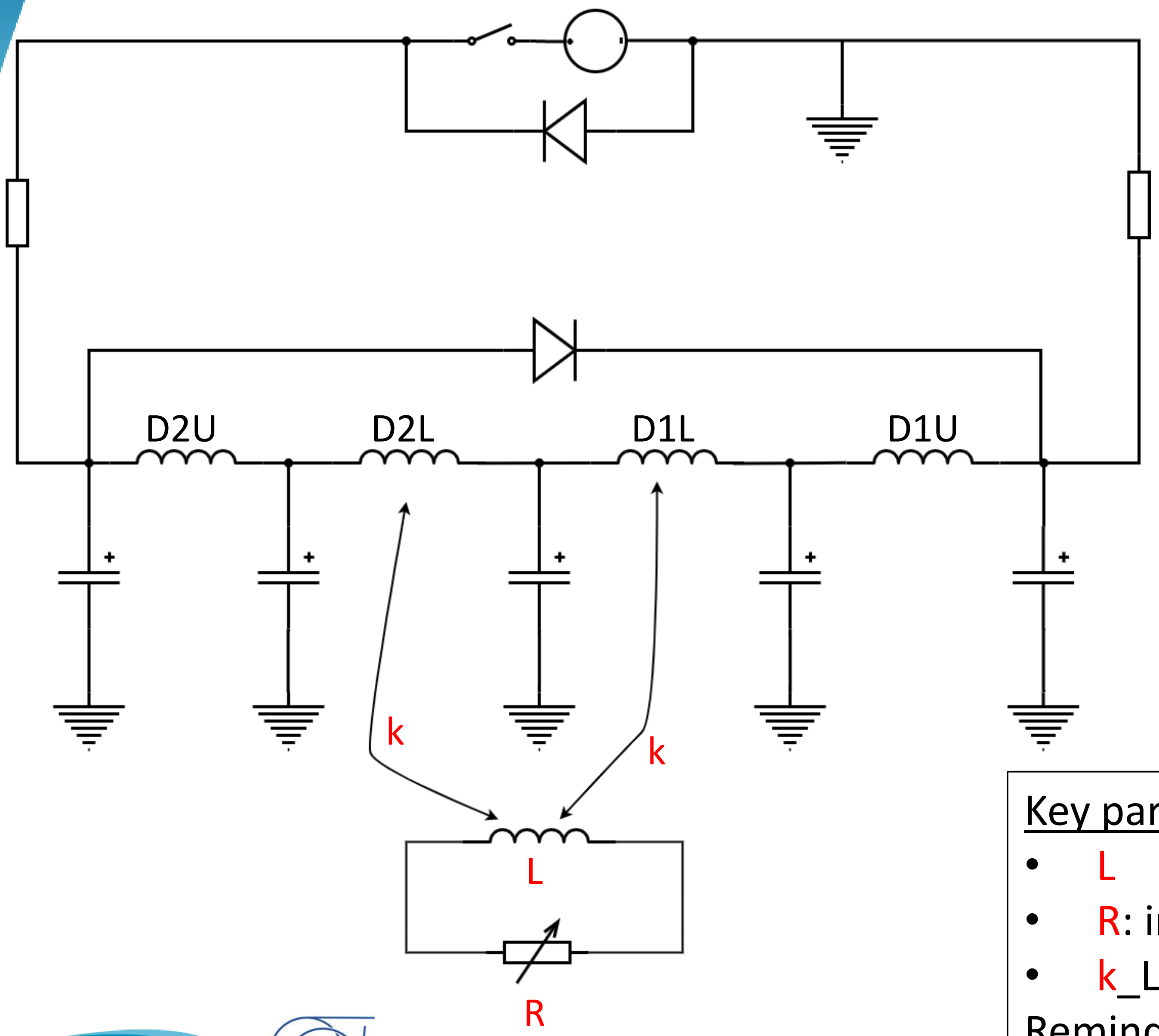
MBHA001 – Update on simulations

E. Ravaioli (CERN)

Thanks to B. Bordini, L. Bottura, F. Mangiarotti, H. Prin, A. Verweij, G. Willering and other colleagues involved (CERN)

3 April 2020

MBHA-001 – Implemented PSPICE model



Sudden magnetic flux variation is modeled as a sudden increase/decrease of the RL loop resistance:

U_{spike}= dϕ/dt = M*dI_{loop}/dt
= k*sqrt(L_{coil}*L)*dI_{loop}/dt

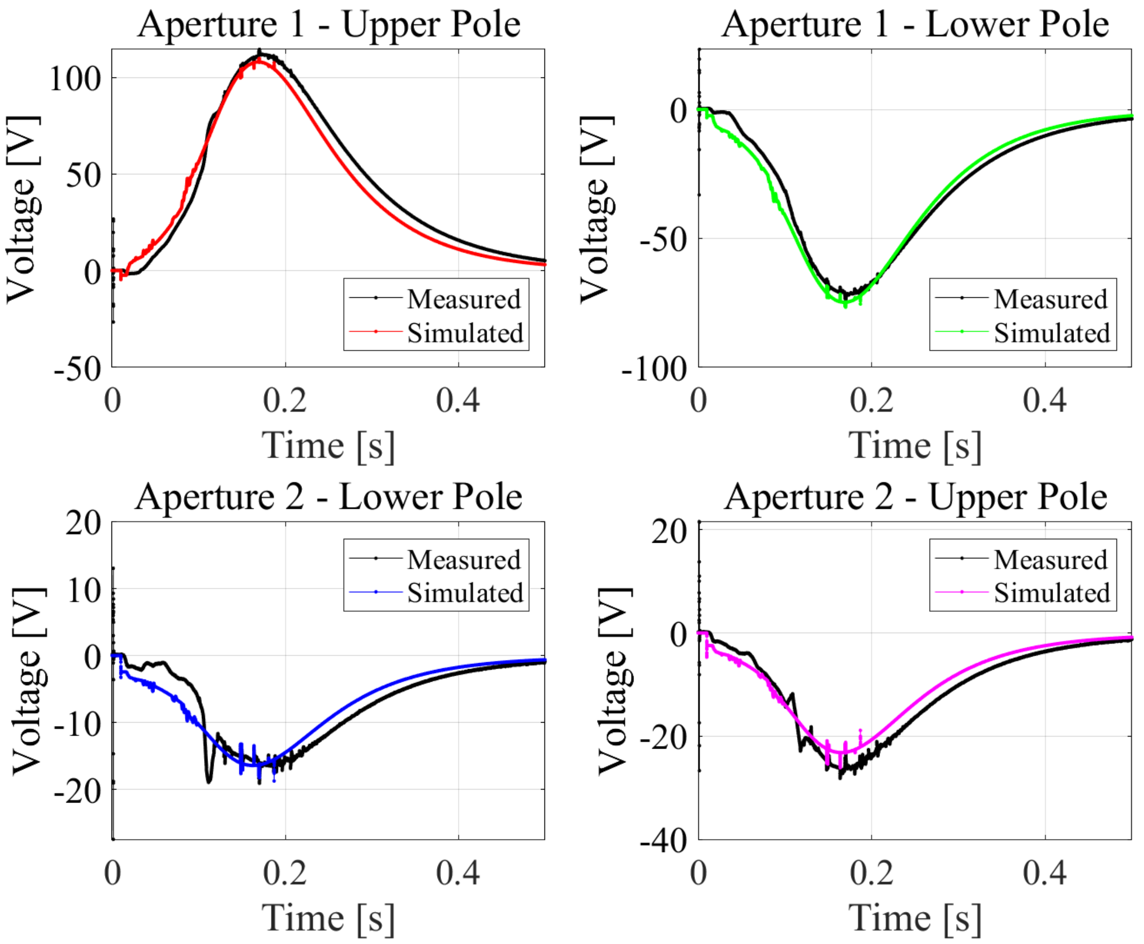
Kirchhoff voltage law for the RL loop:
k*sqrt(L_{coil}*L)*dI_{coil}/dt+L*dI_{loop}/dt+R*I_{loop}=0

To achieve different spike polarities across the coils, the RL loop is only coupled with two of the four coils [in this example: D1L, D2L].
This model doesn't assume any short circuit

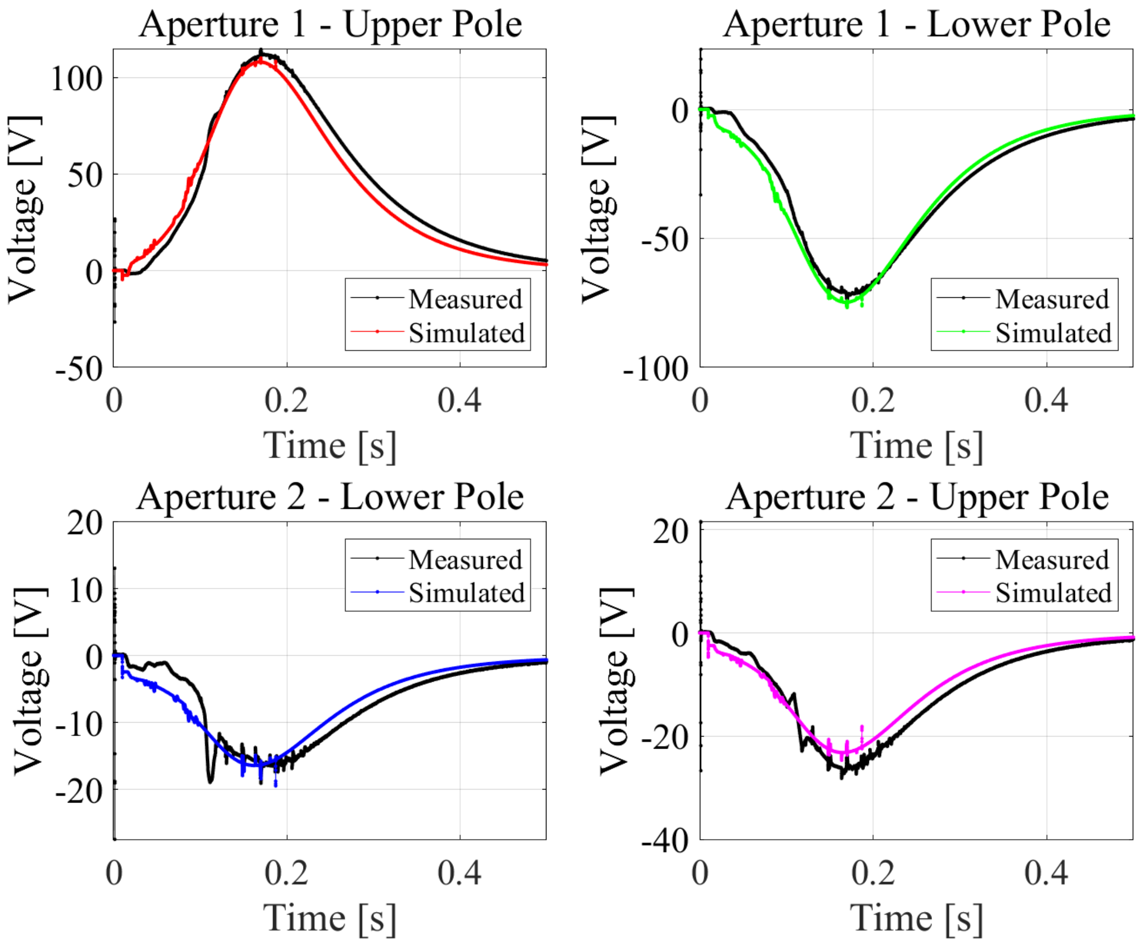
Key parameters
- L
- R: intermittently changing its value
- k_L_D1L, k_L_D2L, k_L_D1U=0%, k_L_D2U=0%

Reminder: k_12 = M_12 / sqrt(L_1*L_2)

MBHA001 – Voltage spikes in the four poles



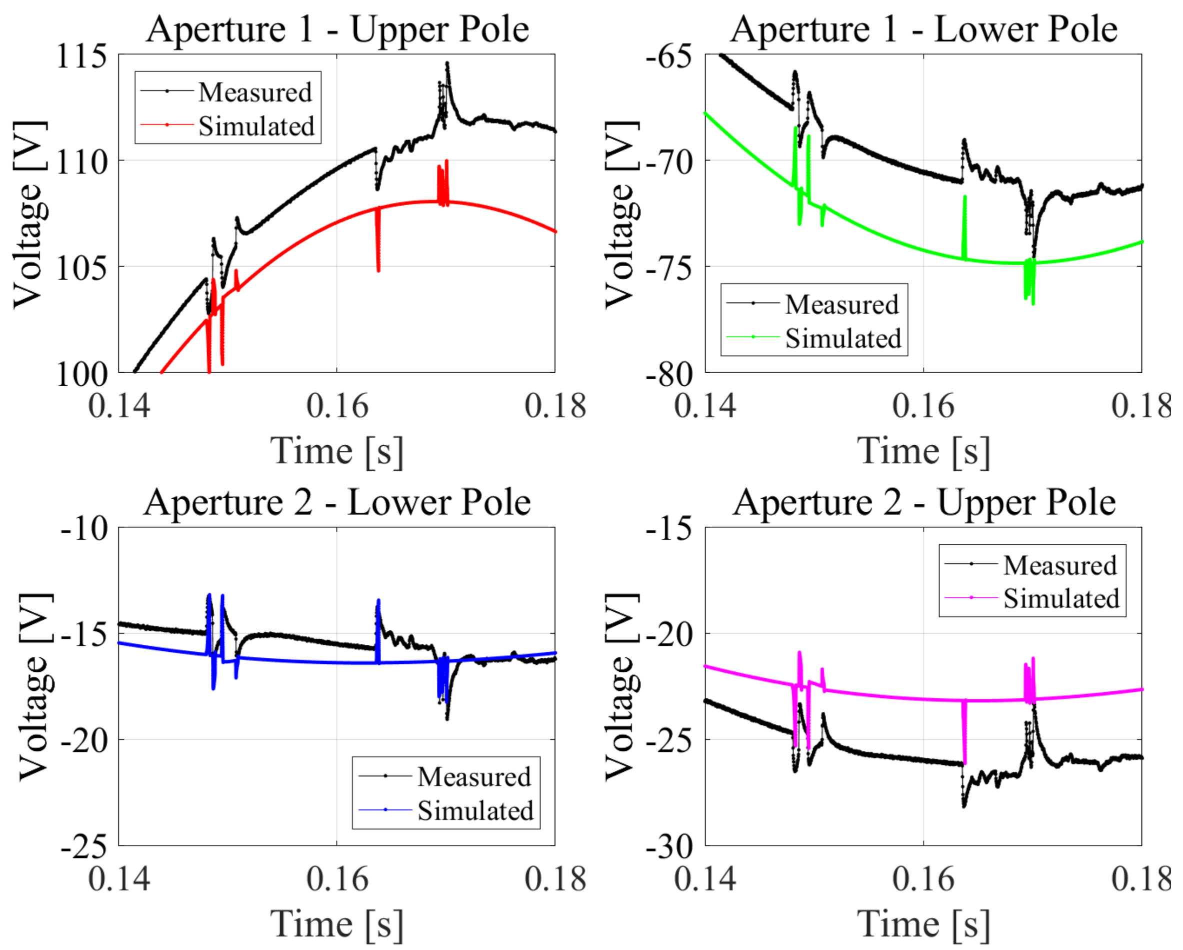
“Old” model with intermittent short circuit



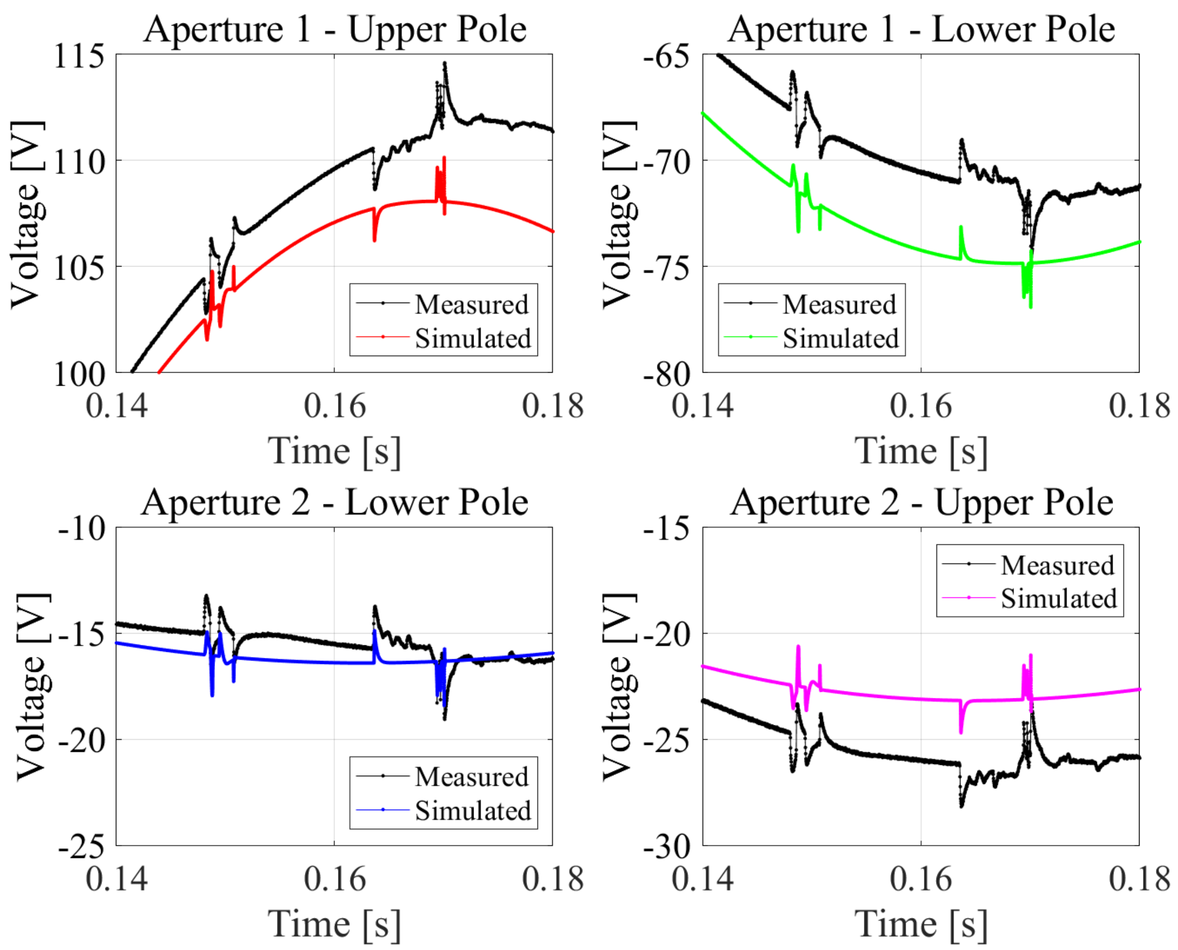
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 μH, R_loop=7 mΩ-1 Ω

MBHA001 – Voltage spikes in the four poles –zoom1



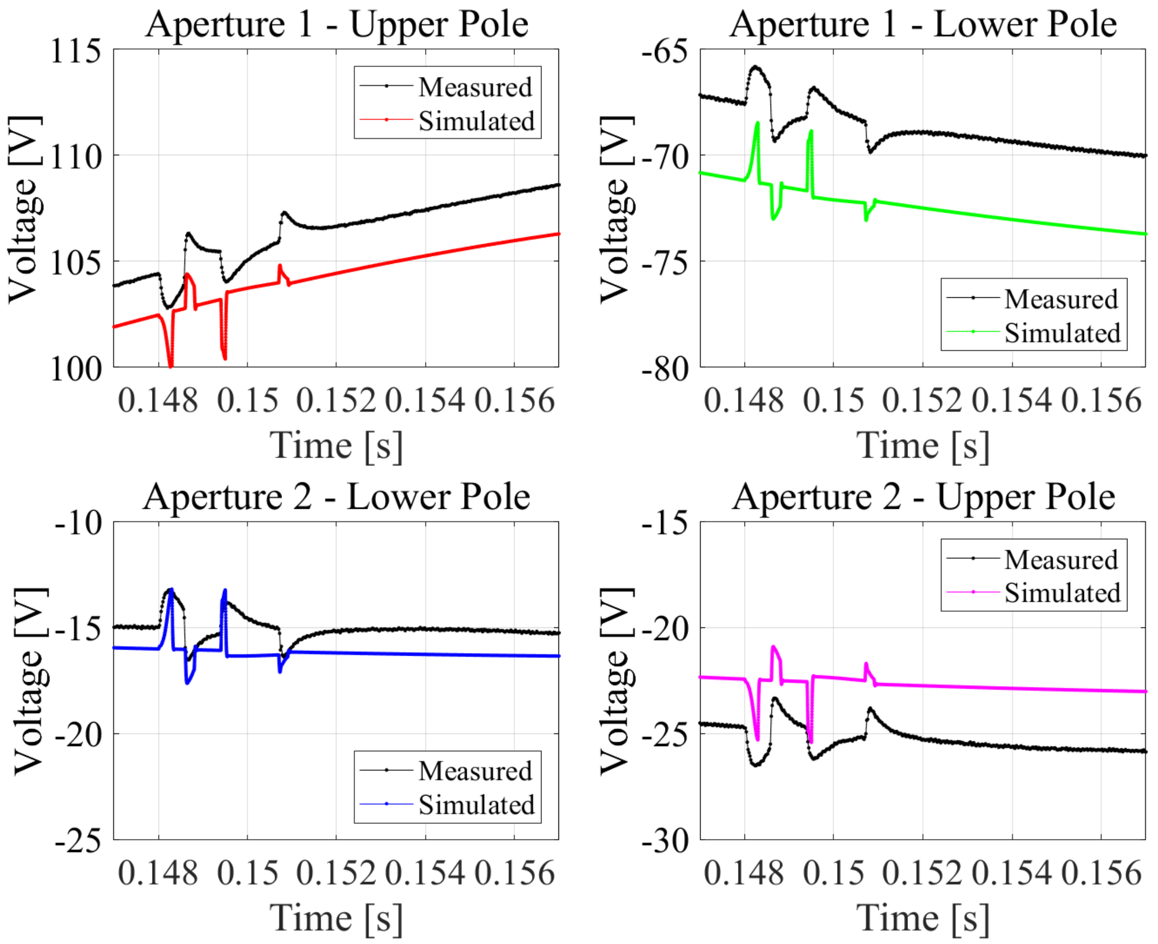
“Old” model with intermittent short circuit



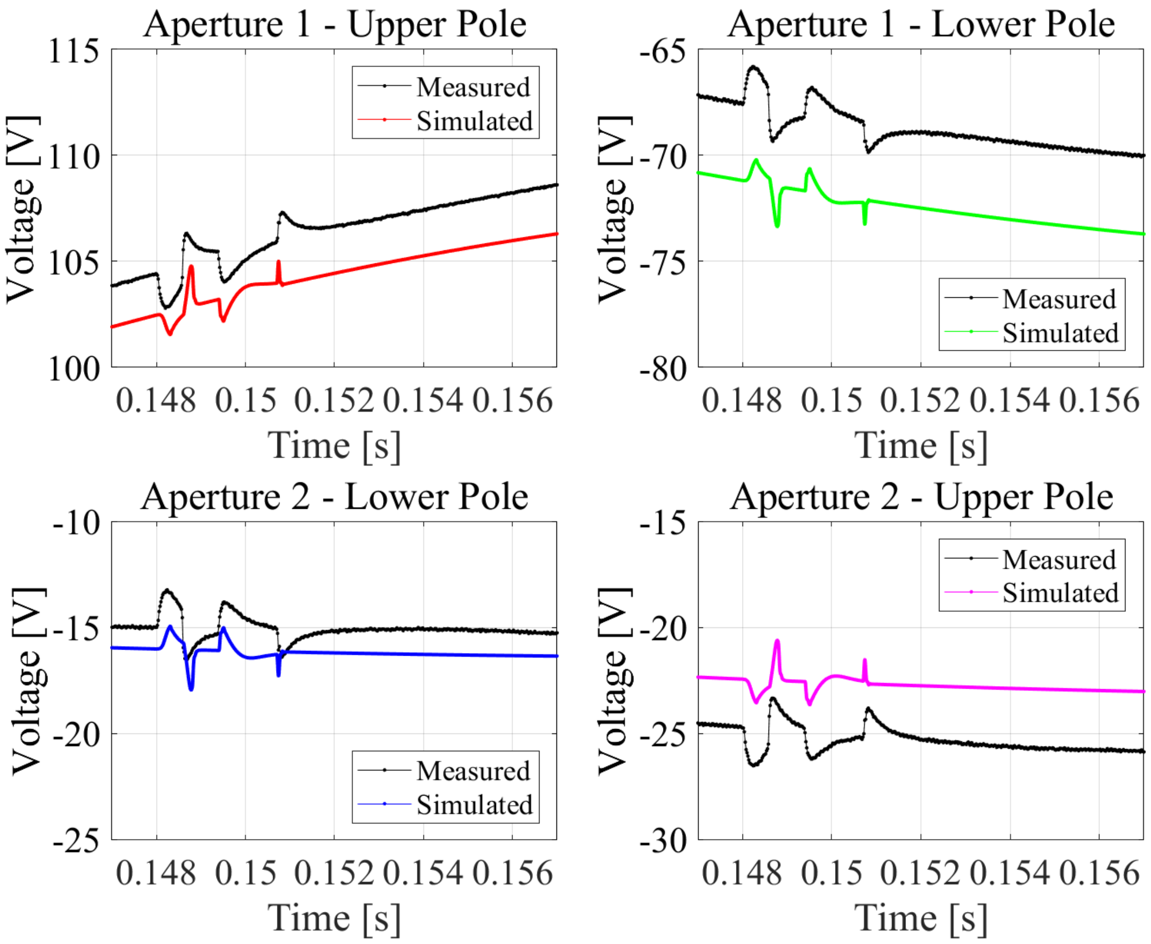
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 μH, R_loop=7 mΩ-1 Ω

MBHA001 – Voltage spikes in the four poles –zoom2



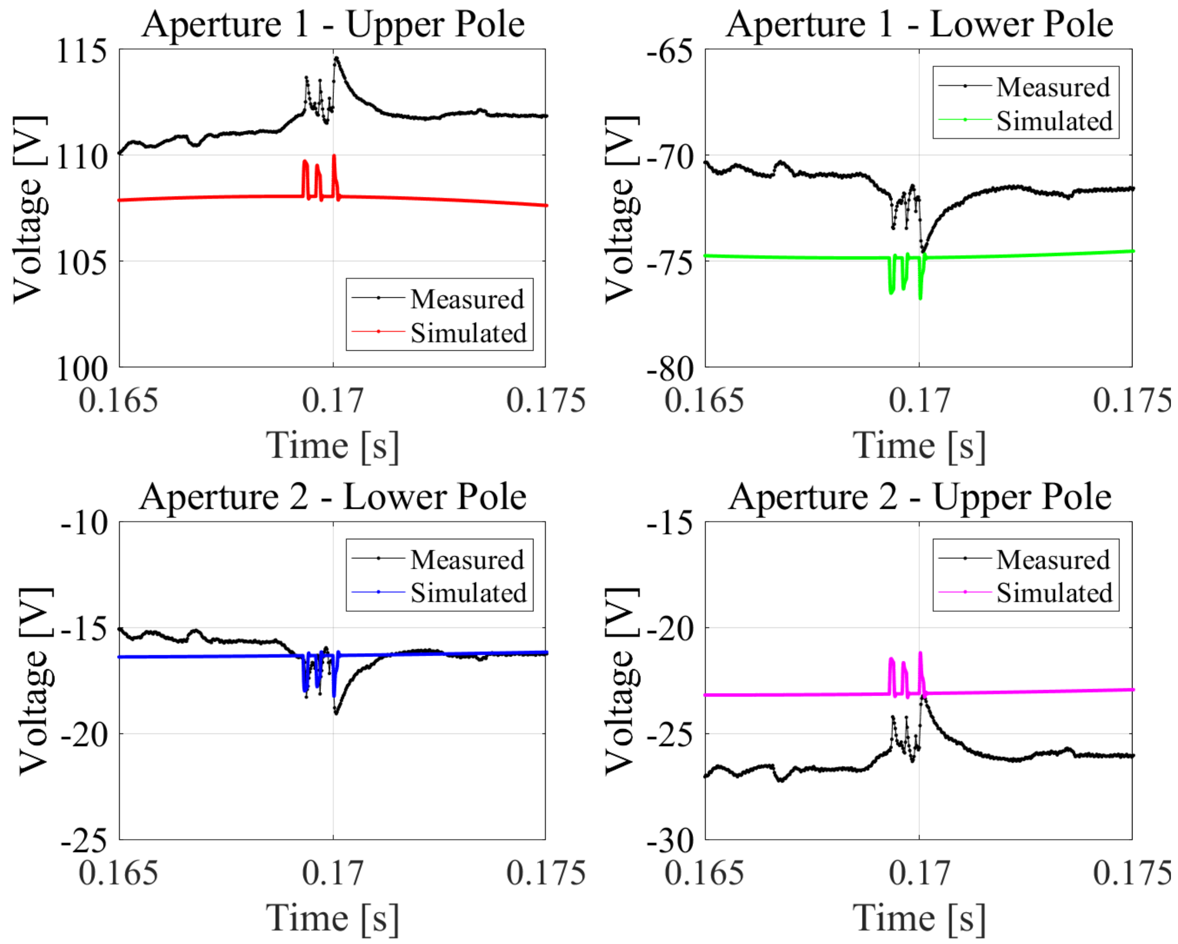
“Old” model with intermittent short circuit



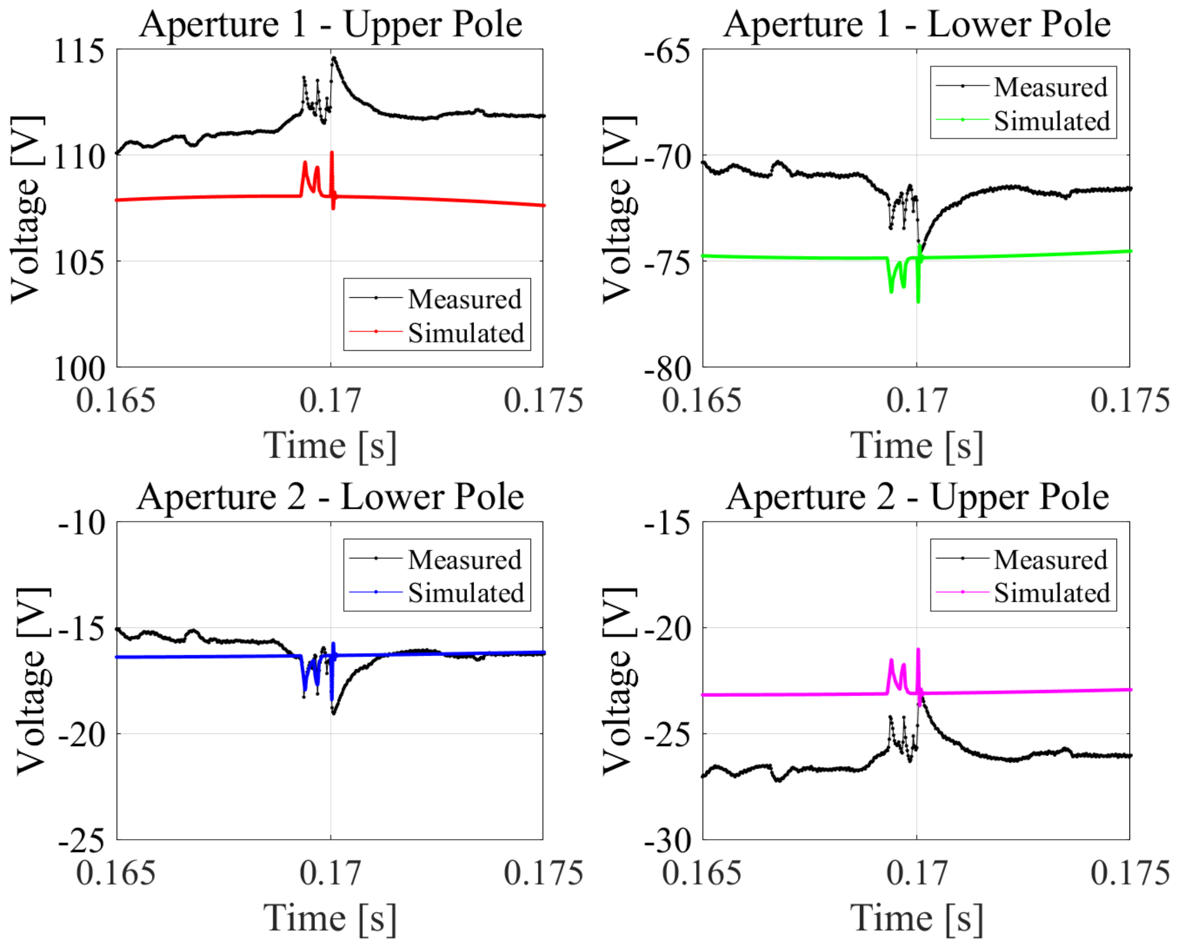
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 µH, R_loop=7 mΩ-1 Ω

MBHA001 – Voltage spikes in the four poles –zoom3



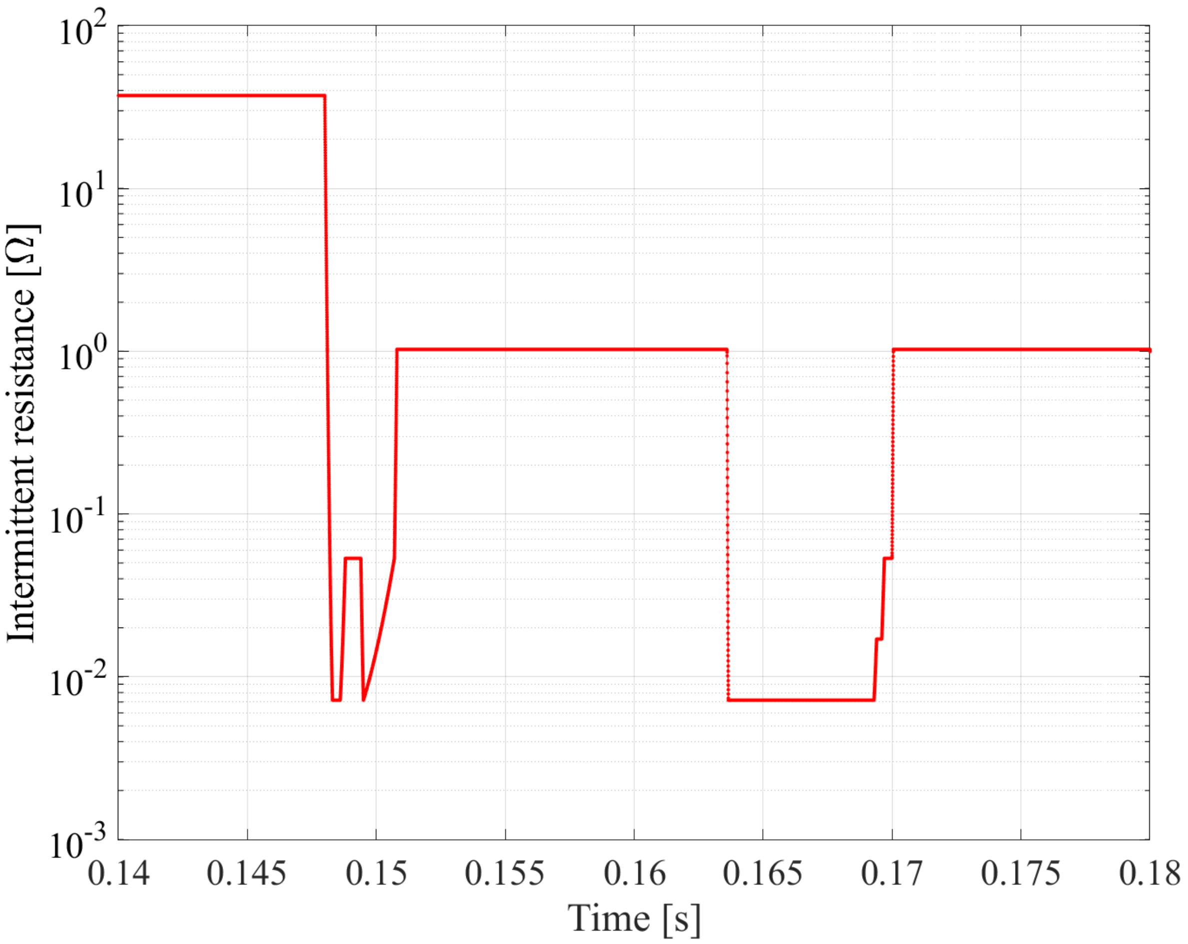
“Old” model with intermittent short circuit

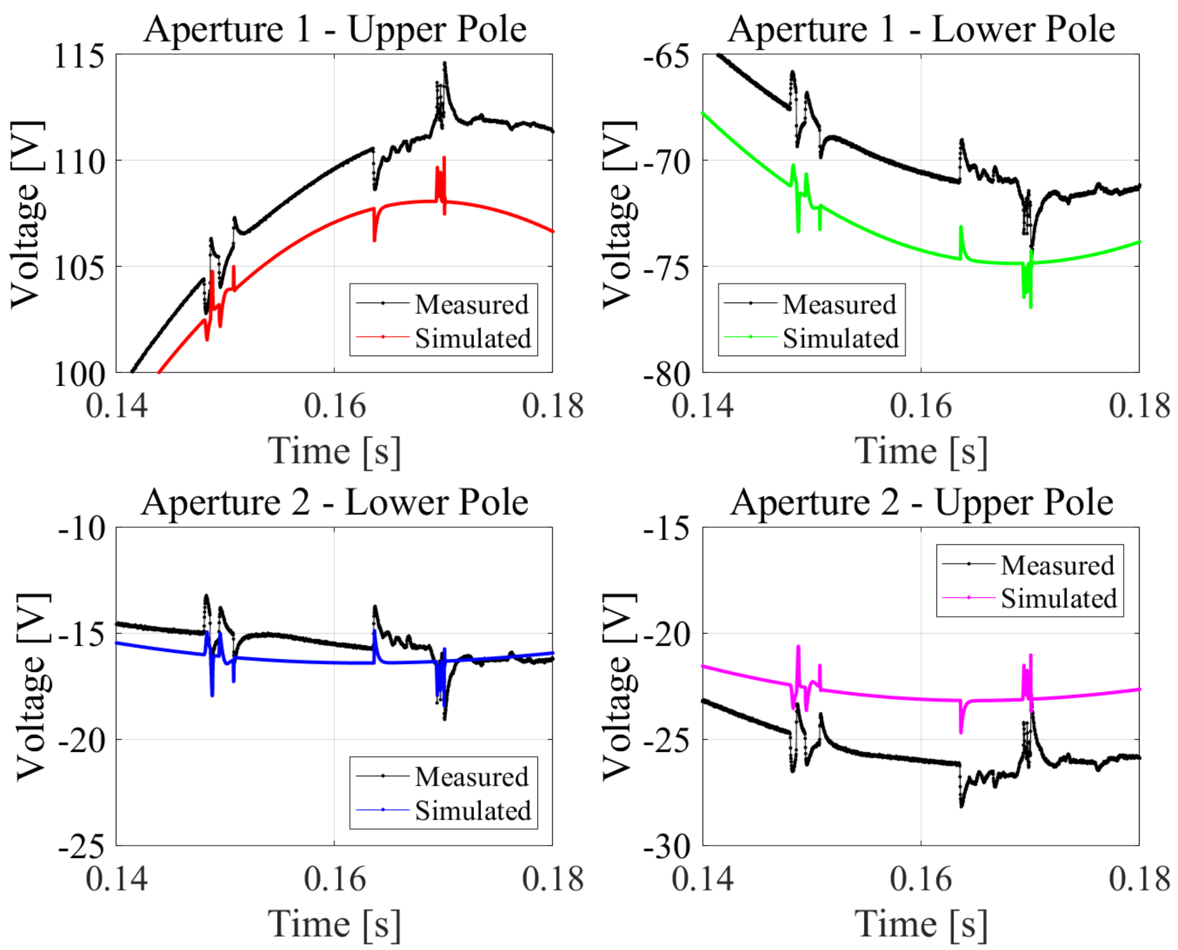


“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 μH, R_loop=7 mΩ-1 Ω

MBHA001 – Intermittent R_loop resistance used in the model





k_loop=4%, L_loop=1.72 μH, R_loop=7 mΩ-1 Ω

A few observations about the spikes obtained with this model

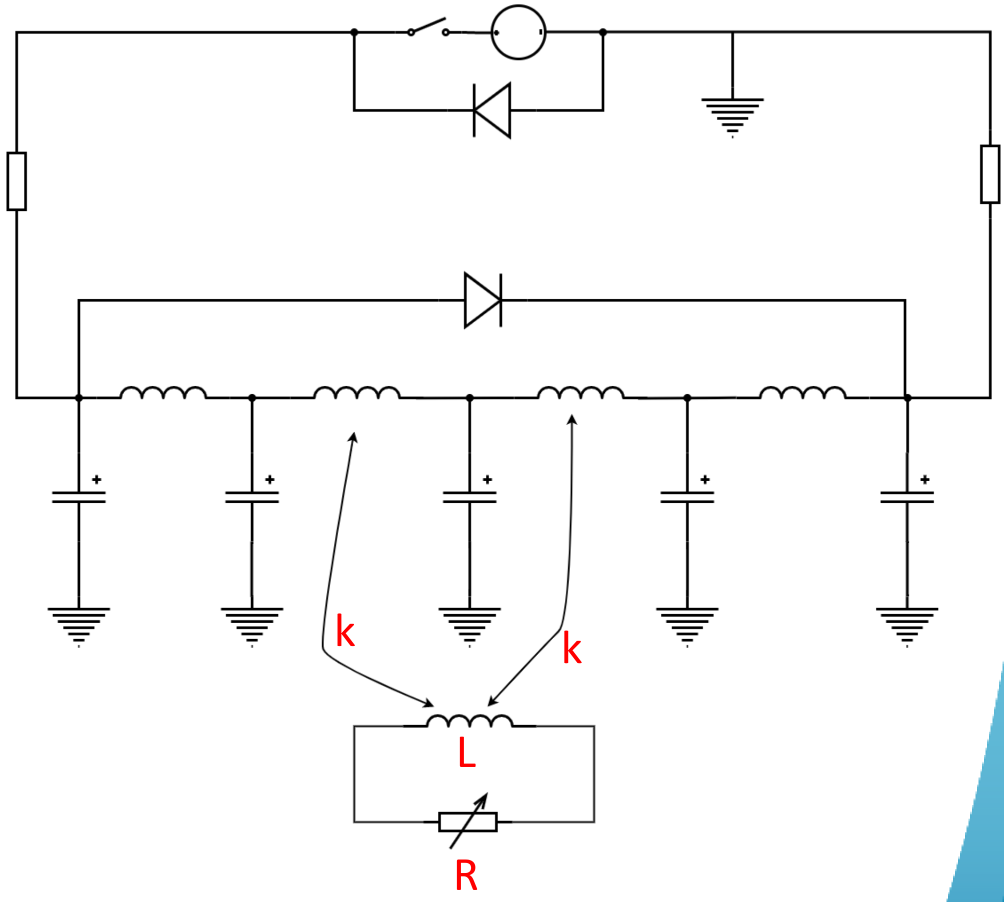
Spike amplitude

- Strongly dependent on coupling between RL loop and magnet
- Dependent on the amplitude and rise time of the RL loop resistance
- Independent of the magnet capacitance to ground
- Independent of the Cold Diode capacitance to ground
- Independent of the coil resistance
- Independent of the circuit warm resistance

Spike decay time

- Dependent on the L/R time constant of the RL loop
- Dependent on the rate of change of the RL loop resistance

In reality, many equivalent RL loops are present, not just one, each disappearing at a different time



Open questions

Spike polarities

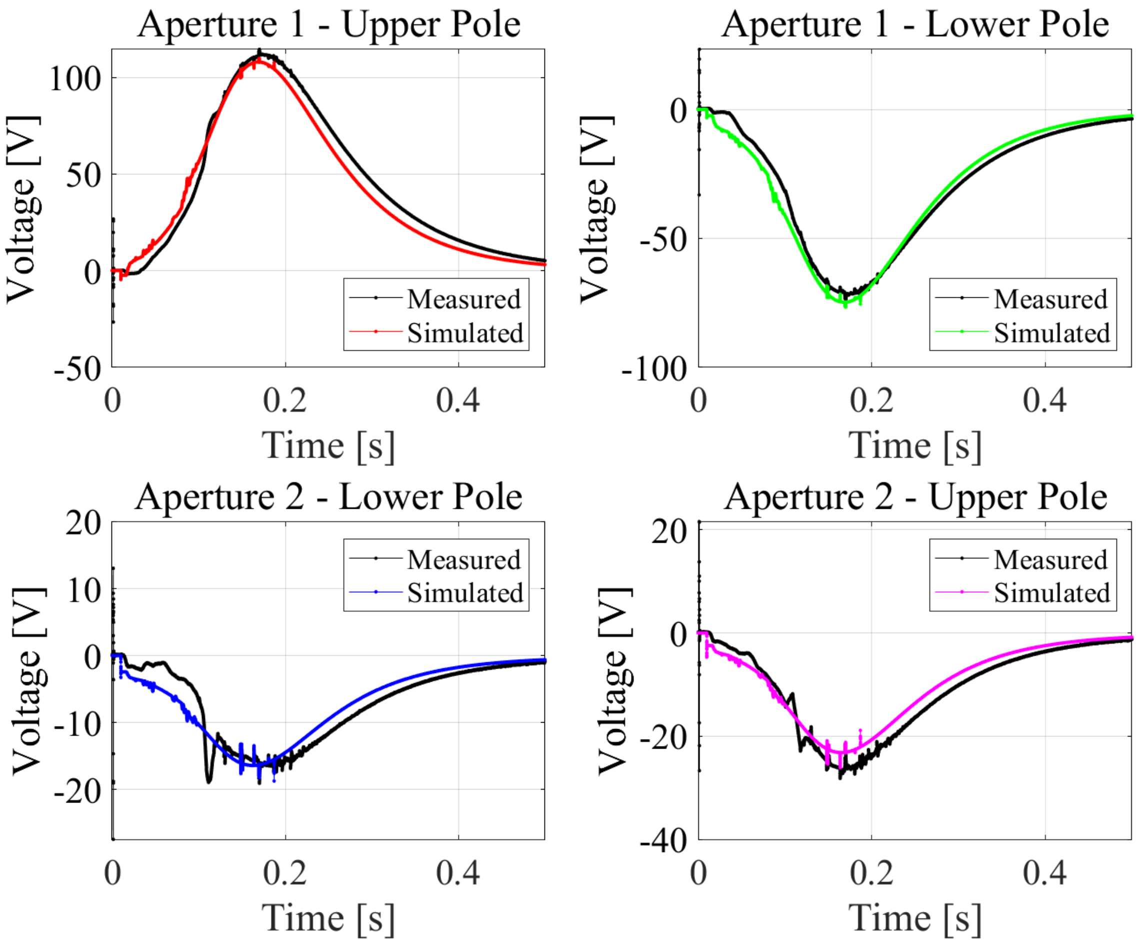
- In this model, the spikes invert polarity when the flux decreases/increases. So in order to have rapid spike polarity inversion one needs to assume a flux that rapidly decreases *and then re-increases*. Is this physical?
- I could reproduce the spike amplitude only assuming a relatively high coupling factor between the RL loop and the coils (>5%). It doesn't seem impossible, because the RL loop is a virtual component… but it gives pause.

Spike occurrence

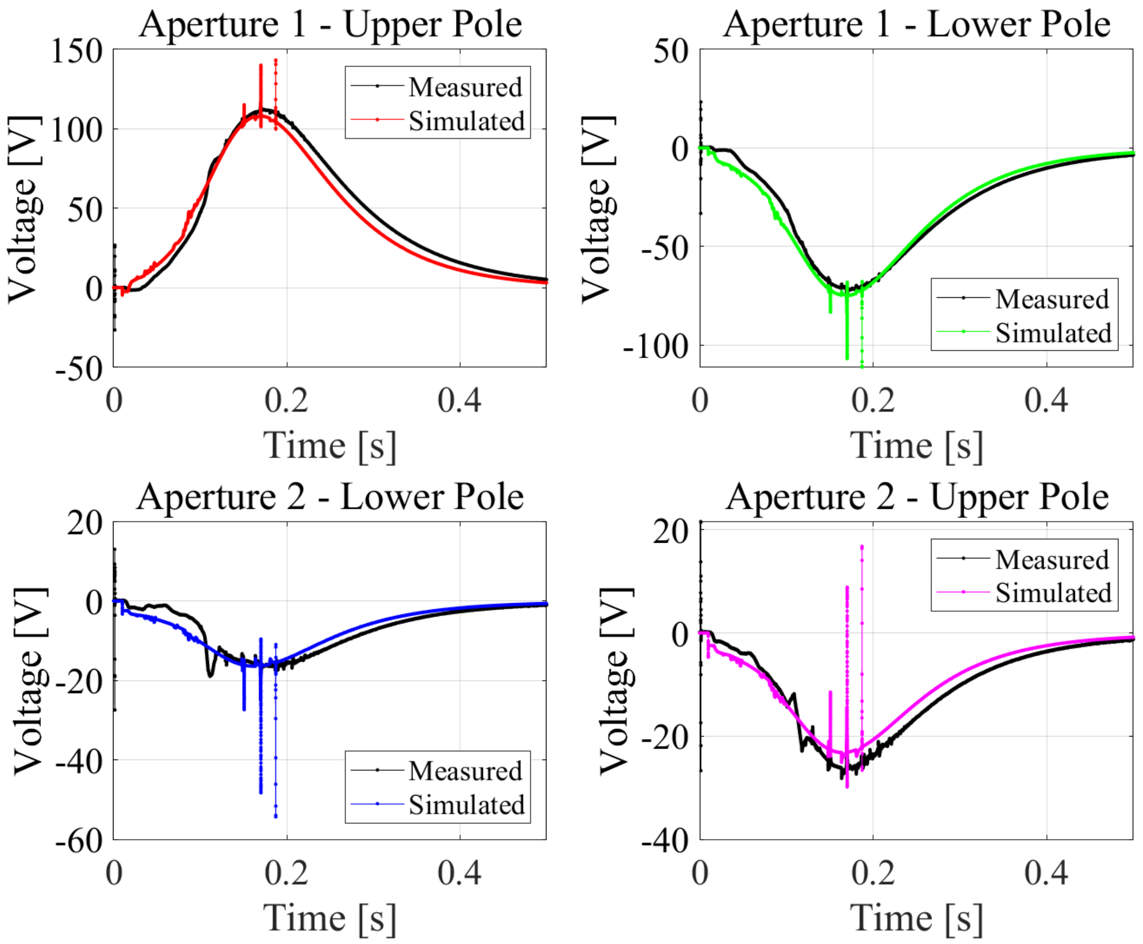
- Why spikes appear more often at a specific magnet dI/dt?
  - Flux jumps?
- Why spikes occur at the beginning and at the end of a discharge at nominal current?

No conclusions yet

MBHA001 – Voltage spikes in the four poles



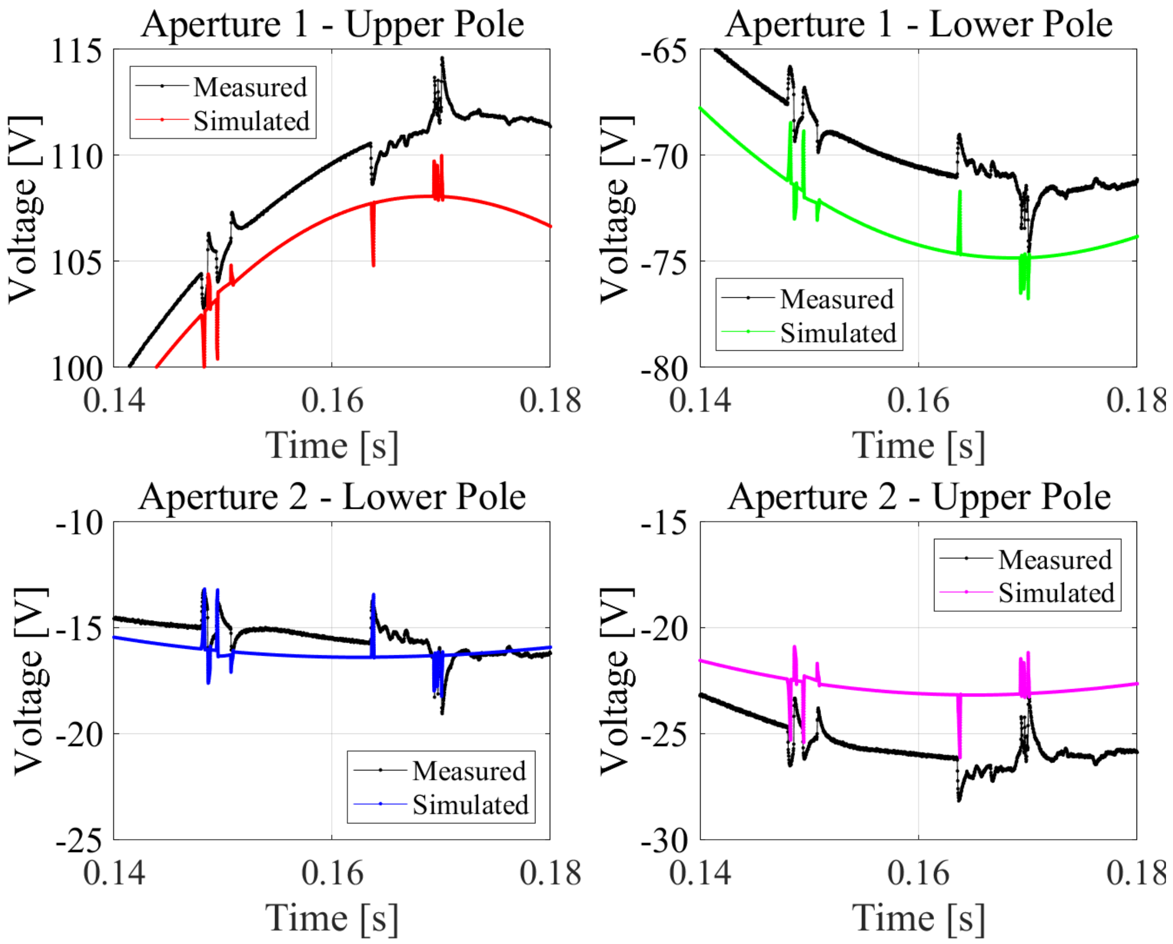
“Old” model with intermittent short circuit



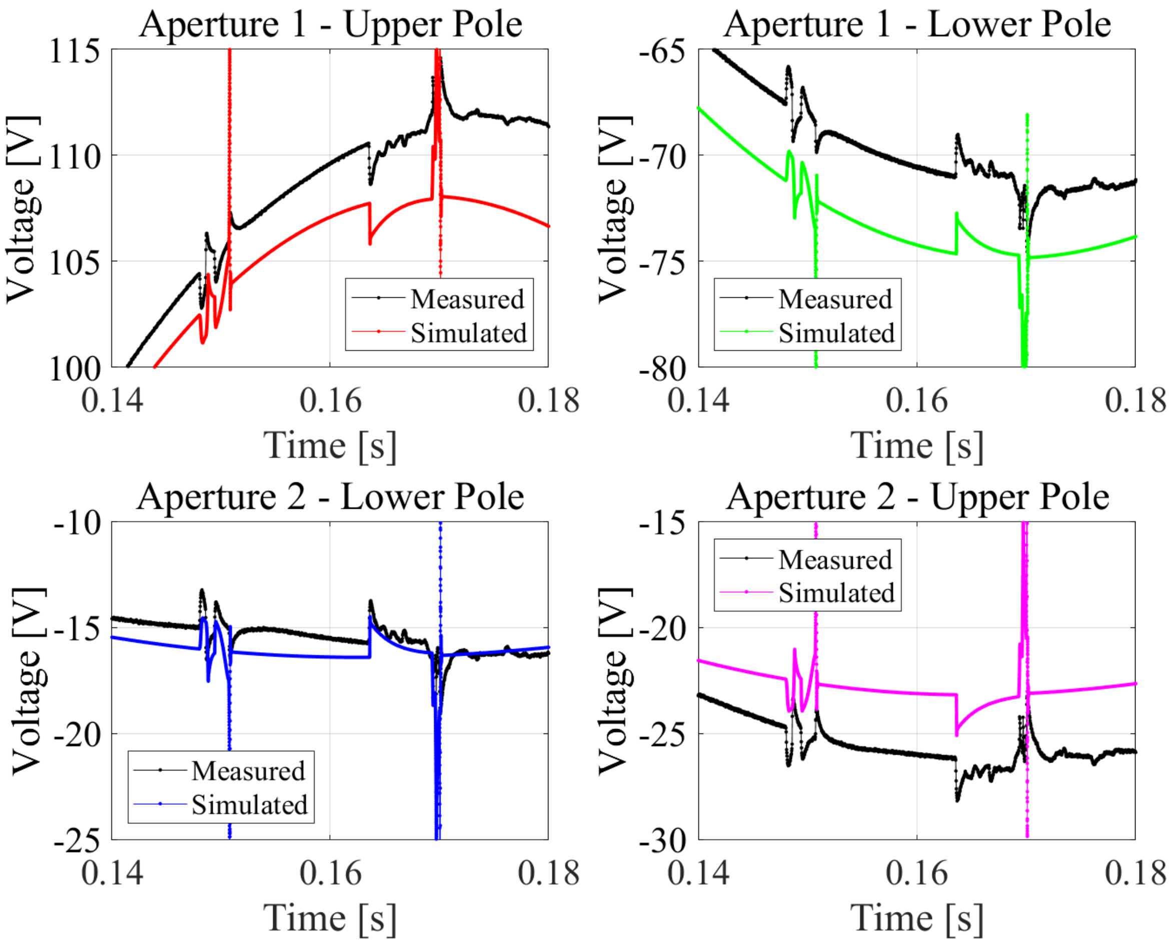
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 µH, R_loop=0.7 mΩ-100 mΩ

MBHA001 – Voltage spikes in the four poles –zoom1



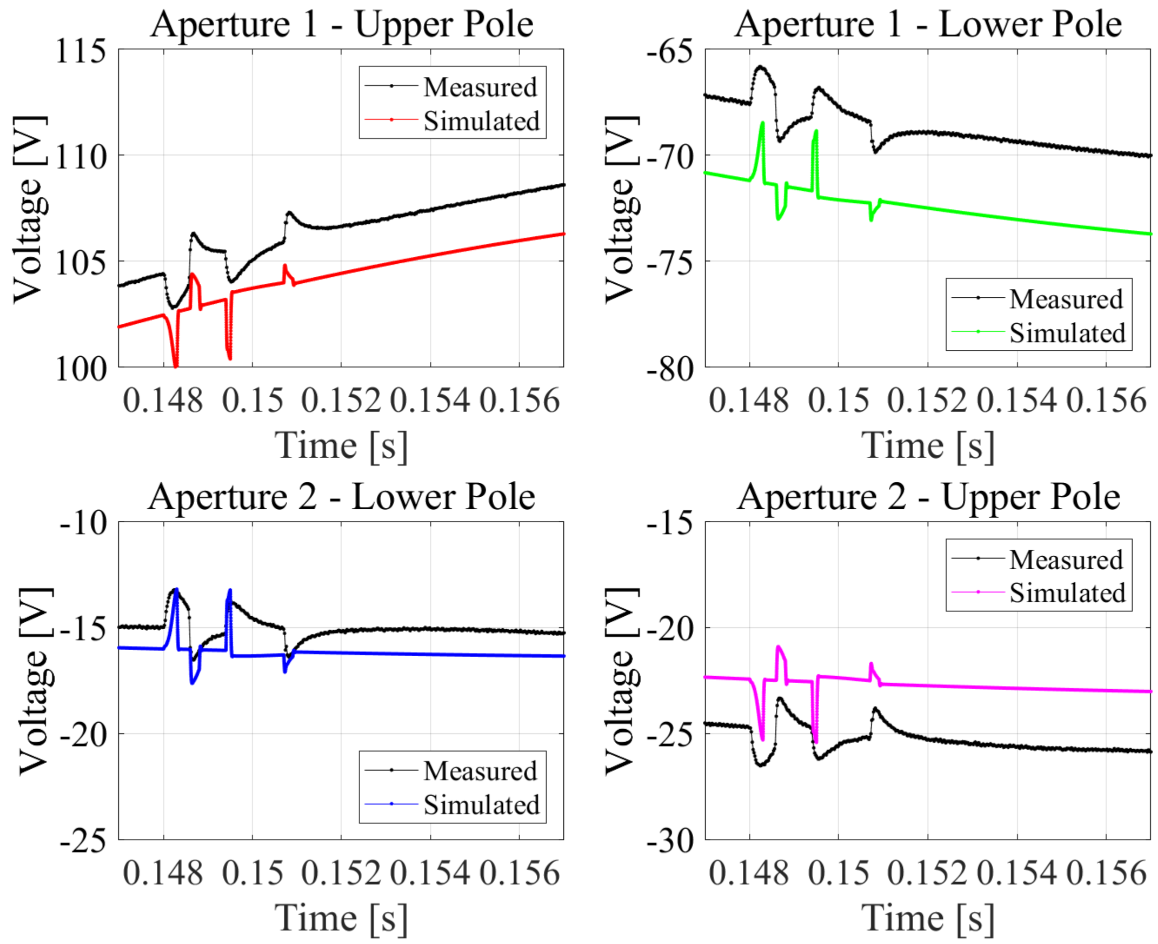
“Old” model with intermittent short circuit



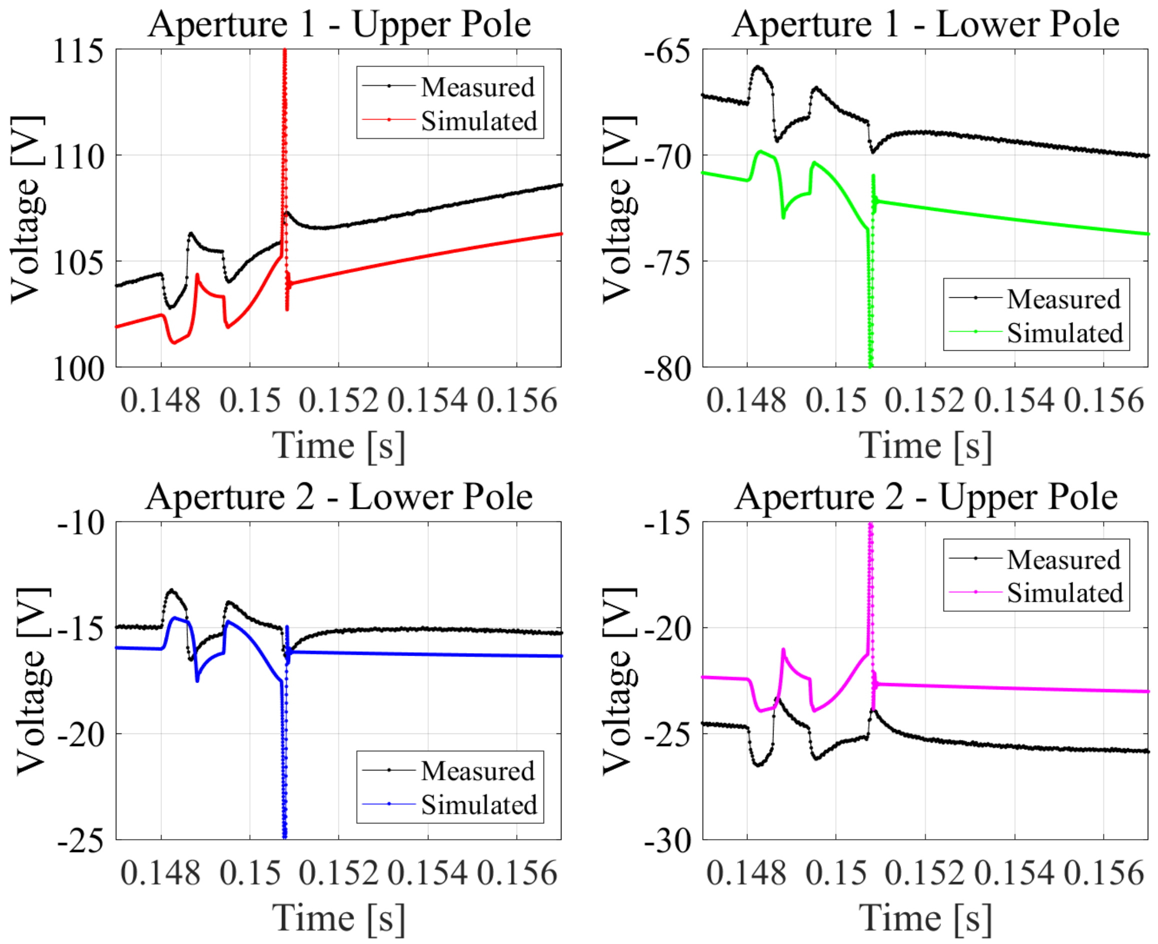
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 µH, R_loop=0.7 mΩ-100 mΩ

MBHA001 – Voltage spikes in the four poles –zoom2



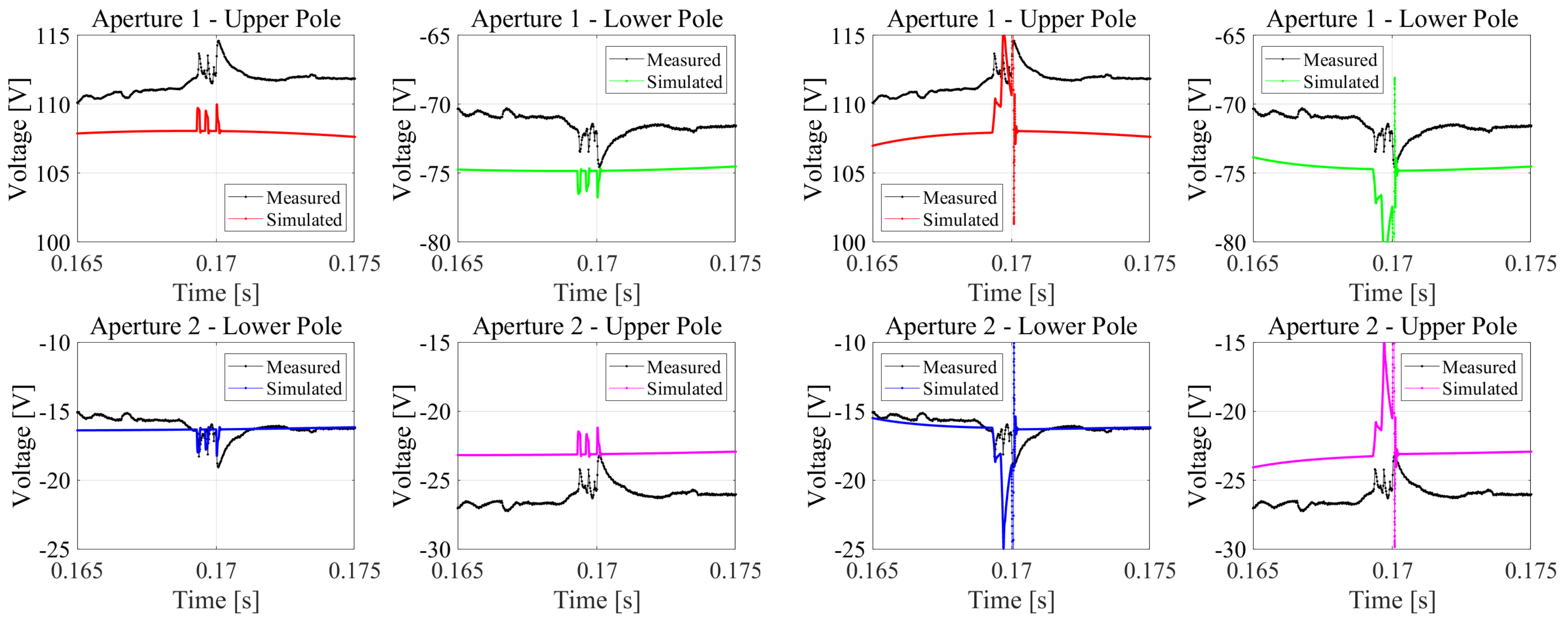
“Old” model with intermittent short circuit



“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 µH, R_loop=0.7 mΩ-100 mΩ

MBHA001 – Voltage spikes in the four poles –zoom3

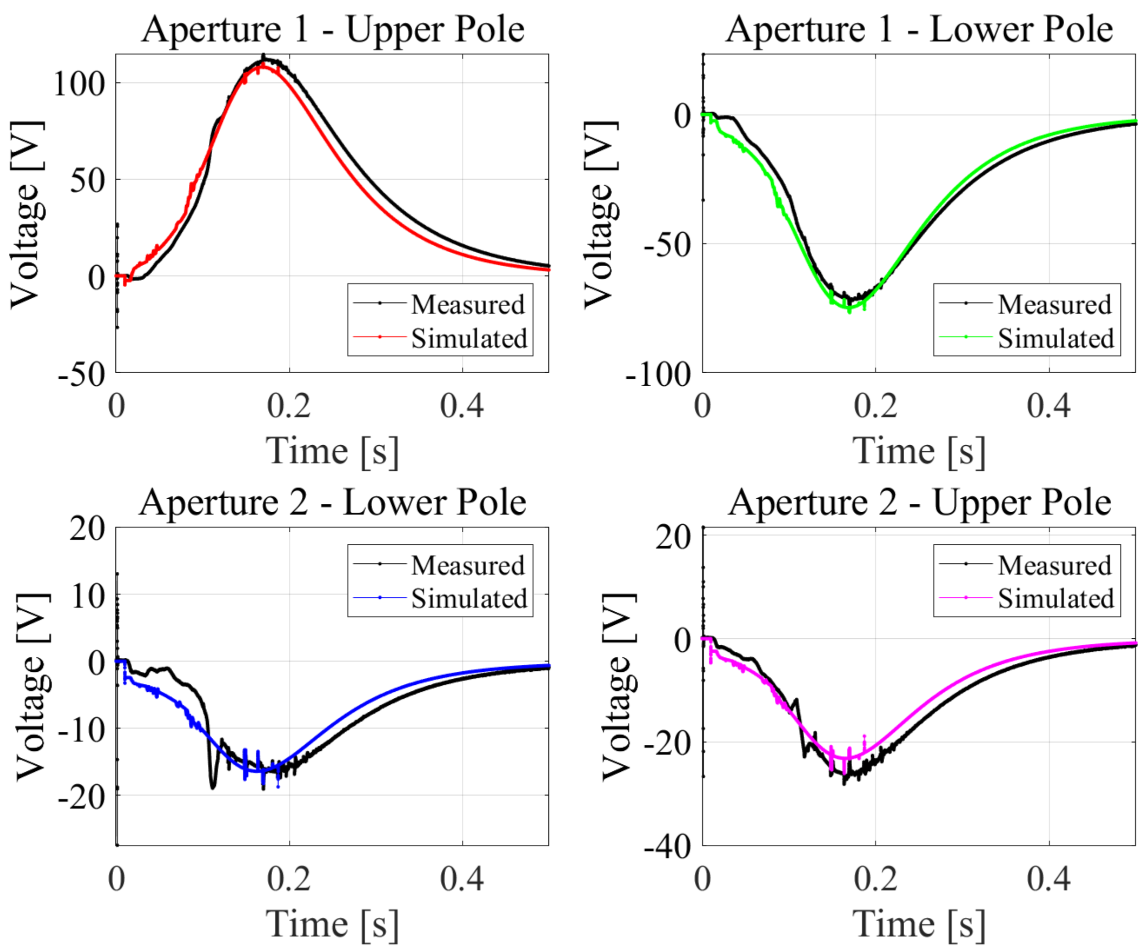


“Old” model with intermittent short circuit

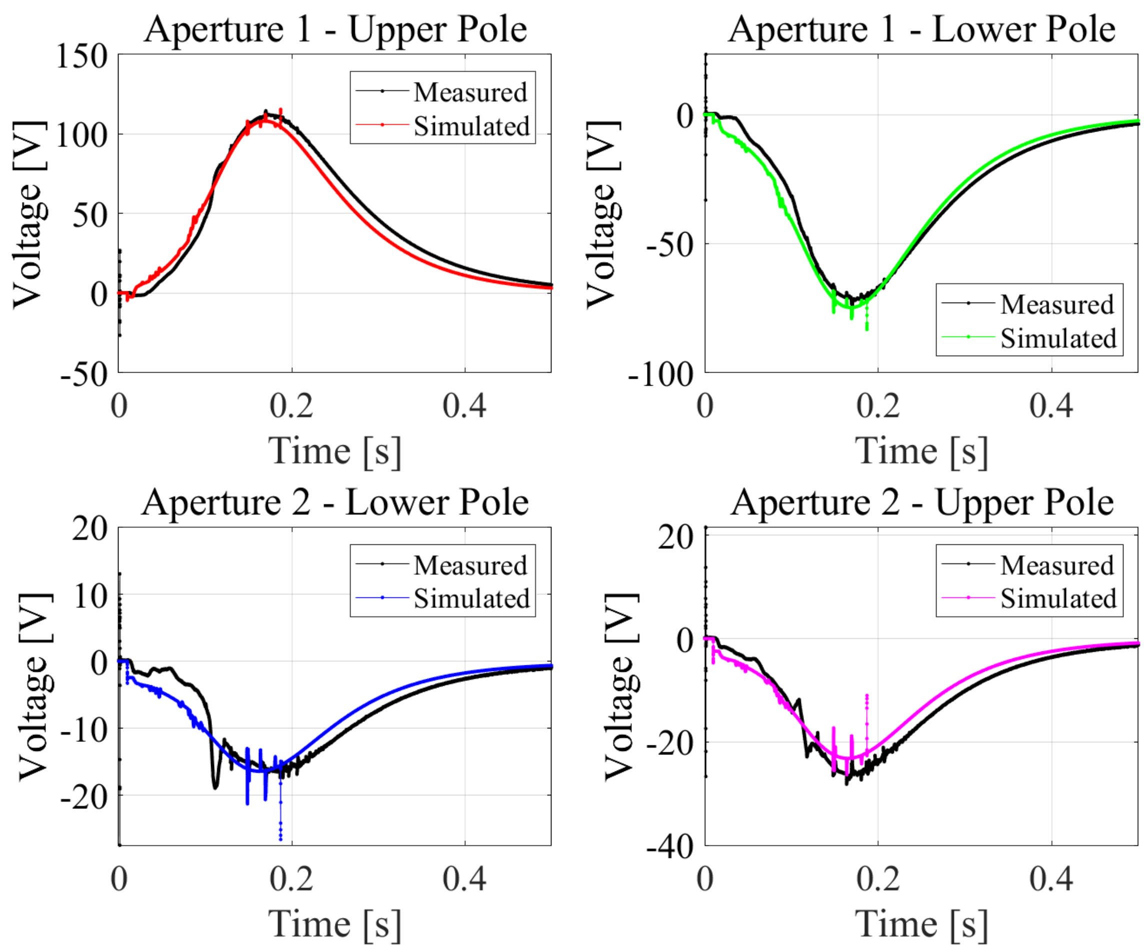
“New” model with intermittent flux changes

k_loop=4%, L_loop=1.72 μH, R_loop=0.7 mΩ-100 mΩ

MBHA001 – Voltage spikes in the four poles



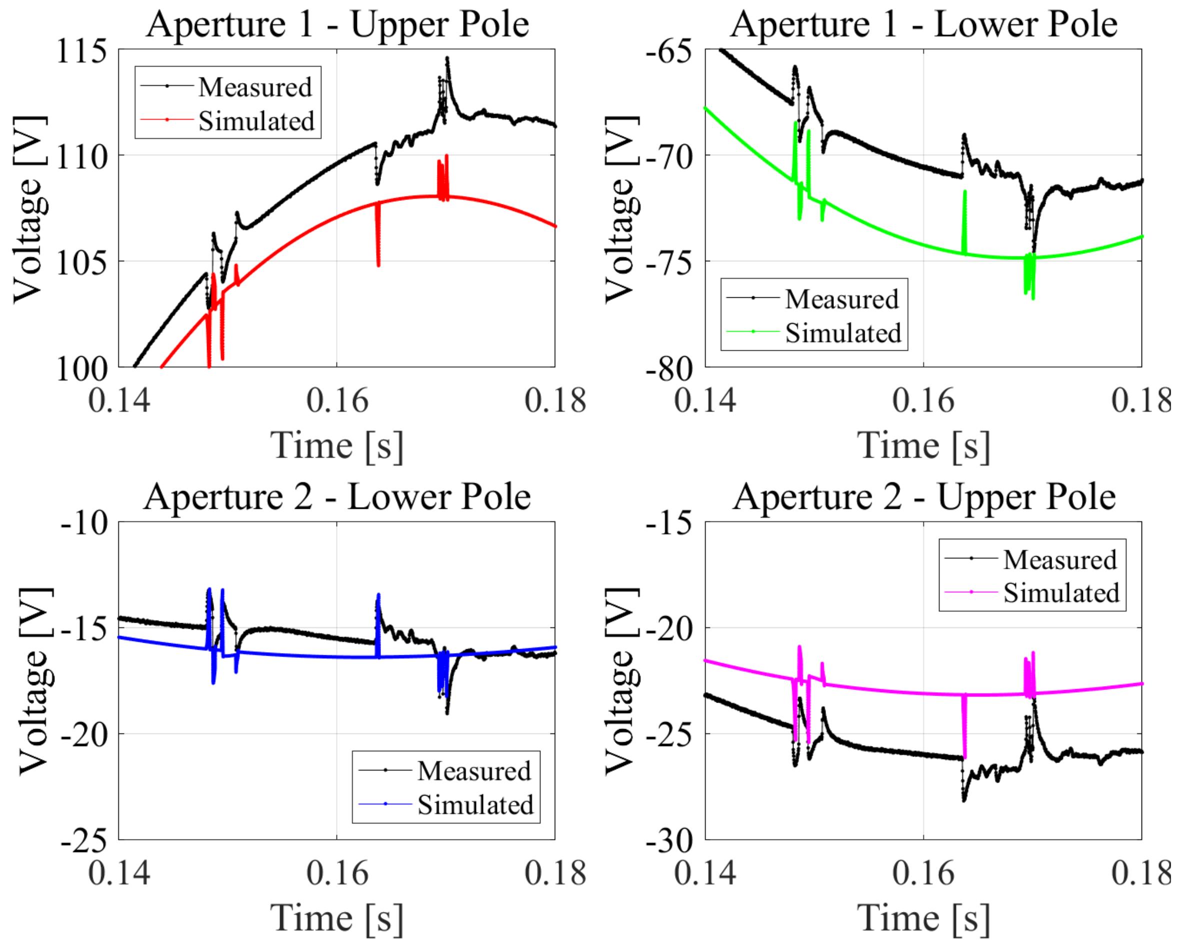
Model with intermittent short circuit



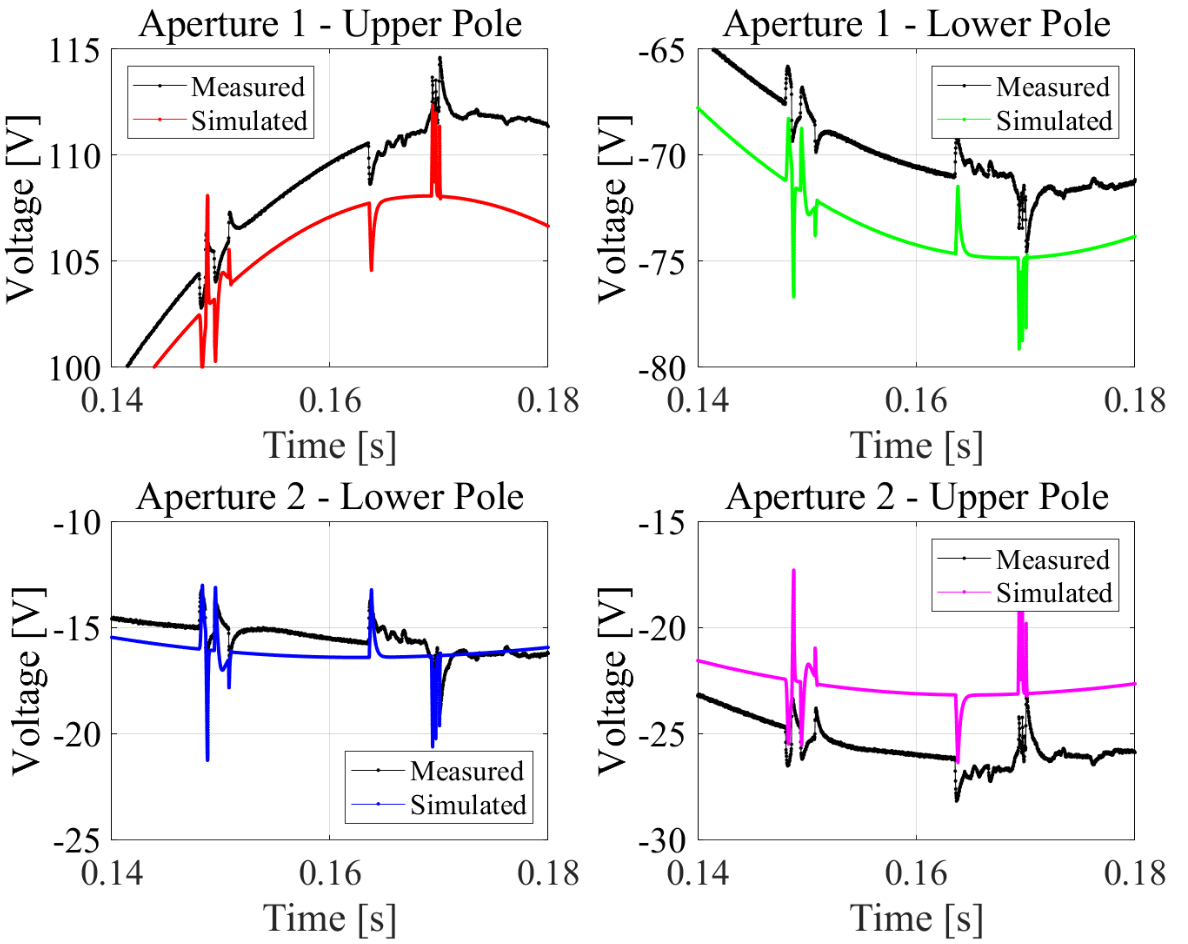
Model with intermittent flux changes

k_loop=10%, L_loop=5 μH, R_loop=20 mΩ-2.4 Ω

MBHA001 – Voltage spikes in the four poles –zoom1



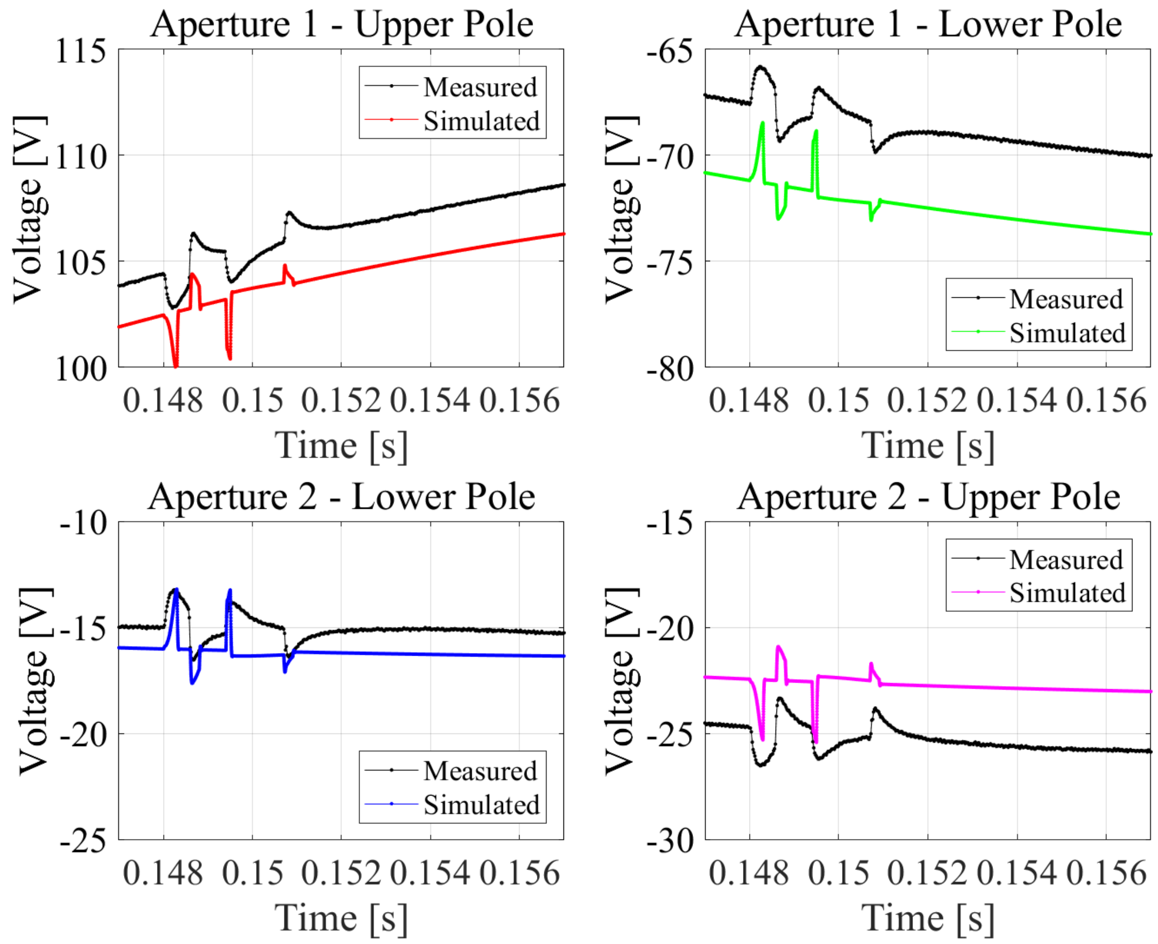
Model with intermittent short circuit



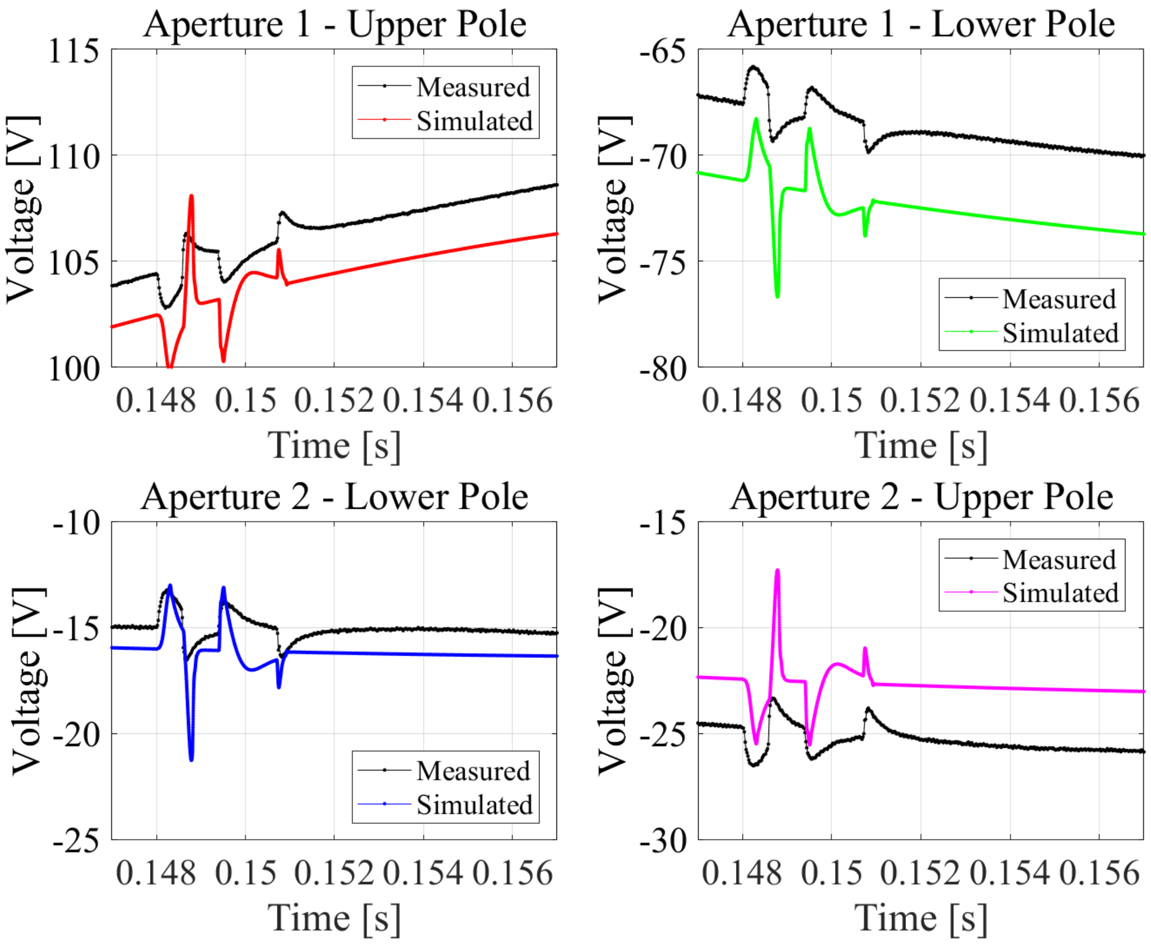
Model with intermittent flux changes

k_loop=10%, L_loop=5 µH, R_loop=20 mΩ-2.4 Ω

MBHA001 – Voltage spikes in the four poles –zoom2



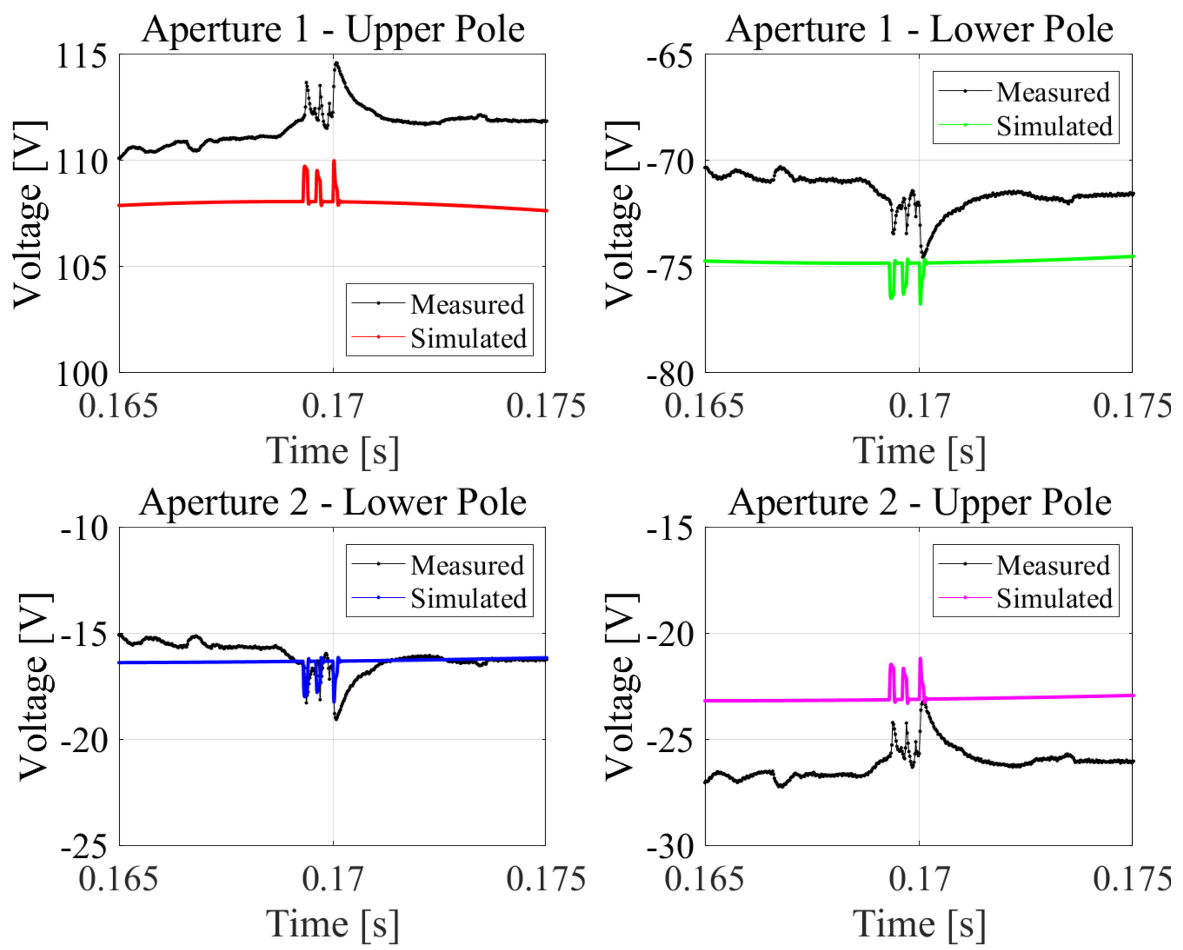
Model with intermittent short circuit

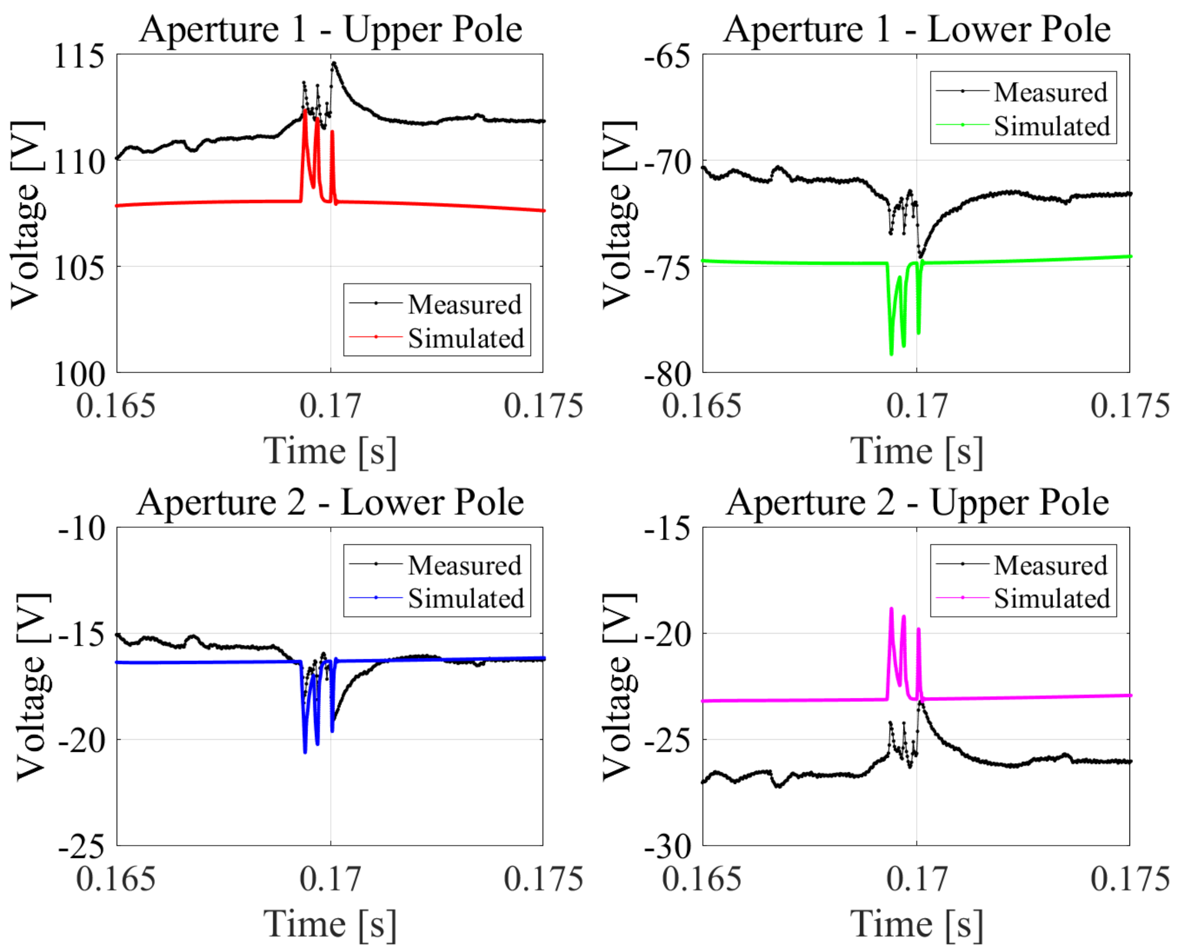


Model with intermittent flux changes

k_loop=10%, L_loop=5 μH, R_loop=20 mΩ-2.4 Ω

MBHA001 – Voltage spikes in the four poles –zoom3





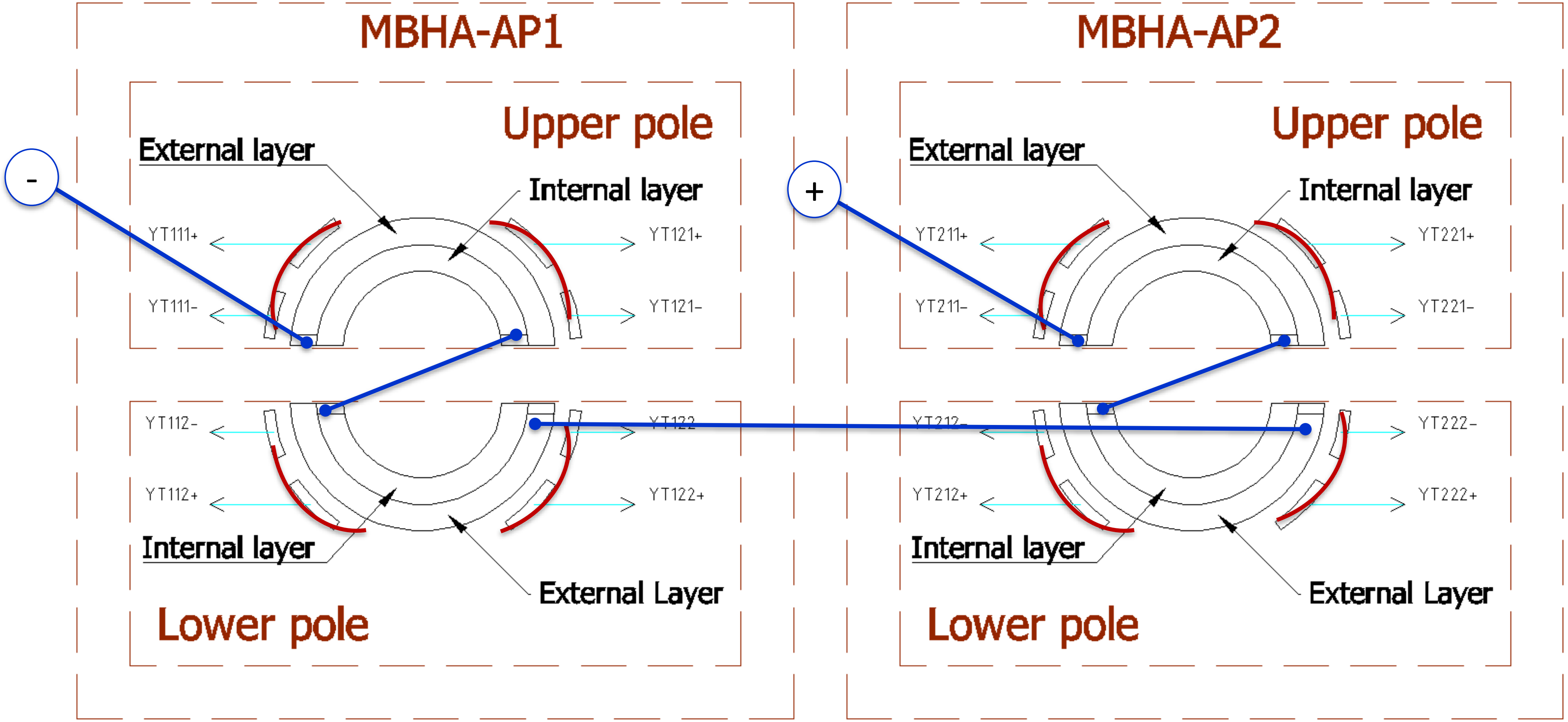
Model with intermittent short circuit

Model with intermittent flux changes

k_loop=10%, L_loop=5 μH, R_loop=20 mΩ-2.4 Ω

Annex

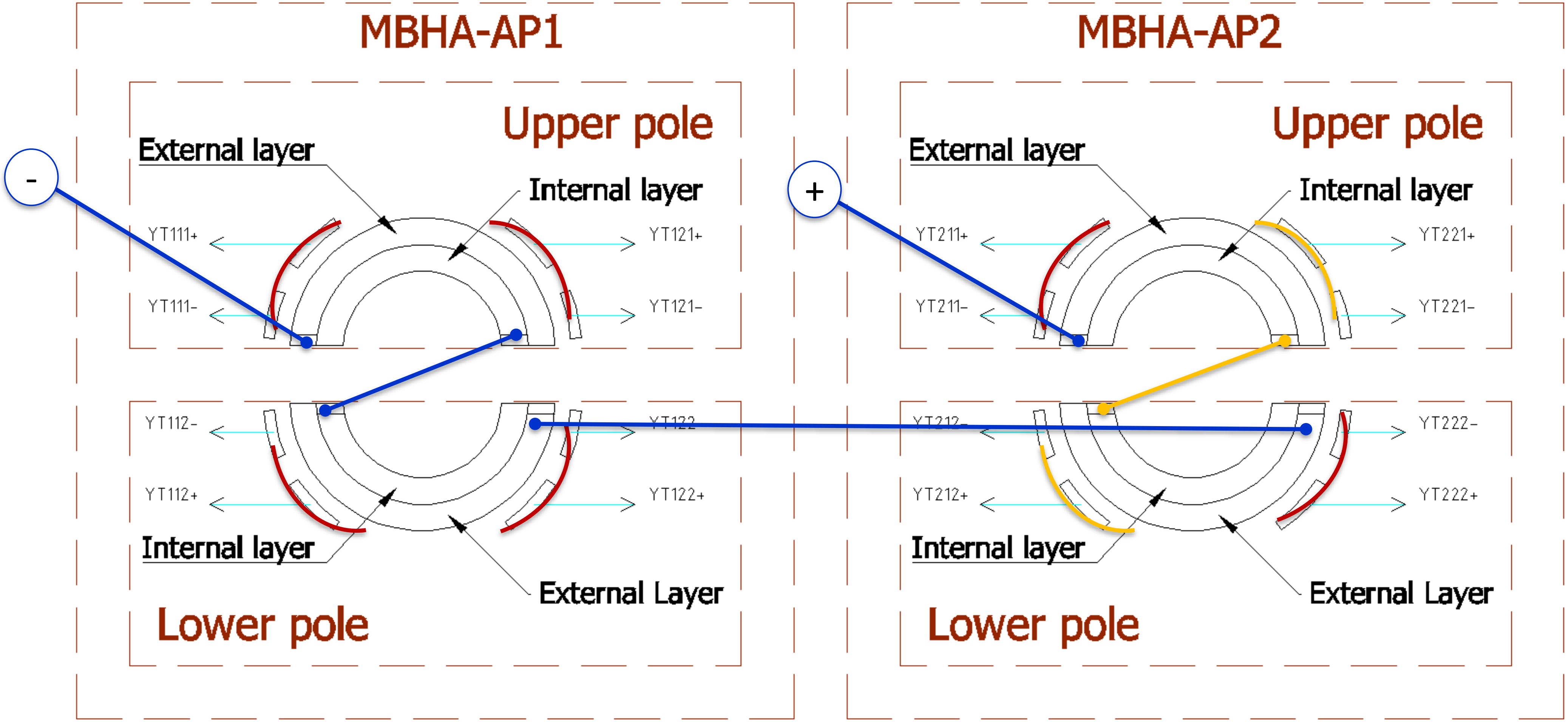
MBHA-001 – Splices, Busbars, QH connections



Looking from the lead end side

Courtesy of H. Prin

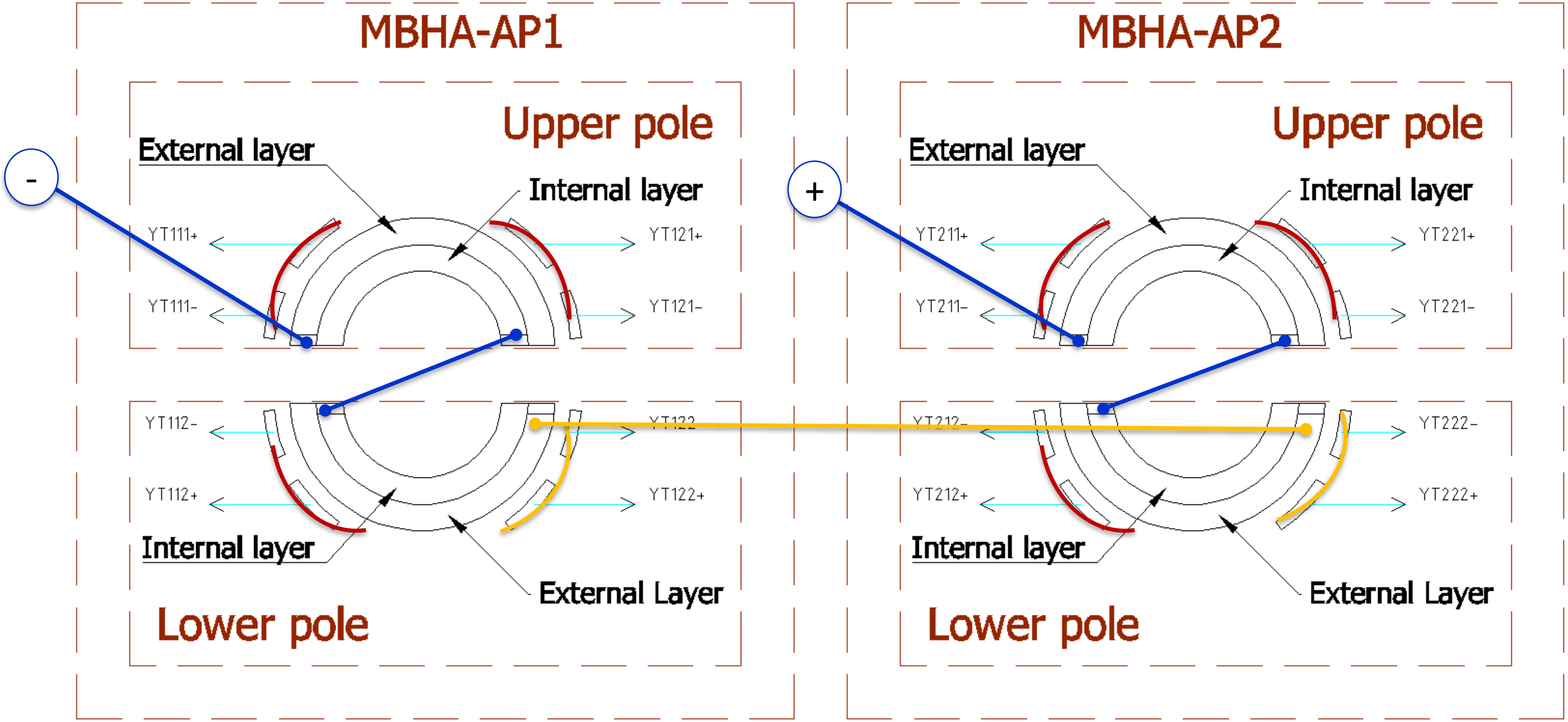
Proposed test: Delay QH acting on conductor closest to D2 splice



Looking from the lead end side

Courtesy of H. Prin

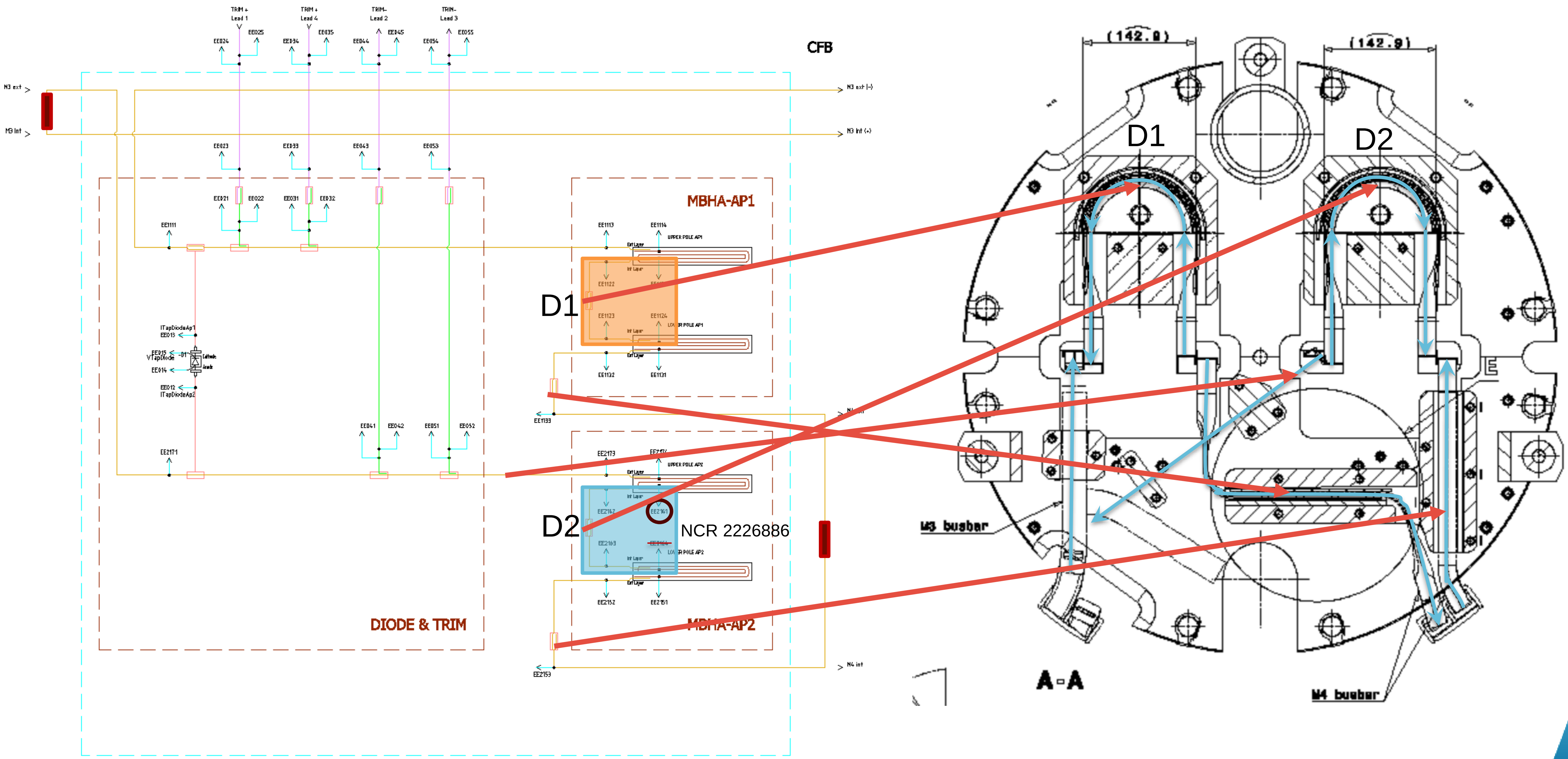
Proposed test: Delay QH acting on conductor closest to D1-D2 splice

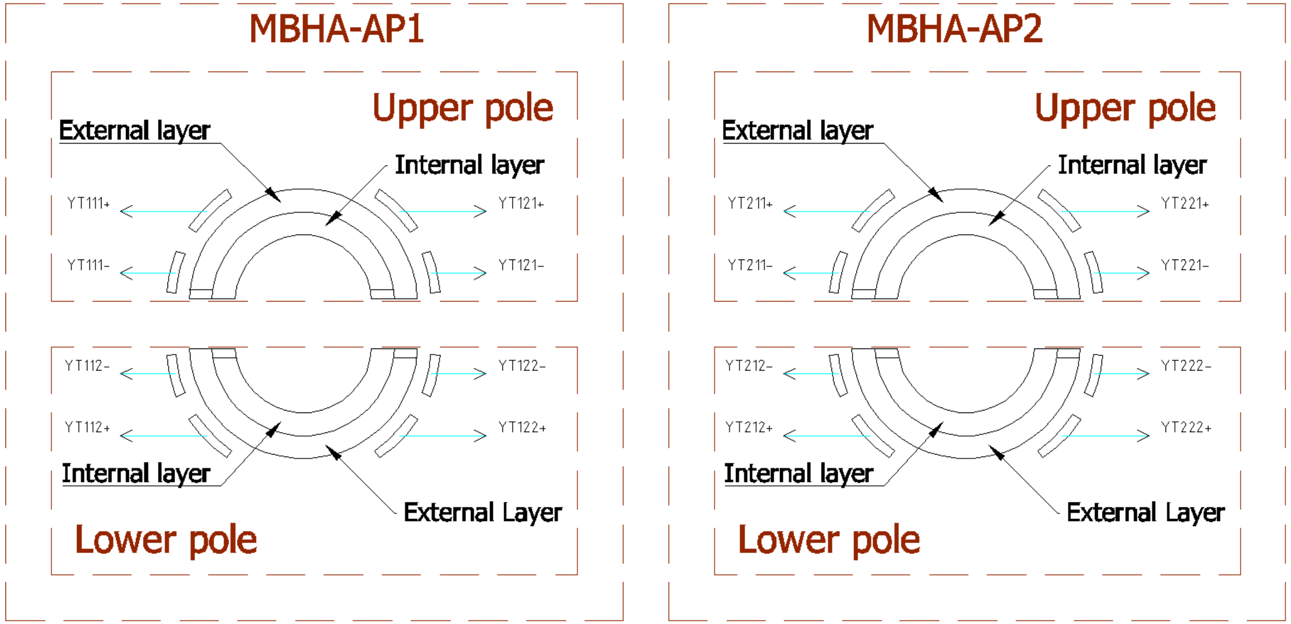


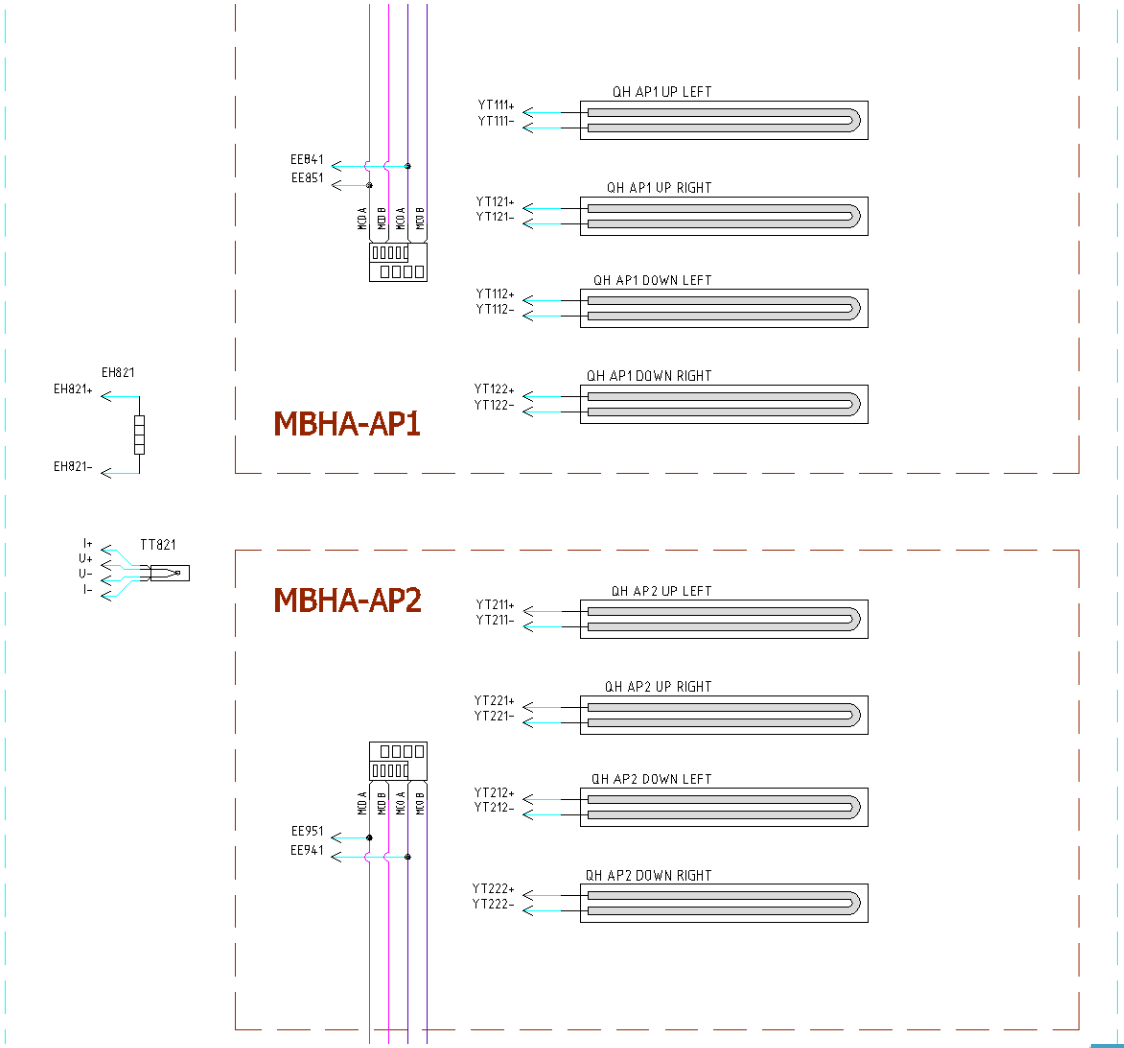
Looking from the lead end side

Courtesy of H. Prin

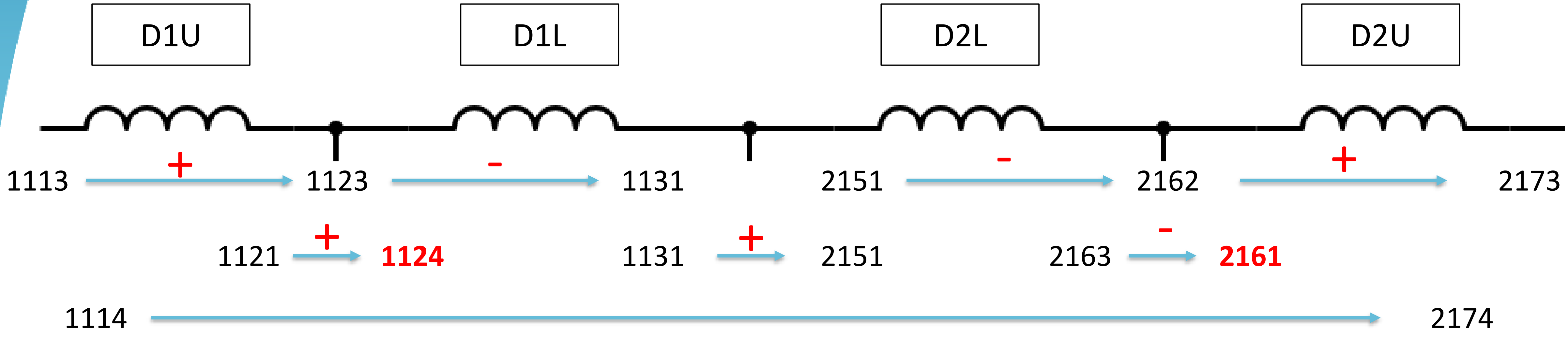
MBHAR cold test configuration

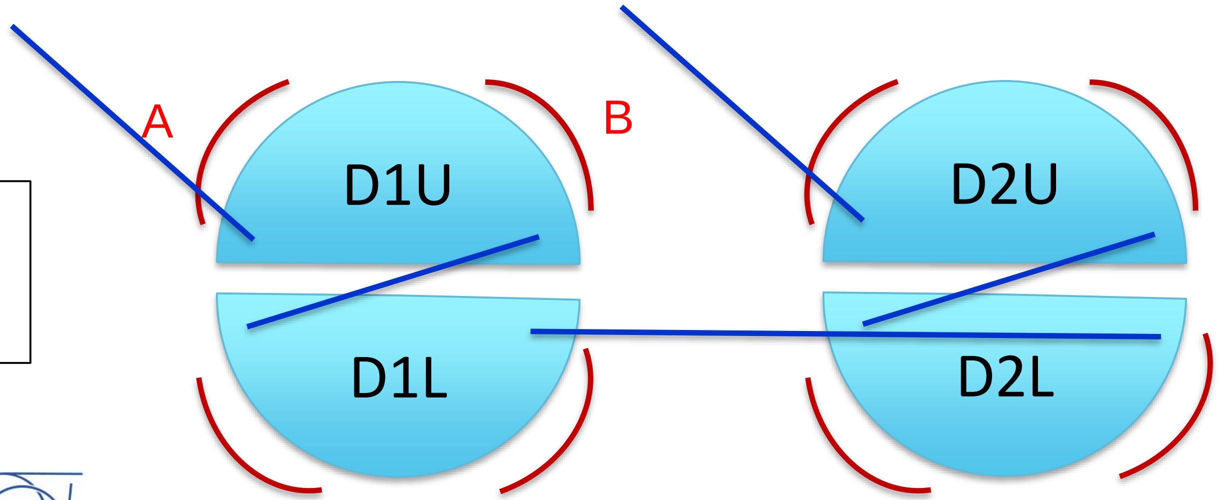



MBHA-AP1
Upper pole
External layer
Internal layer
YT111+
YT111-
YT121+
YT121-
YT112-
YT112+
YT122-
YT122+
Internal layer
External Layer
Lower pole
MBHA-AP2
Upper pole
External layer
Internal layer
YT211+
YT211-
YT221+
YT221-
YT212-
YT212+
YT222-
YT222+
Internal layer
External Layer
Lower pole


EE841
EE851
QH AP1 UP LEFT
YT111+
YT111-
QH AP1 UP RIGHT
YT121+
YT121-
QH AP1 DOWN LEFT
YT112+
YT112-
QH AP1 DOWN RIGHT
YT122+
YT122-
MBHA-AP1
EH821
EH821+
EH821-
TT821
I+
U+
U-
I-
MBHA-AP2
QH AP2 UP LEFT
YT211+
YT211-
QH AP2 UP RIGHT
YT221+
YT221-
QH AP2 DOWN LEFT
YT212+
YT212-
QH AP2 DOWN RIGHT
YT222+
YT222-
EE951
EE941

Signals on the voltage taps

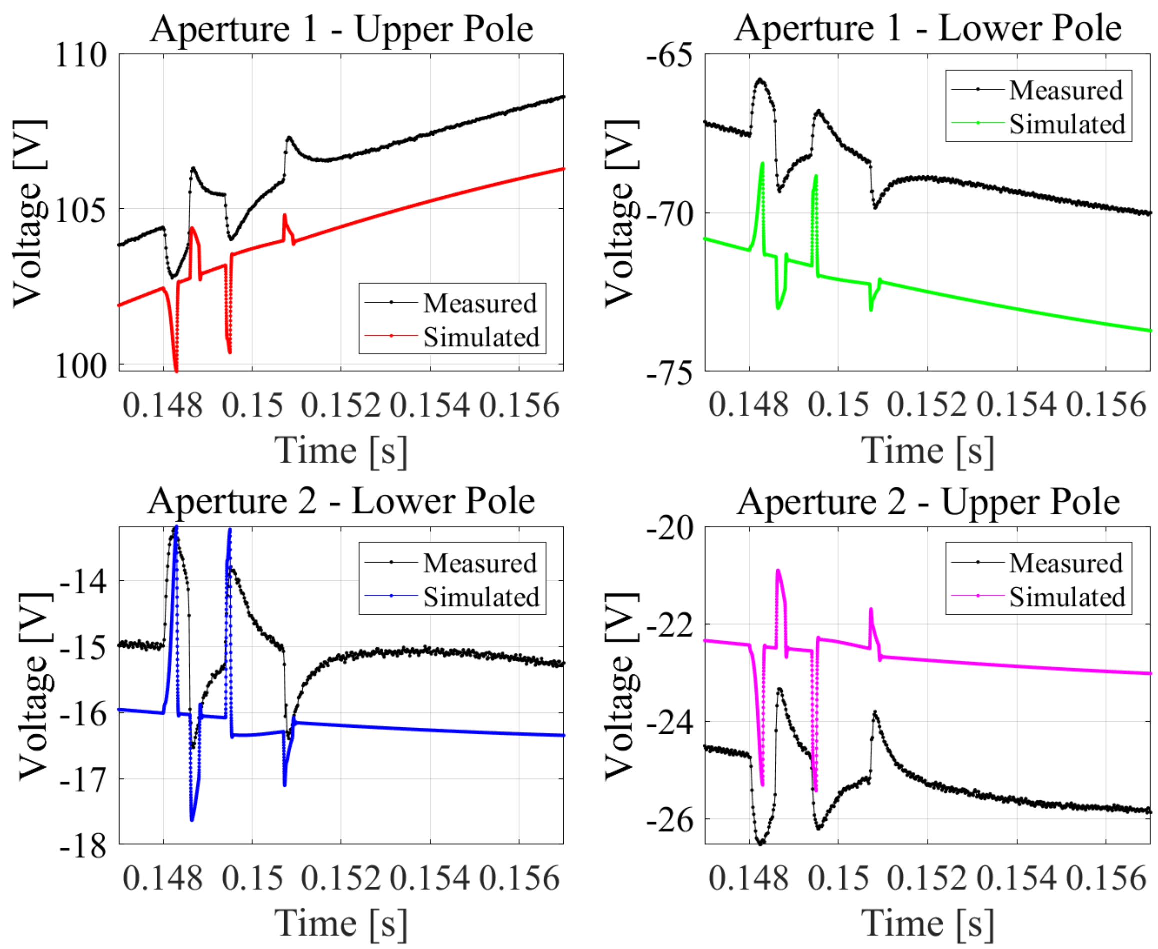


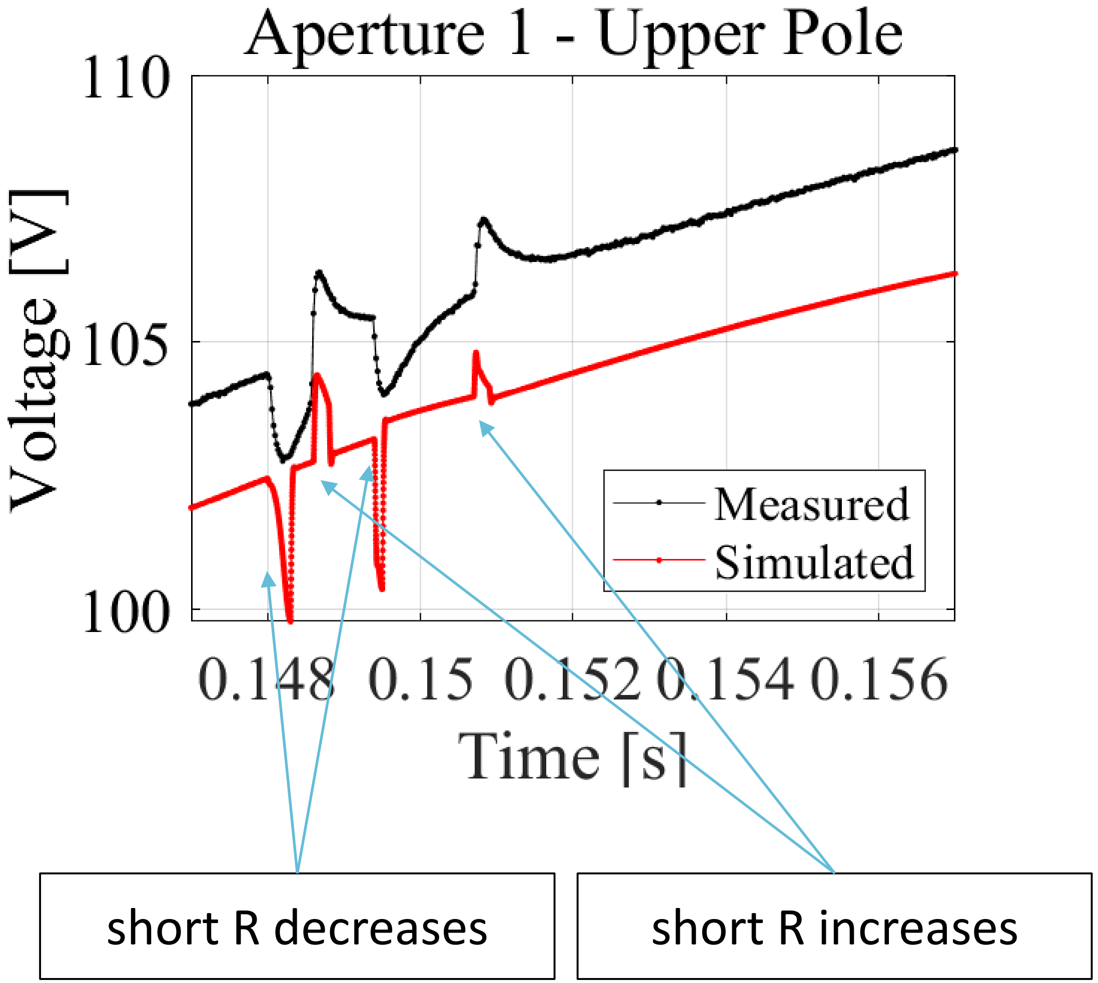


Looking from the lead end side

What is the QH circuit that is closest to tap **2161**?
A or B?

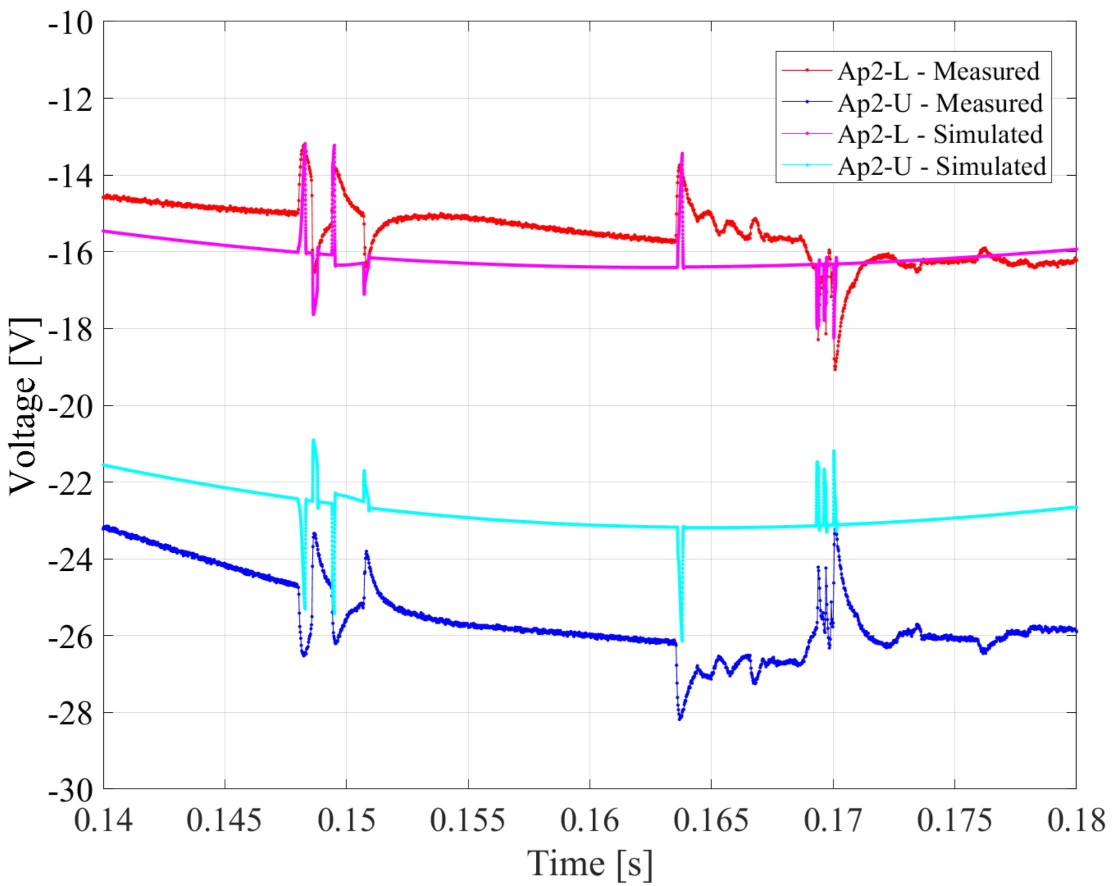
MBHA001 – Polarities of the voltage spikes in the four poles

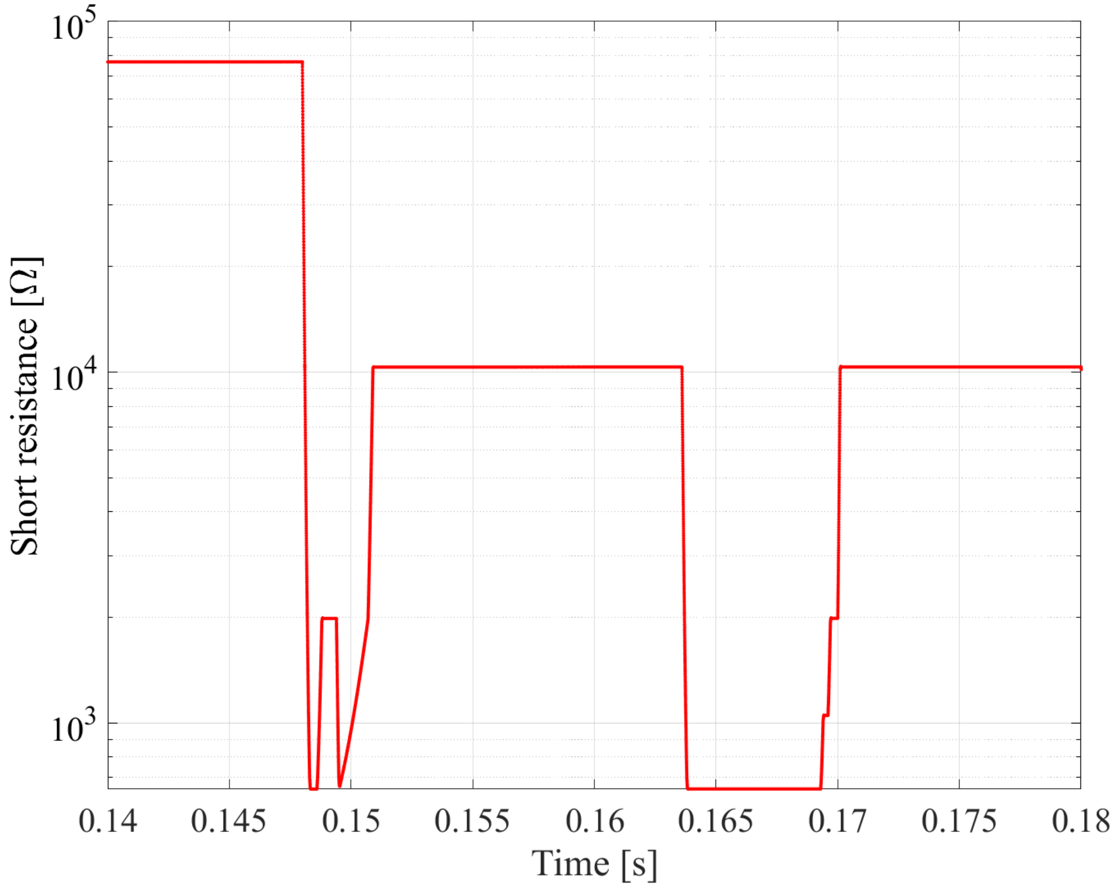




- The change of the voltage spike polarities is likely caused by the change of the short circuit resistance (short appearance / ”disappearance”)

MBHA001 – Short-circuit changing resistance





- Voltage spike polarities and amplitudes can be reproduced with an intermittent short circuit
- Short resistance is changed in the range 650 Ω – 10 kΩ during the simulation (intermittent short)
- Time required to change the resistance significantly influences the amplitude of the voltage spikes

[This is not the only combination of parameters that can reproduce the amplitude of the spikes]