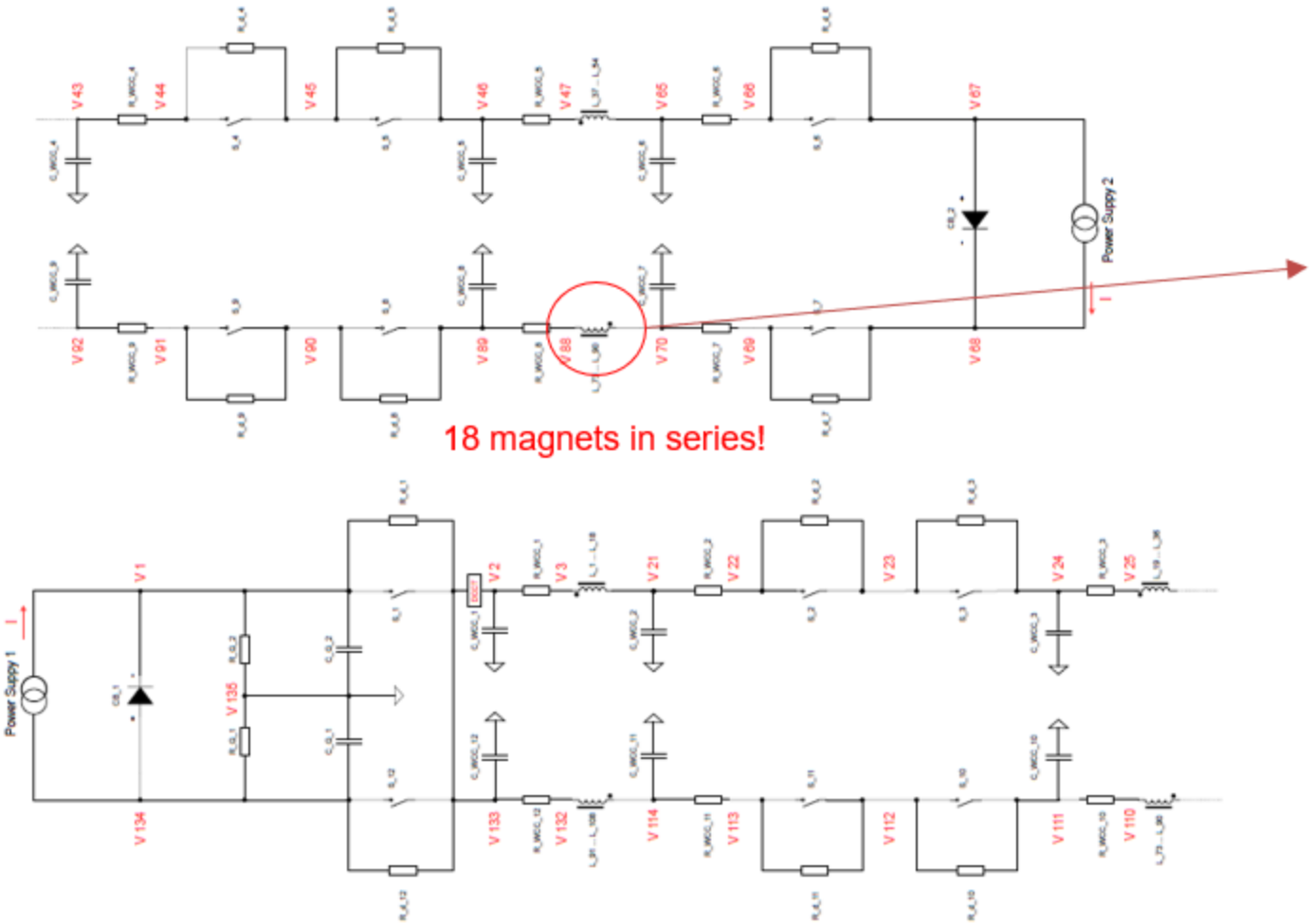
```
* PSPICE SIS100 Inductance Table for one Magnet
* Sub Model of Inductance Table for one Magnet
* Model Inductance Table
.subckt inductance_table (IN OUT)
E_E1 IN OUT TABLE {V(IN)}=(
+(0,0.00055)
+(100,0.00055)
+(200,0.00055)
+(300,0.00055)
+(400,0.00055)
+(500,0.00055)
+(600,0.00055)
+(700,0.00055)
+(800,0.00055)
+(900,0.00055)
+(1000,0.00055)
+(1100,0.00055)
+(1200,0.00055)
+(1300,0.00055)
+(1400,0.00055)
```

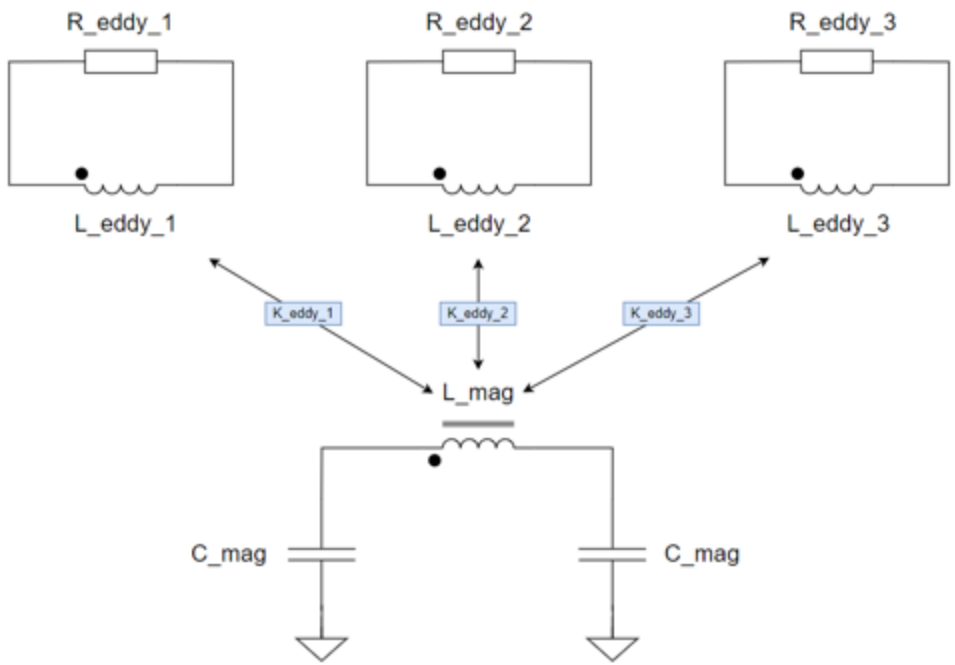
$$i = \int \frac{1}{L} u \, dt$$

GSOURCE in PSpice

Simulation of eddy-current effect

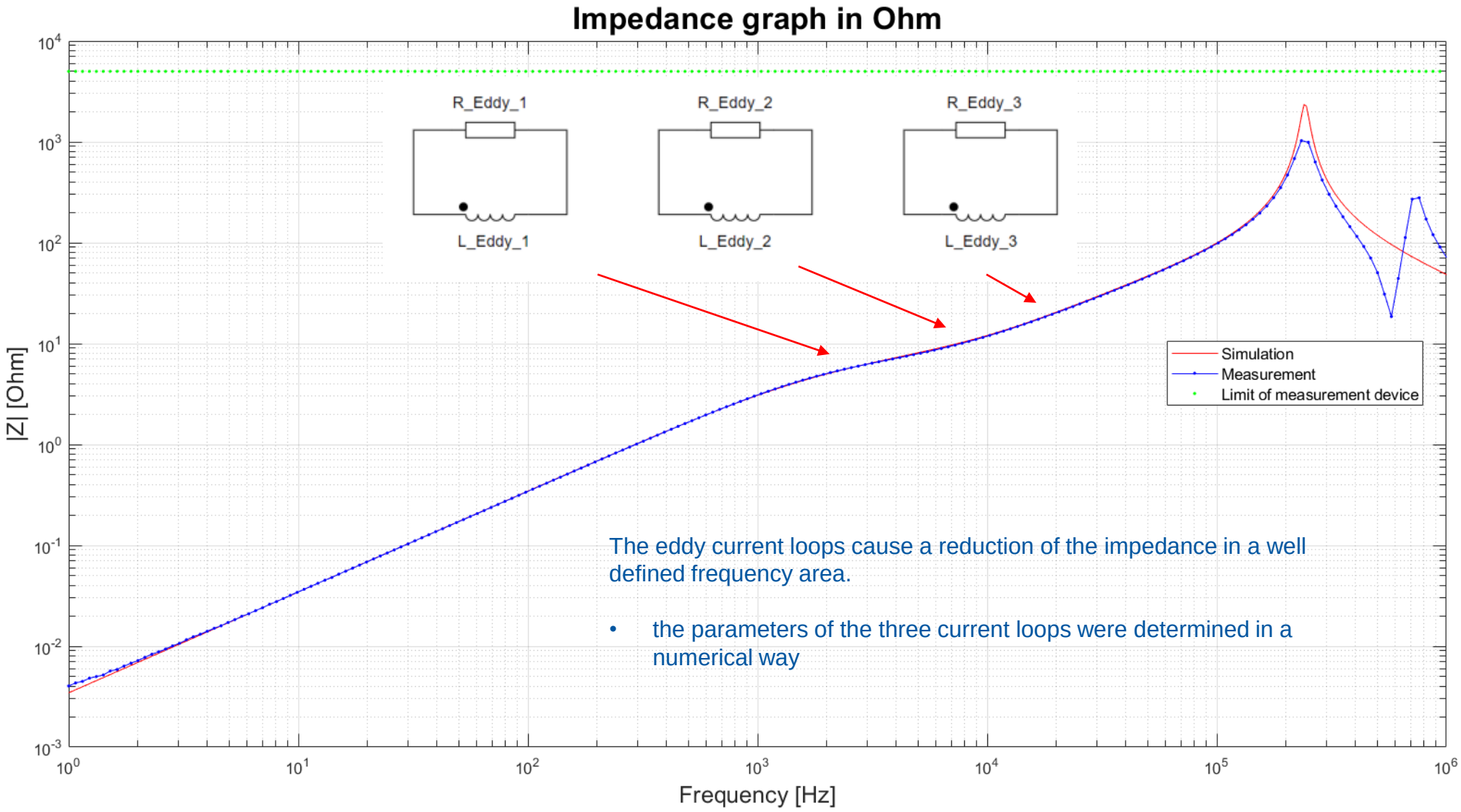
SIS100 dipole model





Each magnet contains this model
- 108 models

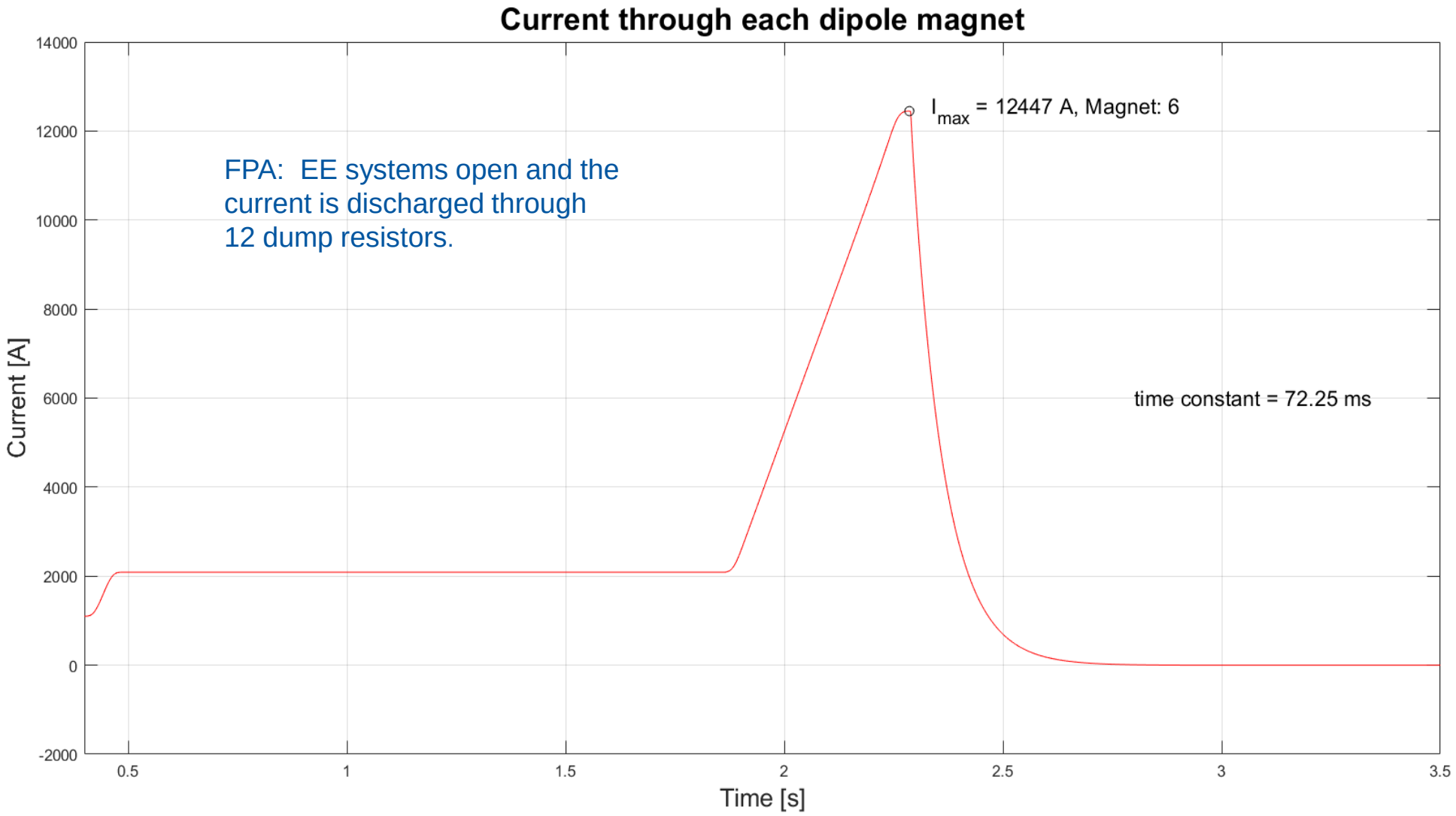
Simulation of eddy-current effect



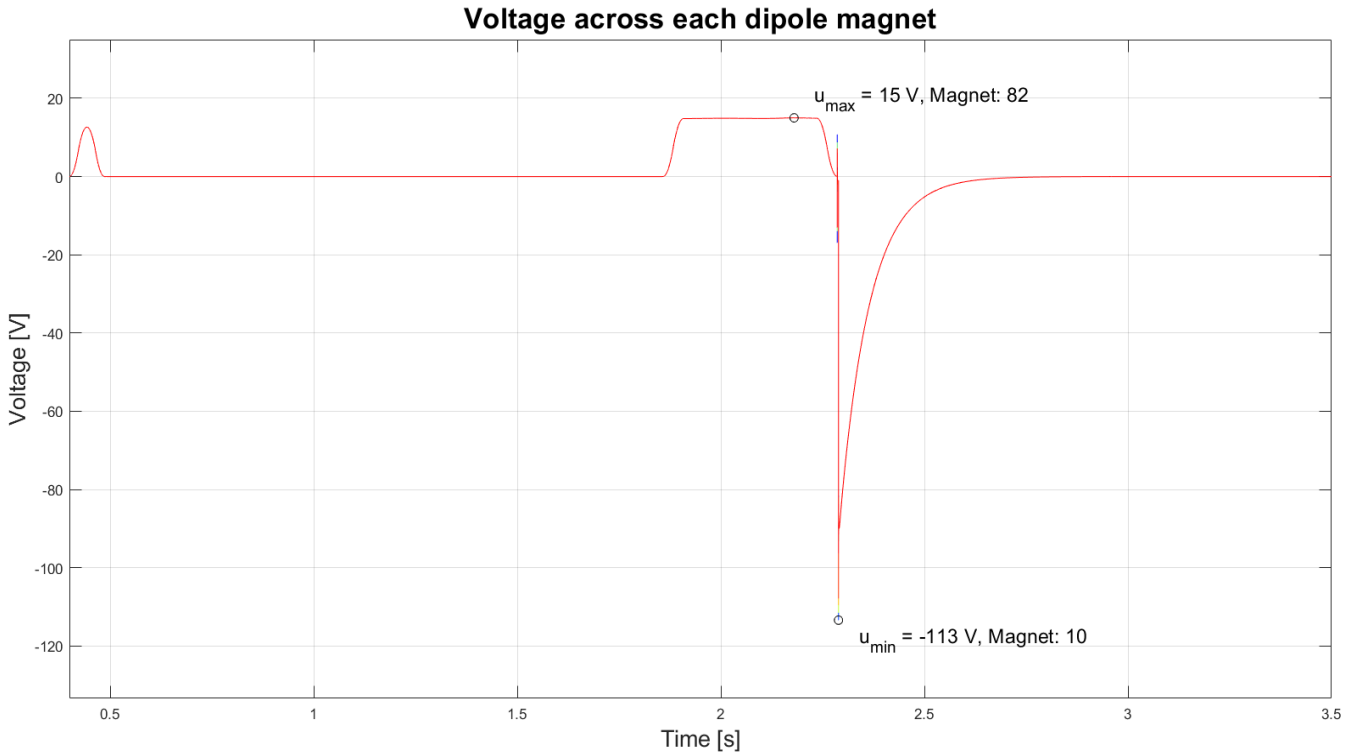
The eddy current loops cause a reduction of the impedance in a well defined frequency area.

- the parameters of the three current loops were determined in a numerical way

FPA simulation of SIS100 dipole circuit (simulation results)



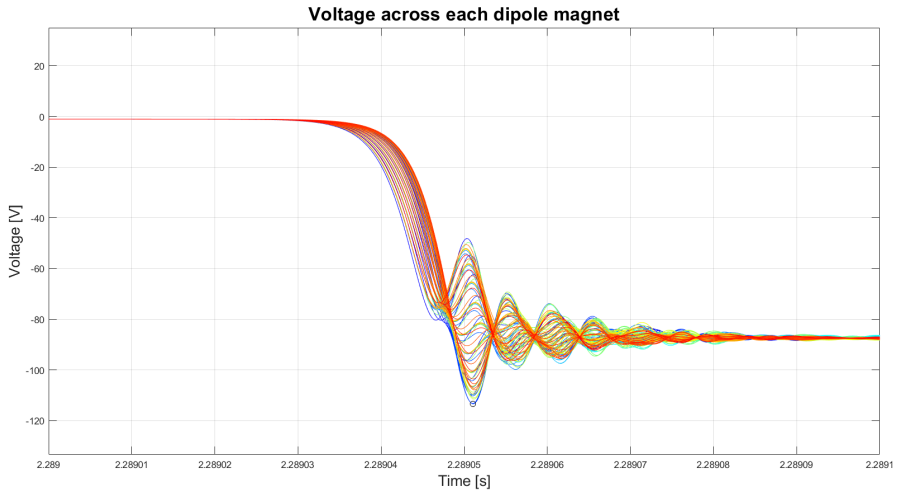
FPA simulation of SIS100 dipole circuit (simulation results)



After FPA all 108 dipole magnets discharged

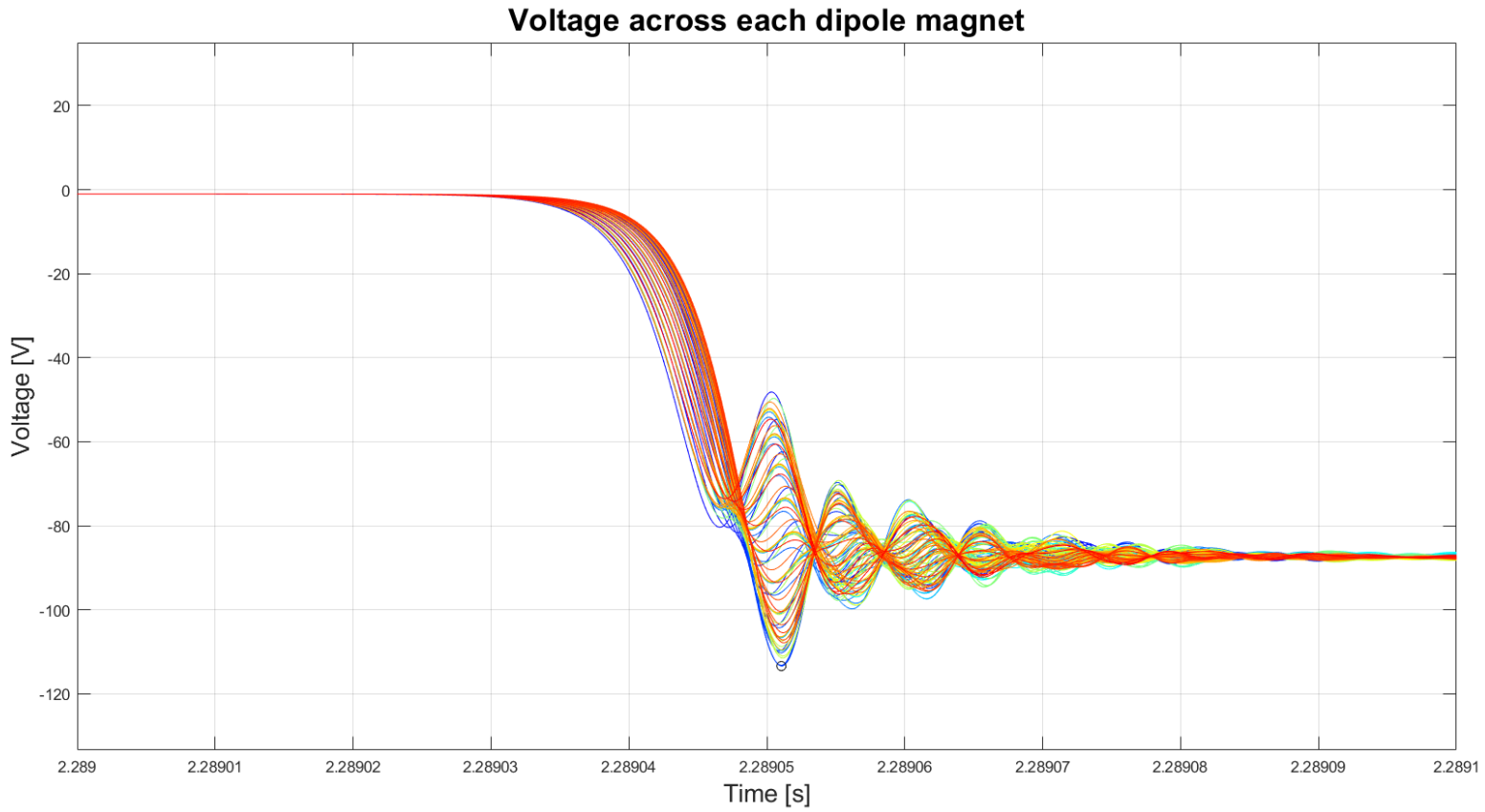
- Investigation of induced voltage

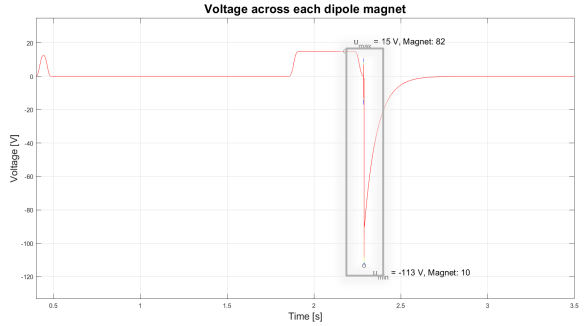
Zoom to FPA



FPA simulation of SIS100 dipole circuit (simulation results)

Zoom to FPA



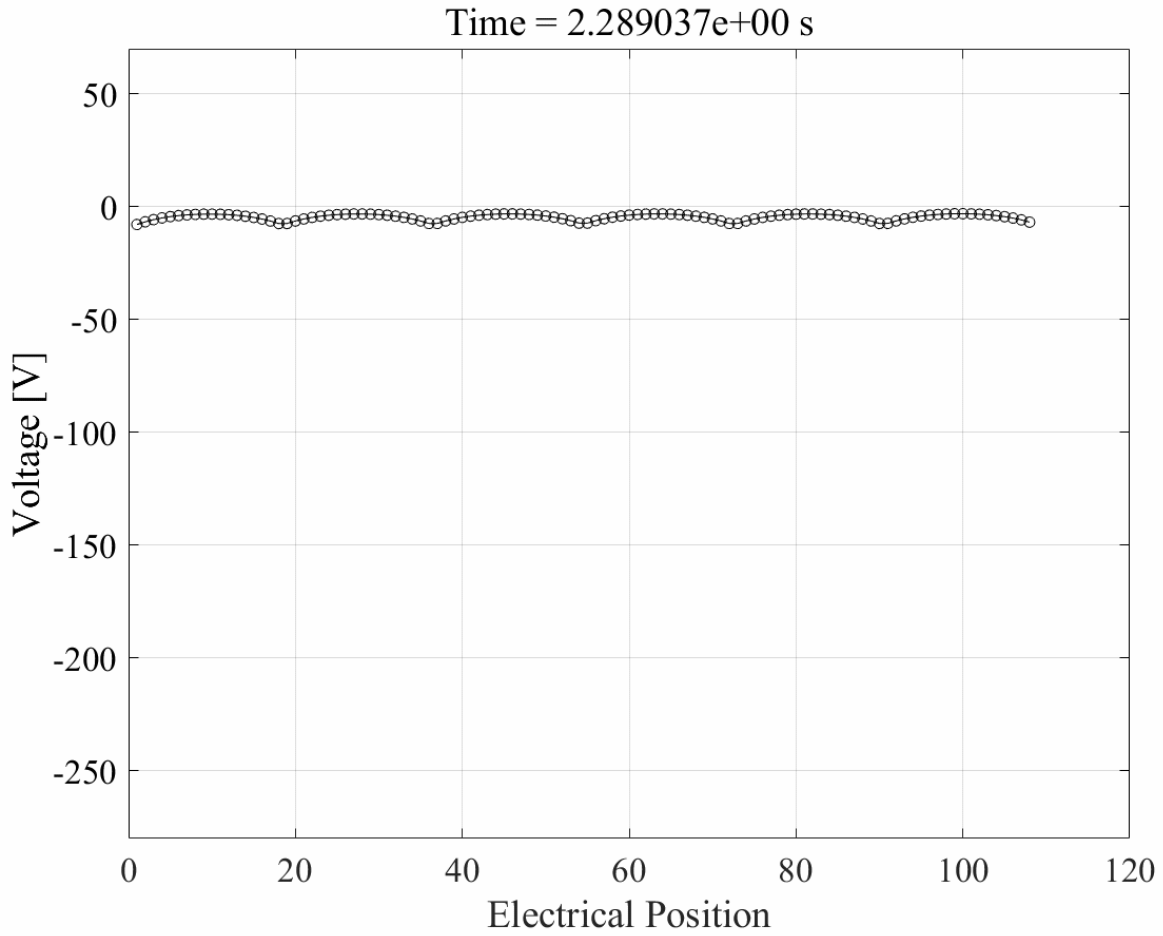


After FPA all 108 dipole magnets discharged

- Investigation of induced voltage

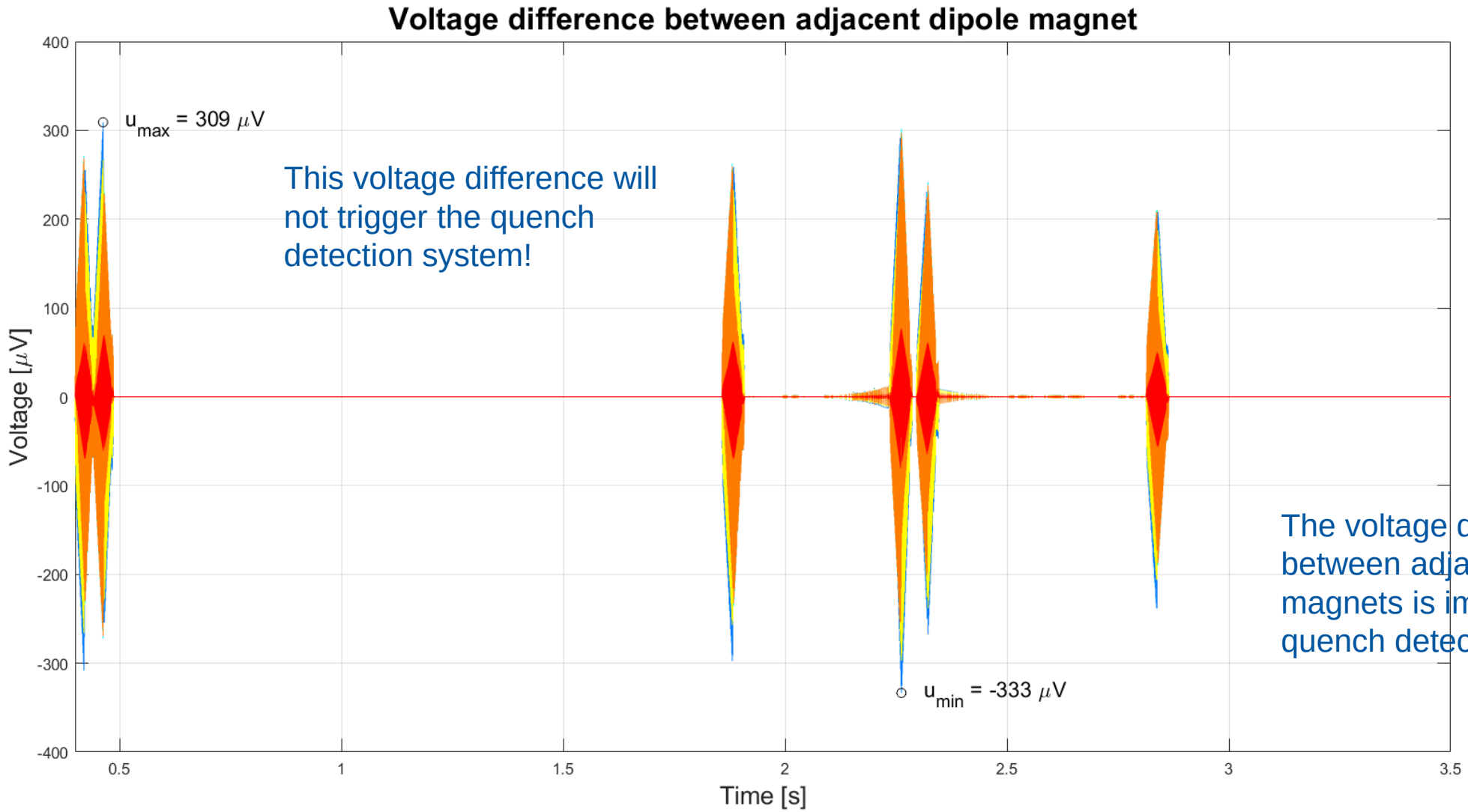
FPA simulation of SIS100 dipole circuit (simulation results)

Voltage across each magnet after FPA animation.



The animation shows how the voltage wave traveling through the circuit

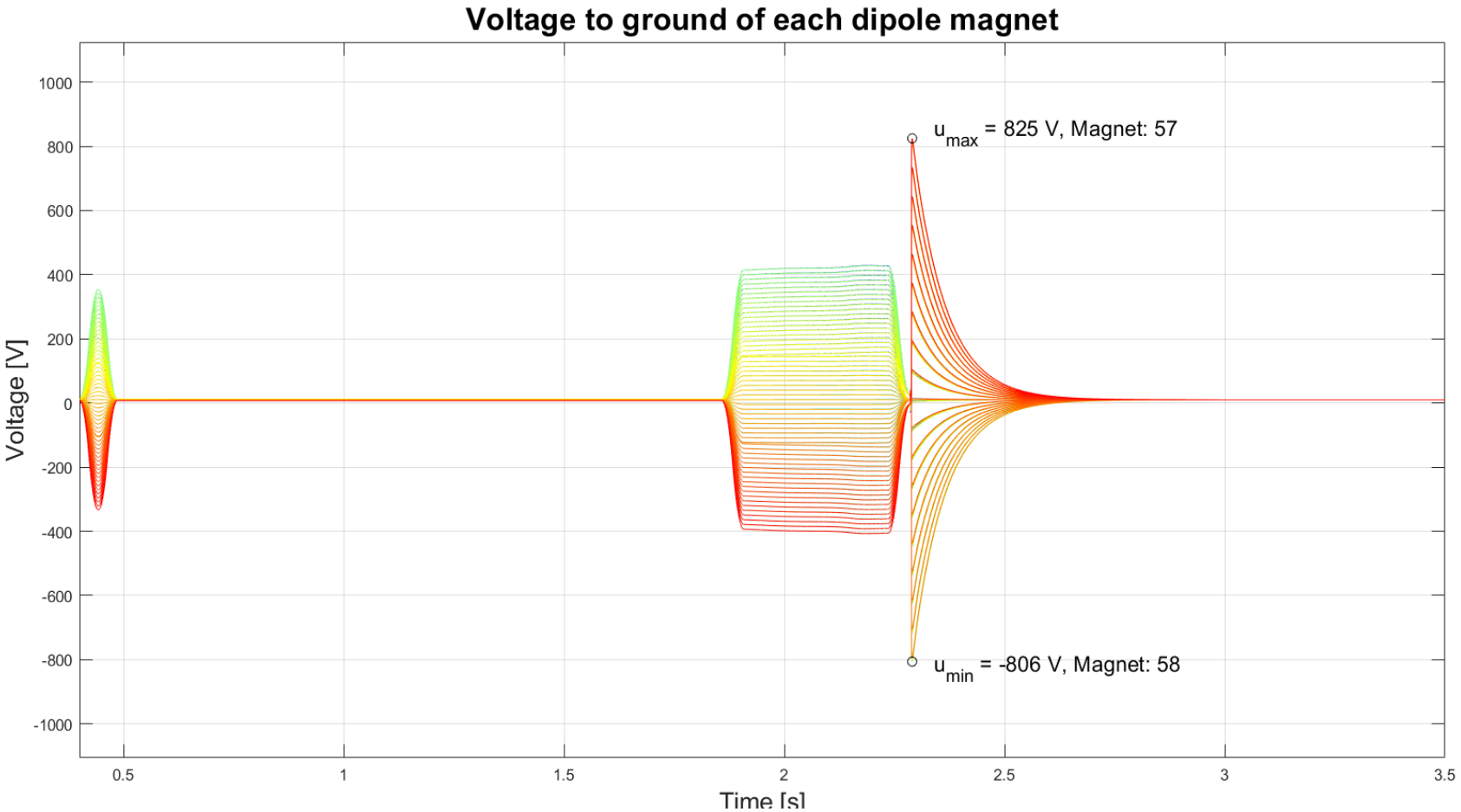
FPA simulation of SIS100 dipole circuit (simulation results)



This voltage difference will not trigger the quench detection system!

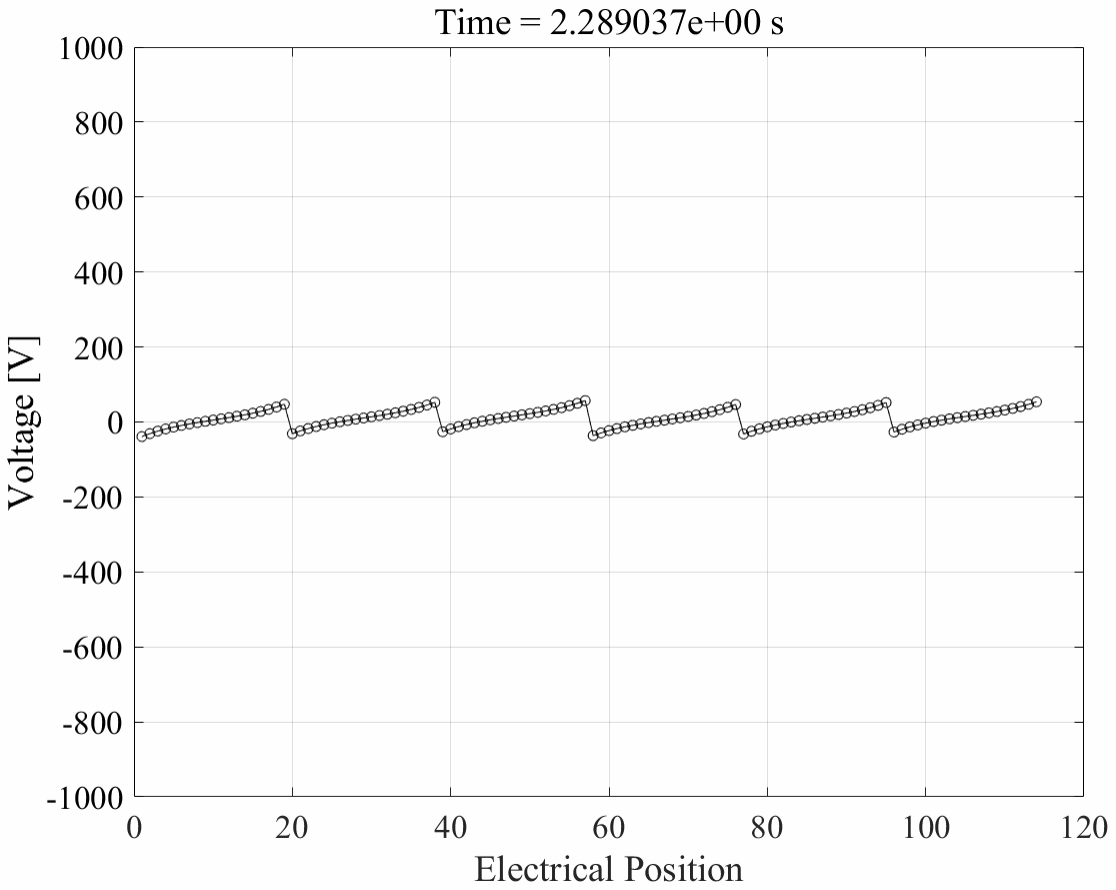
The voltage difference between adjacent dipole magnets is important for the quench detection system

FPA simulation of SIS100 dipole circuit (simulation results)



Huge voltage peak after FPA.

Voltage to ground of each magnet after FPA animation.



The animation shows how the voltage wave traveling through the circuit

Conclusion

STEAM-SING

- Using the STEAM library is very convenient and time-saving
- Python-based notebooks allow to build large electrical circuits
- Changes can be done very quickly and easily
- Interface with other STEAM tools

SIS100 circuit

- Very good match of the impedance measurements with the PSpice model
- The transient investigation showed that the FPA case will not cause a damage in the circuit
- The quench detection system should work properly during the normal operation

Thank you very much for your attention