DESIGN AND TESTS OF EXTRACTION KICKER SYSTEM

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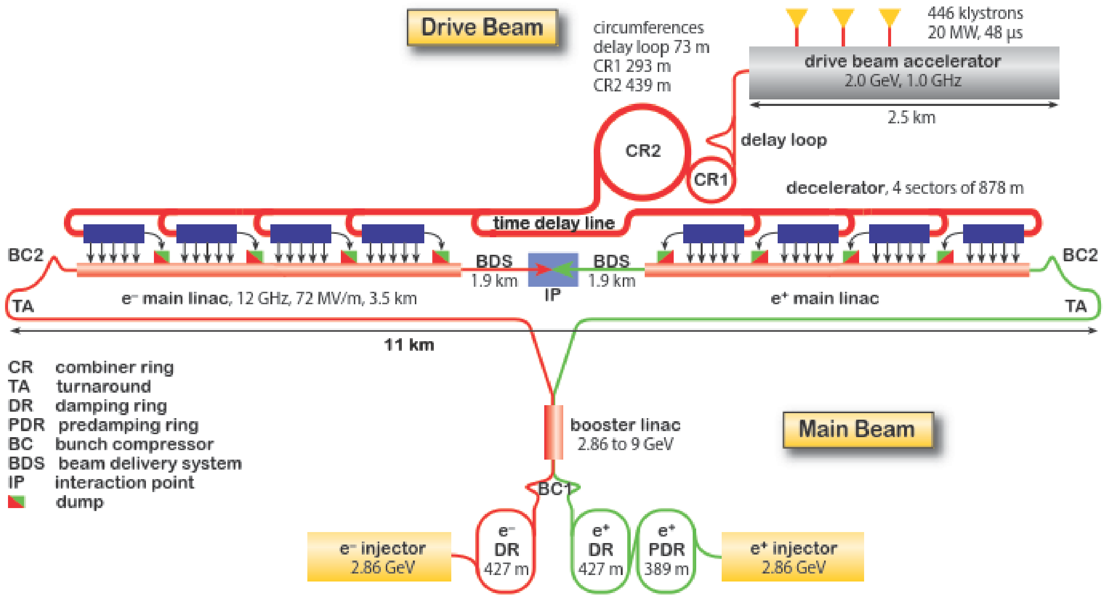
Acknowledgement to M. Pont and N. Ayala (ALBA)

CLIC = Compact Linear Collider.

- International collaboration working on a concept for a machine to collide electrons and positrons at energies up to 3 TeV.
- $\mathcal{L} = 10^{34} - 10^{35}$ cm^{-2}s^{-1}→ beam emittance reduction → PDRs and **DRs**.
  - Several injection and **extraction** systems.
- Acc. gradient = 100 MV/m achieved by:
  - using NC RF structures (f = 12 GHz).
  - **two-beam scheme**: drive beam is decelerated in PETS and the generated RF is used to accelerate the main beam.



Damping Rings

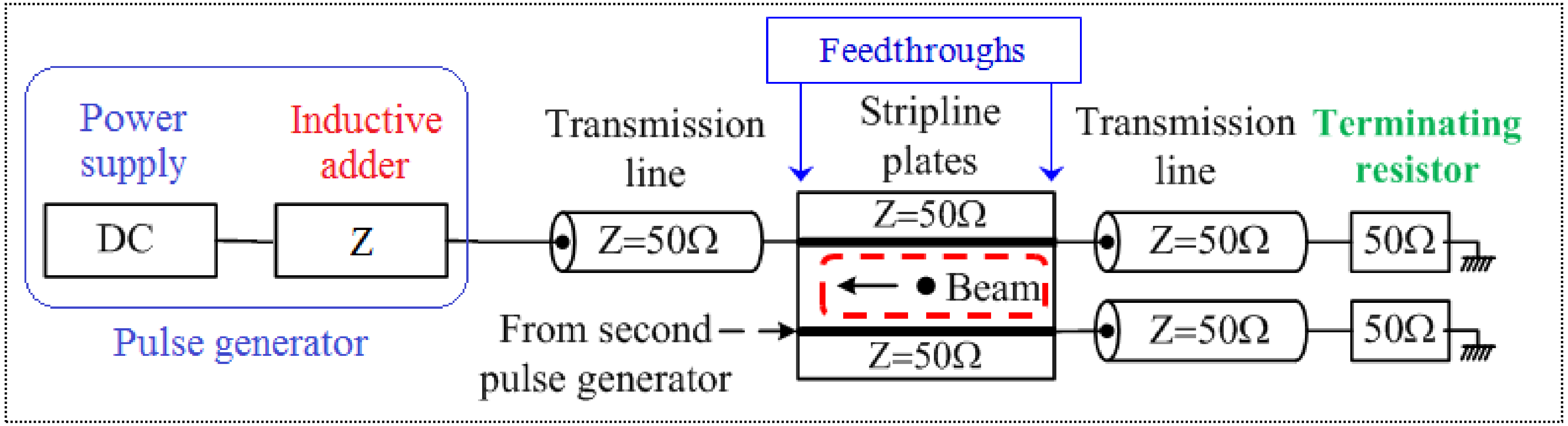
Ultra-low emittance with high bunch charge → beam dynamics and technical challenges.

Extracted normalized emittance = 500 nm (horizontal), 5 nm (vertical).

If decision to proceed in 2019 → construction could technically start in 2026, duration 6 years for 380 GeV (11 km Linac) → physics could start before 2035.

2. Extraction Kicker System for CLIC DRs

Previous studies demonstrated that the stripline kicker is the most suitable technology.



(Courtesy of J. Holma)

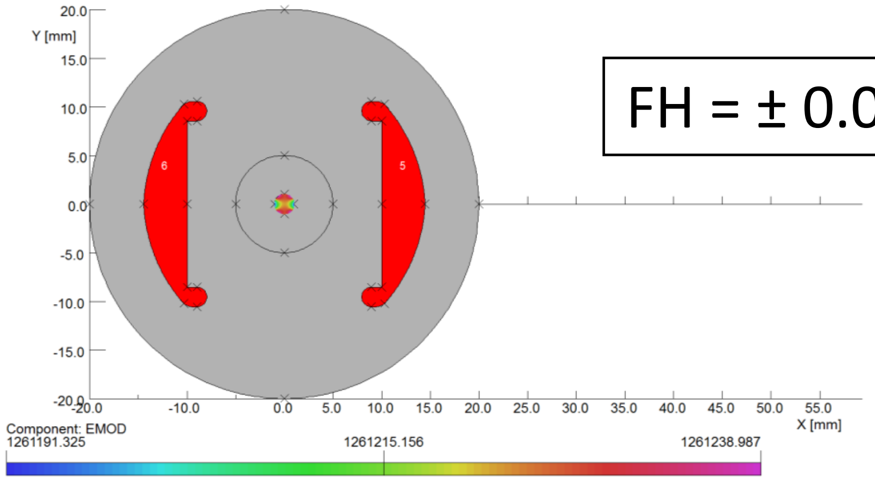
Striplines parameters	Values	Inductive adder parameters	Values
Beam energy	2.86 GeV	Pulse rise and fall time	100 ns
Deflection angle	1.5 mrad	Pulse flat-top	900 ns
Aperture	20 mm	Extraction stability	± 0.02%
Effective length	1.7 m	Repetition rate	50 Hz
Extraction inhomogeneity	± 0.01%		

2. Extraction Kicker System for CLIC DRs

Main Challenges

<u>Striplines</u>

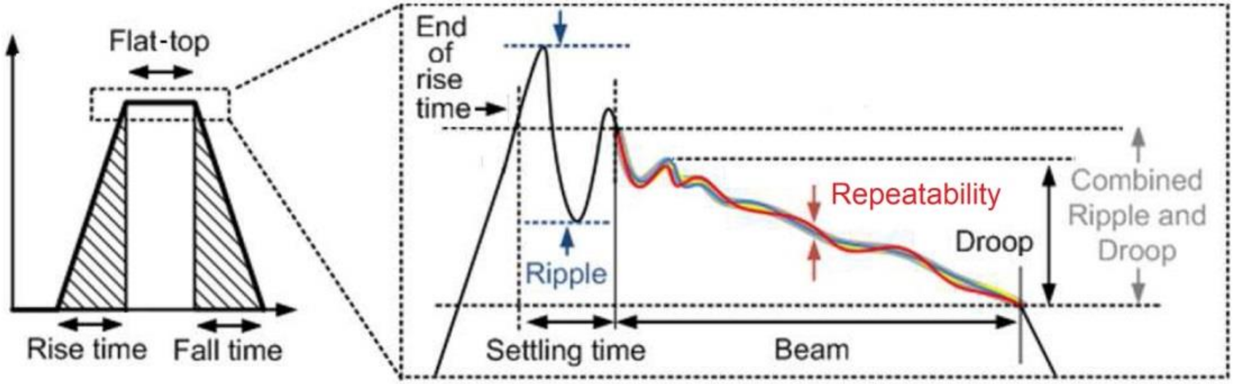
- Excellent **field homogeneity**: ± 0.01% over 1 mm radius.
- Very low reflections: S_{11} < 0.1 up to 10 MHz.
- Very low **beam coupling impedance**: 0.05 Ω/n in the longitudinal plane and 200 kΩ/m in the transverse plane.



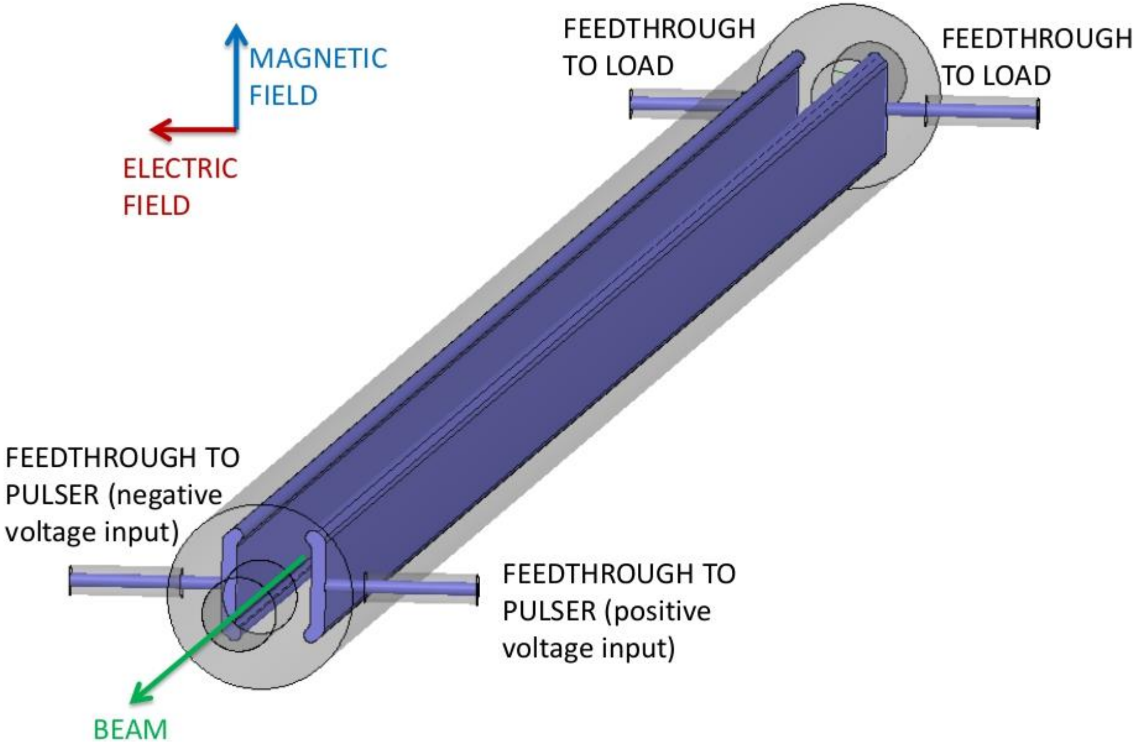
FH = ± 0.0018%

<u>Inductive Adder</u>

- Extremely tight requirements for flat-top stability and repeatability:
  - Flat-top repeatability: ± 0.01%
  - Flat-top stability: ± 0.02%
- Rise/fall times ≤ 100 ns desired.



Striplines: Operation Modes



- Stripline kickers operate as **two coupled transmission lines**.
- 2 TEM modes with two different characteristic impedances:
  - **Odd mode**: current flow in opposite directions.
  - **Even mode**: current flow in the same direction.
- For ultra-relativistic beams, and for a perfect impedance matching between both operation modes:

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

3. Stripline Technology

Design, fabrication, laboratory tests and further optimization of the prototype striplines for beam extraction from the CLIC DRs.

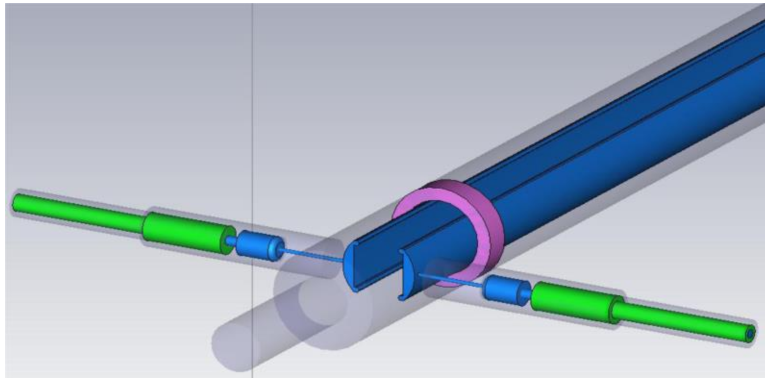
- ➢Methodology can be extended to striplines for any low emittance ring.

Design studies & fabrication (VP):

- Impedance matching
- Field homogeneity
- Power transmission
- Beam coupling impedance
- High order modes
- Electrode heating
- Manufacturing tolerances

Laboratory test and measurements:

- Power reflection
- Beam coupling impedance
- HV DC conditioning



Further optimization studies:

- New method for matching characteristic impedances
- Transient studies of the striplines
- Review of horizontal beam coupling impedance

3. Stripline Technology

Some pictures…

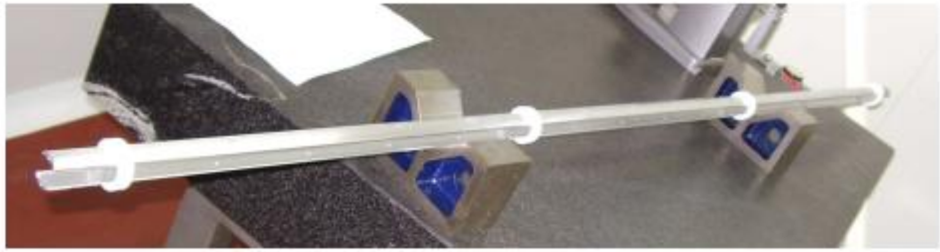


Figure 4.13: Picture of the electrodes assembled with the Macor rings, outside the beam pipe.

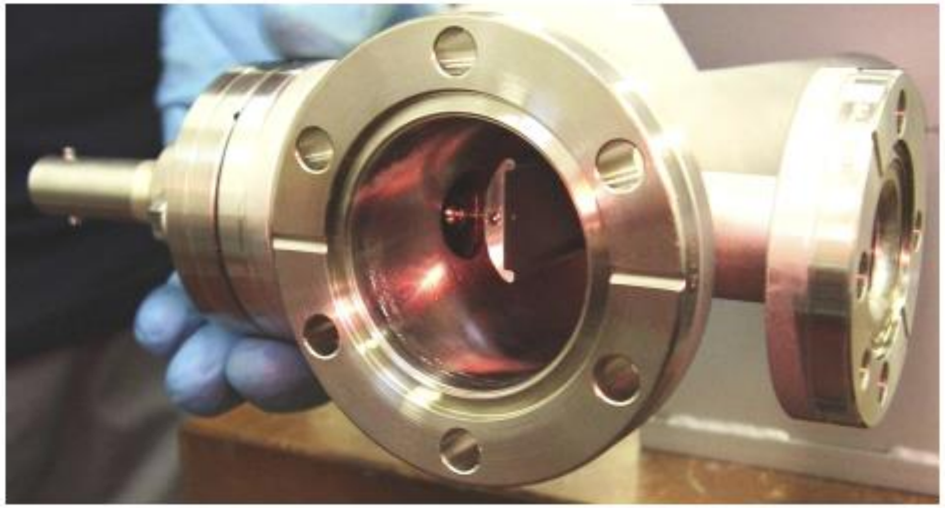
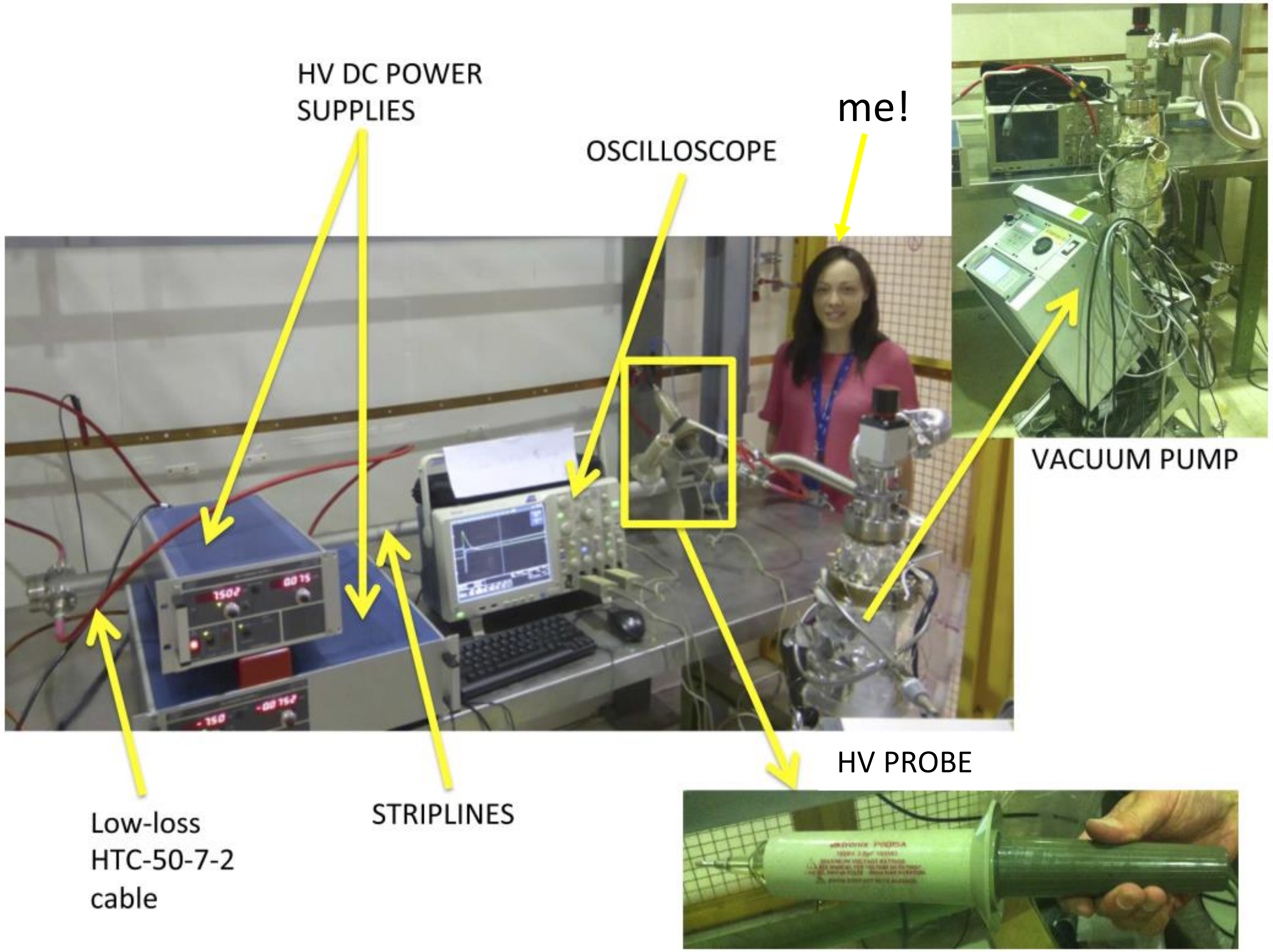


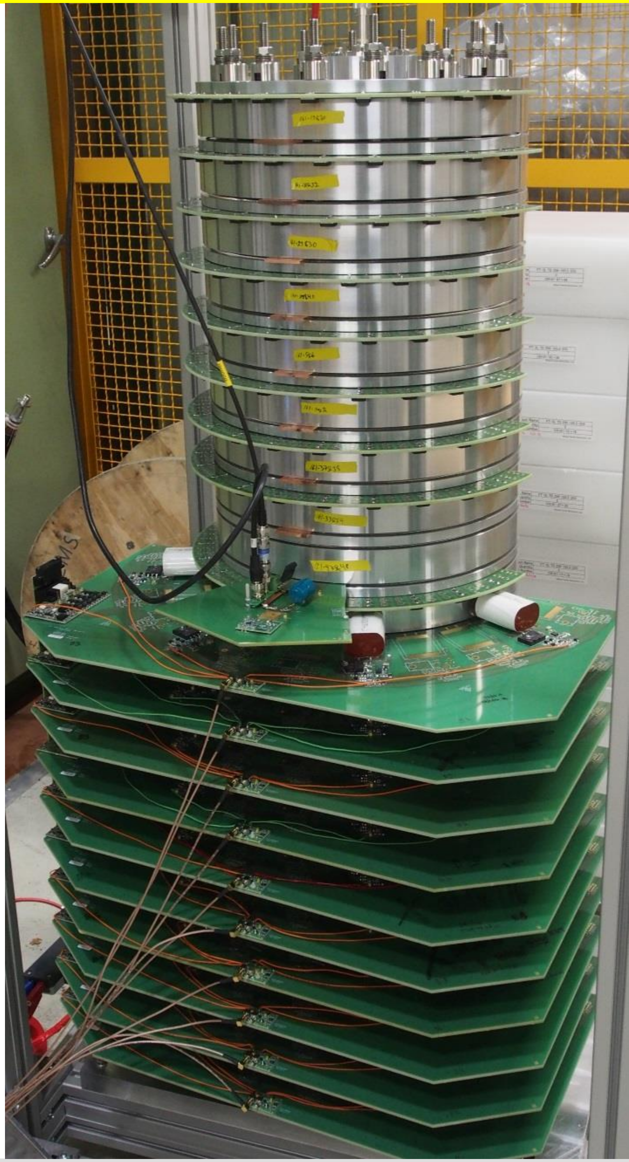
Figure 4.14: Picture of the electrodes, electrode connections and beam pipe flanges



4. Inductive Adder Technology (on behalf of J. Holma)

Status of CLIC DR Inductive Adders

- The first full-scale 20-layer, 12.5 kV, prototype inductive adder for CLIC DR extraction kicker system is currently under testing.
- The best measured flat-top/waveform stabilities until now:
  ±0.02 % over 900 ns for a flat-top pulse at 6.3 kV
  ±0.02 % over 160 ns for a "controlled decay waveform" at 6.3 kV.
- Next steps:
  - Measurements at nominal voltage 12.5 kV, with waveform stability to ±0.02 % over 900 ns.
  - Assembly and test of the 2nd full-scale, 20/28-layer, prototype: combined 12.5 kV/17.5 kV extraction kicker + dump kicker modulator.
  - Design of LabVIEW-based automated waveform correction control system.
  - Future measurements of two 12.5 kV inductive adders with a stripline kicker installed in a beamline in an accelerator test facility (e.g. at Alba in Spain, in 2018).



4. Inductive Adder Technology (on behalf of J. Holma)

Measurements on a Decay & Flat-top Waveforms

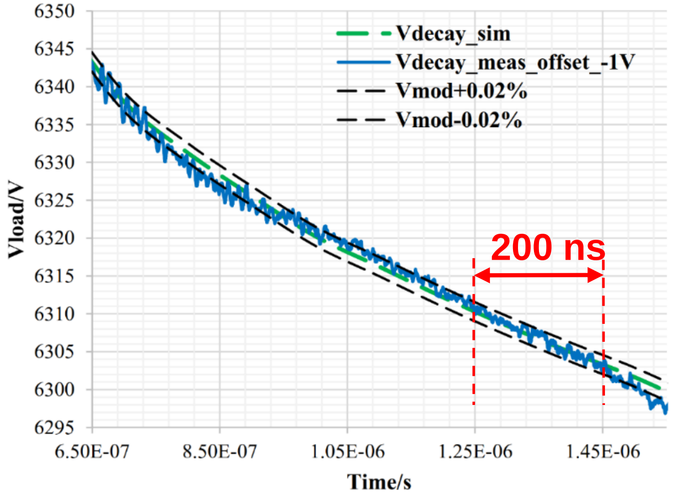
- Setup: 17 constant voltage layers +1 active analogue modulation layer
- Load voltage: 6.3 kV
- Load current: ~125 A (50 Ω load)
- **Decay waveform stability (top):**

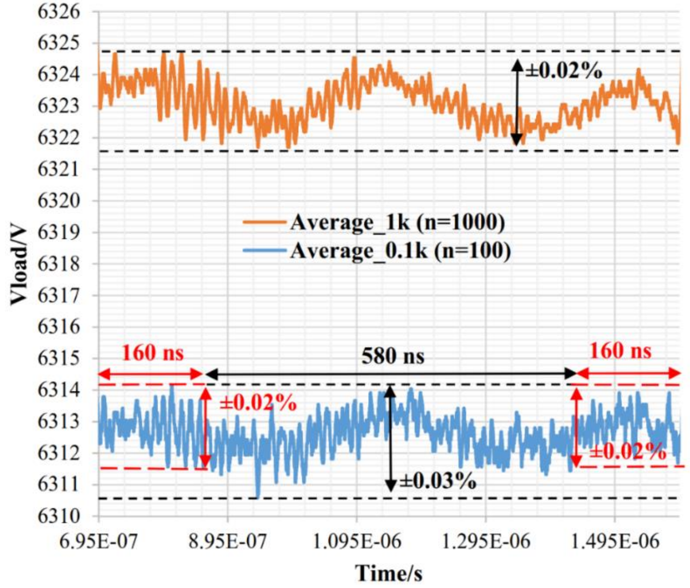
±0.02 % over 200 ns, ±0.05 % over 900 ns (160 ns required for CLIC DR 2 GHz baseline)

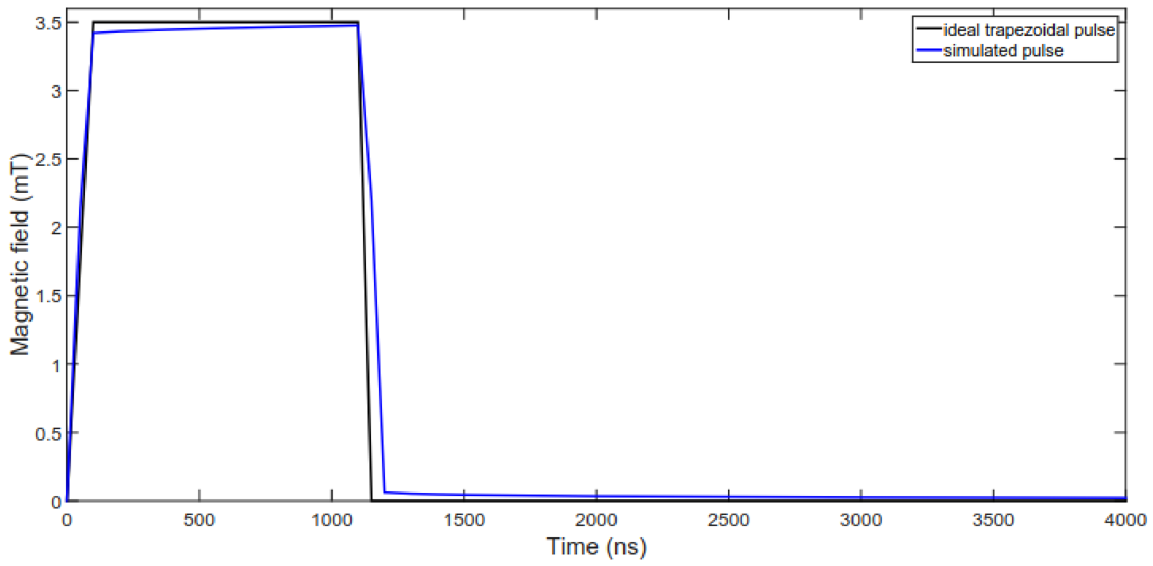
- **Flat-top pulse stability (bottom):**

±0.02 % over 900 ns (measured for an average of 1000 pulses, top curve)

- **The specifications for the inductive adders for the CLIC DR kicker systems are very probably feasible.**

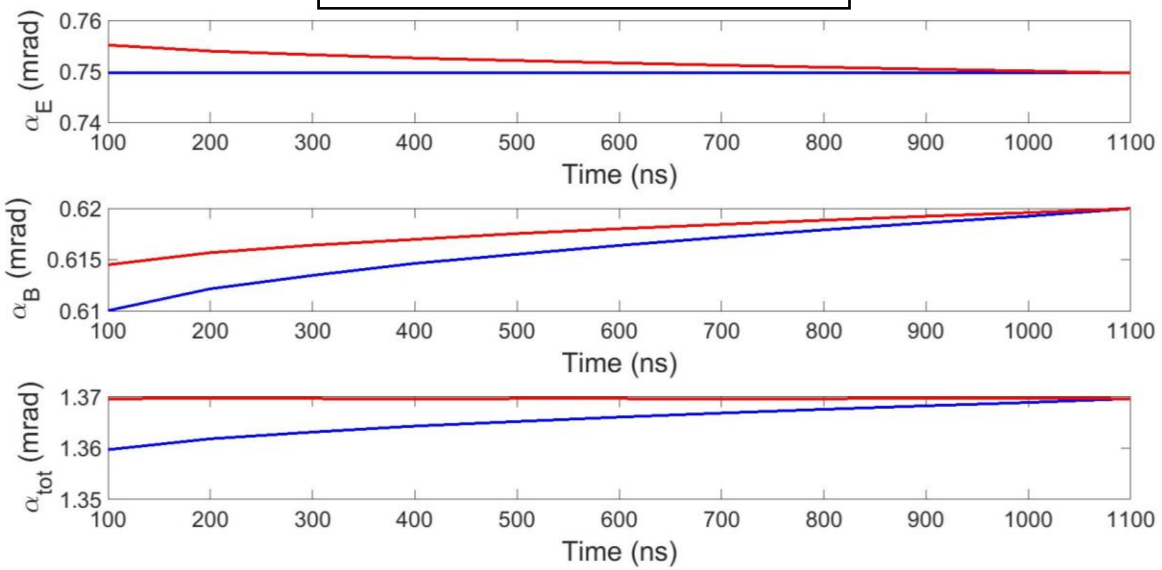






Stripline impedance is frequency dependent. Hence, magnetic field is not constant during the flat-top of a trapezoidal current pulse.

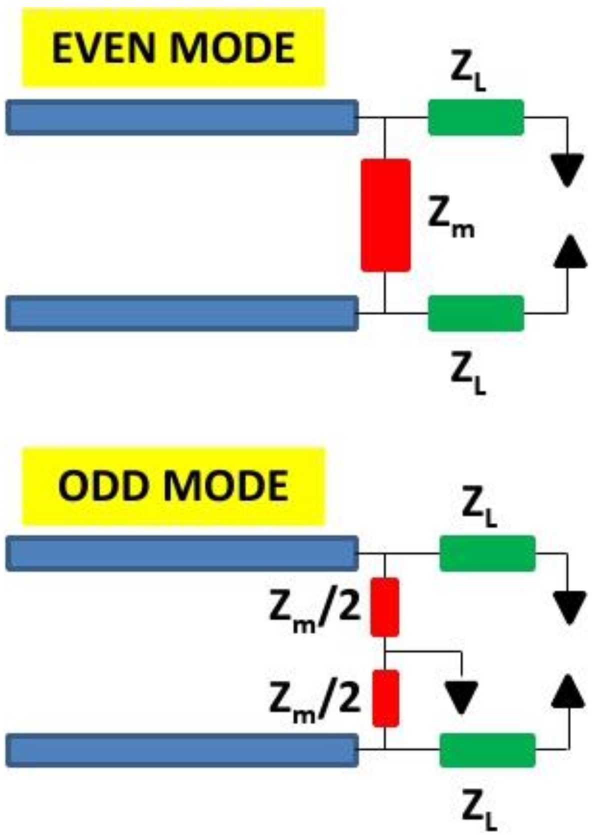
before modulation
after modulation



It will be compensated by **modulating** the electrodes **current/voltage** during the flat-top of the pulse.

- ➢ Modulation layer in the inductive adder

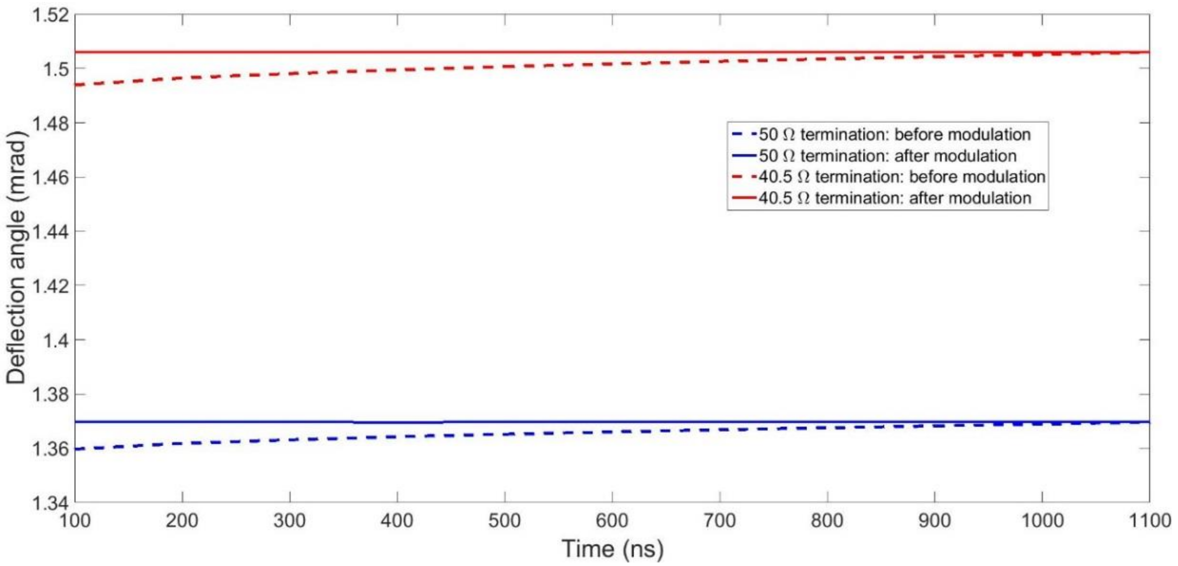
5. Transient Studies of the Striplines



<u>Proposal</u>: connect a matching resistor Z_m between the electrodes, on the load side of the striplines.

- Z_m does not affect the even mode signals
- In the odd mode, current flows through Z_m

$$\boxed{Z_m = 450\ \Omega}$$

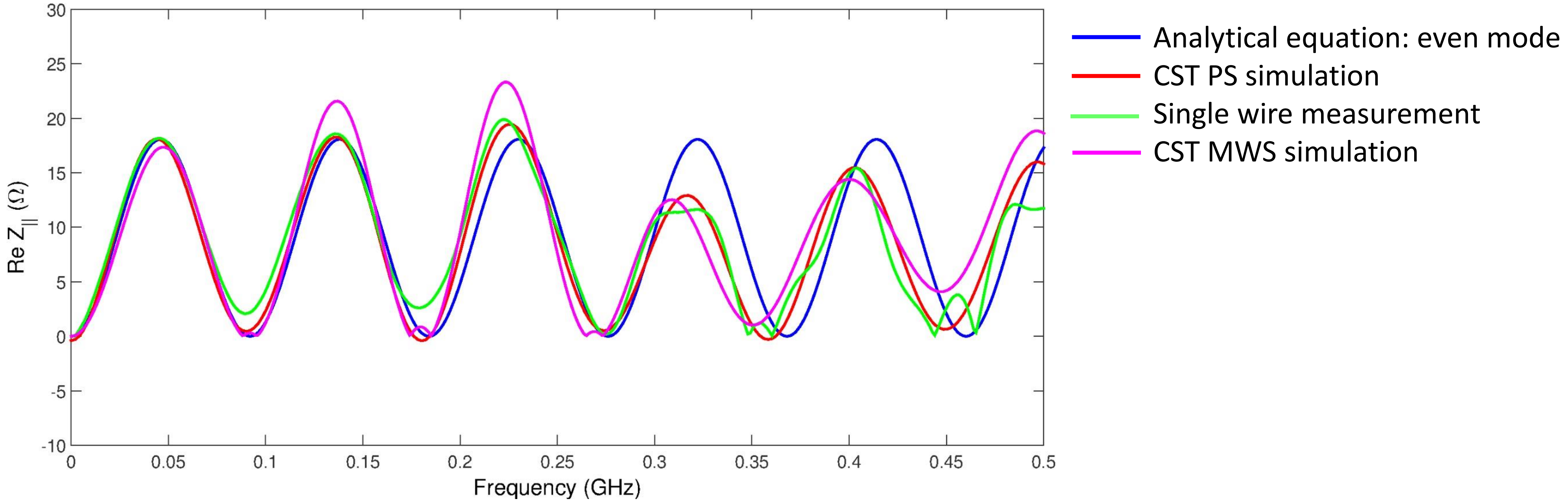


Thus both even and odd mode characteristic impedances of the striplines are matched.

Longitudinal beam coupling impedance

The longitudinal beam impedance has been studied analytically, numerically with CST PS and measured in laboratory with the single wires method.

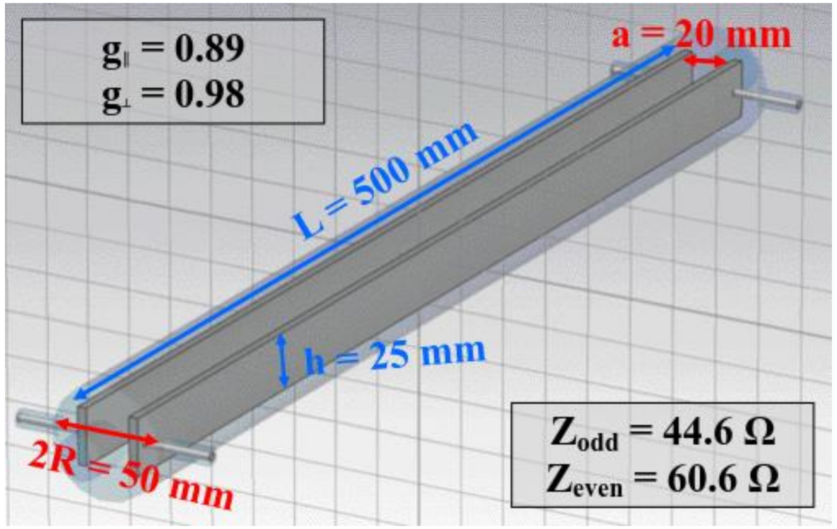
$$Z_{\parallel} = \boldsymbol{Z_c} g_{\parallel}{}^2 \left[\sin^2\left(\frac{\omega L}{c}\right) + j\sin\left(\frac{\omega L}{c}\right)\cos\left(\frac{\omega L}{c}\right)\right]$$



6. Review of the Beam Coupling Impedance

Horizontal beam coupling impedance

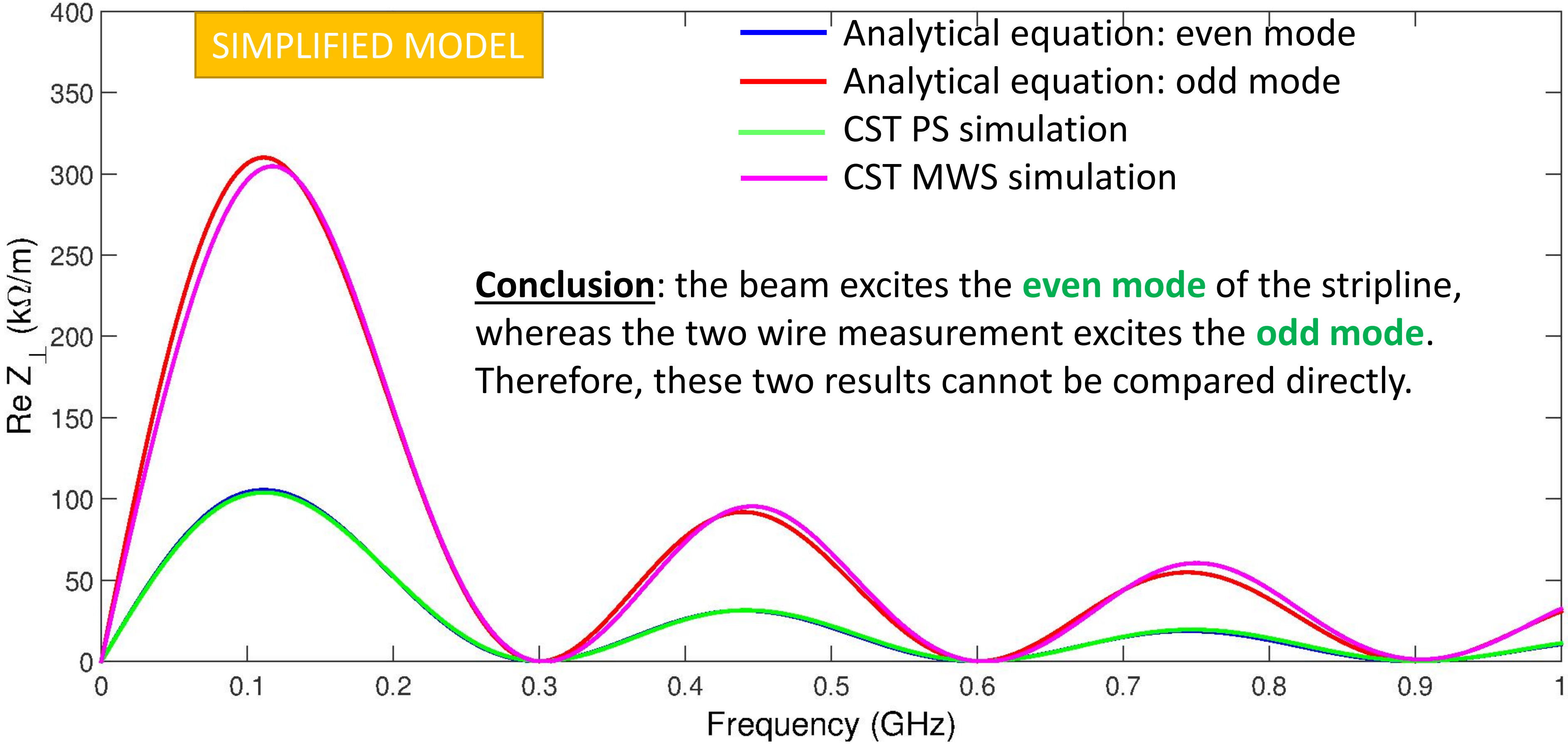
- The dipolar component of the horizontal beam coupling impedance has been studied analytically, numerically with CST PS and measured in laboratory with the two wires method.
  - ➢ Significant differences between the predicted horizontal impedance, beam simulation and the two wires measurement were found.



New approach: identify which stripline mode is excited when the beam passes through the centre of the aperture, and when two wires are inserted into the stripline aperture.

Horizontal beam coupling impedance

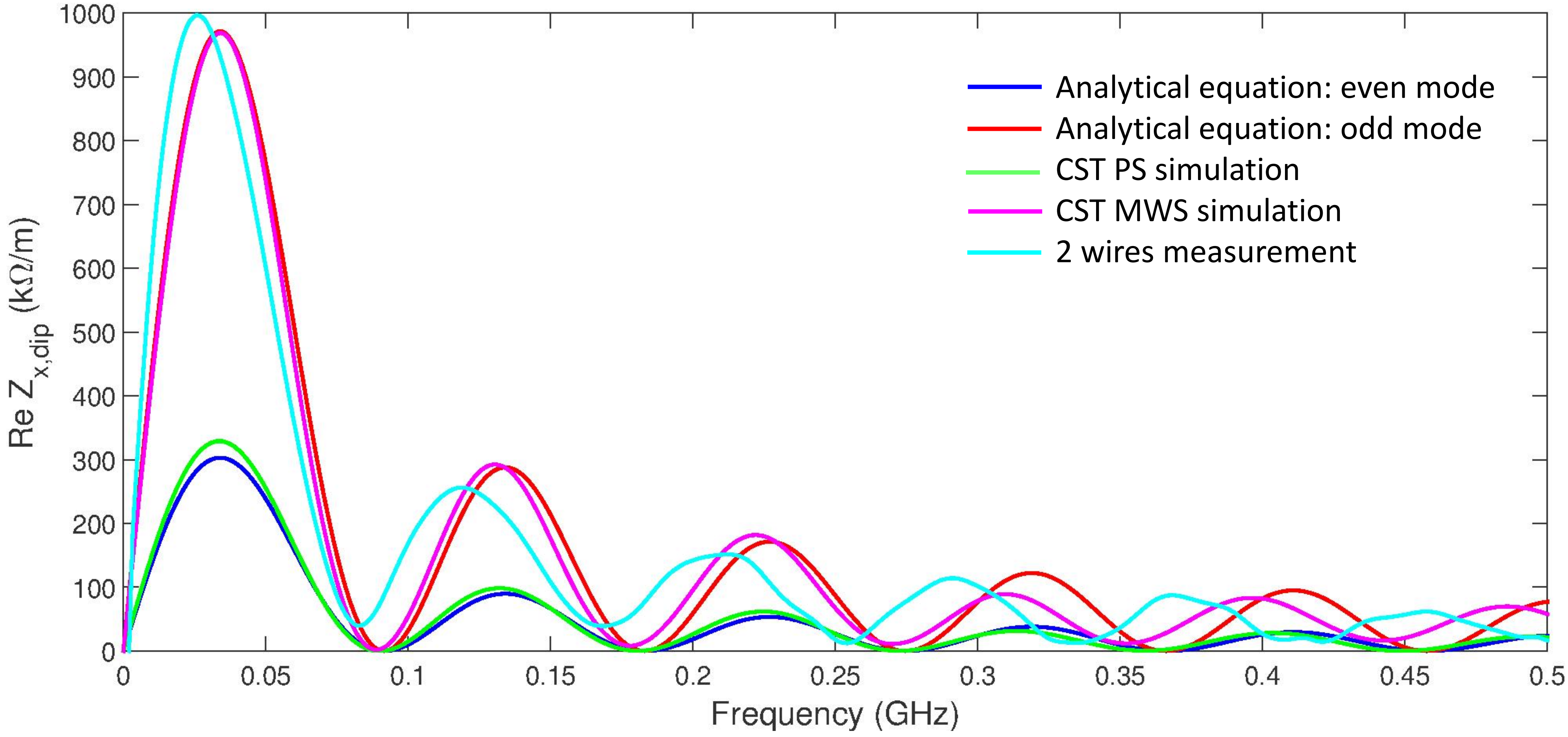
$$Z_{x,diff} = \frac{c}{\omega}\frac{1}{x}\frac{\partial Z_{\parallel}'}{\partial x} = \mathbf{Z_c} g_{\perp}^2 \frac{c}{\omega(a/2)^2}\left[\sin^2\left(\frac{\omega L}{c}\right) - \sin\left(\frac{\omega L}{c}\right)\cos\left(\frac{\omega L}{c}\right)\right]$$



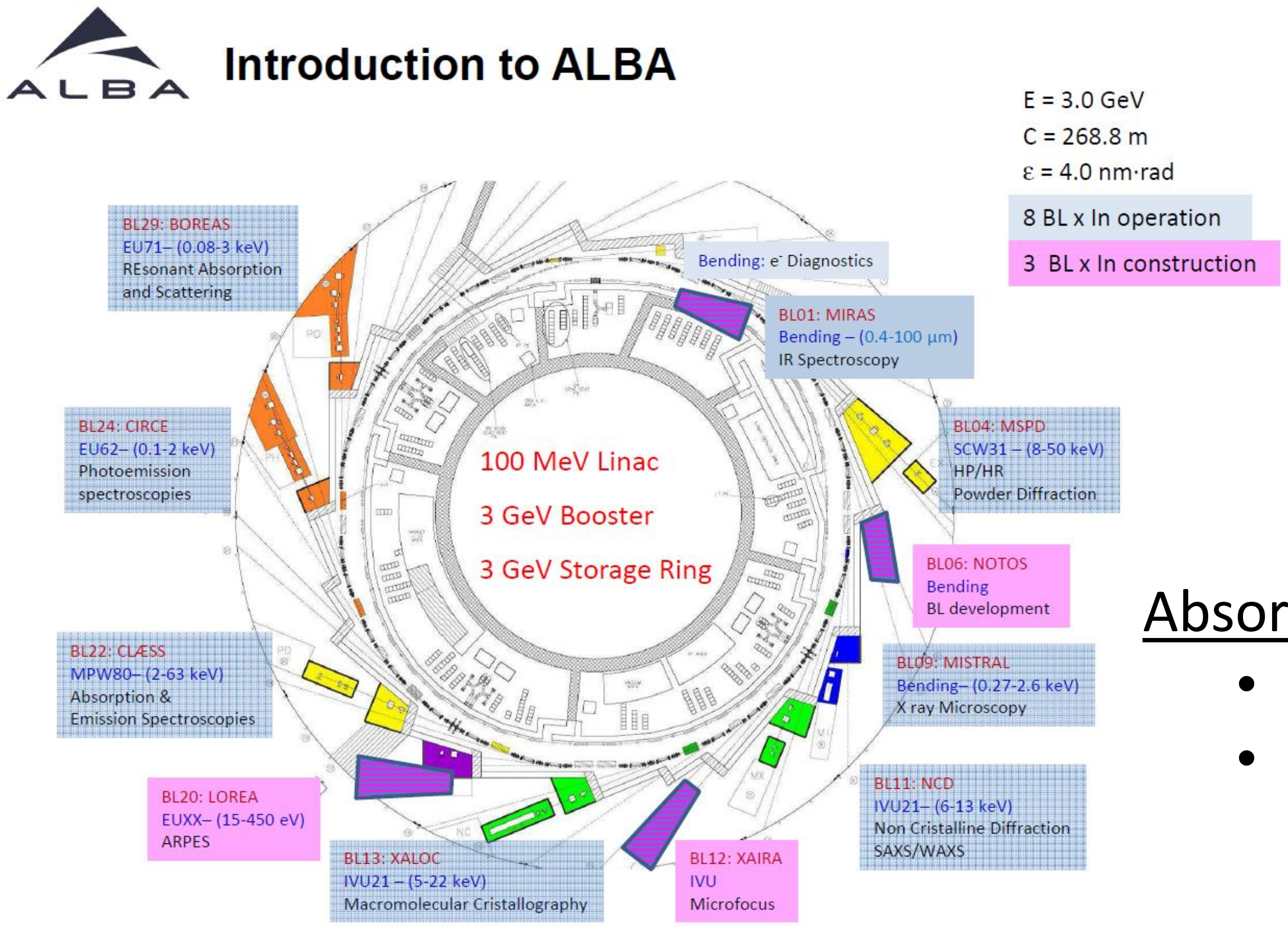
Conclusion: the beam excites the **even mode** of the stripline, whereas the two wire measurement excites the **odd mode**. Therefore, these two results cannot be compared directly.

Horizontal beam coupling impedance

REAL MODEL



Installation and beam conditioning



<u>Absorber</u>:

- Protecting the stripline from SR.
- Don't limit the horizontal aperture of the ring.
  - ➢ Proposed solution: striplines vertically placed.

7. Striplines Installation and Beam Conditioning at ALBA

Installation and beam conditioning

First installation & conditioning (January 2017)

- The striplines were not terminated (T = 80°C)
- I > 110 mA → P & T started to increase.
  - SR hitting the Macor rings?
  - Photo desorption on the absorber due to SR?
  - Overheating of the electrodes?

Second installation & conditioning (March 2017)

- The striplines were terminated
- I > 135 mA → P started to increase.
  - SR hitting the Macor rings?
  - Photo desorption on the absorber due to SR?

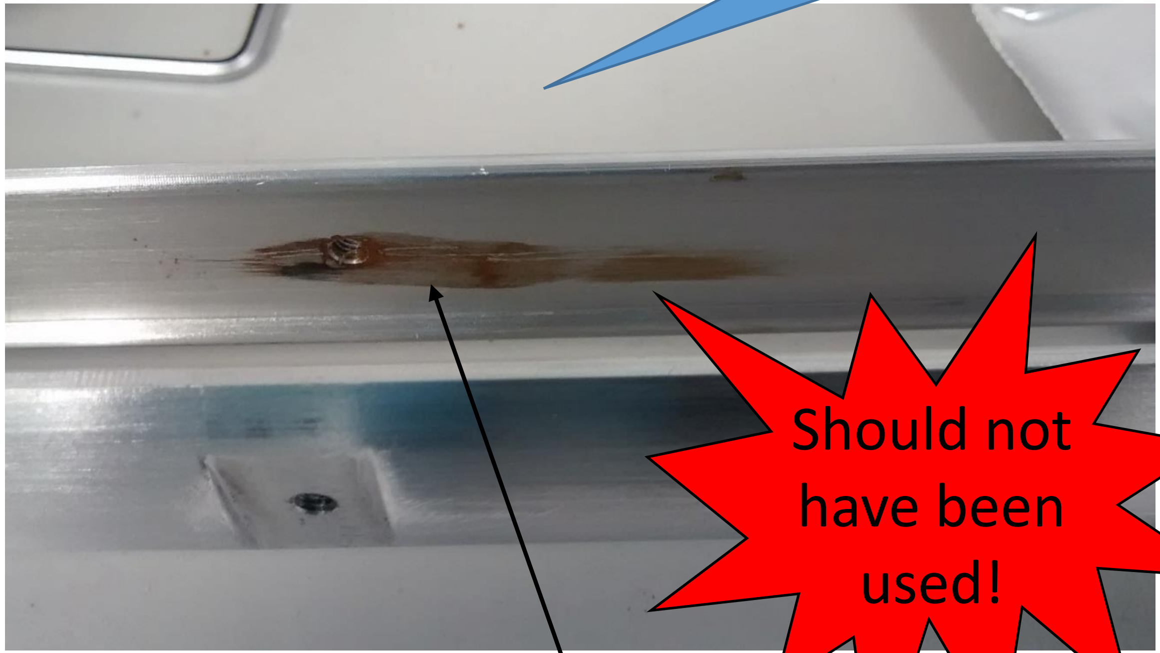
7. Striplines Installation and Beam Conditioning at ALBA

Several issues on the Macor Rings

Marks of SR

Broken ring

Marks of Loctite



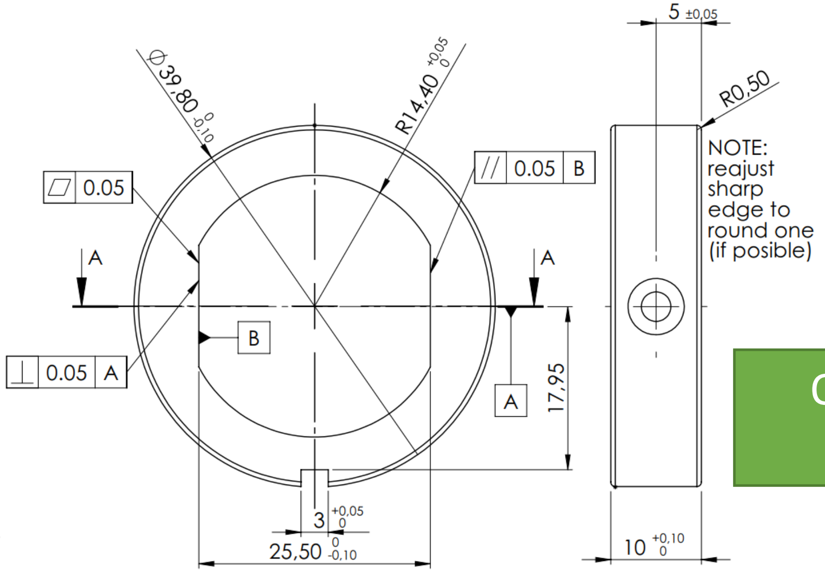
Should not have been used!

Removed with acetone

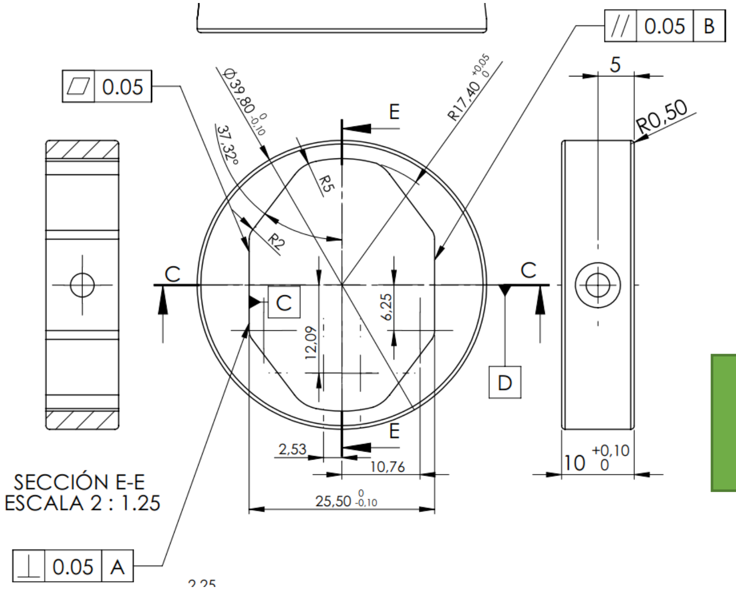
New Macor Rings

Proposal:

- Replace both upstream and downstream rings with new ones with a different shape.
- The other two rings were replaced by new Macor rings with the original shape.



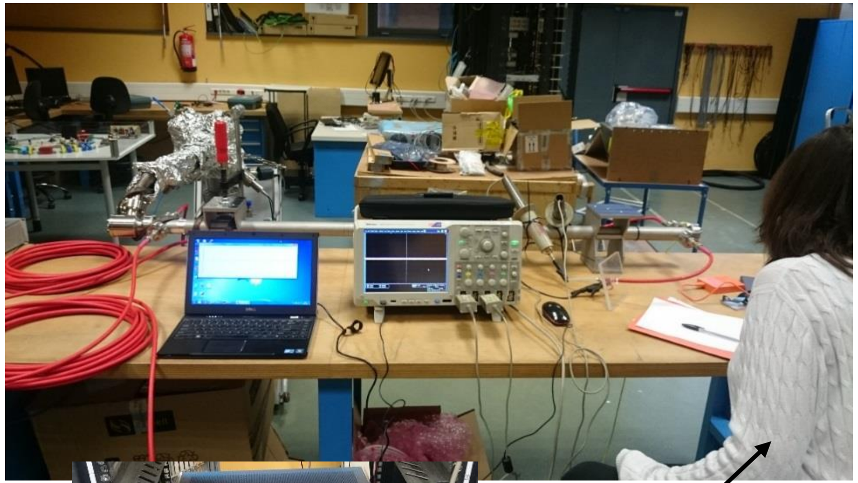
ORIGINAL SHAPE



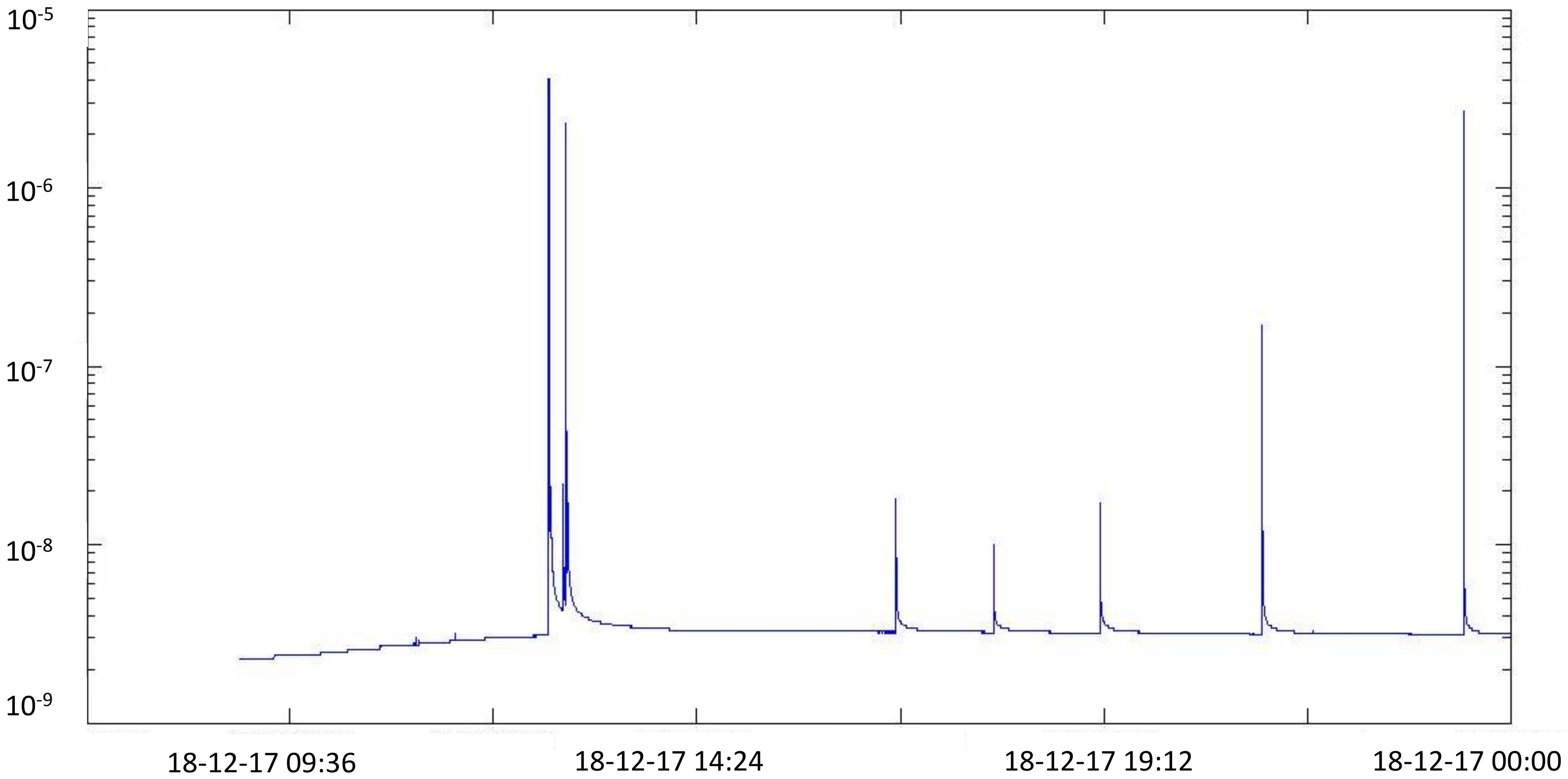
MODIFIED SHAPE

HV DC conditioning

HV DC conditioning prior its installation in the storage ring (December 2017 – January 2018):



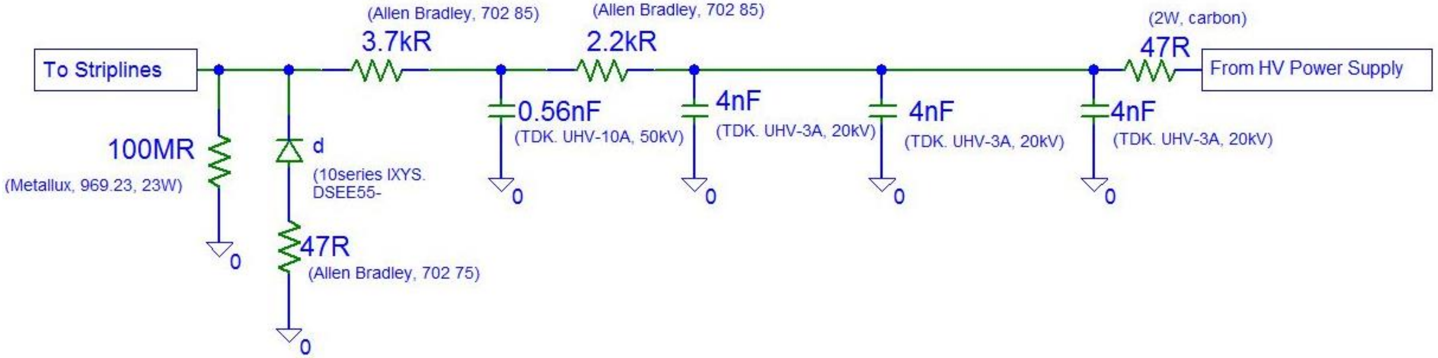
me again!

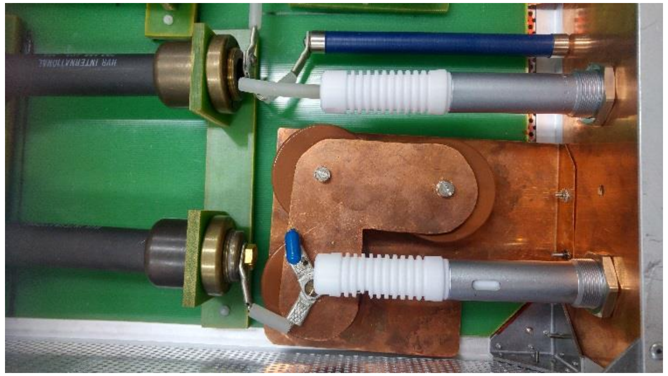


Courtesy of N. Ayala (ALBA).

8. Beam Measurements of the Striplines at ALBA

- Beam coupling impedance:
  - Measurement of the beam impedance of the total ring before and after the installation of the striplines.
- Transverse field homogeneity:
  - The electrodes will be powered by DC HV power supplies and will not be resistively terminated:
    - Only electrostatic field will be used to deflect the beam.
    - Low-pass filters are required to protect the power supplies from the voltage delivered (45 – 60 V) due to image currents.





8. Summary

- Beam extraction from the DRs will be done by fast kicker systems: striplines + inductive adders.
- Many design and optimization studies have been done on the striplines, as well as laboratory tests.
- A transient study of the magnetic field as well as a review of the dipolar component of the horizontal impedance of the striplines has been done and well understood.
- The striplines have been installed at ALBA, and after conditioning of the machine, beam measurements will be carried out.
  - Beam impedance measurements will be start soon.
  - Field homogeneity measurements are waiting for the filter manufacturing.
- The complete extraction kicker system (striplines + inductive adders) might be tested at ALBA during this year.

THANKS FOR YOUR ATTENTION!
ANY QUESTIONS?