STUDIES OF THE STRIPLINE KICKER FOR BEAM EXTRACTION FROM THE CLIC DRs

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Acknowledgment to M.J. Barnes (CERN) and M. Pont (ALBA)

1. Introduction

The agreement between data from **measurements** and **simulations** will serve to give confidence in the models used for the design of the striplines for beam extraction from the CLIC DRs:

- Laboratory measurements without beam:
  - Reflection parameter in both operation modes: good agreement.
  - Longitudinal beam coupling impedance (single wire method): good agreement.
  - Transverse beam coupling impedance (two wires method and single wire): poor agreement (1st part).
  - HV DC breakdown conditioning, up to ±10.8 kV.

- Beam measurements in ALBA:
  - Installation of the striplines in ALBA (Montse's talk).
  - Measurements with (and without) DC HV power supplies (3rd part).
  - Measurements with the inductive adder (Janne's talk): transient studies to match the output waveform to the transient response of B (4th part).

2. Disagreement in Transverse Beam Coupling Impedance

LONGITUDINAL BEAM COUPLING IMPEDANCE

- The **longitudinal beam coupling impedance** is defined as the ratio between the longitudinal beam voltage and the beam current for a beam circulating in the centre of the striplines, and has been calculated analytically:

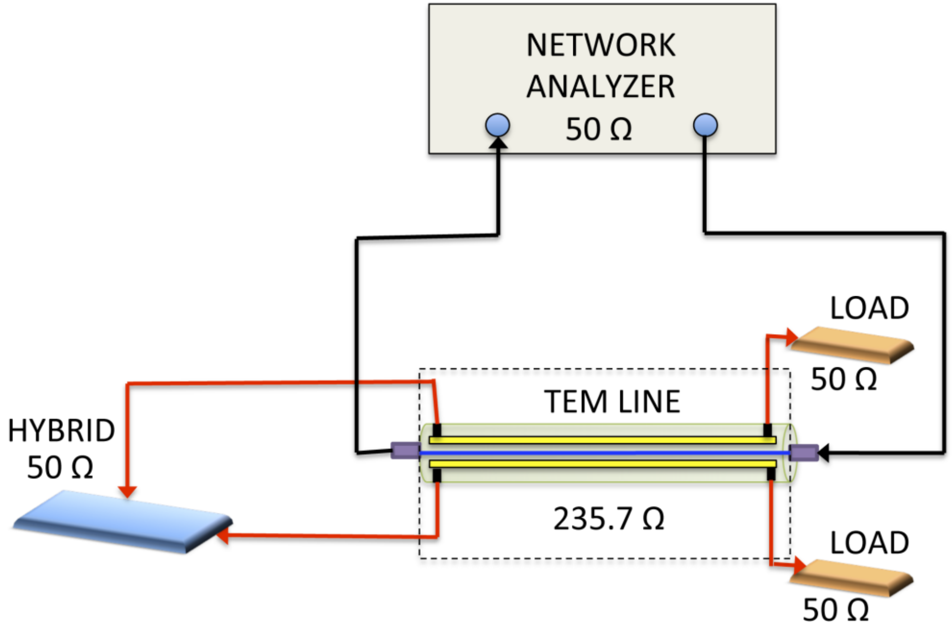
$$Z_{\parallel} = Z_{common} {g_{\parallel}}^{2} \left[\sin^2\left(\frac{\omega L}{c}\right) + j\sin\left(\frac{\omega L}{c}\right)\cos\left(\frac{\omega L}{c}\right) \right]$$

✓ Note: a longitudinal beam coupling impedance for a displaced beam can be also calculated.

- It has also been simulated using CST Particle Studio, and measured in laboratory using the single wire method:

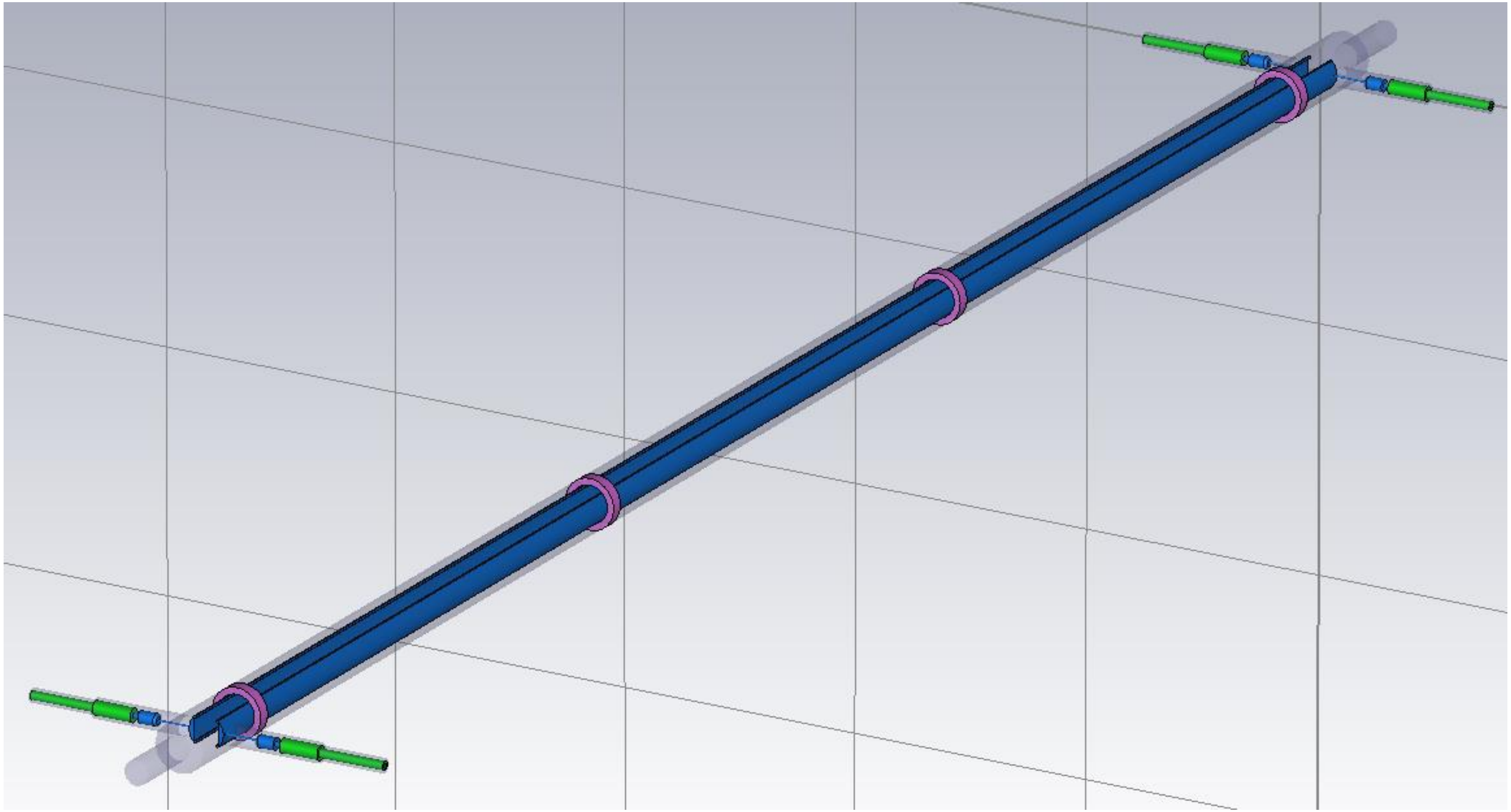
$$Z_{\parallel} = -2Z_{line} \ln S_{21}$$

- This measurement has also been compared with a simulation of the single wire method in CST Microwave Studio.

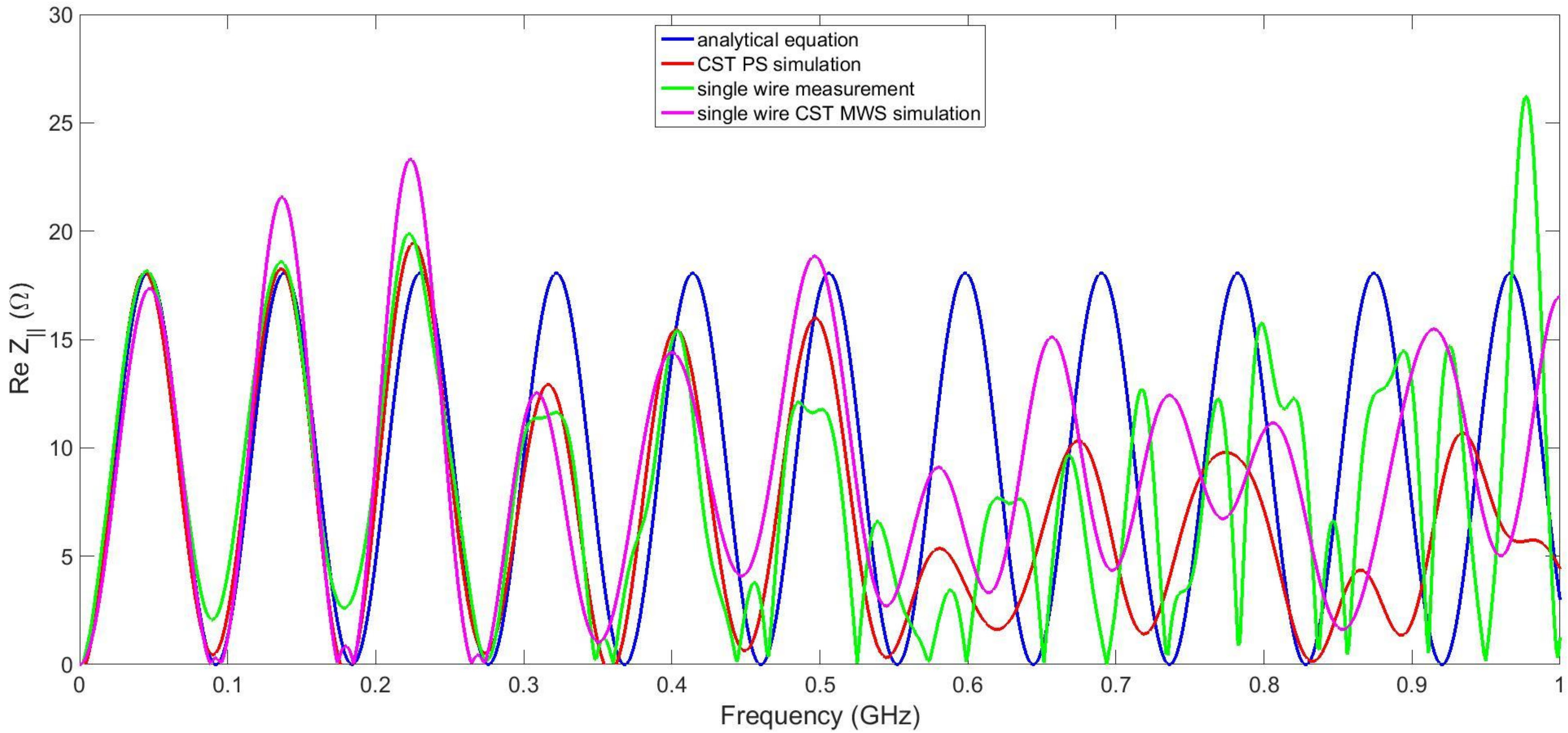


2. Disagreement in Transverse Beam Coupling Impedance

LONGITUDINAL BEAM COUPLING IMPEDANCE



LONGITUDINAL BEAM COUPLING IMPEDANCE



- The longitudinal beam coupling impedance measured agrees well with the CST PS up to around 450 MHz, whereas the wire simulation is slightly different but still quite good.
- The analytical equation is a good approximation up to 300 MHz.
- Disagreement at higher frequencies due to the effect of the feedthroughs and Macor rings.

2. Disagreement in Transverse Beam Coupling Impedance

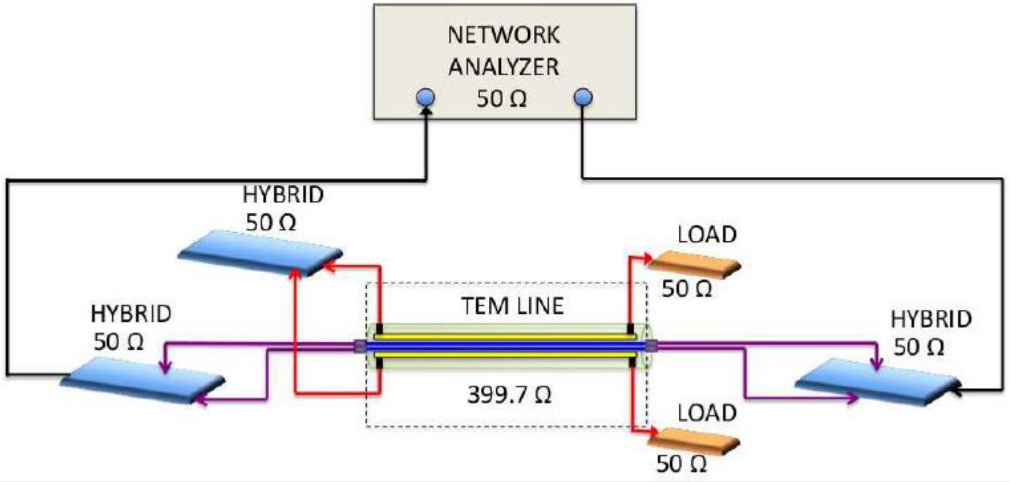
DIPOLAR HORIZONTAL BEAM COUPLING IMPEDANCE

- The dipolar component of the horizontal beam coupling impedance is analytically calculated from the longitudinal beam coupling impedance, using the Panofsky-Wenzel theorem: **this theorem relates the longitudinal and transverse effects for a given mode** *[Dynamic Devices: A Primer on Pickups and Kickers. D. A. Goldberg, G. R. Lambertson]*.

$$Z_{x,comm} = \frac{c}{\omega}\frac{1}{x}\frac{\partial Z_{\parallel}}{\partial x} = \mathbf{Z_{comm}}\left(\frac{g_{\perp}}{g_{\parallel}}\right)^2 \frac{c}{\omega b^2}\left[\sin^2\left(\frac{\omega L}{c}\right) - \sin\left(\frac{\omega L}{c}\right)\cos\left(\frac{\omega L}{c}\right)\right]$$

$$Z_{x,diff} = \frac{c}{\omega}\frac{1}{x}\frac{\partial Z'_{\parallel}}{\partial x} = \mathbf{Z_{diff}} g_{\perp}^2 \frac{c}{\omega b^2}\left[\sin^2\left(\frac{\omega L}{c}\right) - \sin\left(\frac{\omega L}{c}\right)\cos\left(\frac{\omega L}{c}\right)\right]$$

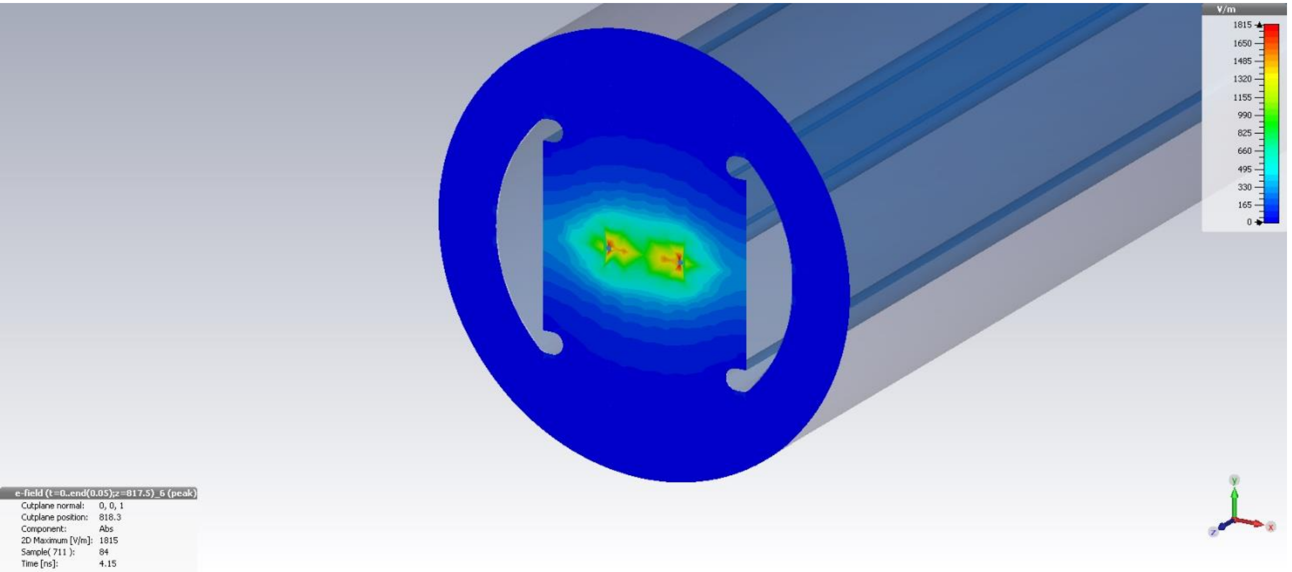
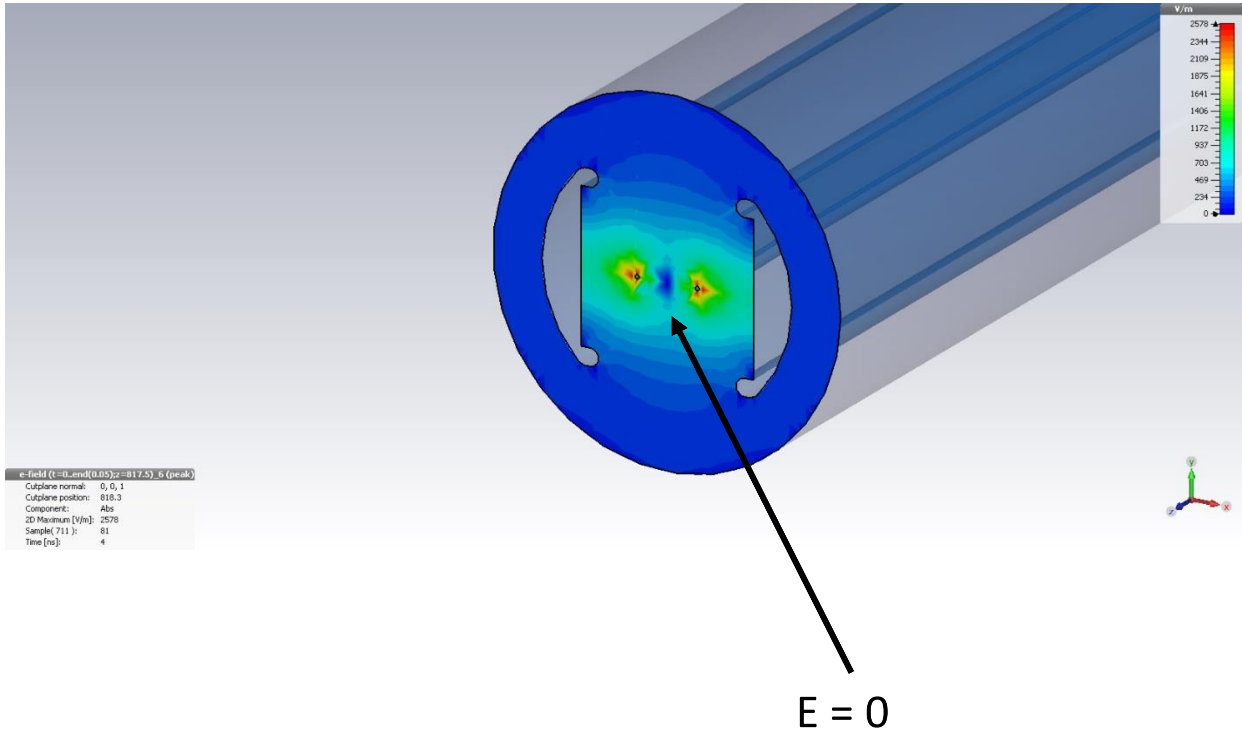
- As for the longitudinal case, the dipolar component of the horizontal impedance can be simulated with CST PS, and measured (and simulated) with the two wires method:



$$Z_{x,dip} = \frac{cZ_{\parallel}}{\omega \Delta^2}$$

2. Disagreement in Transverse Beam Coupling Impedance

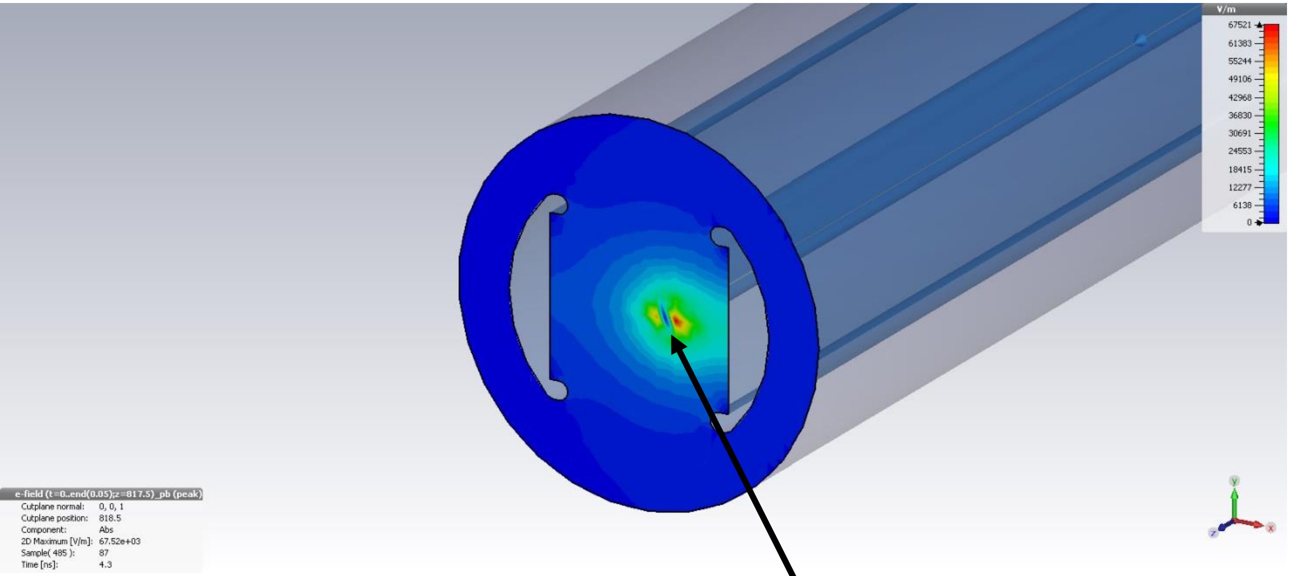
DIPOLAR HORIZONTAL BEAM COUPLING IMPEDANCE

TWO WIRES: DIFFERENTIAL (ODD) MODE	TWO WIRES: COMMON (EVEN) MODE
	

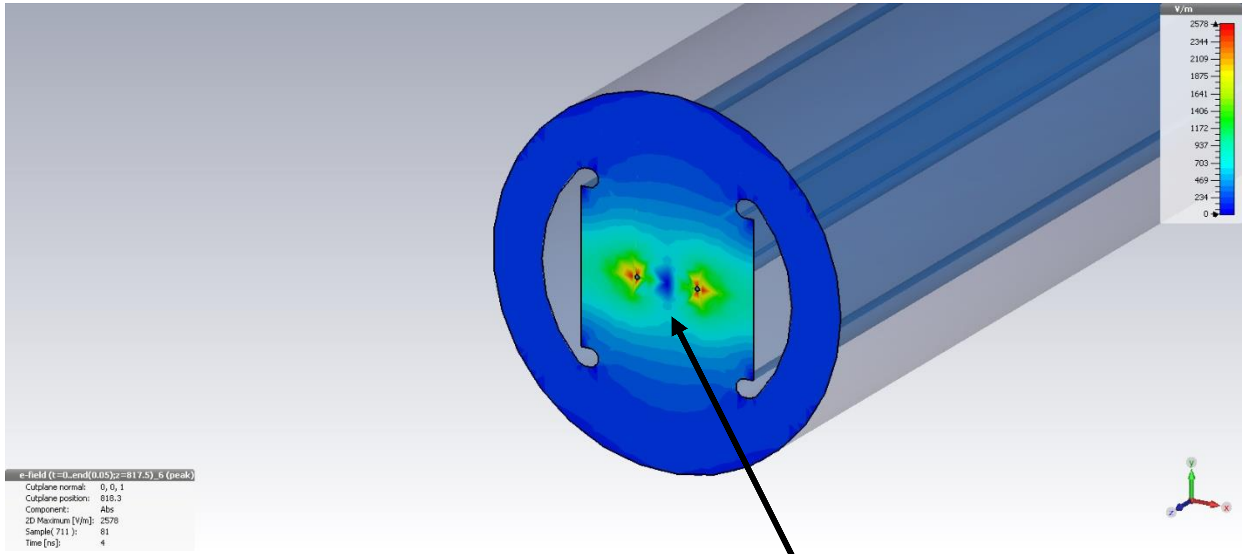
DIPOLAR HORIZONTAL BEAM COUPLING IMPEDANCE

OFF-CENTRED BEAM

TWO WIRES: COMMON (EVEN) MODE



E = 0



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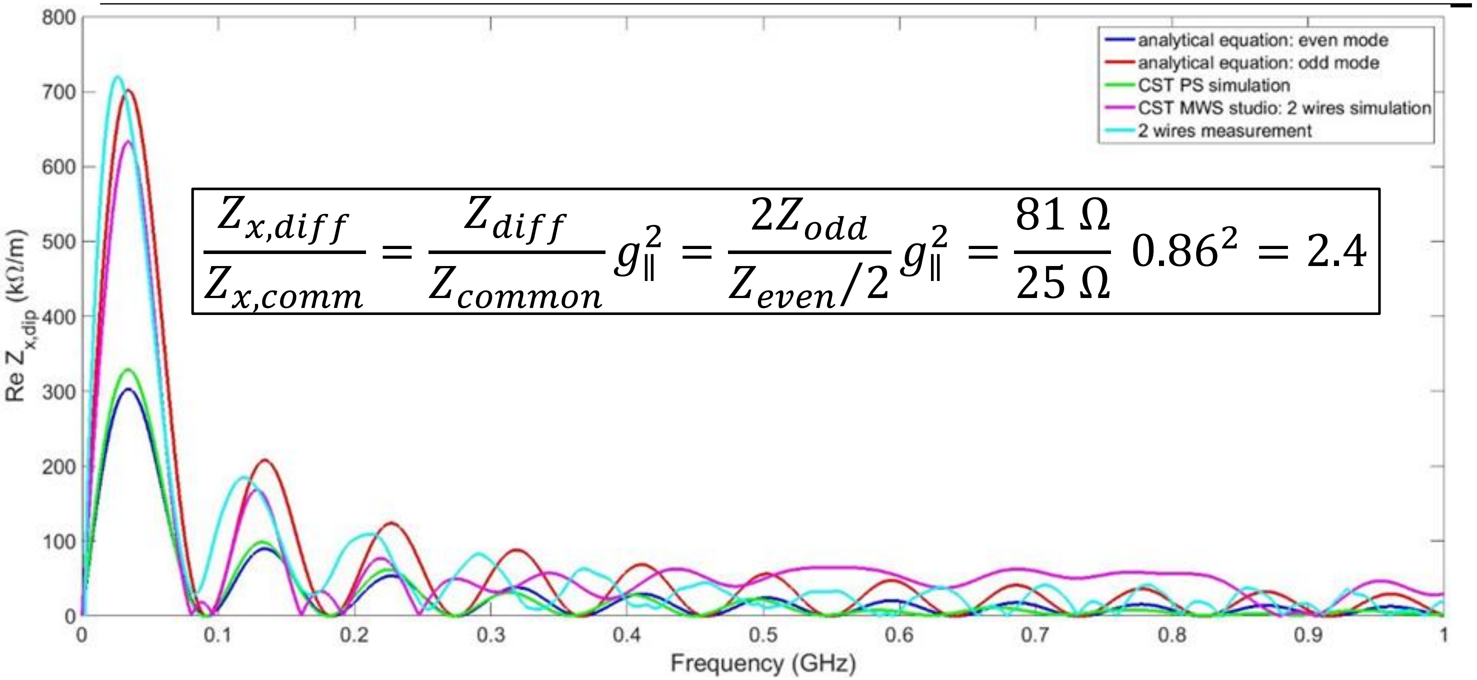
DIPOLAR HORIZONTAL BEAM COUPLING IMPEDANCE



$$\frac{Z_{x,diff}}{Z_{x,comm}} = \frac{Z_{diff}}{Z_{common}} g_{\parallel}^2 = \frac{2Z_{odd}}{Z_{even}/2} g_{\parallel}^2 = \frac{81\ \Omega}{25\ \Omega}\ 0.86^2 = 2.4$$

- CST PS simulation agrees well with the analytical equation in the even mode: the image currents created by the beam excites this TEM mode.
- Measurements agrees well with CST MWS simulation and the analytical equation in the odd mode: the two wires inside the striplines excites this TEM mode.
- We expect a value around 300 kΩ/m: it will be confirmed (hopefully) by the beam measurements in ALBA.

3. Planning of Measurements in ALBA

1) Measurements without HV DC power supplies: **Beam coupling impedance**

- The stripline assembly, together with the absorber, could have an impact on the ring impedance.
  - ❑ Measuring the beam impedance of the total ring before and after the installation of the striplines.
  - ❑ Single bunch measurements as a function of beam current.
- Following impedance measurements of the striplines, they will be replaced by a beam pipe and measurements remade: this will allow the influence of the absorber to be assessed.
- The power dissipation due to the wakefields has been calculated to be 40 W; from these only 6 W will stay in the electrodes, whereas 34 W will be dissipated through the 50 Ω loads.
  - ✓ Note: A maximum dissipated power lost of 10 W, in each electrode, has been estimated to keep the temperature below 80 degrees.

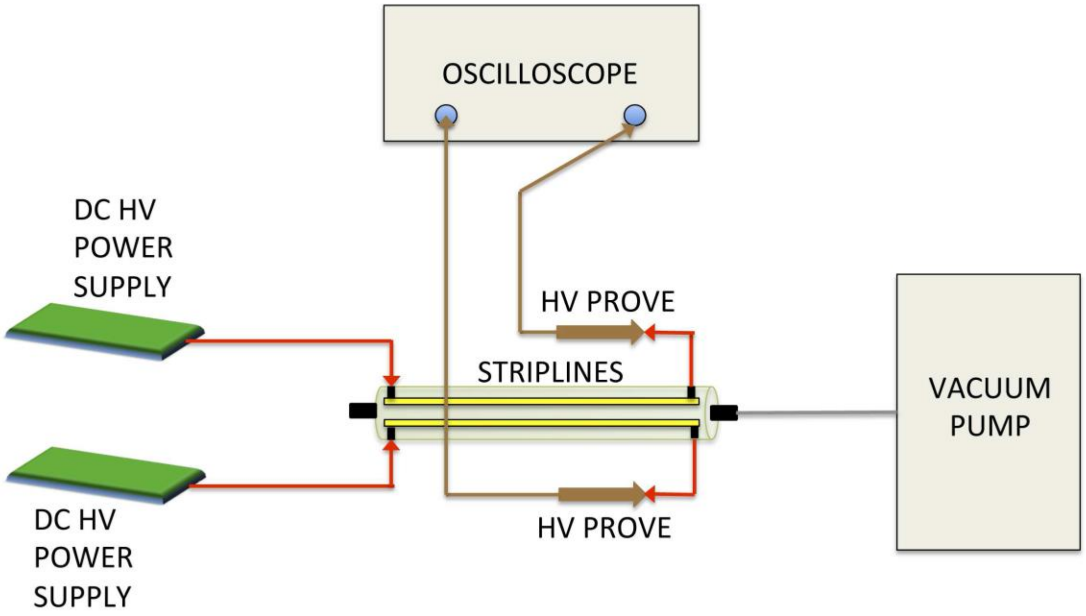
3. Planning of Measurements in ALBA

2) Measurements with the HV DC power supplies: **Transverse field homogeneity**

- The electrodes will be powered by DC HV power supplies and will not be resistively terminated.
  - ➢ Powering the electrodes with DC voltage does not result in higher field inhomogeneity.
    - ❑ Only electrostatic field will be used to deflect the beam (the striplines will be open-circuited).
    - ❑ One issue that could appear when the terminations are not present is that the 40 W would be entirely dissipated on the electrodes.

2) <u>Measurements with the HV DC power supplies</u>: **Transverse field homogeneity**

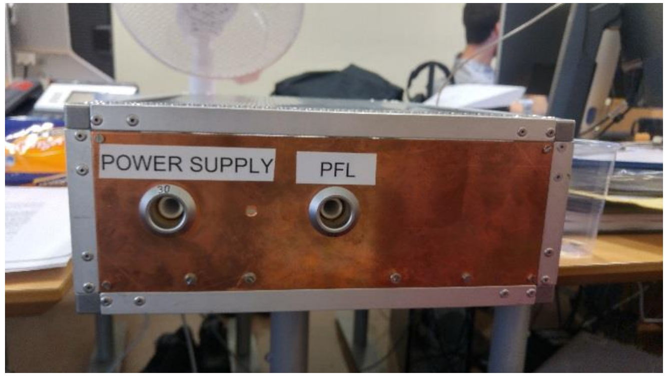
- In previous measurements at CERN, the highest DC voltage that was safely applied to the striplines was ±10.8 kV (nominal pulsed voltage = ±12.5 kV).
  - ✓ The HV DC power supply with negative polarity failed at -10.8 kV, and we could not test the DC breakdown above this value.
  - ✓ Influence of the beam on breakdown voltage is unknown.

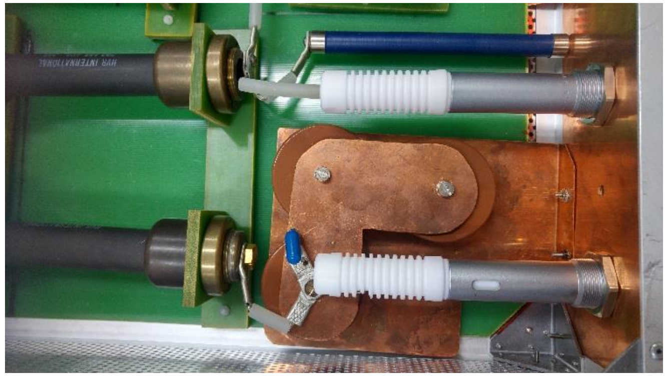


3. Planning of Measurements in ALBA

2) Measurements with the HV DC power supplies: **Transverse field homogeneity**.

- Two FUG power supplies have been bought by ALBA.
- A voltage of 45 V to 60 V will be delivered to the FUG power supplies due to the image currents flowing through the electrodes, when a beam of 150 mA is circulating through the striplines [calculations done by ALBA].
  - ➢ A low-pass filter could be used to protect the FUG power supplies (presently being studied).





  - ➢ Another solution could be to create a closed loop where the image currents can circulate, and the 45 – 60 V will not be delivered to the power supplies (presently being studied).

3. Planning of Measurements in ALBA

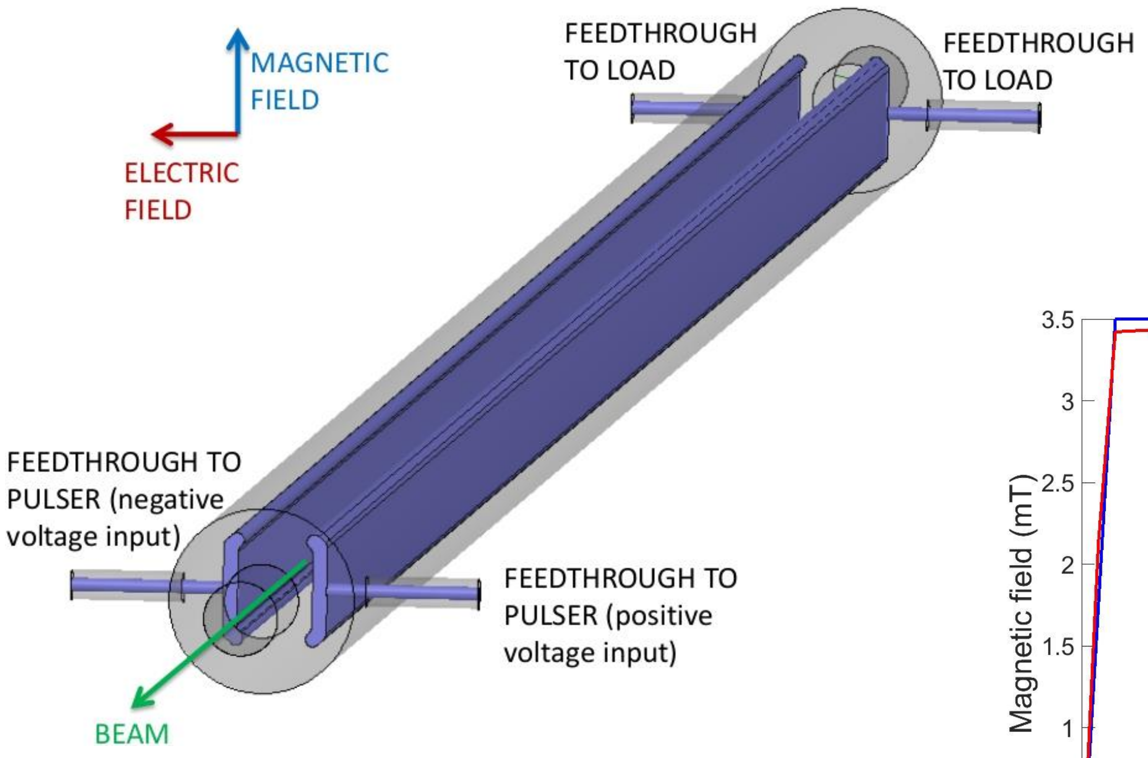
3) Measurements with the Inductive Adder: **Field flat-top stability, pulse-pulse repeatability, longitudinal field homogeneity**.

- Two inductive adders (J. Holma's presentation) are expected to be supplied by CERN to ALBA at the end of 2017.

- There is some concern about the radiation next to the beam line and its potential influence upon the MOSFETS of the inductive adders.
  - ❑ The inductive adder could be placed in another area and connected to the striplines by using 10 – 15 m long cables.

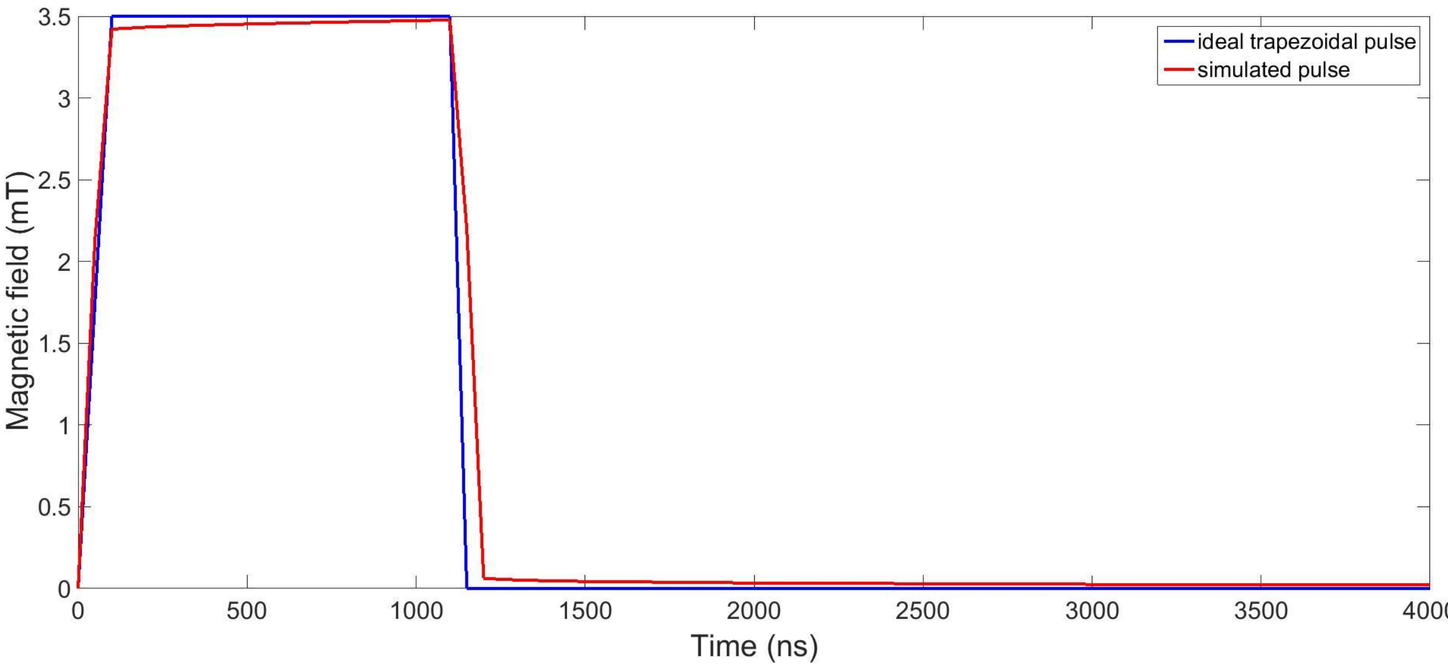
- Transient studies of the magnetic field pulse have been completed (see next slides). The result of these studies have changed the pulse "flat-top" requirements, which will be considered before installing the inductive adders in ALBA.

4. Transient Studies of the Striplines



Deflection angle of the extracted beam

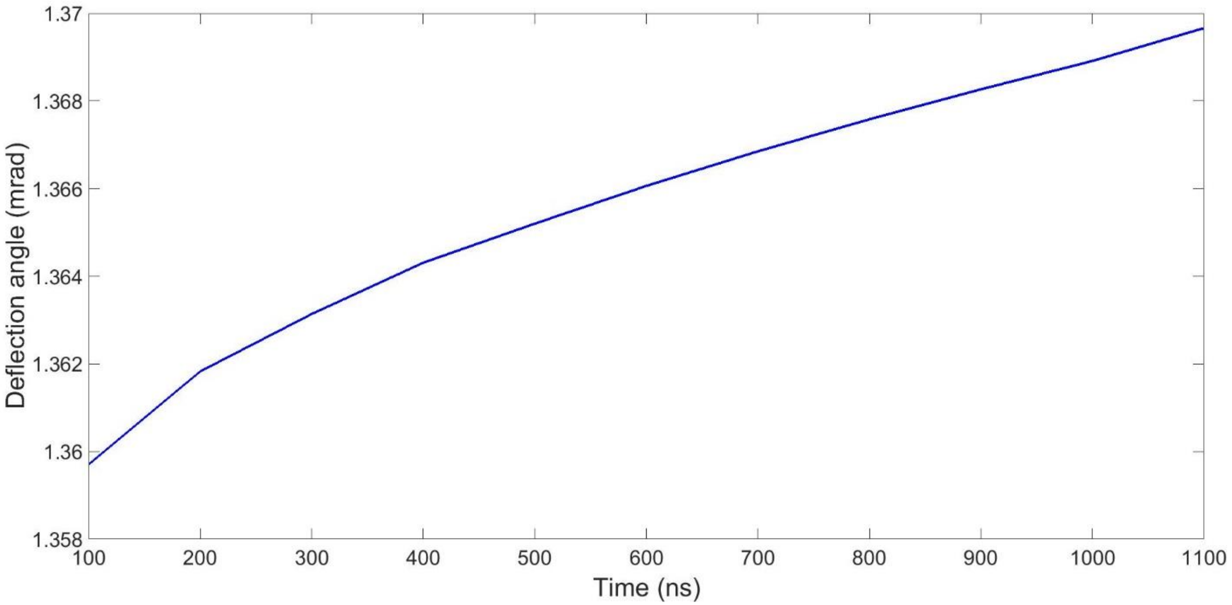
$$v \approx c \rightarrow \alpha_{tot} = \alpha_E + \alpha_B = 2\alpha_E$$



When exciting the striplines with a trapezoidal current pulse, the magnetic field changes during the flat-top of the pulse.

4. Transient Studies of the Striplines

- The total deflection angle corresponds to both the electrostatic and the magnetic field contribution to the deflection angle.

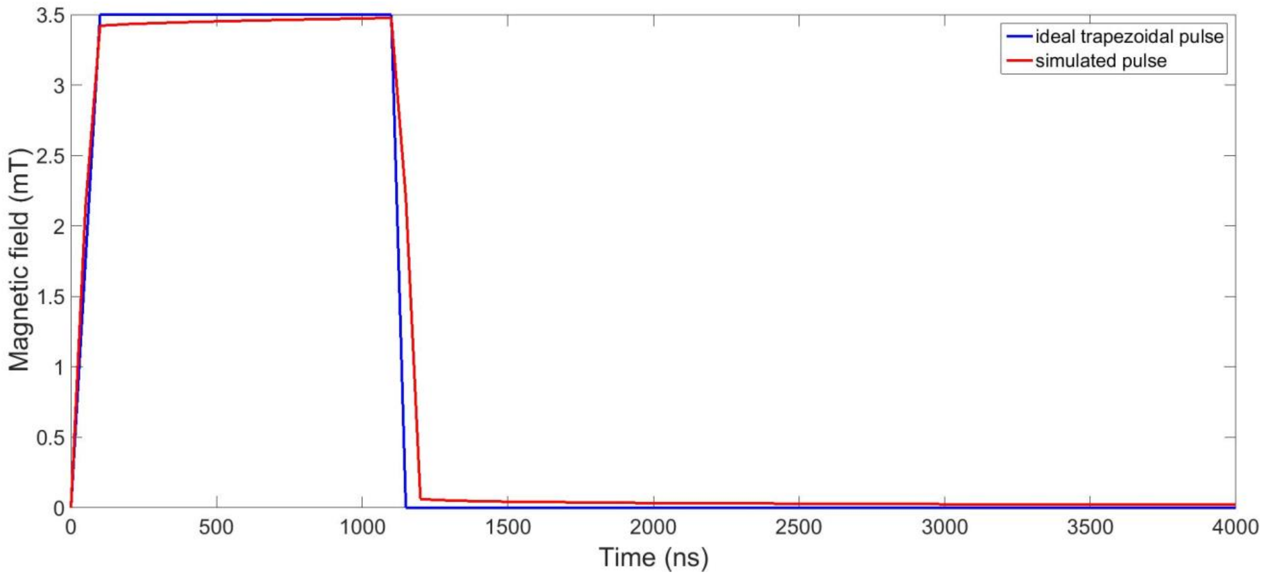


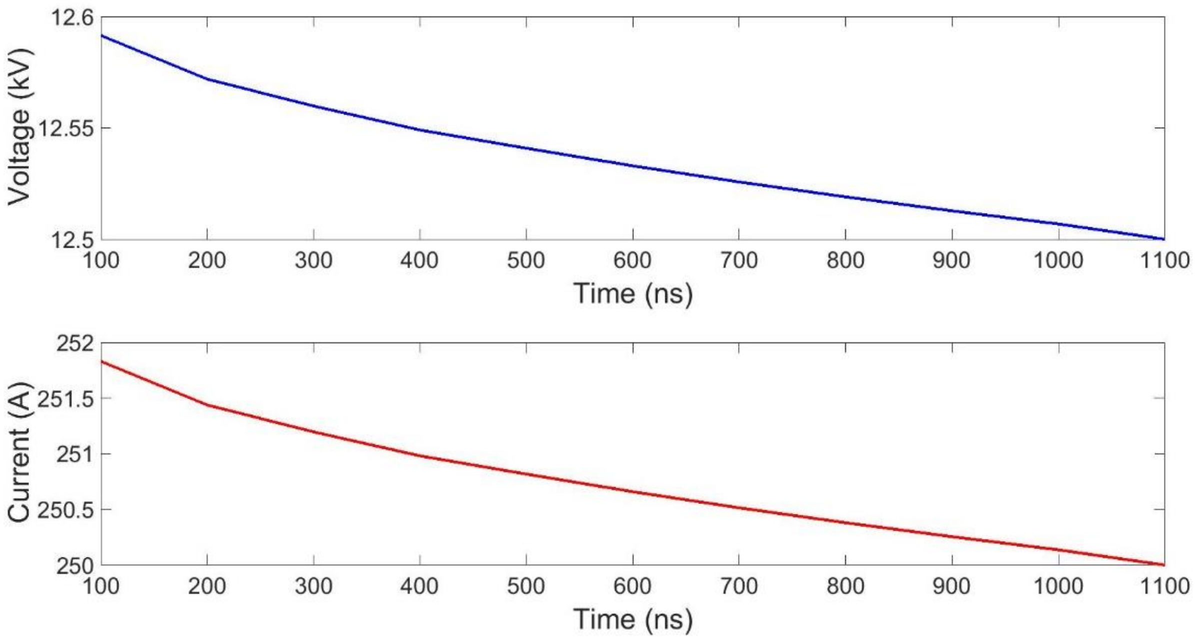
The total deflection angle increases from 1.3597 mrad to 1.3697 mrad, which corresponds to an increase of 0.73%. In addition, the deflection angle is less than the required 1.5 mrad (±12.5 kV, ±250 A, terminated at 50 Ω).

- The variation of the magnetic field, and therefore the total field during the pulse flat-top, can be theoretically compensated by **modulating the electrodes current/voltage** during the flat-top of the pulse.
- An **"ideal" waveform** has been calculated by considering the total compensation required, to achieve a flat deflection pulse.

4. Transient Studies of the Striplines

- The modulation corresponds to a modulation of the output voltage/current of the power supply, for an ideal **50 Ω termination**.

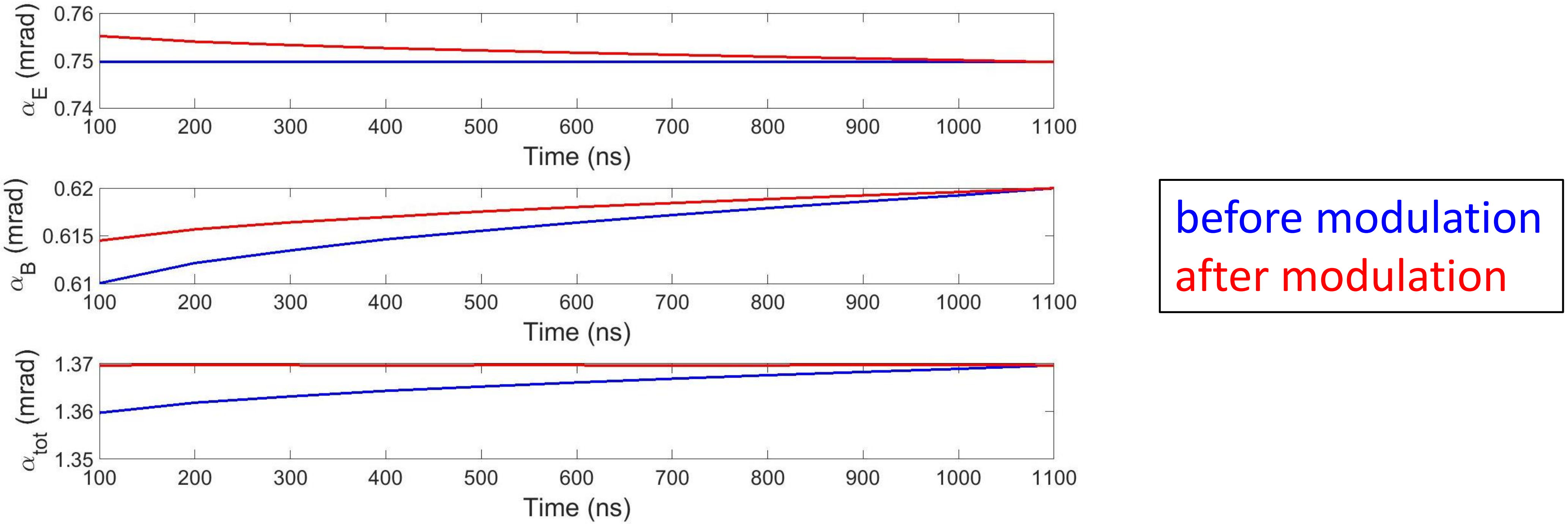




- The modulated voltage/current pulse has been specified as the flat-top of the driving waveforms in Opera2D electrostatic and transient magnetic analyses to predict the deflection angle.

4. Transient Studies of the Striplines

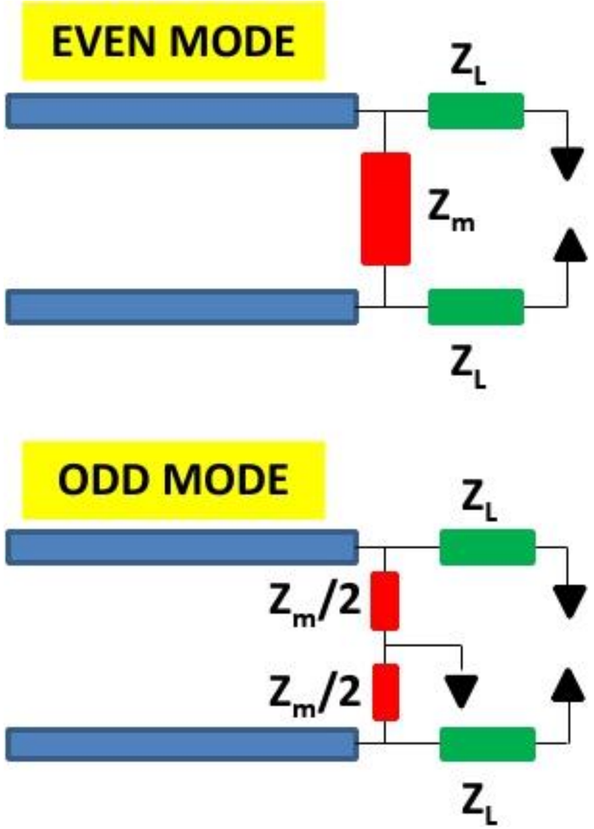
- After modulation, the increase of the deflection angle during the flat-top is reduced by more than a factor 100: from 0.73% to 0.006%.

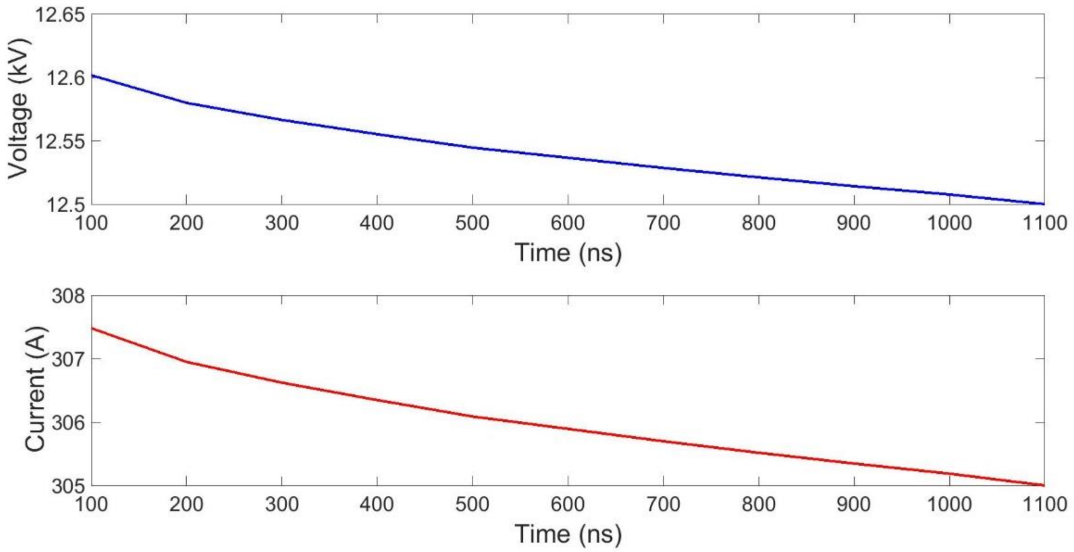


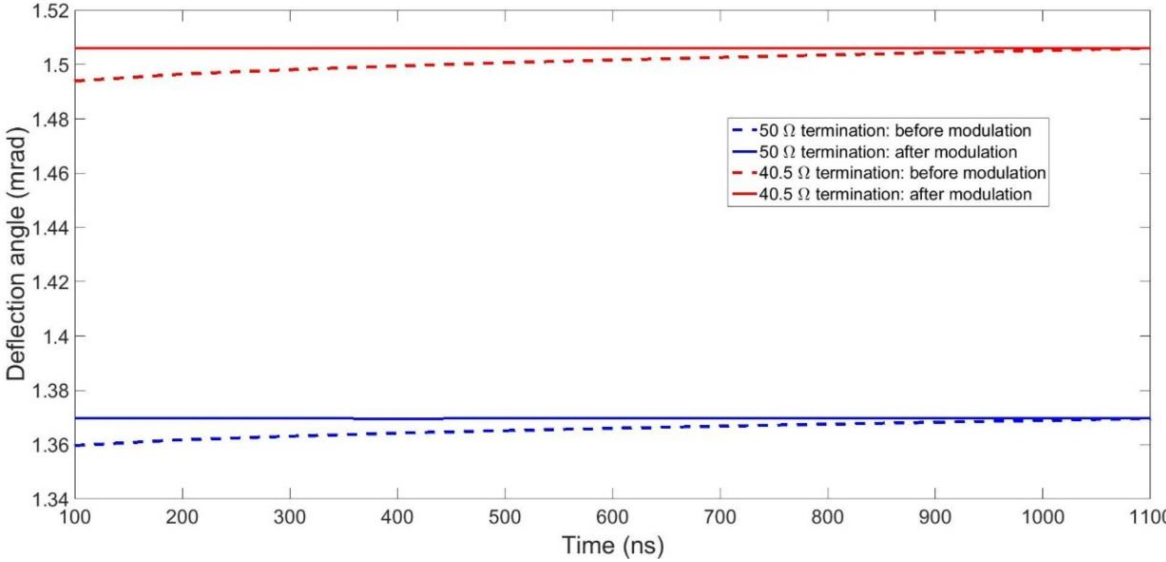
- The deflection angle is less than the required 1.5 mrad. The reason is the mismatching of the odd mode characteristic impedance between the striplines (40.5 Ω) and the termination loads (50 Ω). The even mode characteristic impedance is still well matched to 50 Ω.

4. Transient Studies of the Deflection Angle

The ideal driving waveforms have also been defined when considering 40.5 Ω terminating resistors. The deflection angle, after the current and voltage pulse modulation, has been calculated.







4. Transient Studies of the Striplines

- With 50 Ω terminating resistors the total deflection angle, in the present configuration (unmodulated waveform), increases during the 1 μs flat-top from 1.3597 mrad to 1.3697 mrad, which corresponds to an increase of 0.73%.
  - ❑ When modulating the pulse current, the predicted deflection angle increases from 1.3696 mrad to 1.3697 mrad, corresponding to an increase of only 0.006%: however, the total deflection angle is still 8.7% less than the required 1.5 mrad.
- Considering 40.5 Ω termination resistors and modulating the pulse current, the flat-top deflection angle increases from 1.506 mrad by only 0.0001%.
  - ❑ The deflection angle of 1.5 mrad is as required for the extraction kicker from the CLIC DRs.
- The pulse modulation has been studied for pulse flat-top lengths from 500 ns to 1 μs with the same results for the modulated waveform.
  - ❑ A length of flat-top less than 900 ns is necessary, since the revolution time in the ALBA Storage Ring is 896 ns.

5. Conclusions

- Disagreements between analytical approximations, simulations and measurements of the dipolar component of the horizontal beam coupling impedance are (hopefully) now well understood.

- Installation and conditioning of the striplines in ALBA are being done: if successful, measurements will begin soon.
  - ❑ Measurements without powering the striplines.
  - ❑ Measurements with DC HV power supplies.
  - ❑ Measurements with the inductive adder.

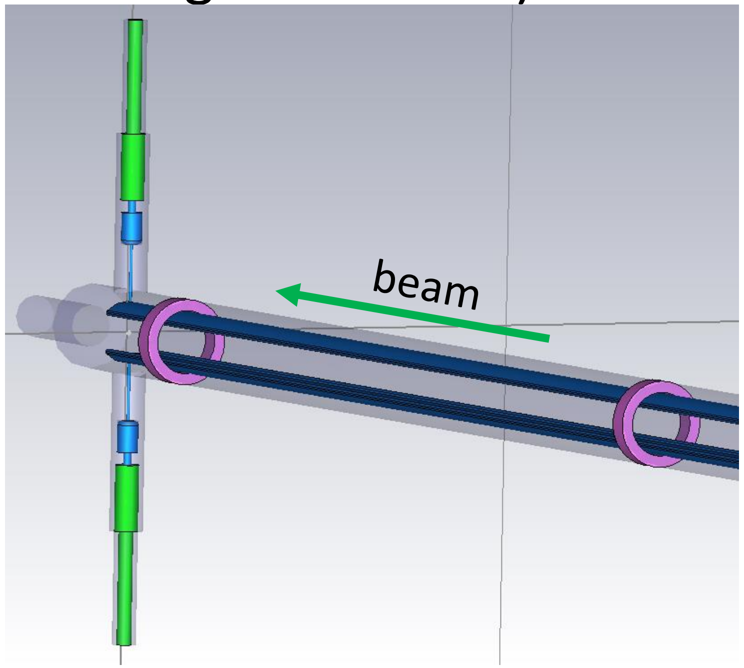
- Several studies are presently being done to protect the power supplies from the beam image currents.

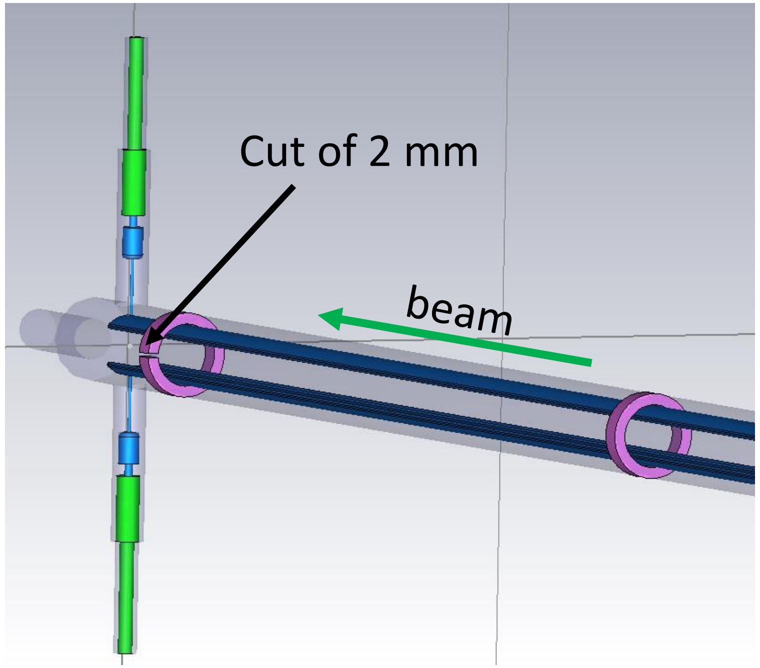
- Transient studies have been completed, which will be taken into account when powering the inductive adders in ALBA.

BACKUP SLIDES

3. Installation of the Striplines in ALBA

- Last week, the striplines have been installed, and a **second conditioning** has been done (Montse's talk). The first conditioning was done last January, and several issues were found: overheating (no loads) and high pressure due to SR in the Macor rings.
- If some problems concerning synchrotron radiation hitting the last Macor ring still arise, a proposal is being studied:
  - ❑ Open the last Macor ring seen by the beam (mechanical aspects of this solution are being considered).





- Reflection parameter in the odd mode ok.
- Reflection parameter in the even mode ok.
- Longitudinal beam coupling impedance ok.
- Transverse beam coupling impedance ok.