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

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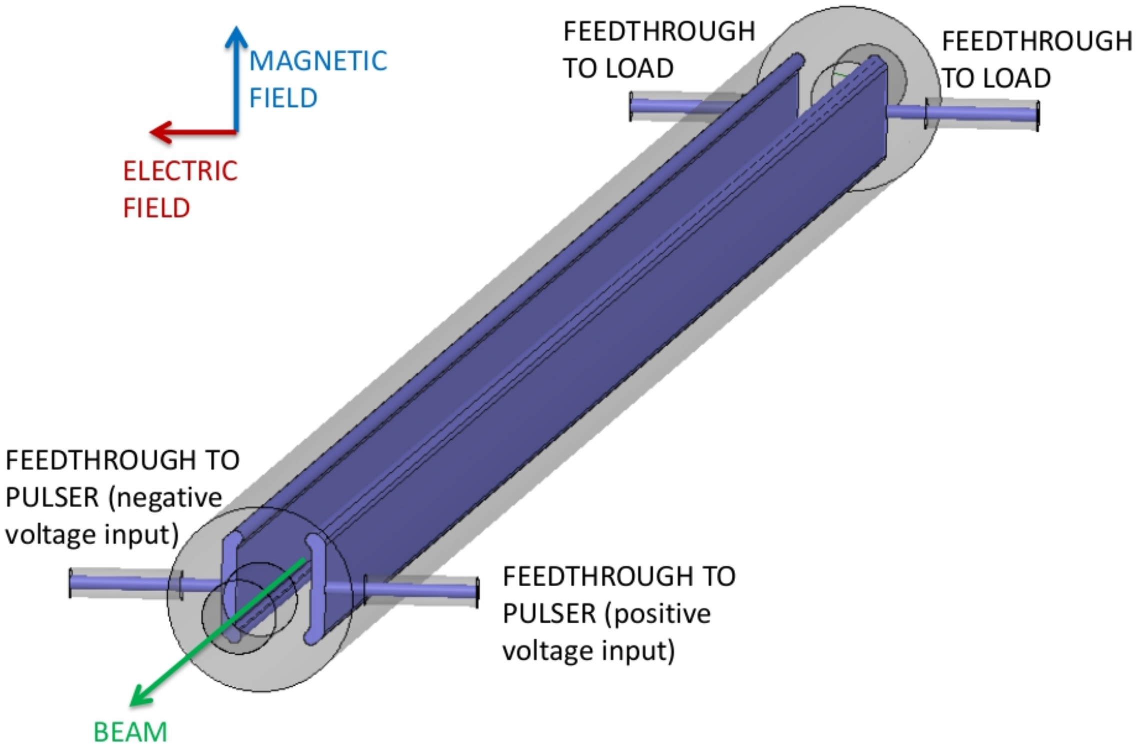
- Stripline kickers are generally assumed to have equal contributions from the electric and magnetic field to the total deflection angle, for ultra-relativistic beams.

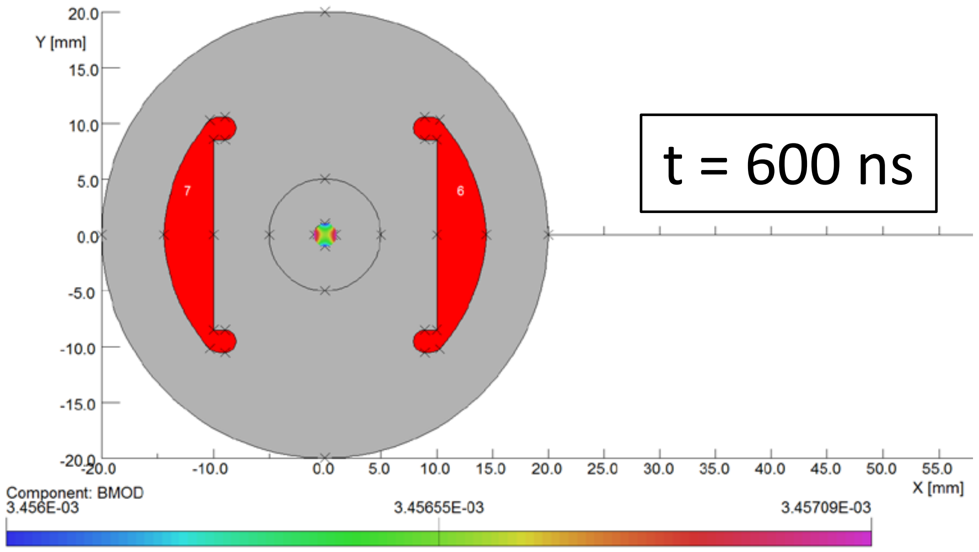


$$v \approx c \rightarrow \alpha_{tot} = \alpha_E + \alpha_B = 2\alpha_E$$

- ❑ The characteristic impedance, field homogeneity and the deflection angle are typically determined by simulating the striplines from an electrostatic perspective.

1. Introduction

- Recent studies show that, when exciting the striplines with a trapezoidal current pulse, the magnetic field changes during the flat-top of the pulse, and this can have a significant effect upon the striplines performances.
  - ❑ The transient solver of Opera2D has been used to study the magnetic field, for the striplines to be used for beam extraction from the CLIC Damping Rings (DRs).

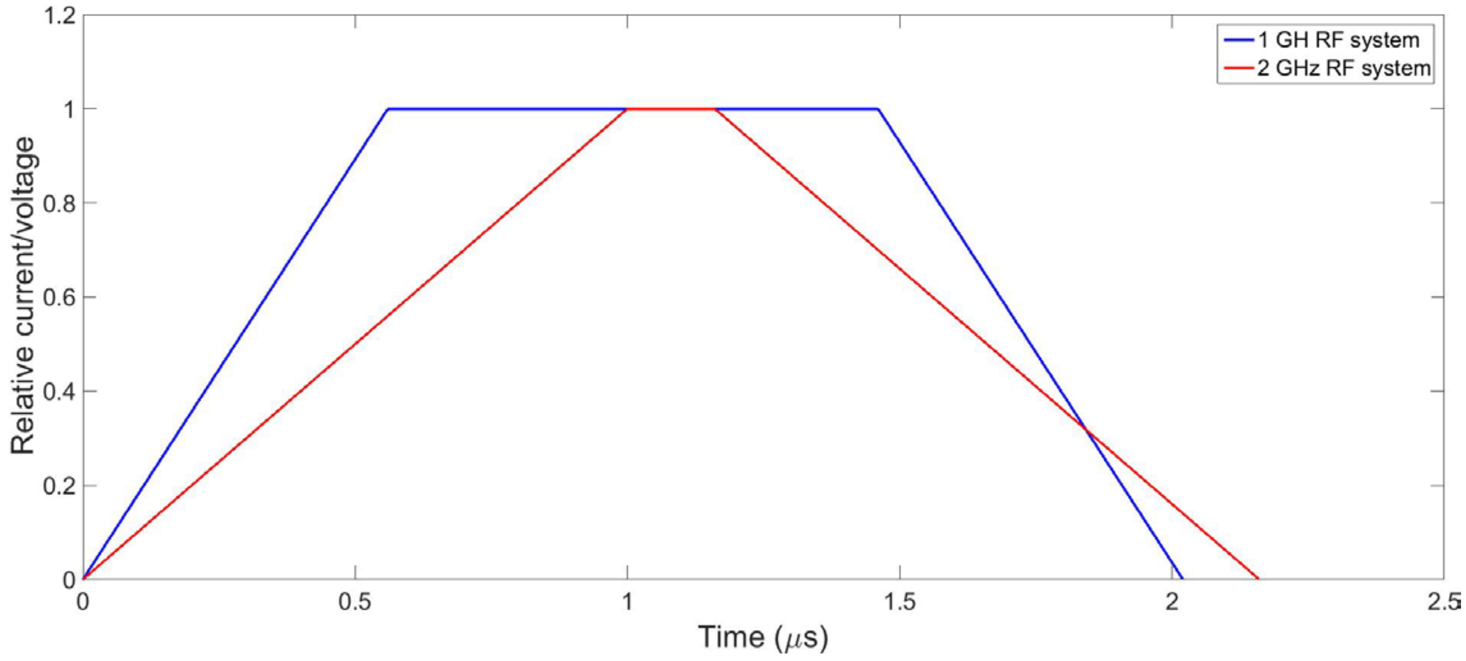


  - ❑ Then, the time dependence of the characteristic impedance, field homogeneity and deflection angle have been calculated.

2. Studies in the Time Domain

- Two RF baselines are considered for the CLIC DR operation:

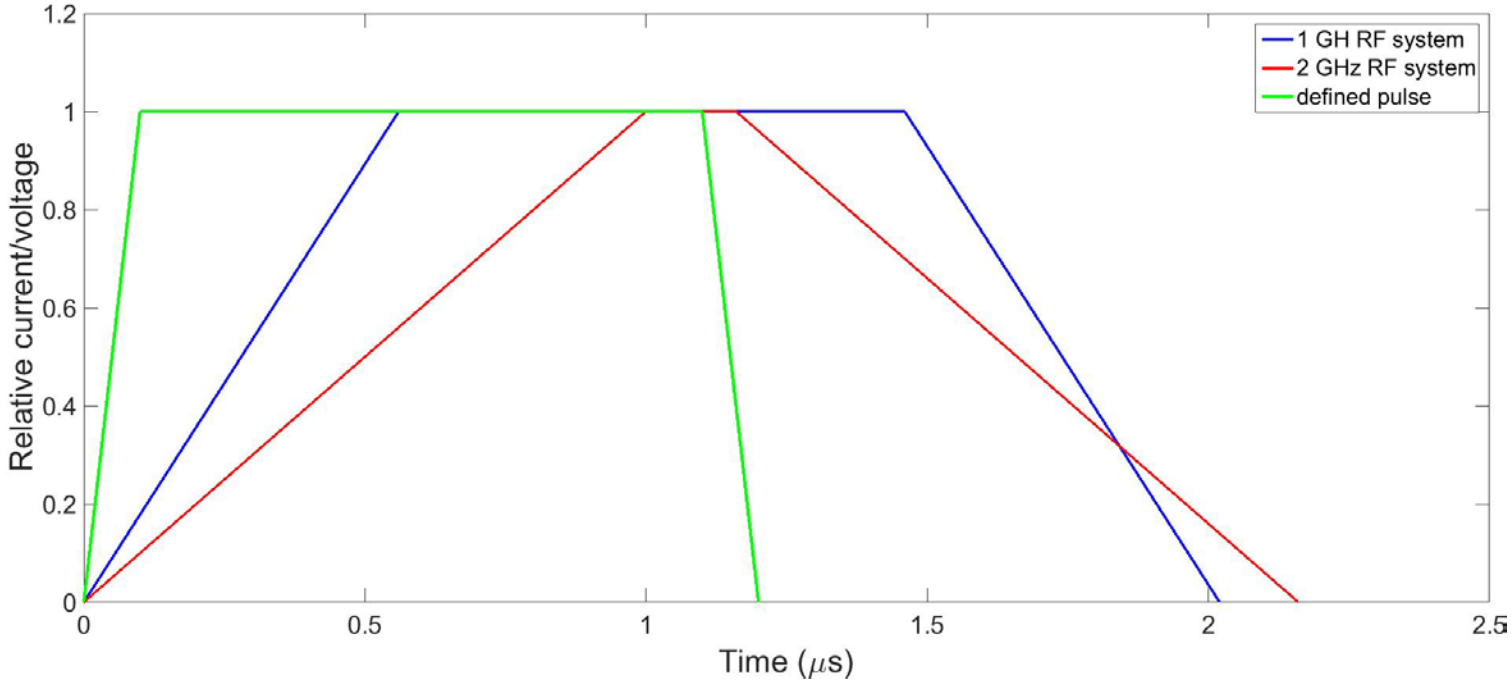
  - ❑ 1 GHz RF system
    - ➢ Pulse of 560 ns rise/fall time and 900 ns pulse flat-top
  - ❑ 2 GH RF system
    - ➢ Pulse of 1 μs rise/fall time and 160 ns flat-top



2. Studies in the Time Domain

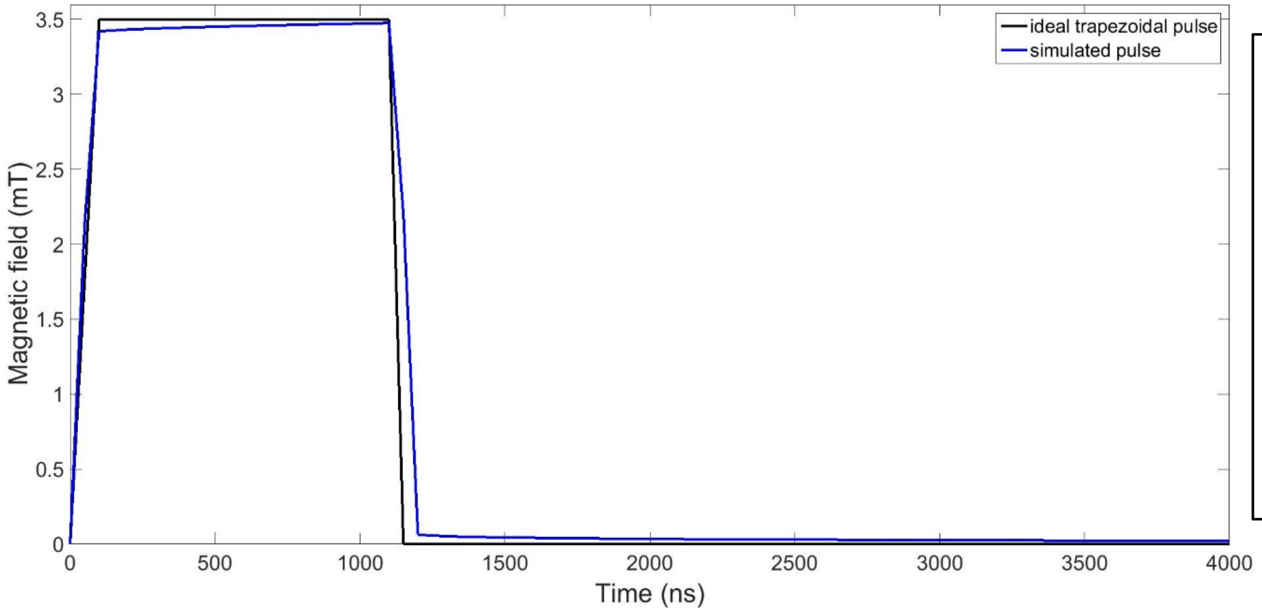
- Inductive adders will be used to generate the pulses for the striplines for the CLIC DRs.
  - ❑ In order to limit the electrical and thermal stresses on the system, the goal is to achieve output current pulse rise and fall times of approximately 100 ns.

- Transient simulations with Opera2D have been carried out, and a pulse of 100 ns rise and fall time and 1 µs flat-top has been considered (value close to the 1 GHz RF system goals).



2. Studies in Time Domain: Magnetic Field

- The “ideal” defined pulse has been used in Opera2D.
- Parameters of the transient simulation:
  - ❑ Electrodes conductivity: $\sigma = 3.03 \times 10^7$S/m (aluminium Al6063).
  - ❑ Termination impedance: 50 Ω is assumed,
    - ➢ results in a nominal ±250 A with ±12.5 kV driving voltage.

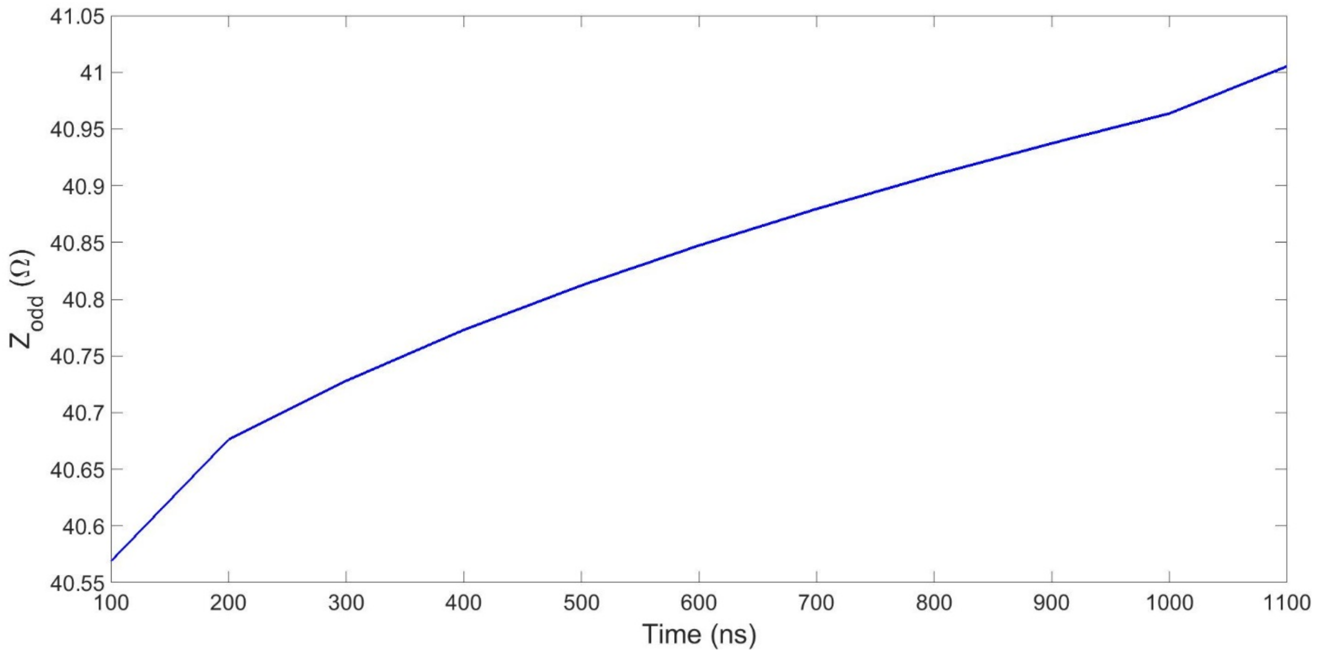


When exciting the striplines with a trapezoidal current pulse, the magnetic field changes during the flat-top of the pulse. There is also a significant effect upon the characteristic impedance, field homogeneity and deflection angle.

The odd mode characteristic impedance, field inhomogeneity and deflection angle have been studied when considering a trapezoidal voltage/current pulse.

2. Studies in the Time Domain: Characteristic Impedance

- The characteristic impedance is calculated from inductance and capacitance: these quantities are calculated from predicted stored magnetic and electrostatic energy, respectively.
  - ❑ When the striplines are pulsed: odd mode characteristic impedance

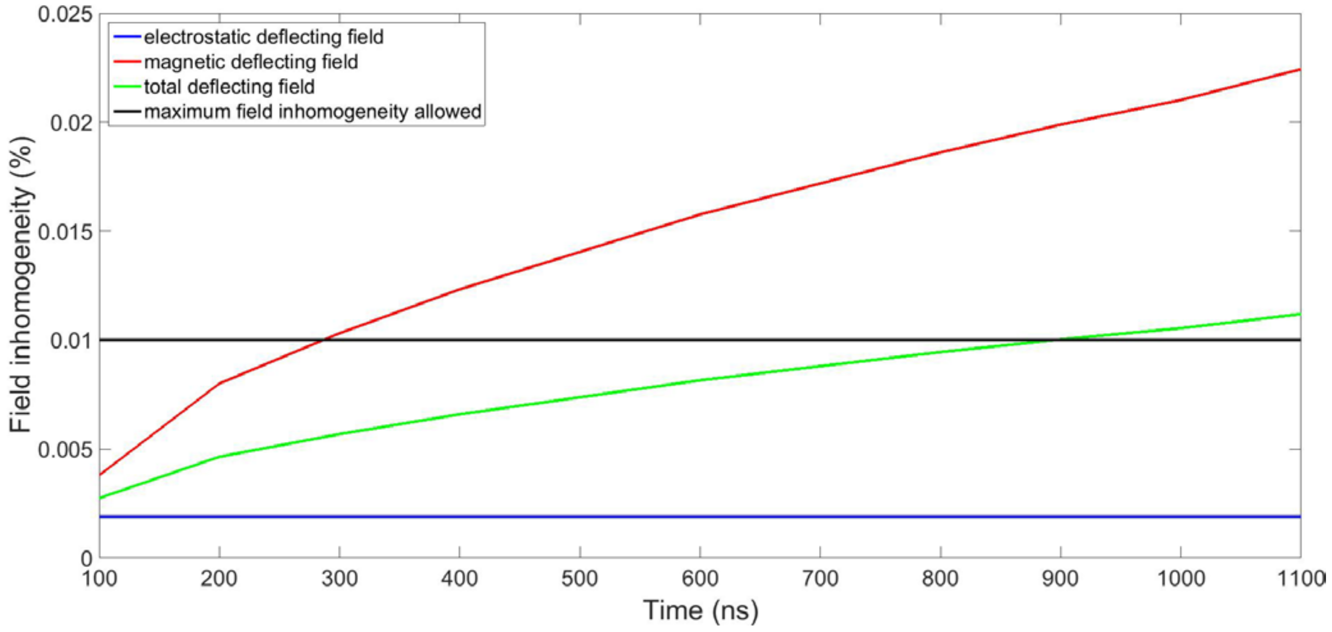


The odd mode characteristic impedance increases from 40.57 Ω at the beginning of the flat-top to 41.01 Ω at the end of the flat-top, corresponding to an increase of 1.1%.

2. Studies in the Time Domain: Field Homogeneity

- The maximum field inhomogeneity, over 1 mm radius at the centre of the striplines aperture, has been specified to be ± 0.01%.

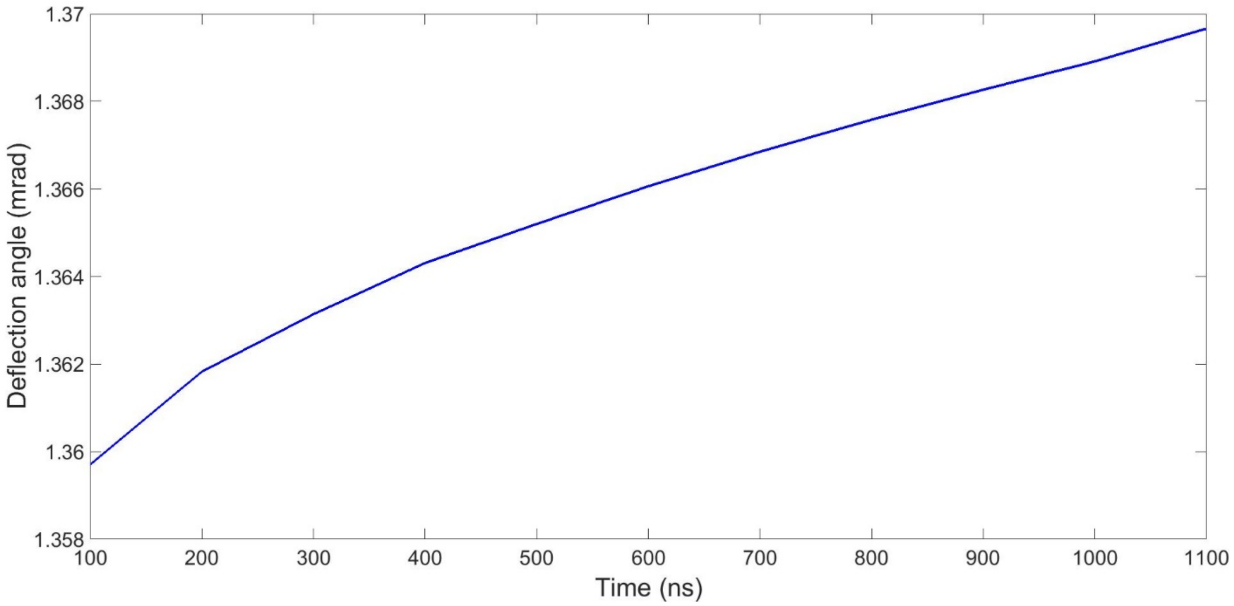
- The electric, magnetic and total field homogeneity have been calculated and compared.



The total field inhomogeneity over 1 mm radius at the centre of the striplines aperture increases from ±0.0028% to ±0.0112%

2. Studies in the Time Domain: Deflection Angle

- The total deflection angle for the extraction kicker of the CLIC DRs has been specified to be 1.5 mrad.
- 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.

2. Studies in the Time Domain

- The increase of the magnetic field, and therefore, the increase of the deflection angle during the flat-top is greater than specified.

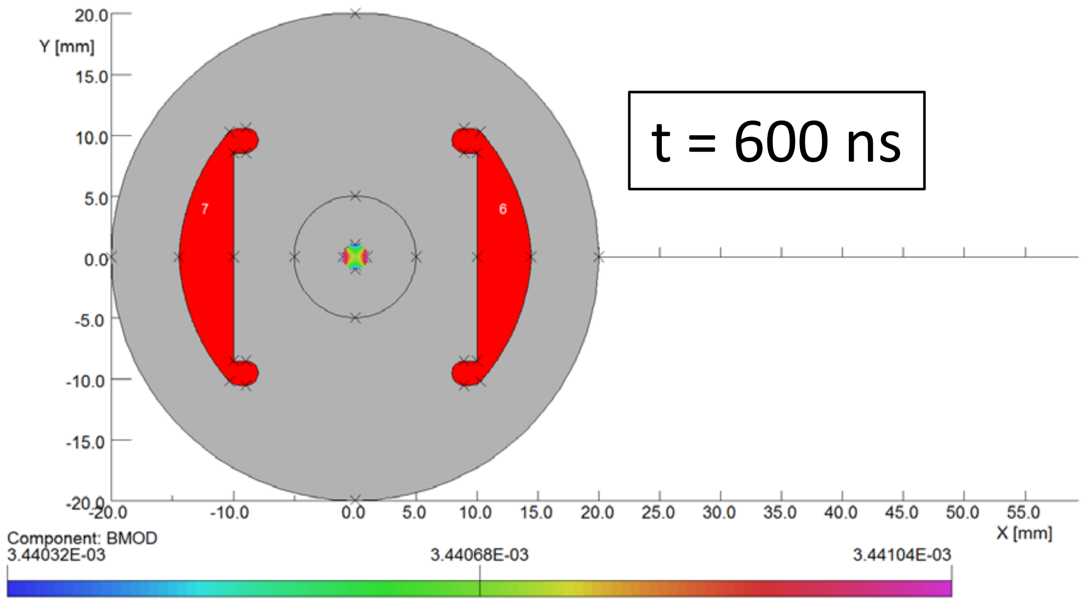
- In an attempt to reduce the increase of the “flat-top” field two proposals will be presented in the following:

  - ❑ Using a thin silver coating on the electrodes

  - ❑ Modulate the pulse to compensate for the variations in the field flat-top.

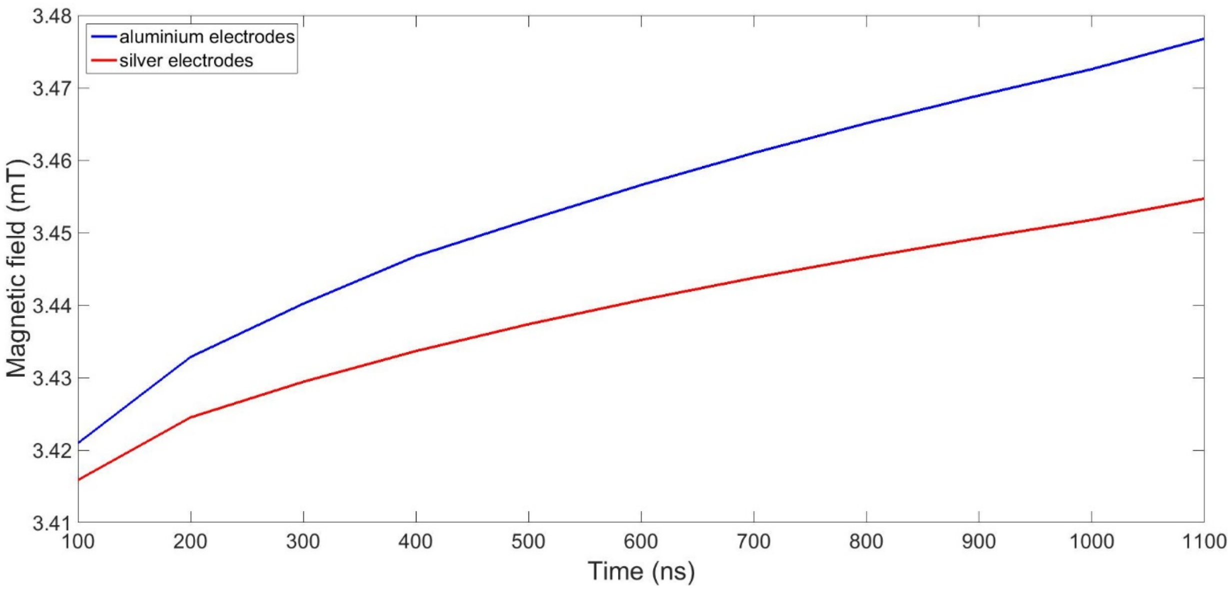
3. Silver Coating

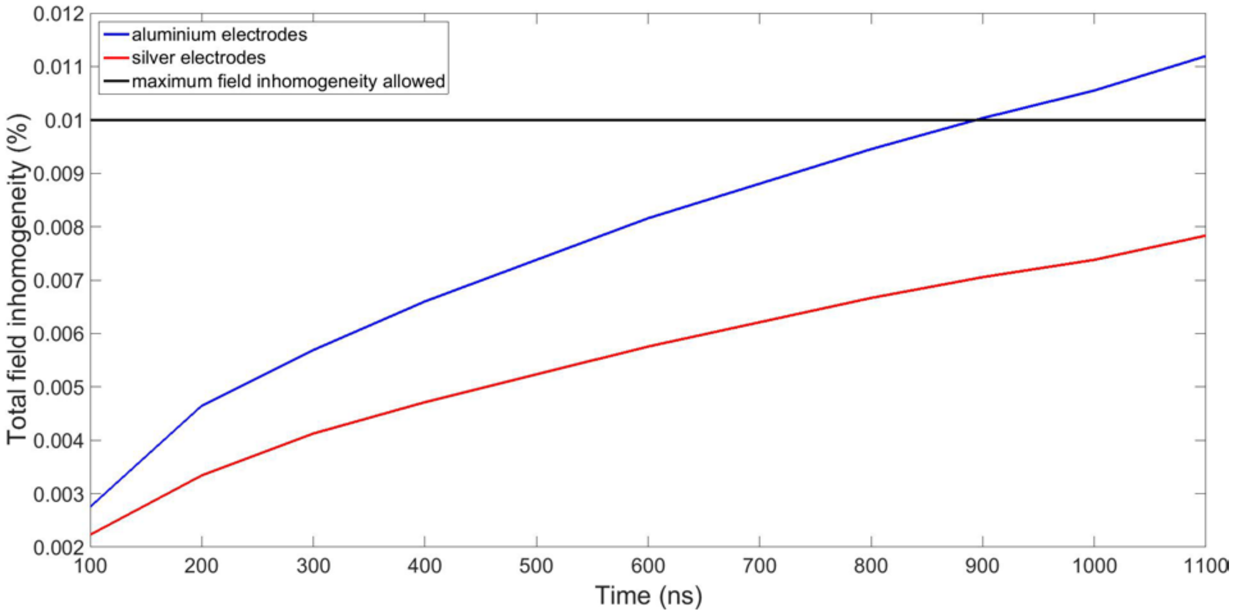
- In order to improve the flatness of the pulse, the electrodes could be coated by a thin layer of silver.
  - ❑ Opera2D does not presently permit a thin layer of silver to be modelled on top of the aluminium.



- Hence, to evaluate the influence of silver, the electrical conductivity of the complete electrodes have been changed to that of silver (6.3×10^{7} S/m).

3. Silver Coating

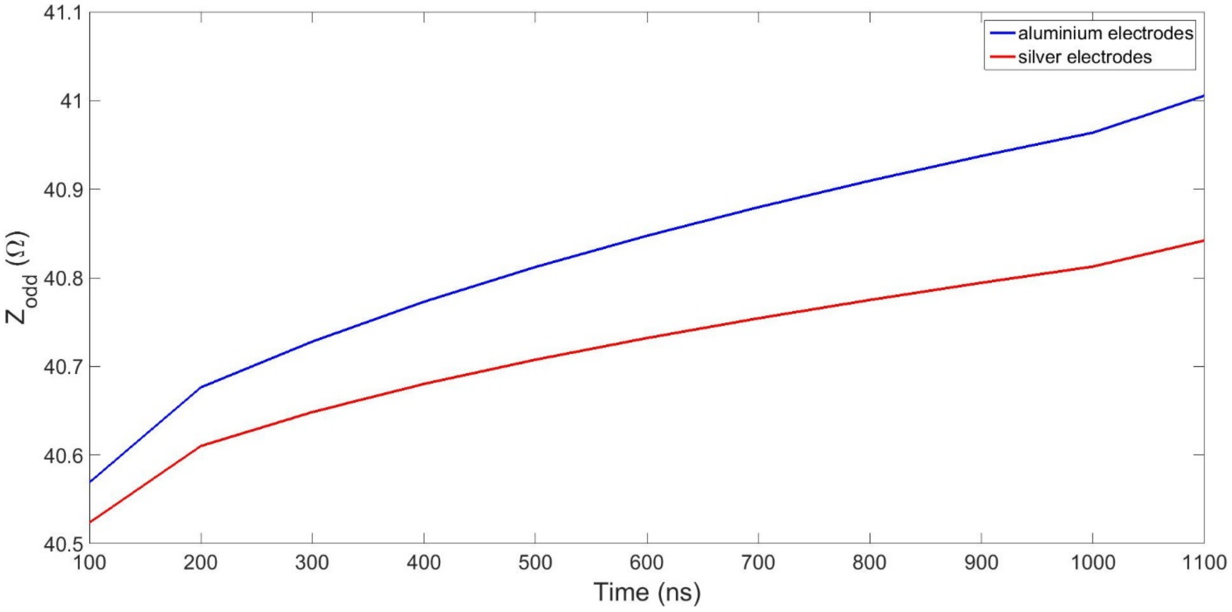


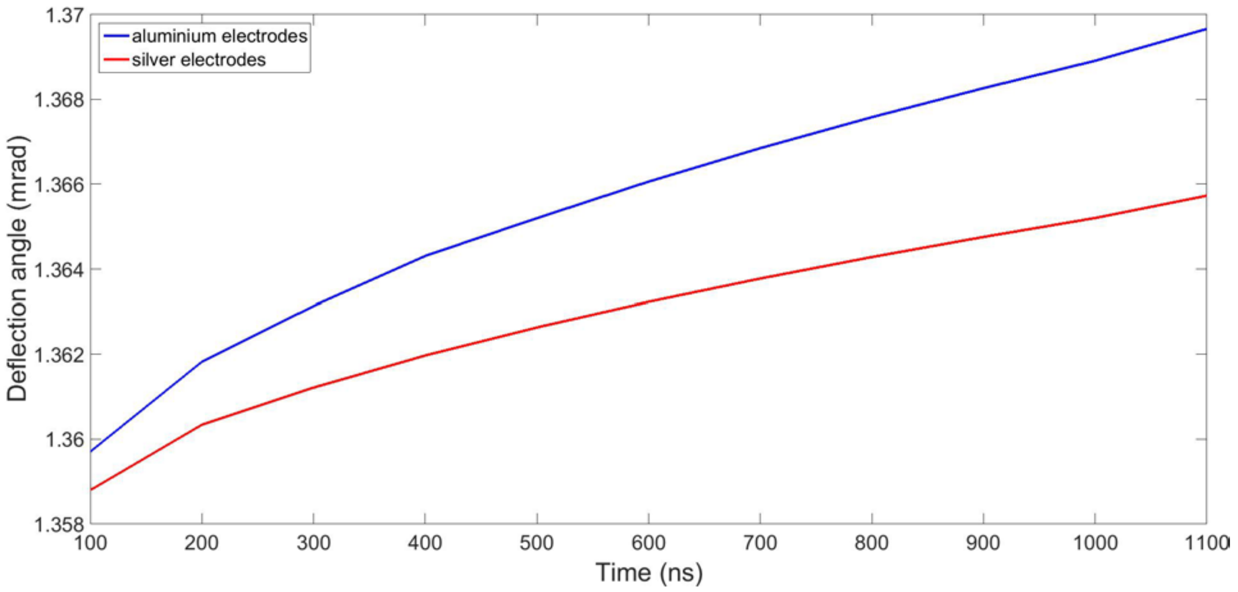


- When using silver, the magnetic field at the beginning and at the end of the flat-top is 3.416 mT and 3.455 mT, respectively: hence the increase of the magnetic field during the pulse flat-top is reduced from 1.63% (aluminium electrodes) to 1.14%.

- Also the field inhomogeneity over the 1 mm radius improves, with a maximum value at the end of the flat-top of ±0.0078% (c.f. 0.0112% for aluminium).

3. Silver Coating





- In addition, the odd mode characteristic impedance ranges from 40.52 Ω to 40.84 Ω during the pulse flat-top: hence the increase of the odd mode characteristic impedance is reduced from 1.1% (aluminium electrodes) to 0.8%.

- The deflection angle, for silver electrodes, changes from 1.359 mrad to 1.366 mrad during the pulse flat-top, which corresponds to an increase of 0.5% (c.f. 0.73% for aluminium).

4. Pulse Modulation

- 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.

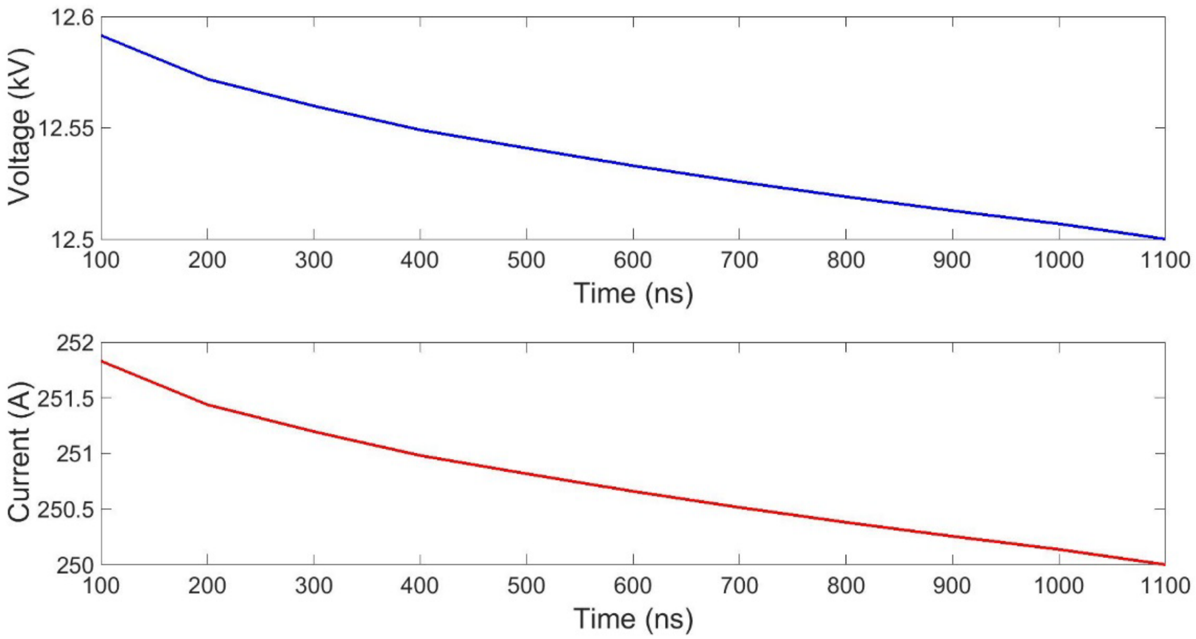
  - The inductive adder has a modulation layer and hence this layer could be used to achieve the required waveforms.

- An “ideal” waveform has been calculated by considering the total compensation required, when trapezoidal waveforms are considered, to achieve a flat deflection pulse.

- This compensation is appropriately applied to the driving current and voltage waveforms, assuming ideal terminating resistors on the output of the electrodes.

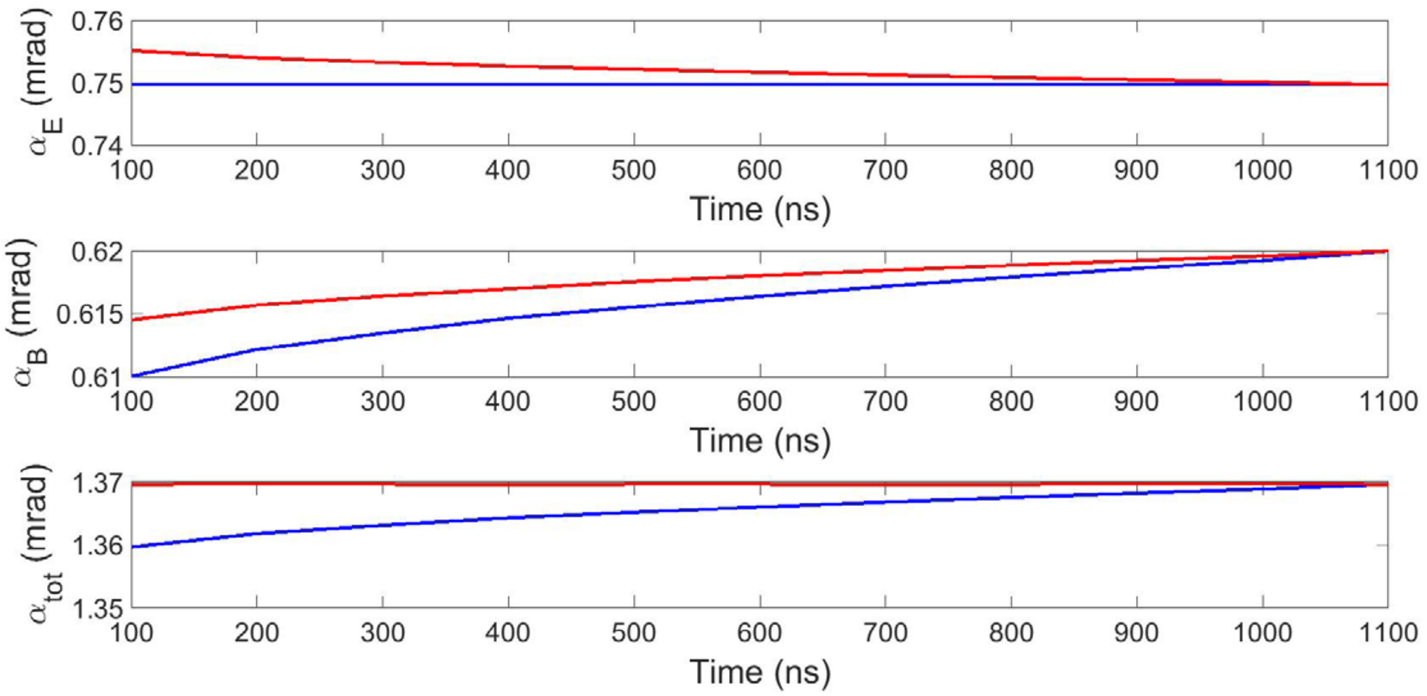
4. Pulse Modulation

- The modulation done 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.



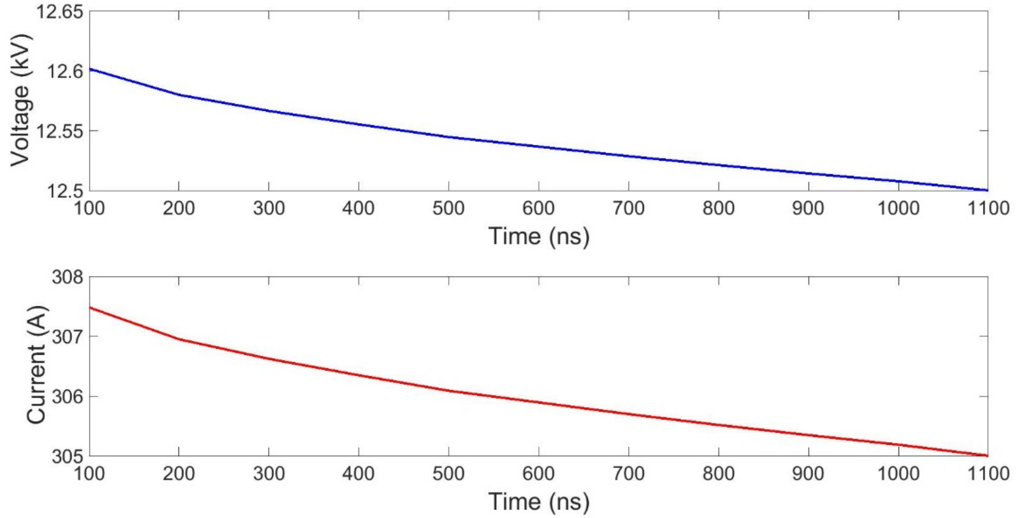
4. Pulse Modulation

- 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%.

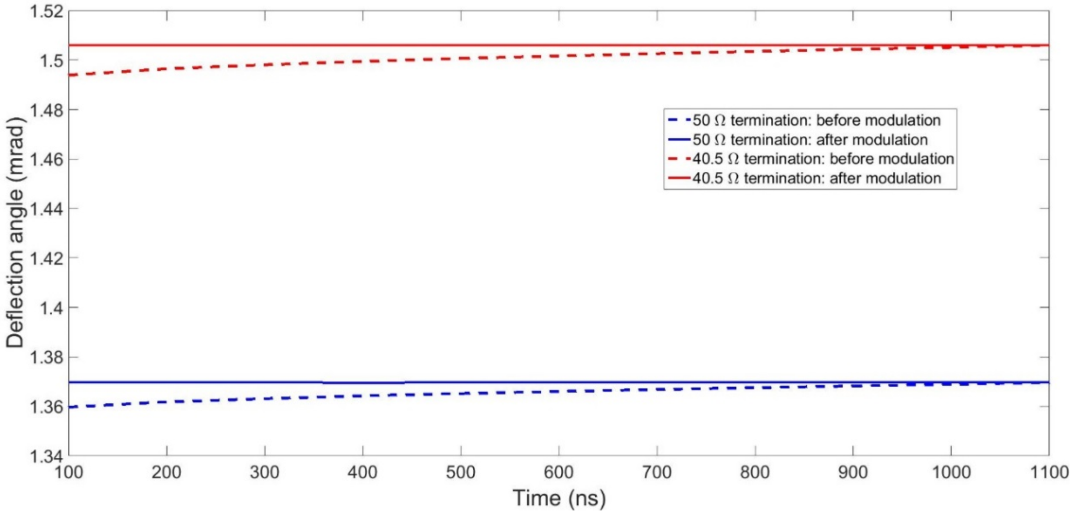


before modulation
after modulation

- 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. Pulse Modulation

- With 50 Ω terminating resistors the total deflection angle, in the present configuration (aluminium plates, unmodulated waveform), increases during the 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.

5. Summary of the Results

Comparison of the relative variation of the deflection angle, field inhomogeneity and odd mode characteristic impedance, when considering the two proposals: silver coating and pulse modulation.

	Al6063 electrodes (unmodulated pulse)	**Silver electrodes (unmodulated pulse)**	**Al6063 electrodes (modulated pulse)**
$\Delta\alpha$	0.73%	0.52%	$\ll$ 0.01%
FH	± 0.0112%	±0.0078%	± 0.0112%
ΔZ_{odd}	1.1%	0.8%	1.1%

- Appropriately modulating the driving waveforms theoretically results in the required flatness of the total deflection angle.
- Terminating the striplines at 40.5 Ω results in the total deflection angle required: 1.5 mrad.

6. Conclusions

- Transient simulations, to study the time dependence of the magnitude of the magnetic field pulse have been carried out in order to consider the effects of a 100 ns rise/fall time pulse, with a flat-top of 1 μs, upon the characteristic impedance and the deflection angle.
  - ❑ The magnetic field, and therefore the magnetic field contribution to the deflection angle is not constant during the flat-top of a trapezoidal current pulse.

- Two means of improving the flatness of the total deflection angle have been proposed:
  - ❑ Coating the electrodes with silver
    - ➢ Silver electrodes give the required field homogeneity but do not result in the flat-top stability specifications being met.
  - ❑ Modulating the pulse created by the inductive adder
    - ➢ Achieves the required flatness of the deflection angle

6. Conclusions

<u>What are the results from the pulse modulation studies?</u>

- The required output pulse shape from the inductive adder, to compensate the time dependence of the impedance of the striplines, has been derived for both 50 Ω and 40.5 Ω terminating resistors.
  - These waveforms theoretically give the required flat-top of the total deflection pulses.
- Termination resistors of 40.5 Ω provide the required deflection angle of 1.5 mrad, with a 12.5 kV driving voltage.
  - To achieve the 1.5 mrad with 50 Ω terminating resistors requires that the nominal driving voltage is increased to 13.7 kV.
- However the field homogeneity is close to, but slightly outside, the specification of ± 0.01% (only achieved with silver coating).
- Pspice simulations to study reflections with 40.5 Ω and 50 Ω terminating resistors will be carried out next.