SPS impedance modeling

C. Zannini, G. Rumolo, B. Salvant, V.G. Vaccaro

Acknowledgments: T. Argyropoulos, M. Barnes, N. Biancacci, J. Bauche, S. Bouleghlimat, F. Caspers, H.A. Day, G. De Michele, E. Metral, N. Mounet, Y. Sillanoli, M. Taborelli, M. Van Stenis, V.G. Vaccaro

Overview

- Updated status of the SPS impedance model

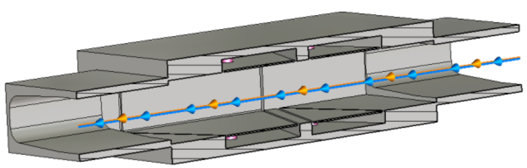
  Improvement of the model

  - Kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - A more realistic model

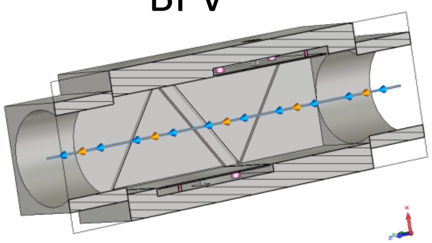
Updated status of the SPS impedance model

- Elements included in the database:
  - Realistic model that takes into account the different SPS vacuum chambers weighted by the respective length and beta function. Also the iron in the magnet is taken into account
  - 19 kickers (CST 3D simulation)
  - 106 BPHs (CST 3D simulations)
  - 96 BPVs (CST 3D simulations)
  - 200 MHz cavities without couplers (CST 3D simulations)
  - 800 MHz cavities without couplers (CST 3D simulations)
  - Enamel flanges

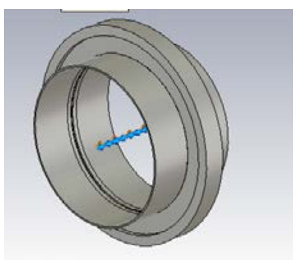
BPH



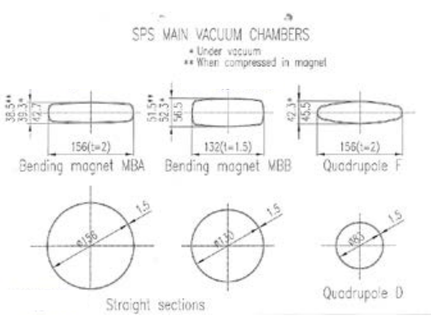
BPV



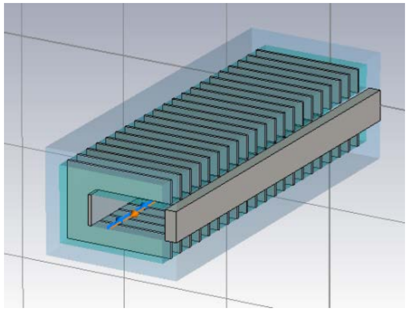
Enamel flanges



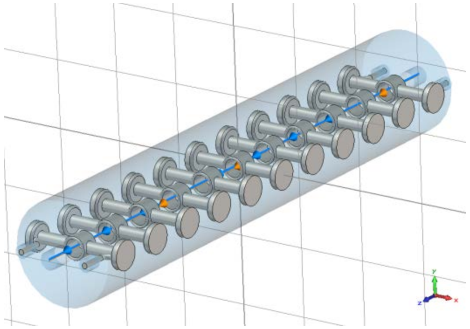
Beam pipe



Kickers



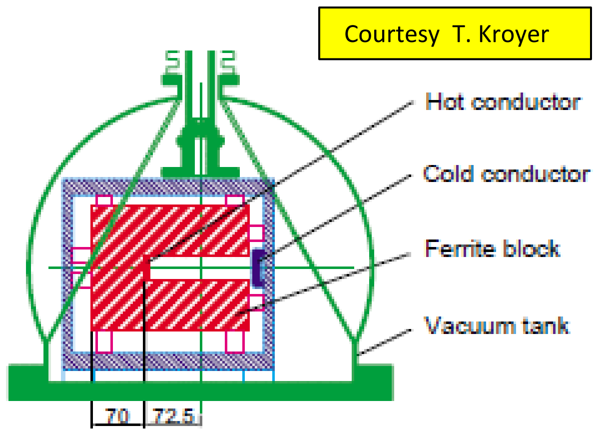
TW 200MHz and 800MHz

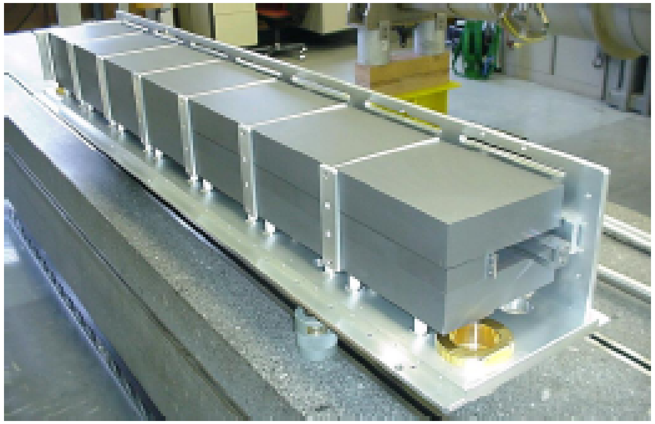


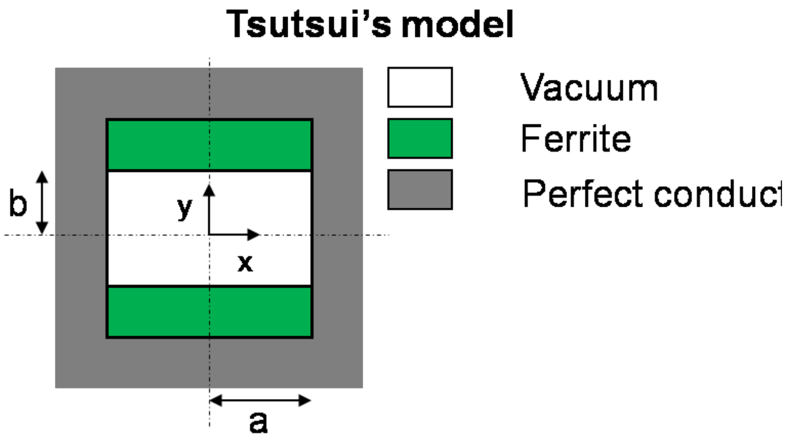
Overview

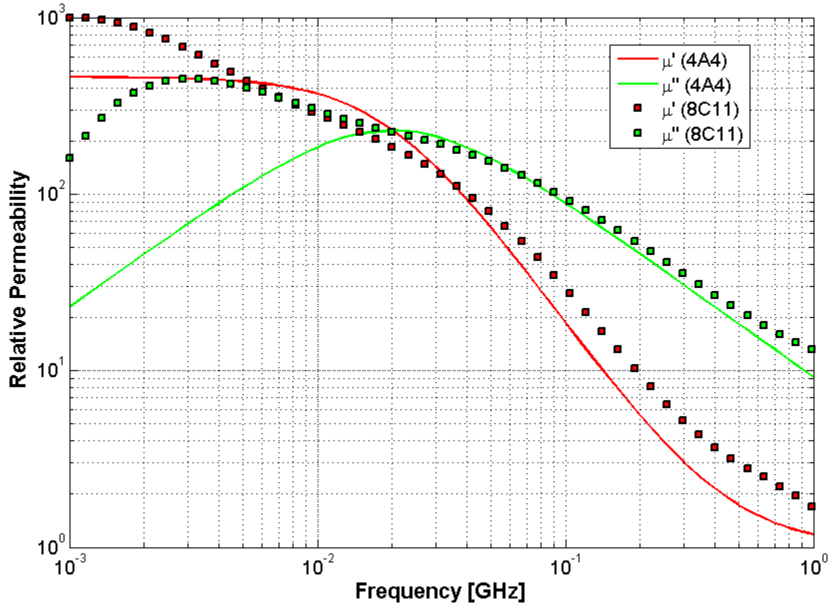
- Updated status of the SPS impedance model
- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

Simplified kicker model

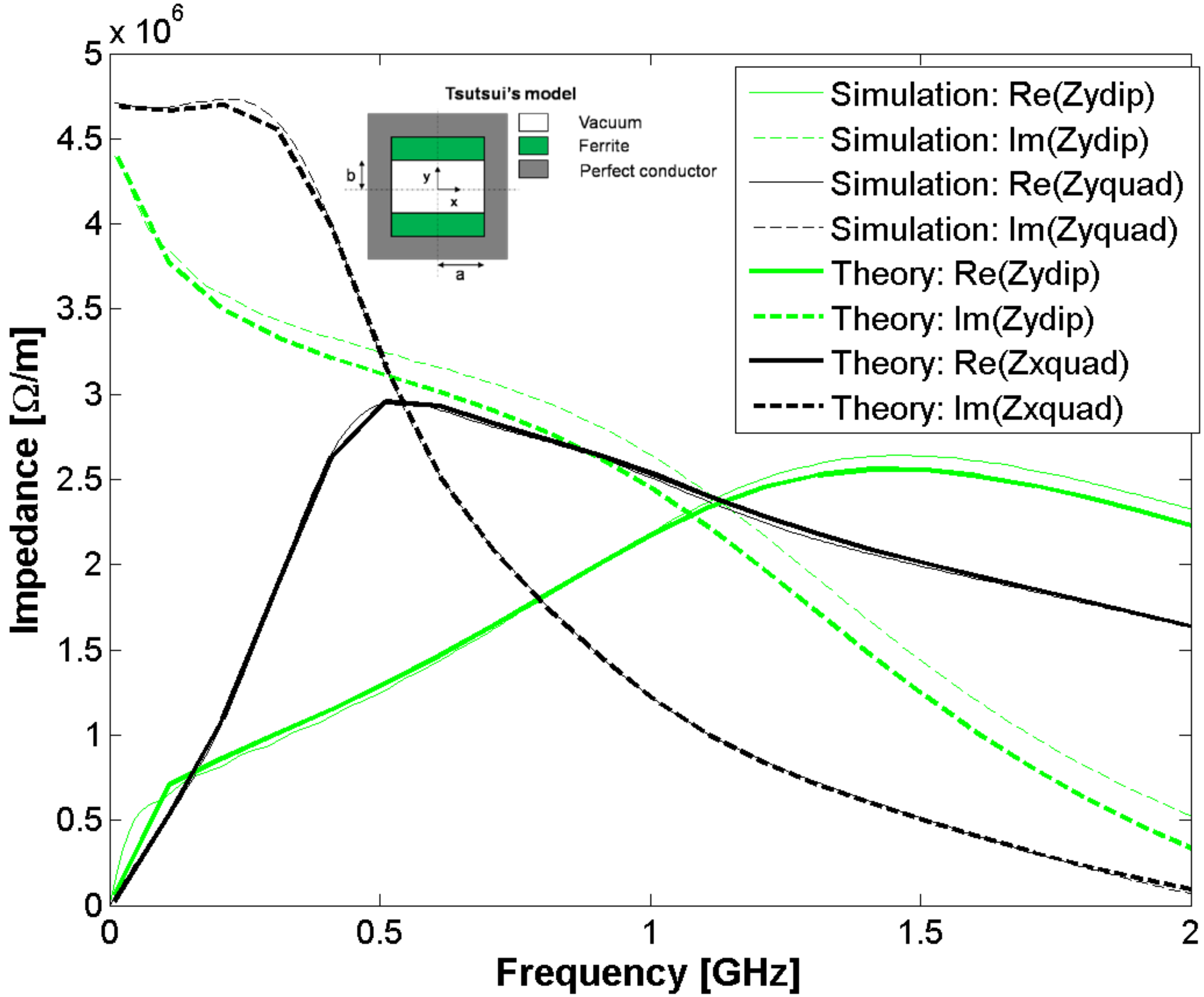






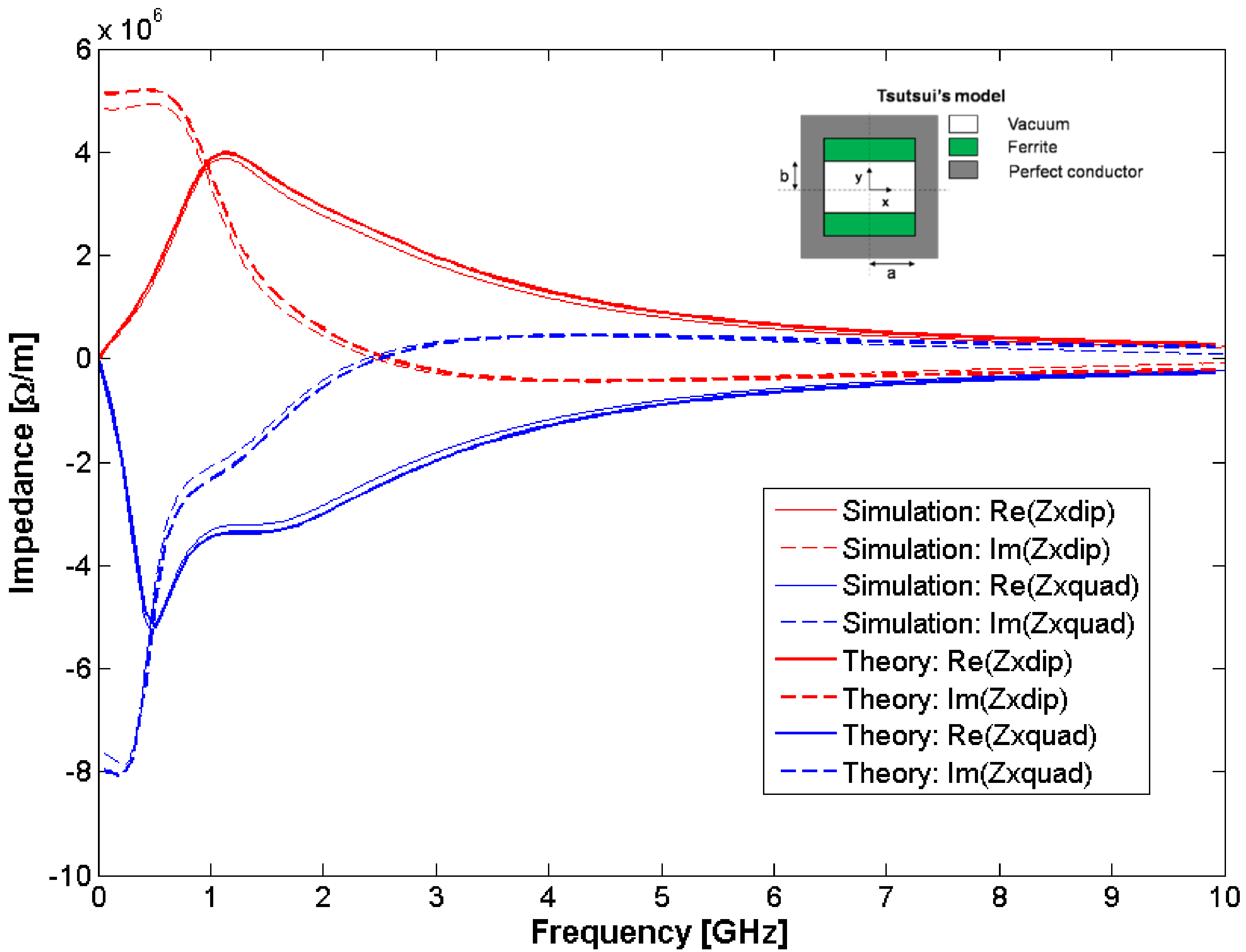


Vertical impedances for all the SPS kickers



The theoretical predictions and simulations are in very good agreement

Horizontal impedance from all the SPS kickers



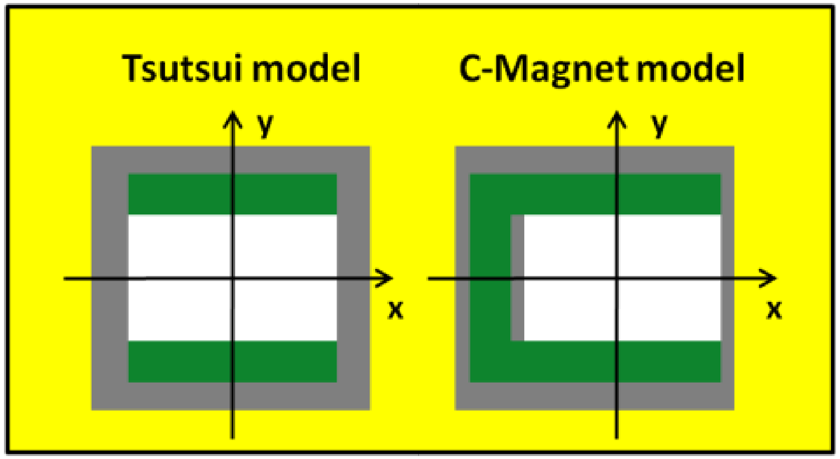
The theoretical predictions and simulations are in very good agreement

We are confident with the 3D TD EM simulation code (CST Particle studio)

Overview

- Updated Status of the SPS impedance model
- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

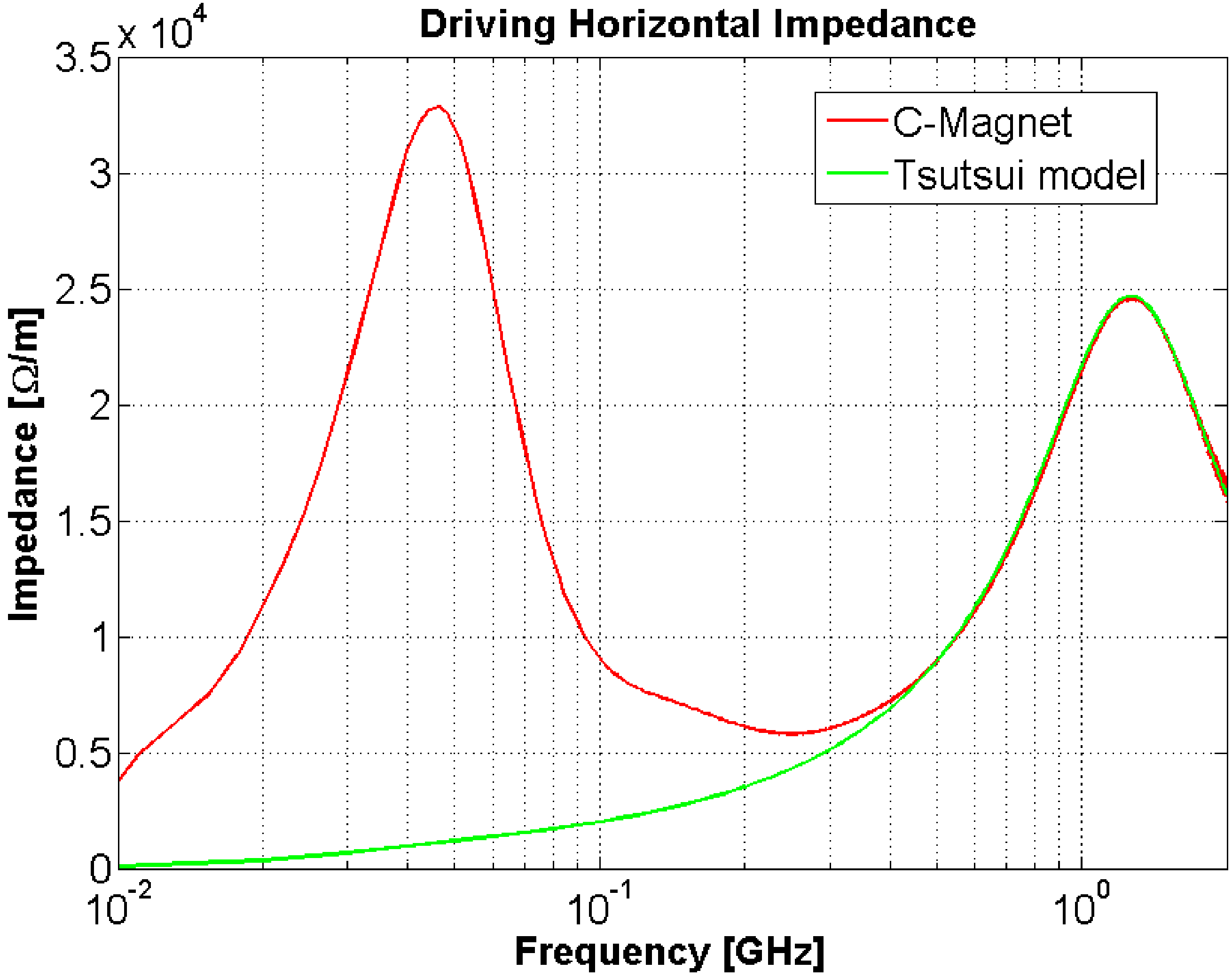
Improving the model



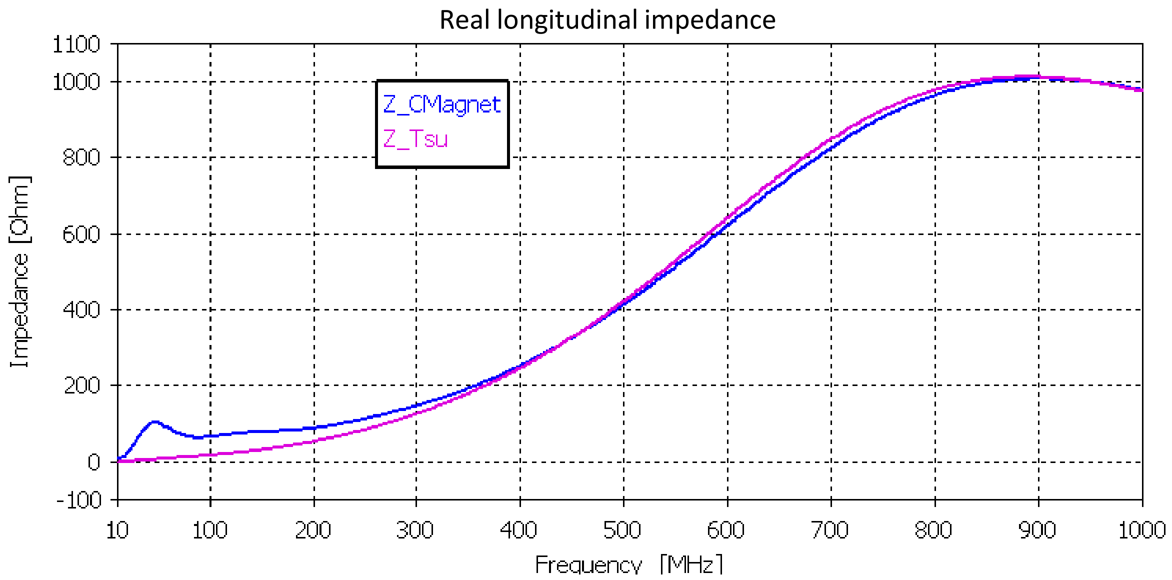
In the real structure there is a TEM propagation (finite length effect)

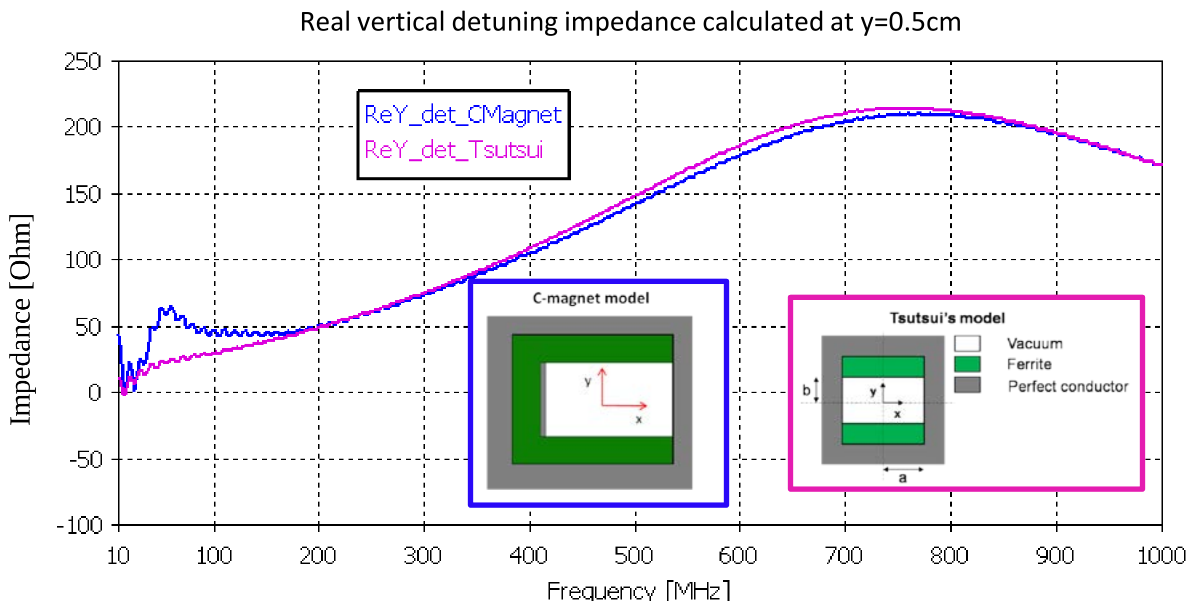
The TEM mode plays a role when the penetration depth in the ferrite becomes comparable to the magnetic circuit length (below few hundred MHZ).

C-magnet: driving horizontal impedance



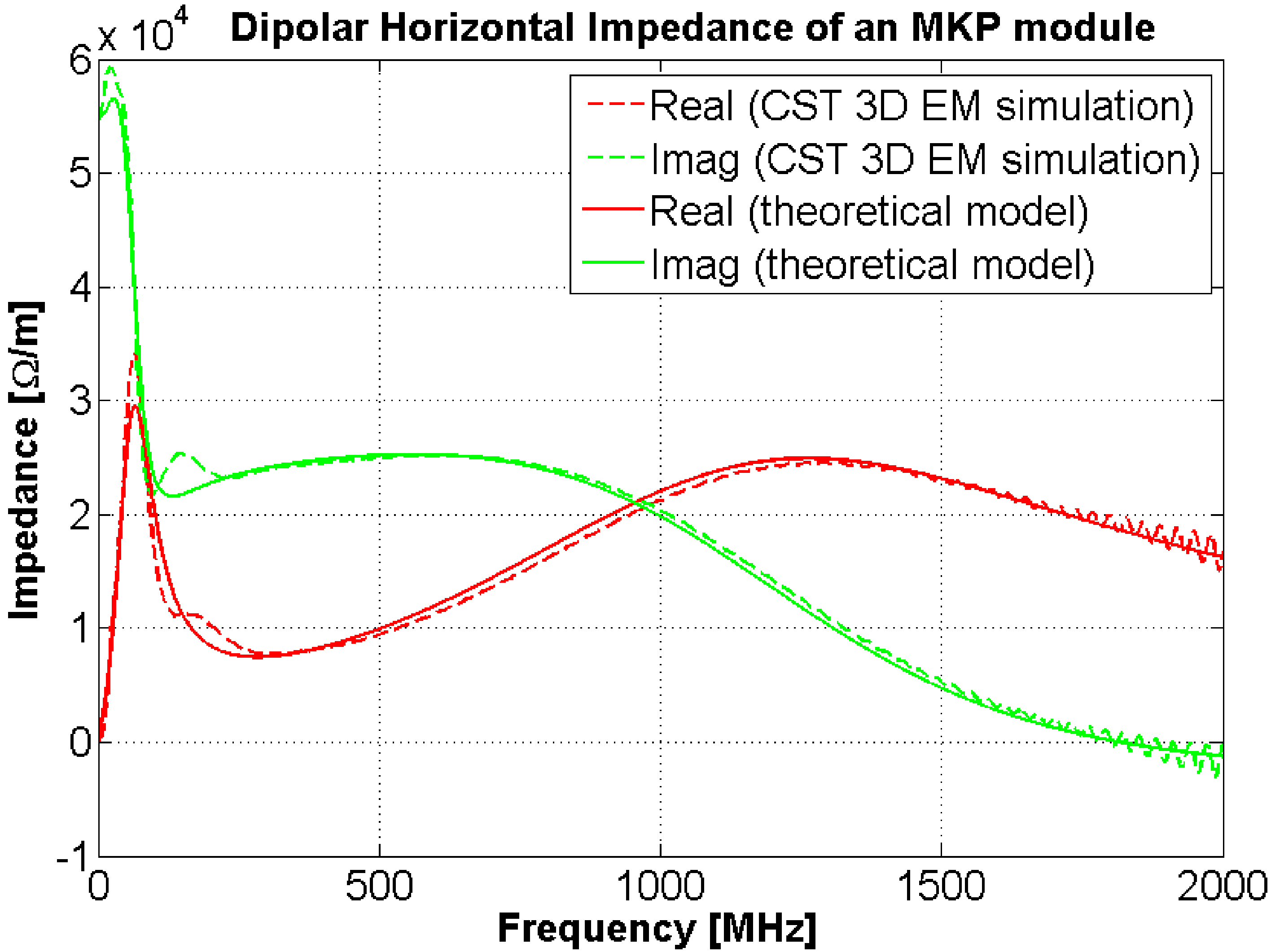
Comparing the two models





We can see the peak also in the longitudinal and vertical impedance

C-Magnet: 3D theoretical model for impedance calculation



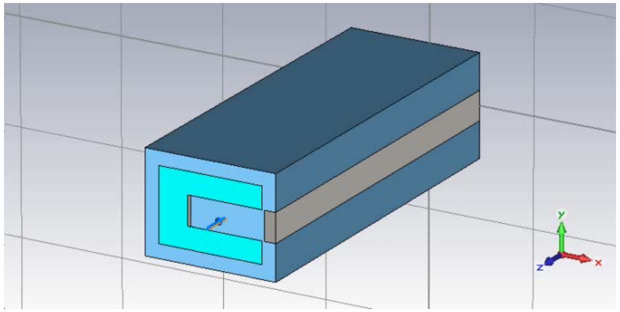
The theoretical predictions and simulations show a very good agreement

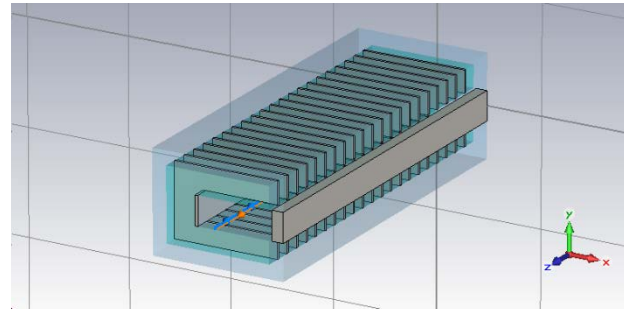
Overview

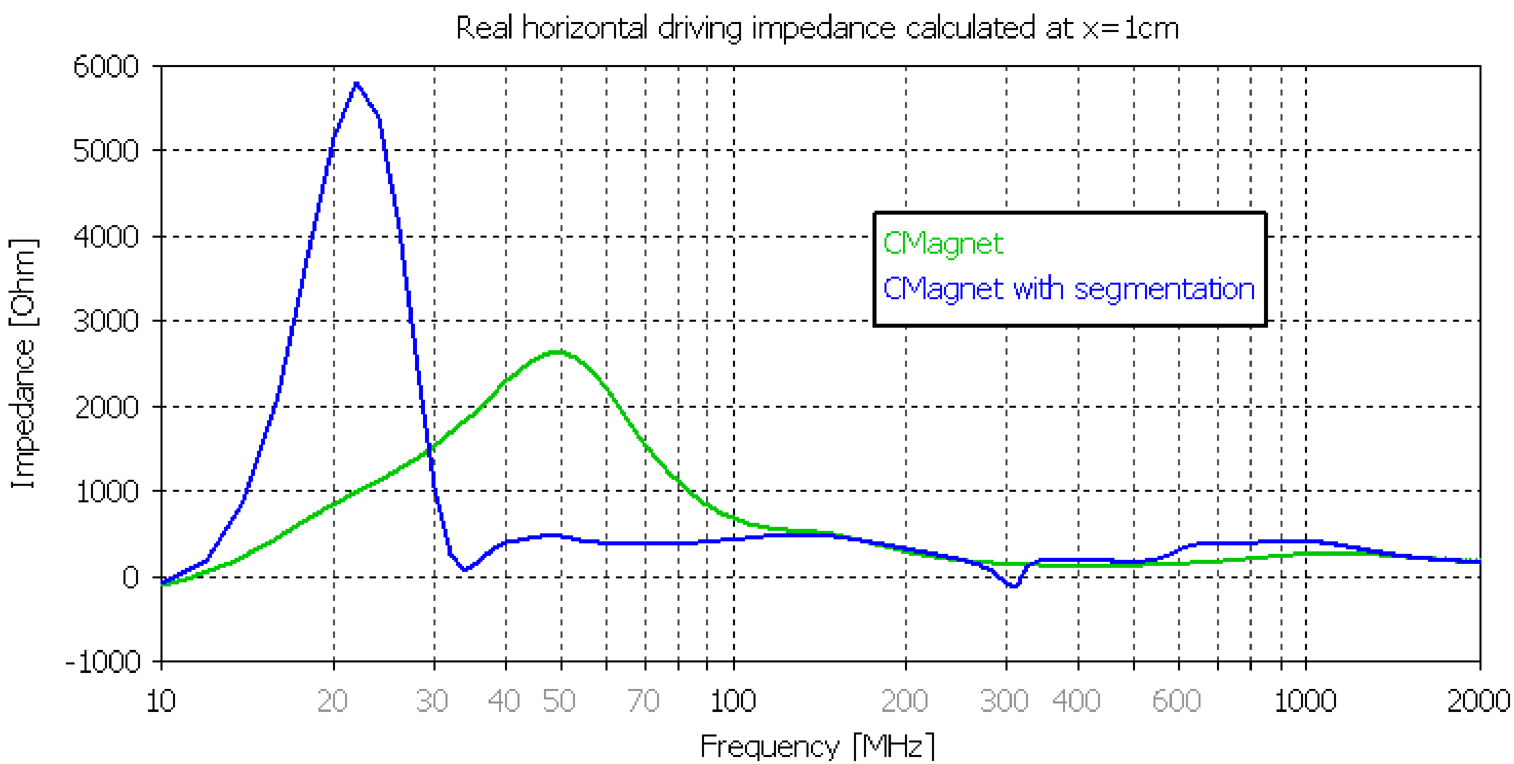
- Updated Status of the SPS impedance model

- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

MKP: horizontal transverse impedance

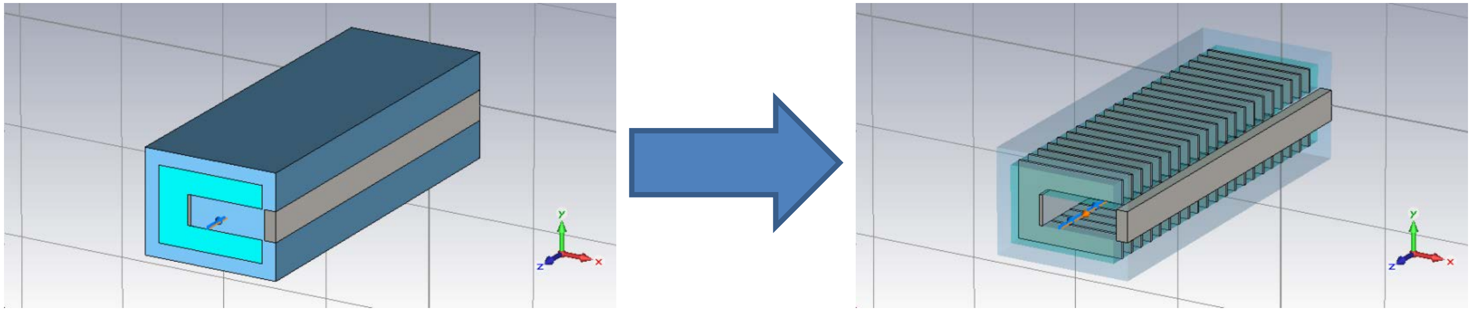


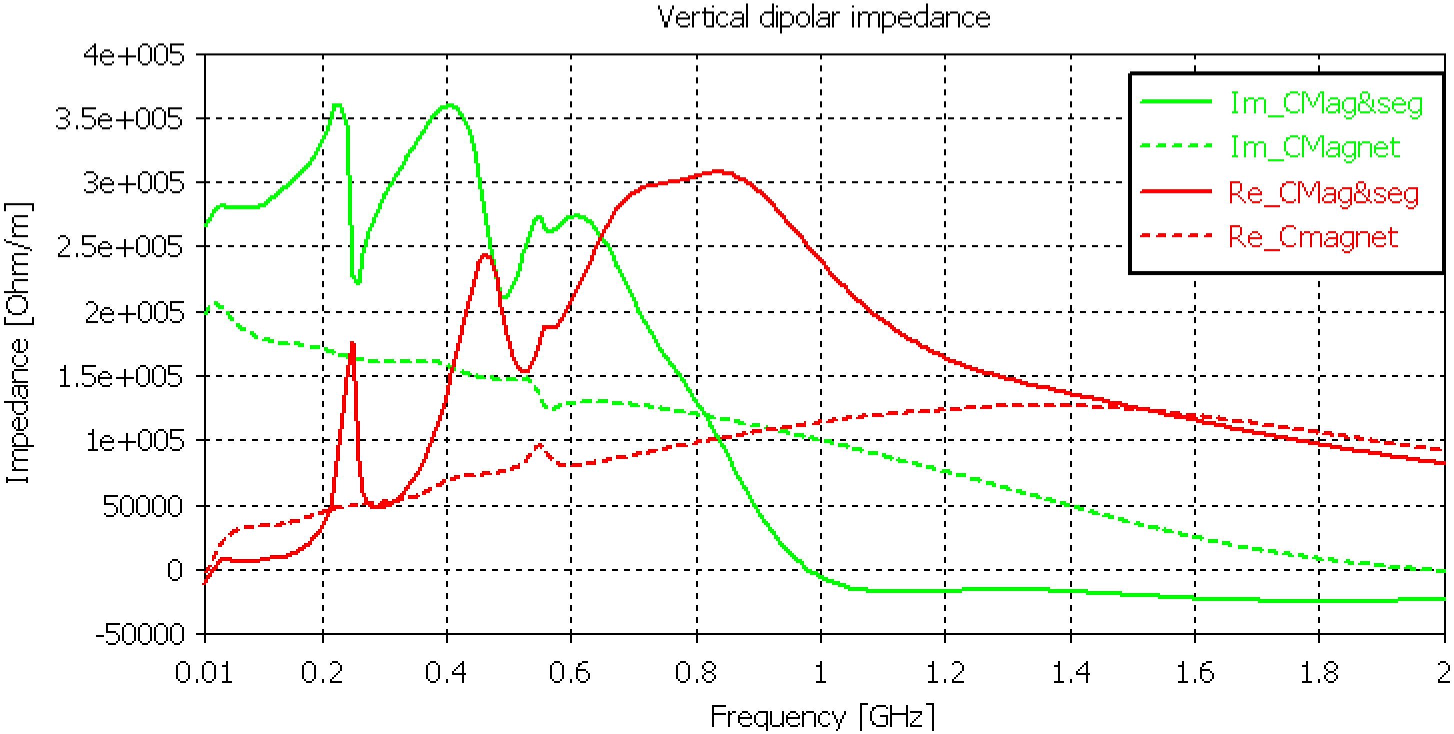




The segmentation seems to affect strongly the TEM peak

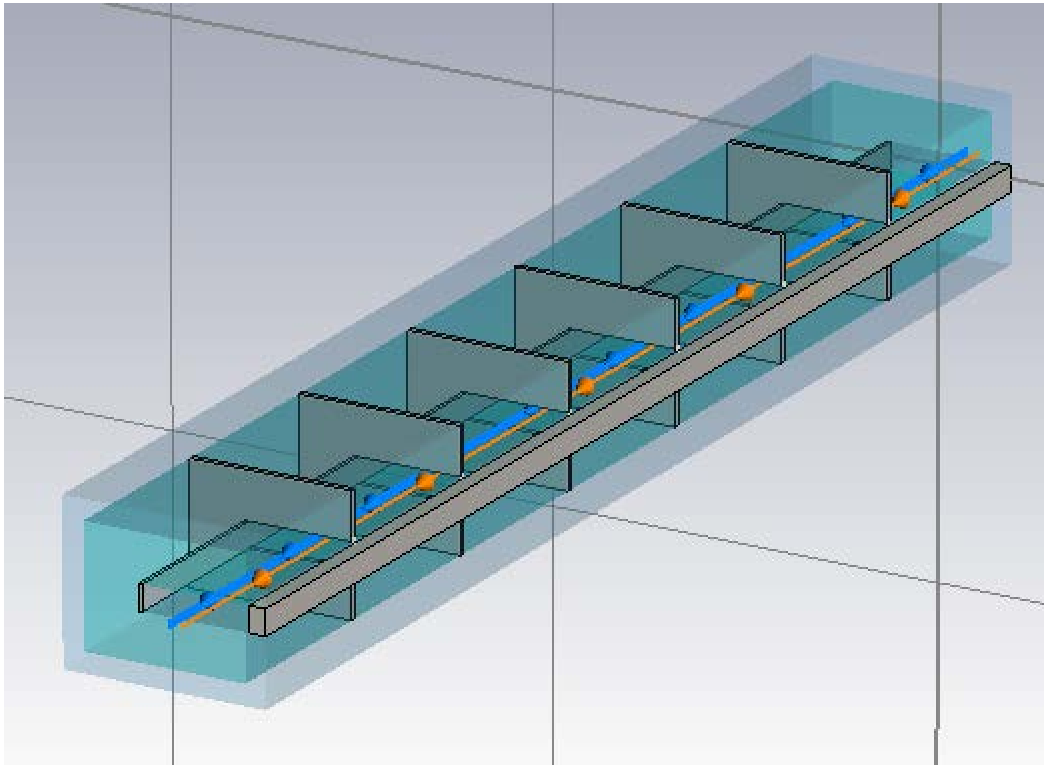
MKP: vertical transverse impedance





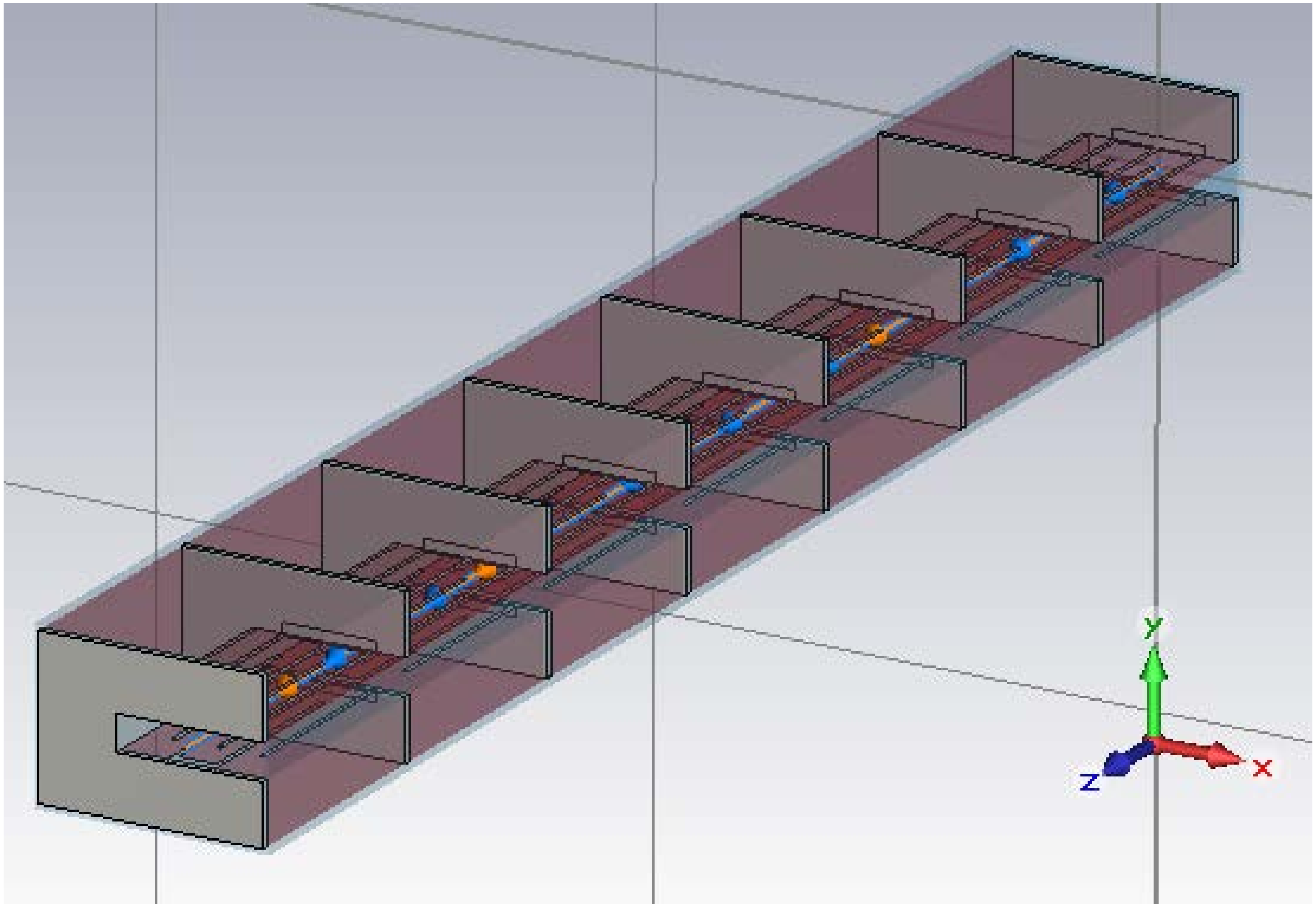
The segmentation has a huge effect on the vertical impedance of the MKP

MKE kickers

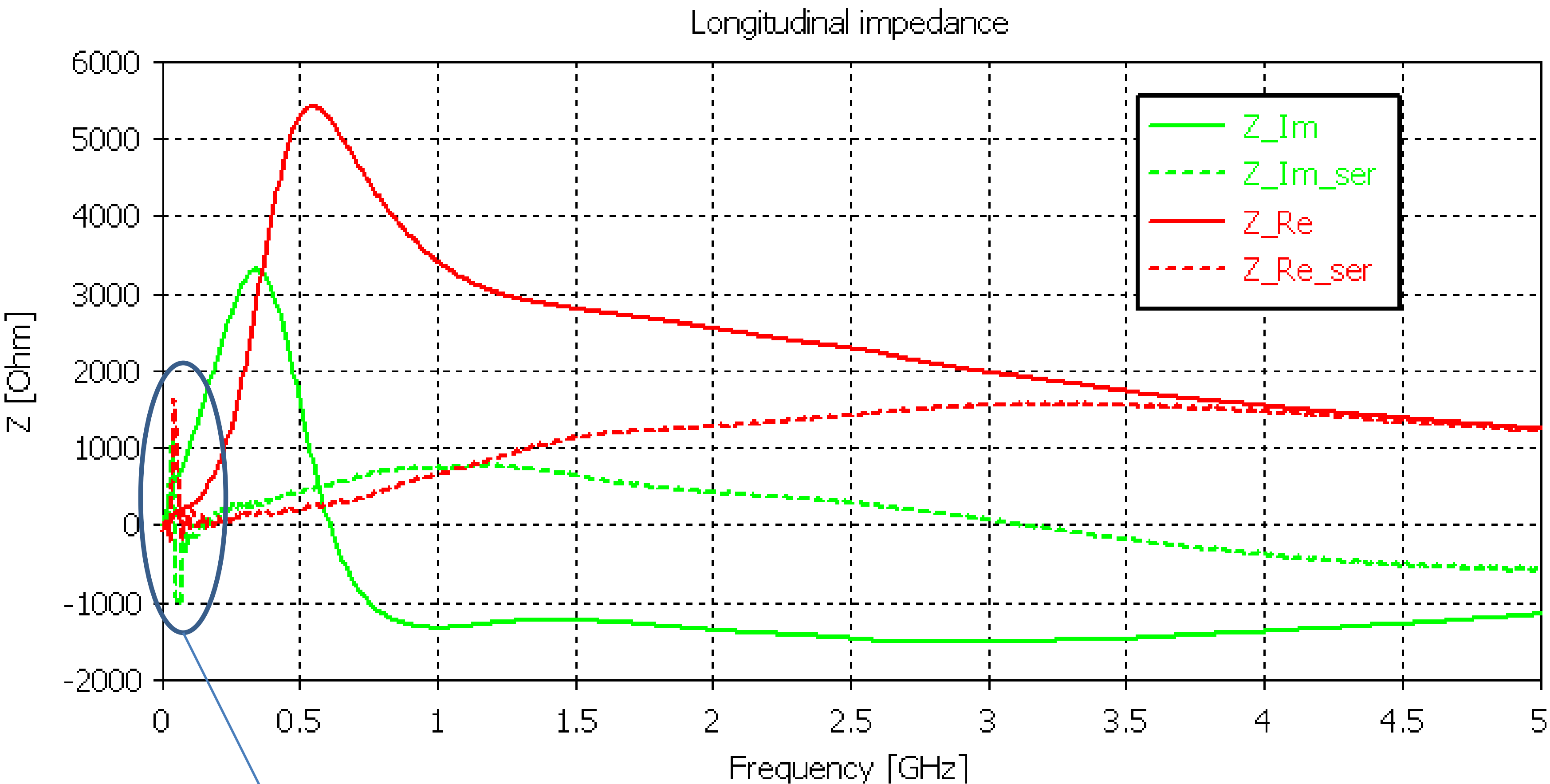


The effect of the segmentation is much less dramatic for the MKE

MKE kicker with serigraphy



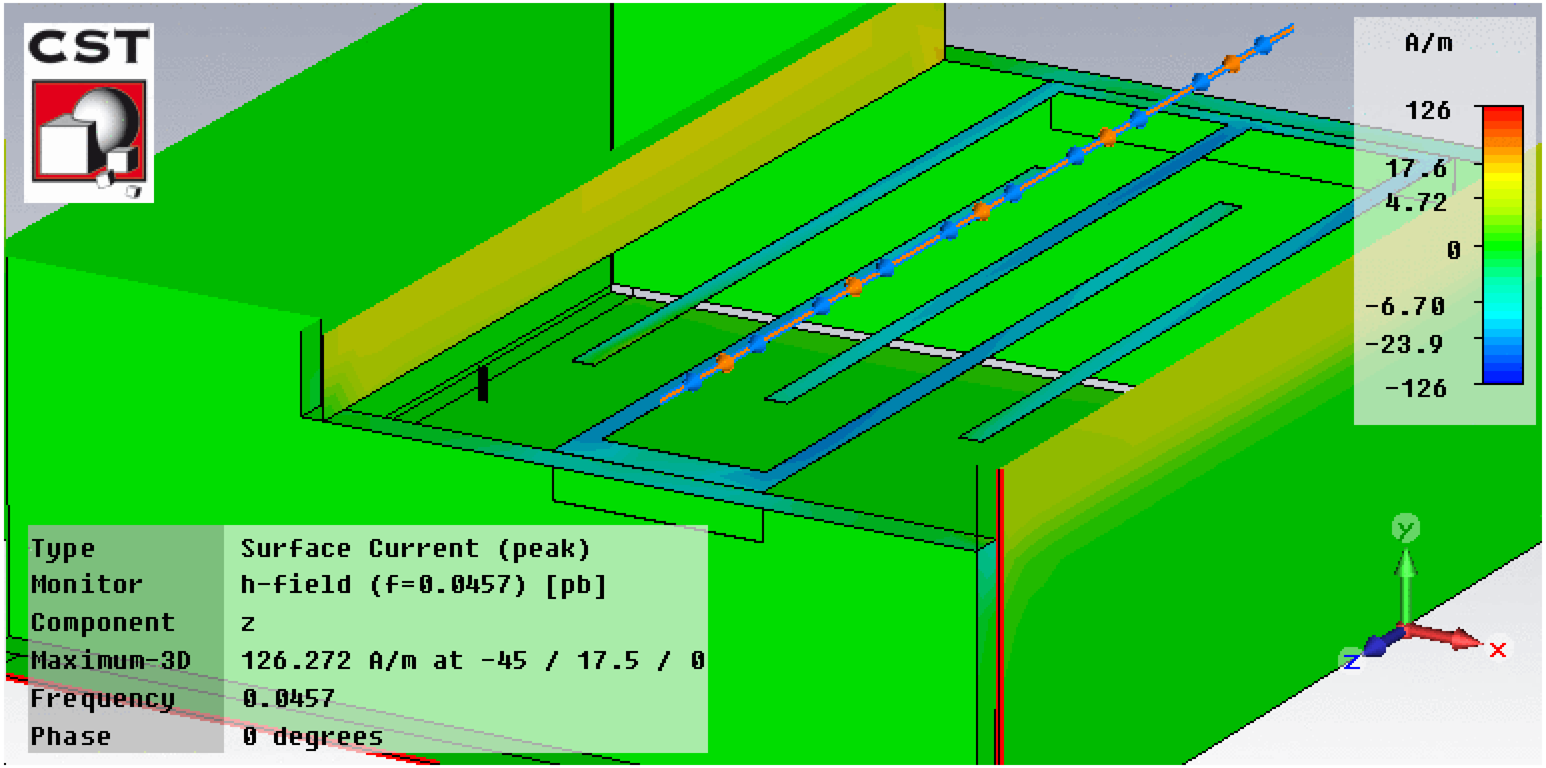
Comparing MKE with and without serigraphy



f=45 MHz

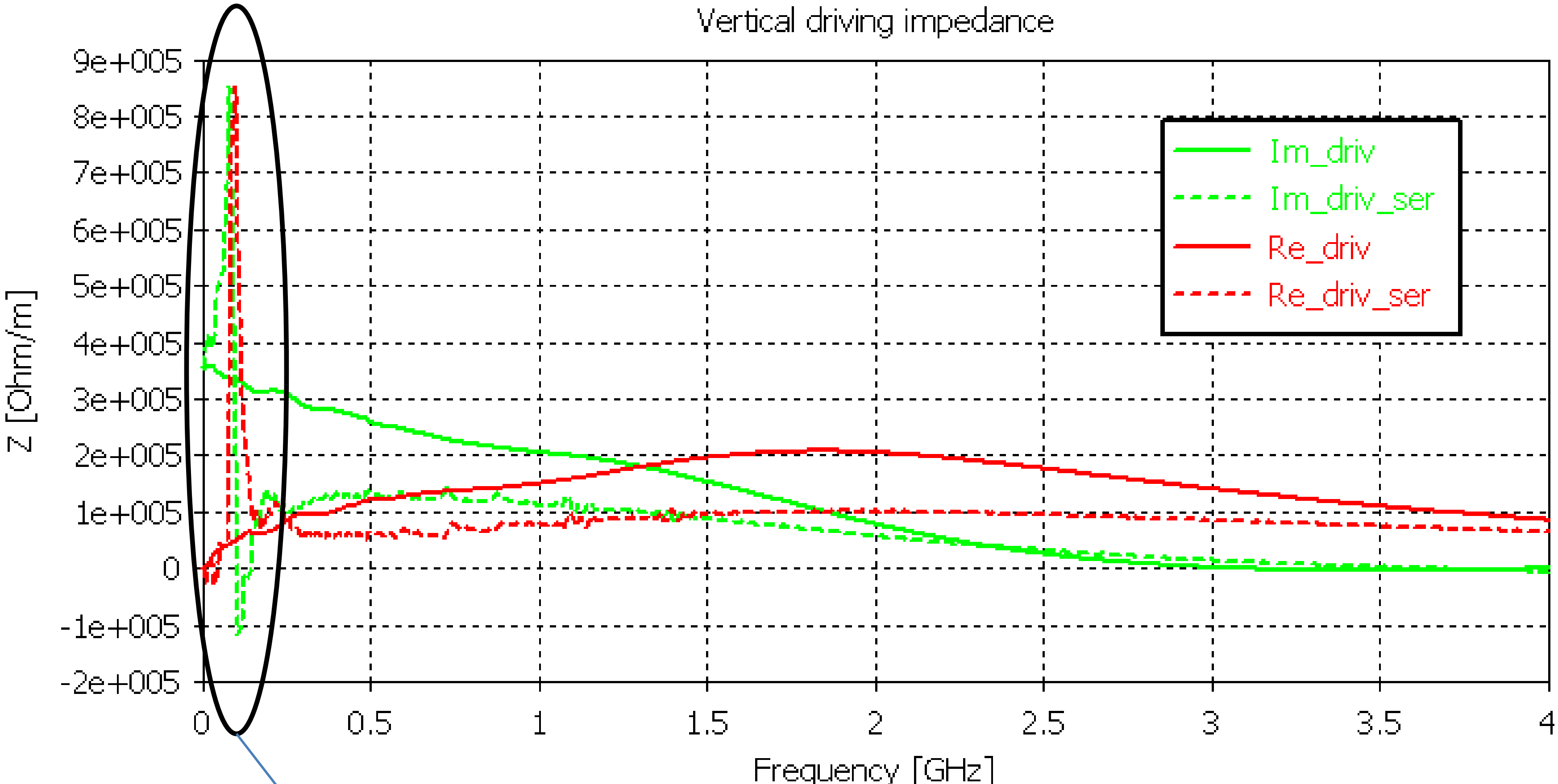
$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}\,\mu_{eff}}} \cong 0.78\ m \cong 4L_{finger}$$

Comparing MKE with and without serigraphy



The simulation of the EM fields seems to confirm that we have a quarter-wavelength resonance

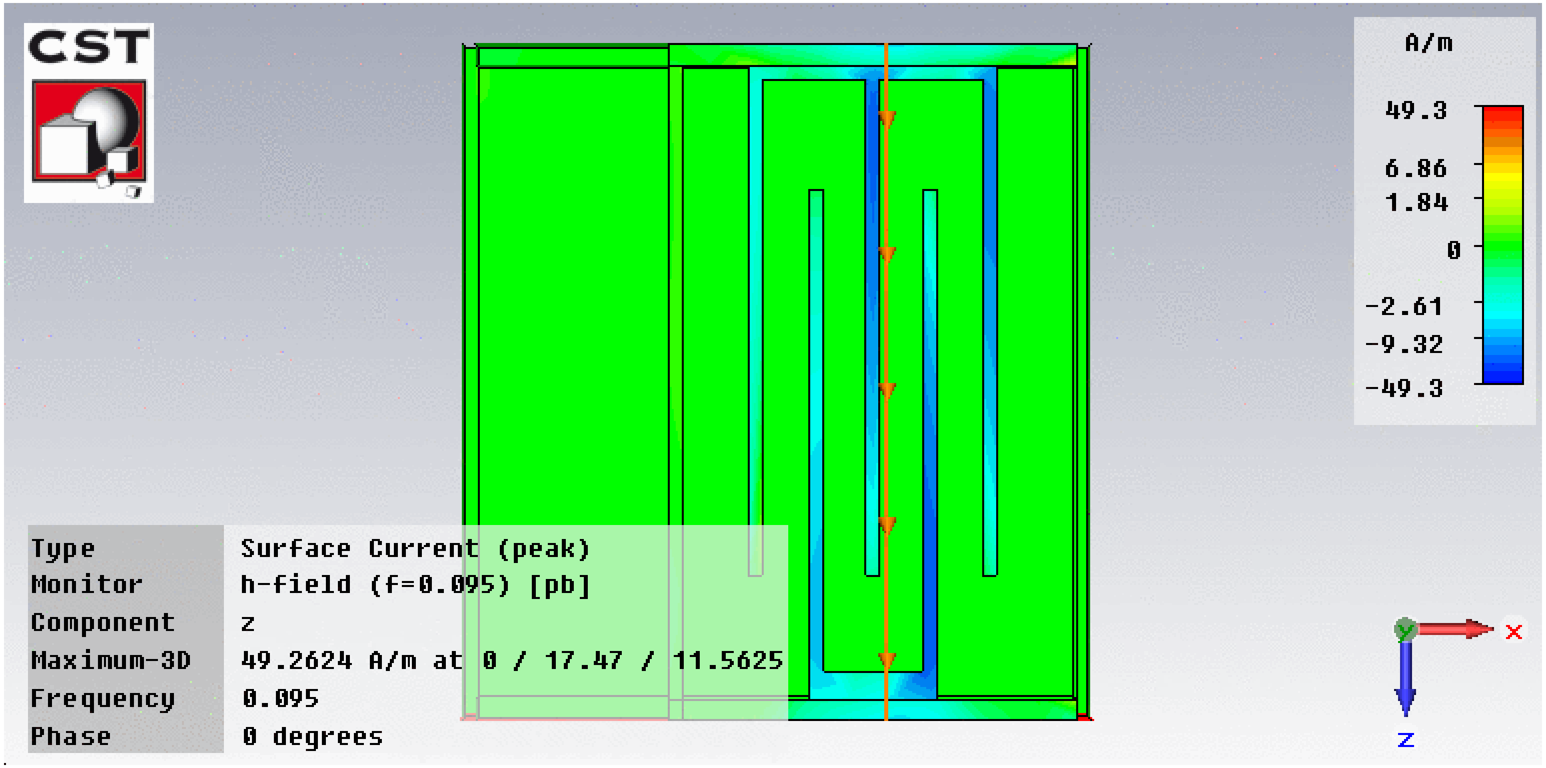
Comparing MKE with and without serigraphy



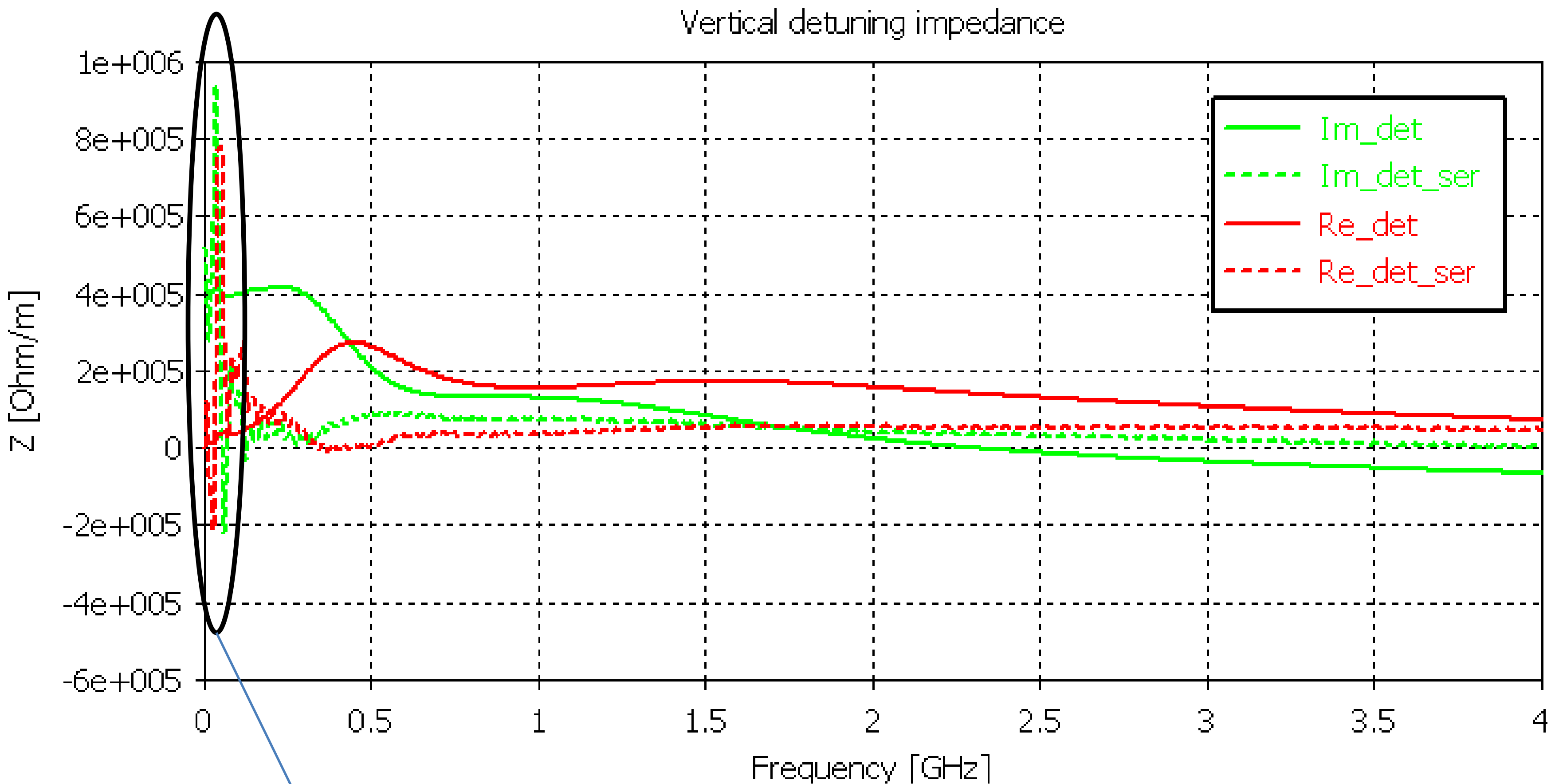
f=95 MHz

A resonance of the same nature appears at a frequency double also in the driving transverse impedance

Comparing MKE with and without serigraphy



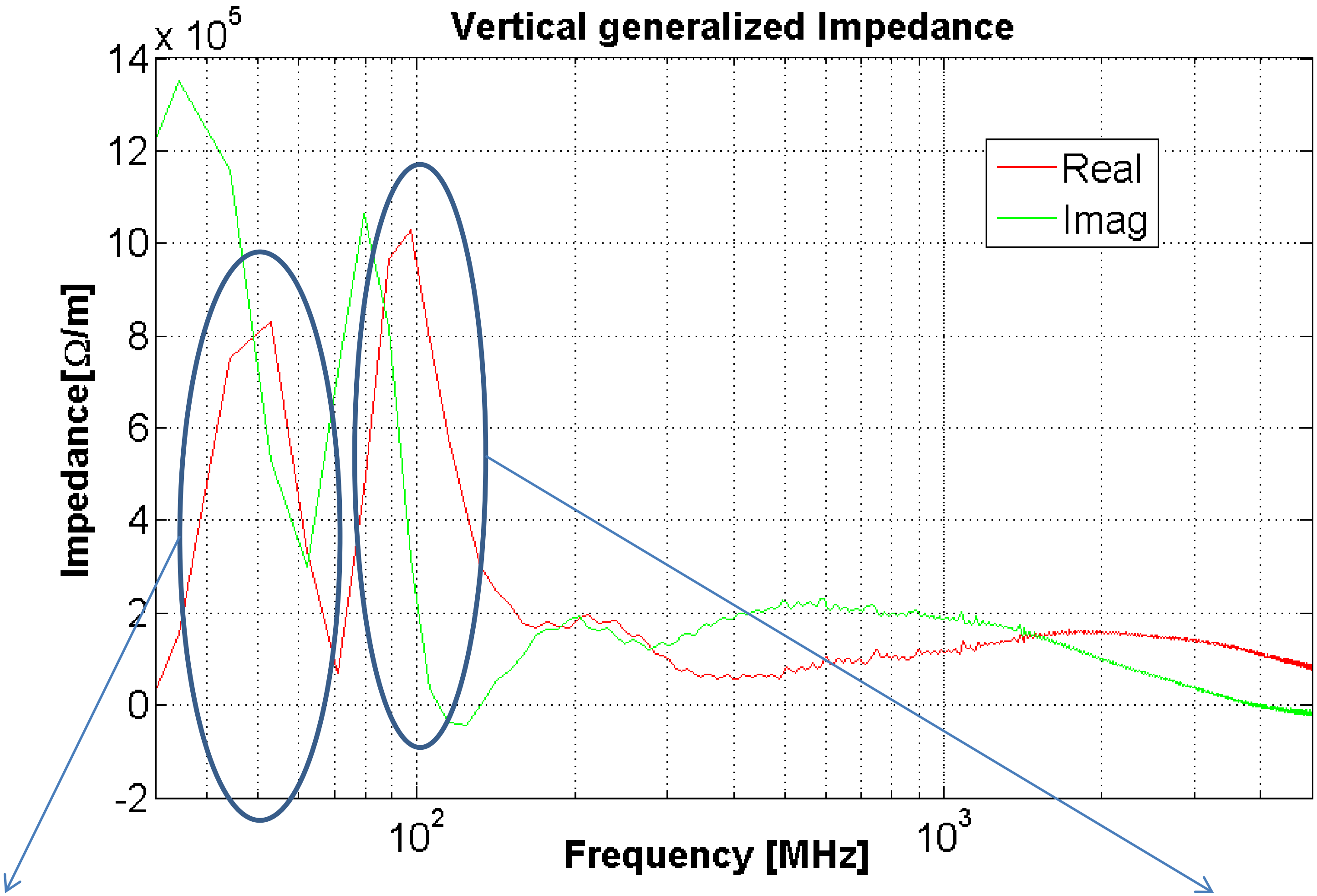
Comparing MKE with and without serigraphy



f=45 MHz

The source is the same as for the longitudinal impedance.

MKE-L with serigraphy

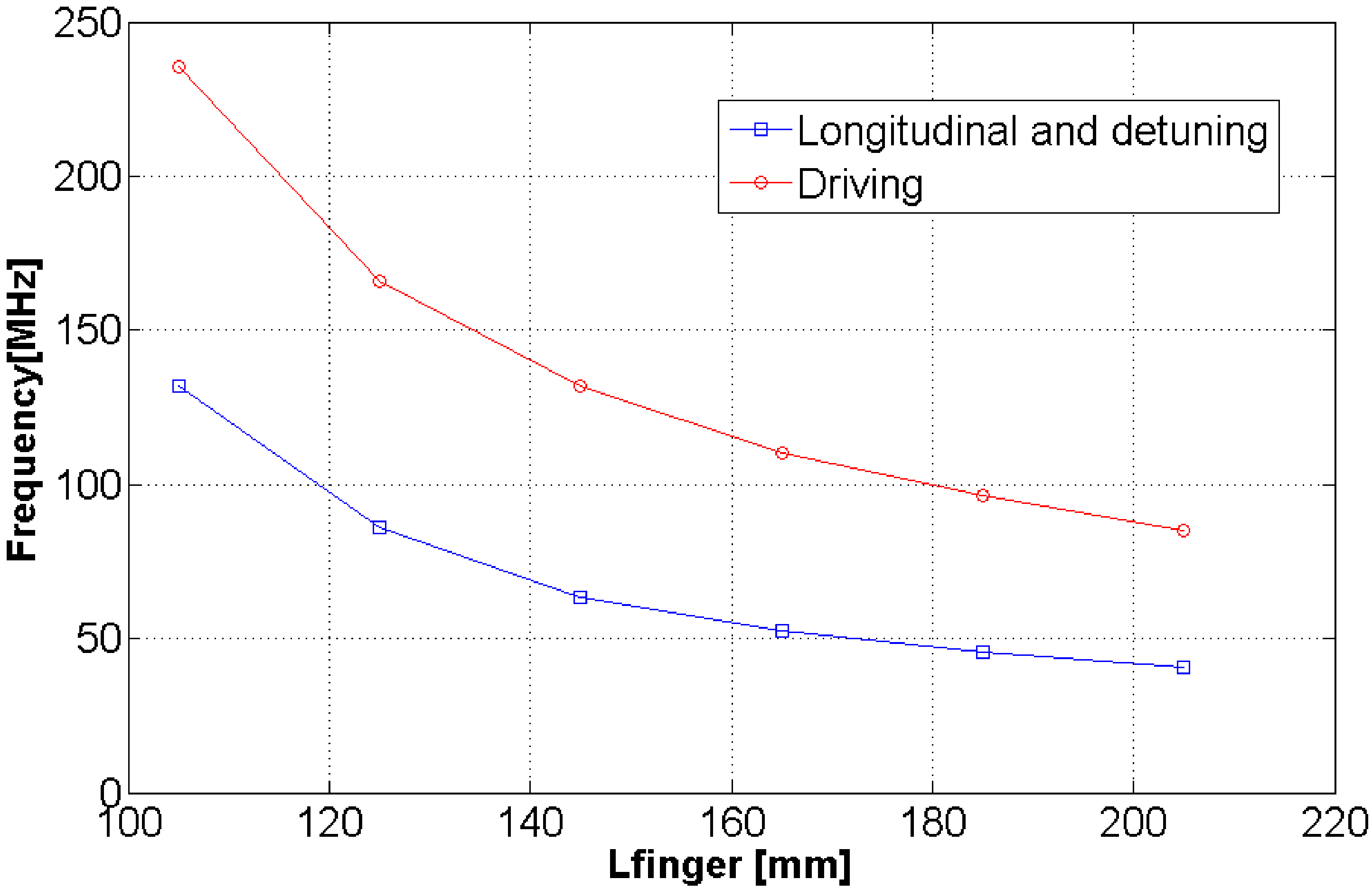


Detuning

Driving

Due to the serigraphy the generalized vertical impedance has two peaks

Frequency peak versus finger length

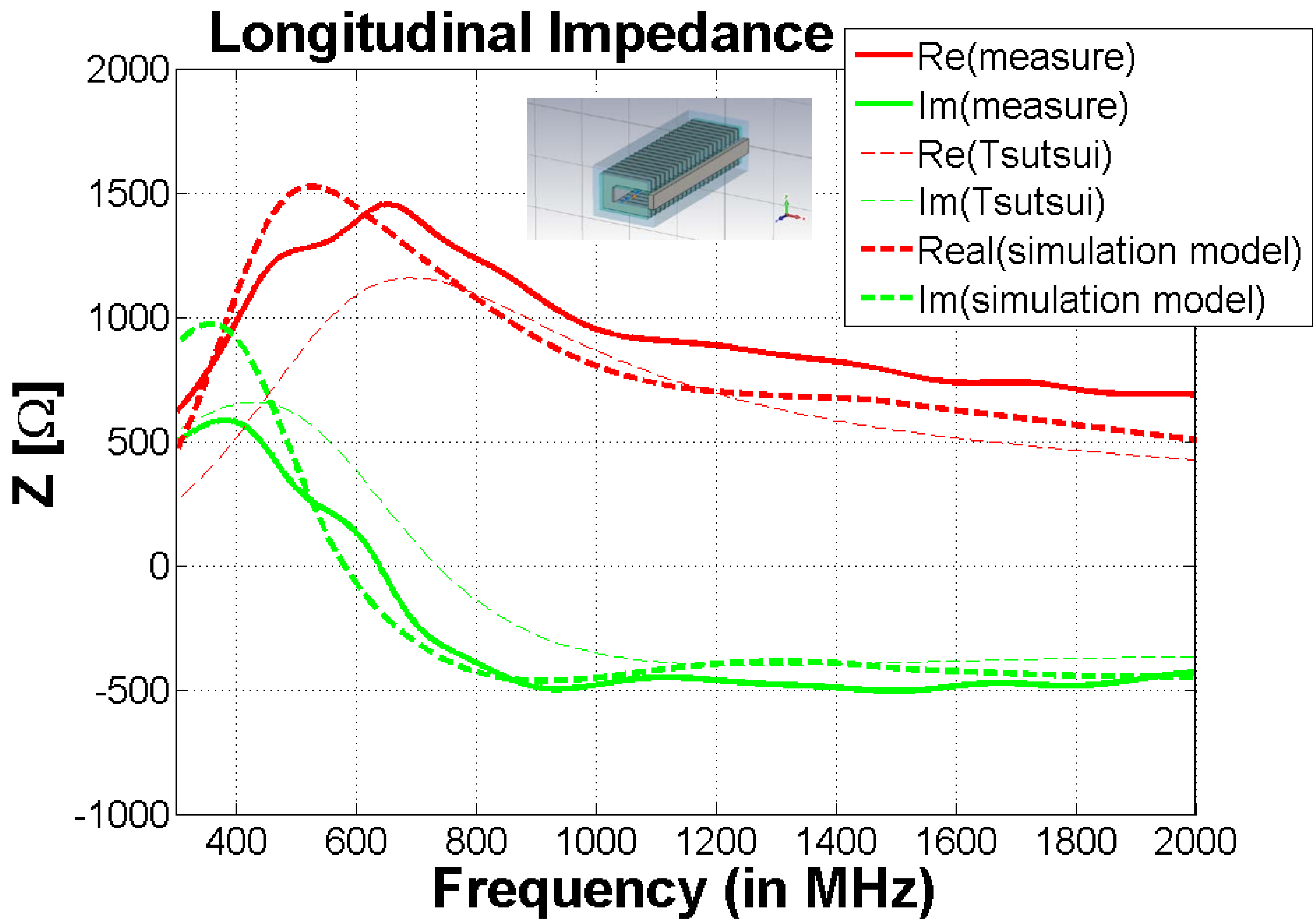


Coherently to what expected the peak strongly depends on the finger length

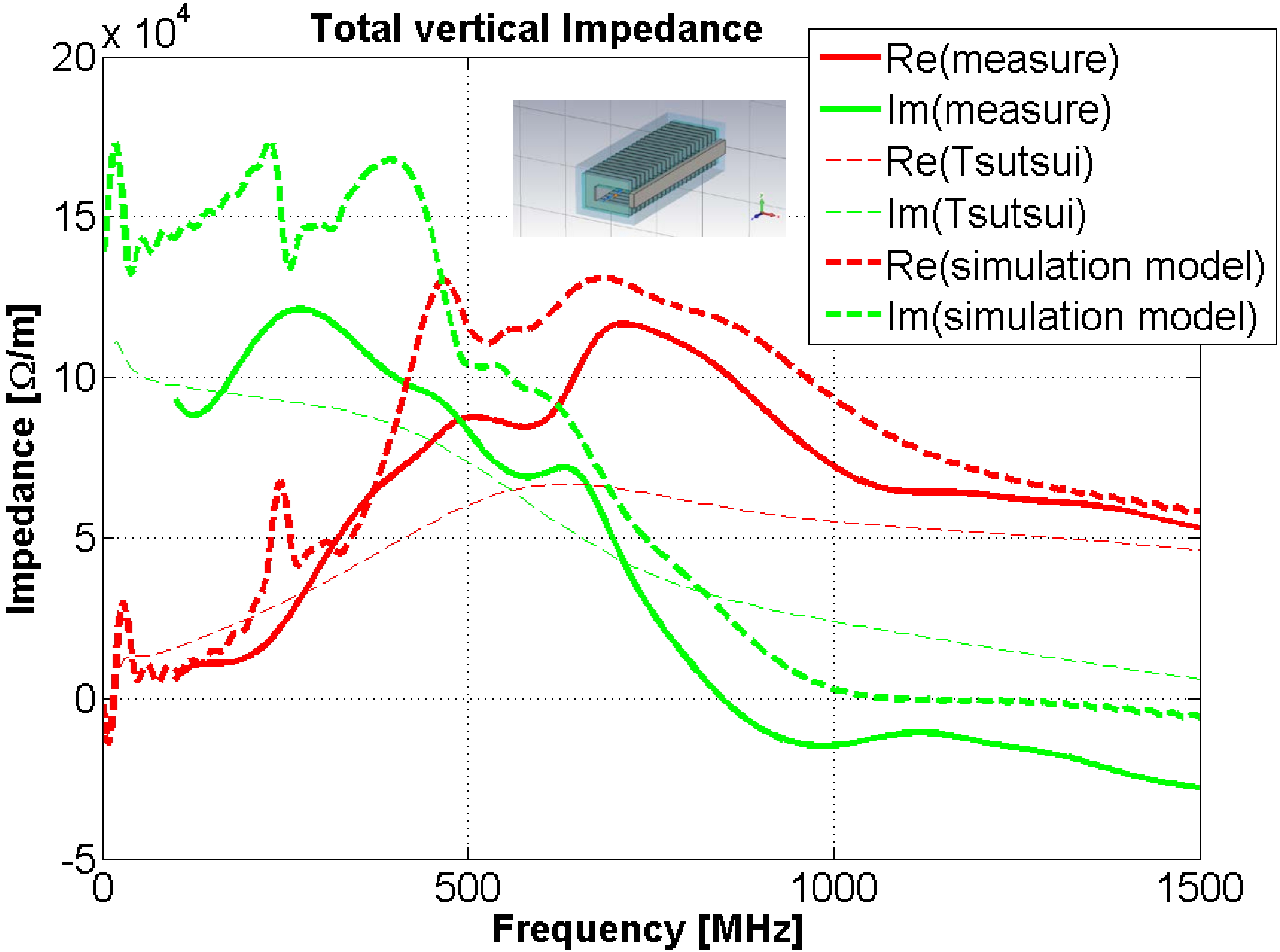
Overview

- Updated Status of the SPS impedance model
- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

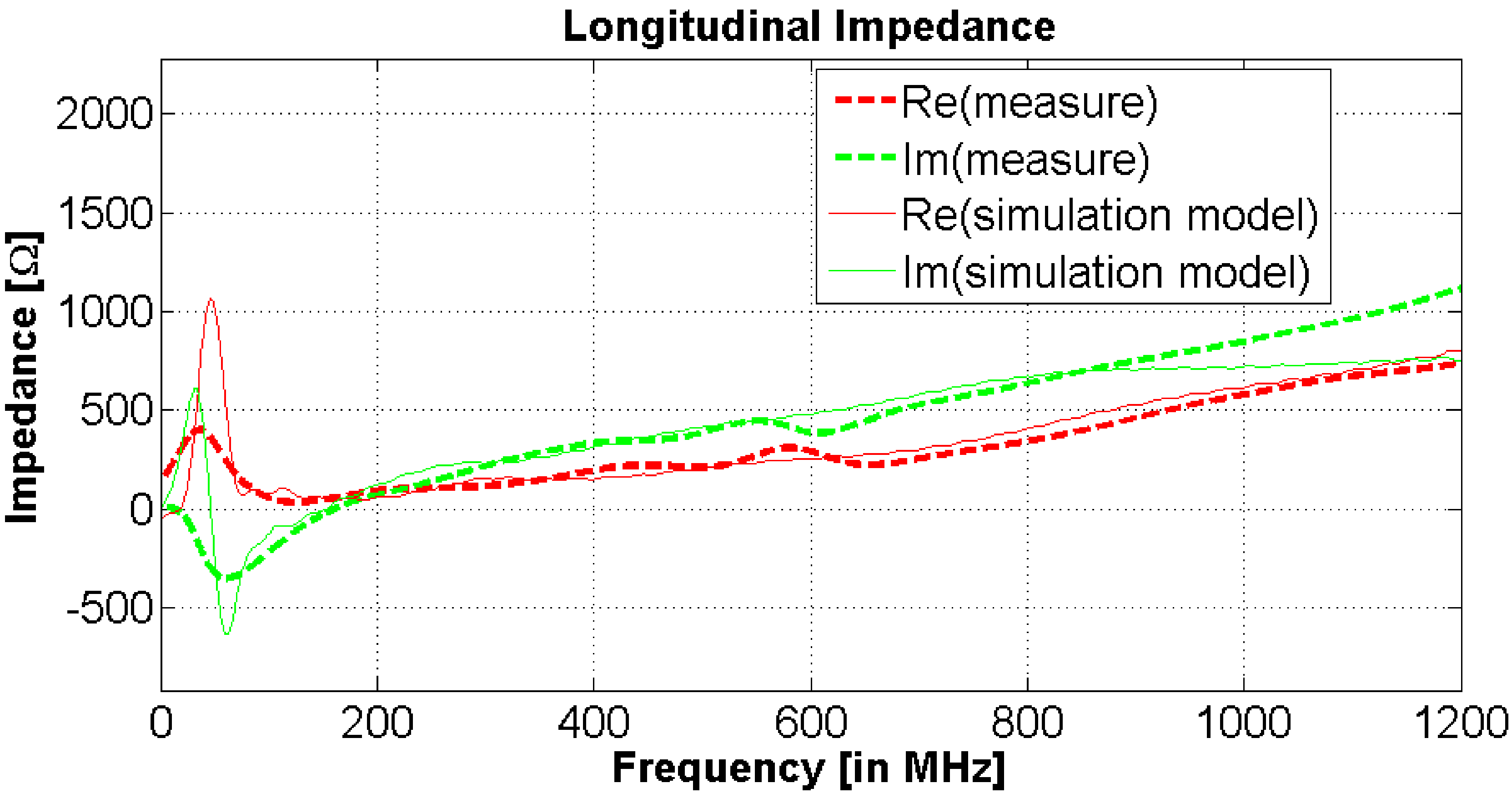
Comparing longitudinal impedance: MKP-L



Comparing total transverse impedance: MKP-L

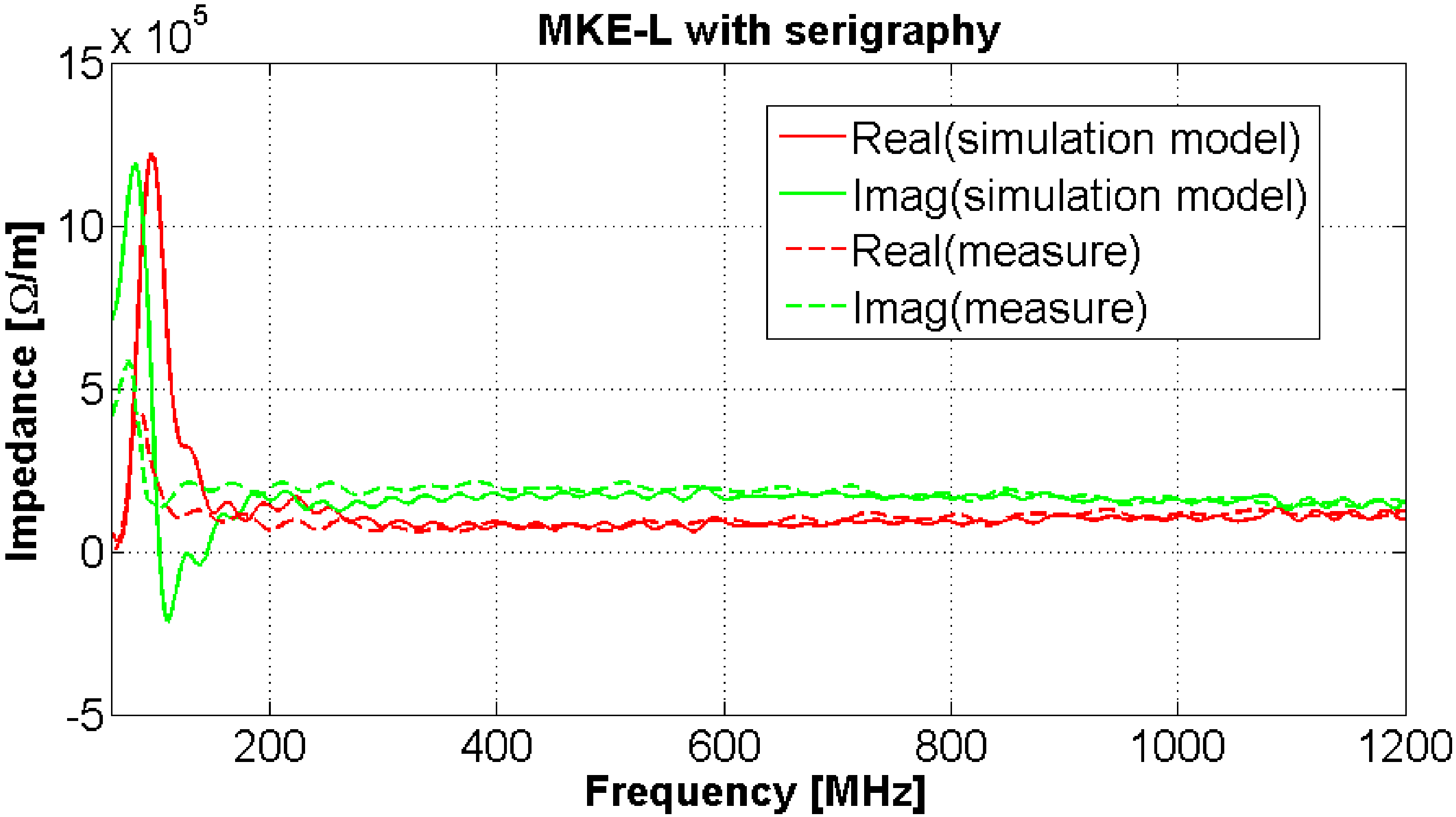


Comparing longitudinal impedance: MKE-L with serigraphy



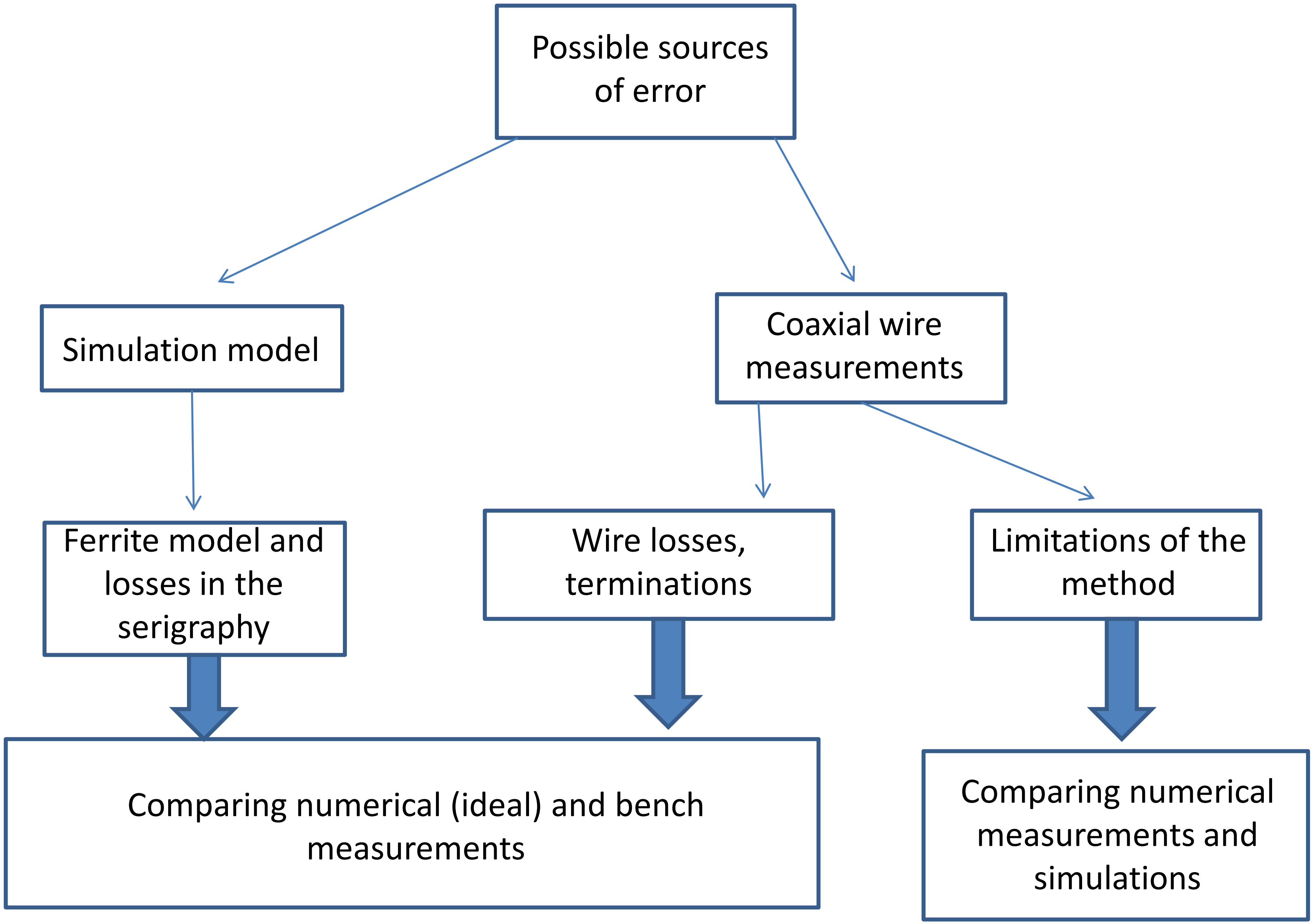
Good agreement except a difference on the low frequency resonance

Comparing longitudinal impedance: MKE-L with serigraphy

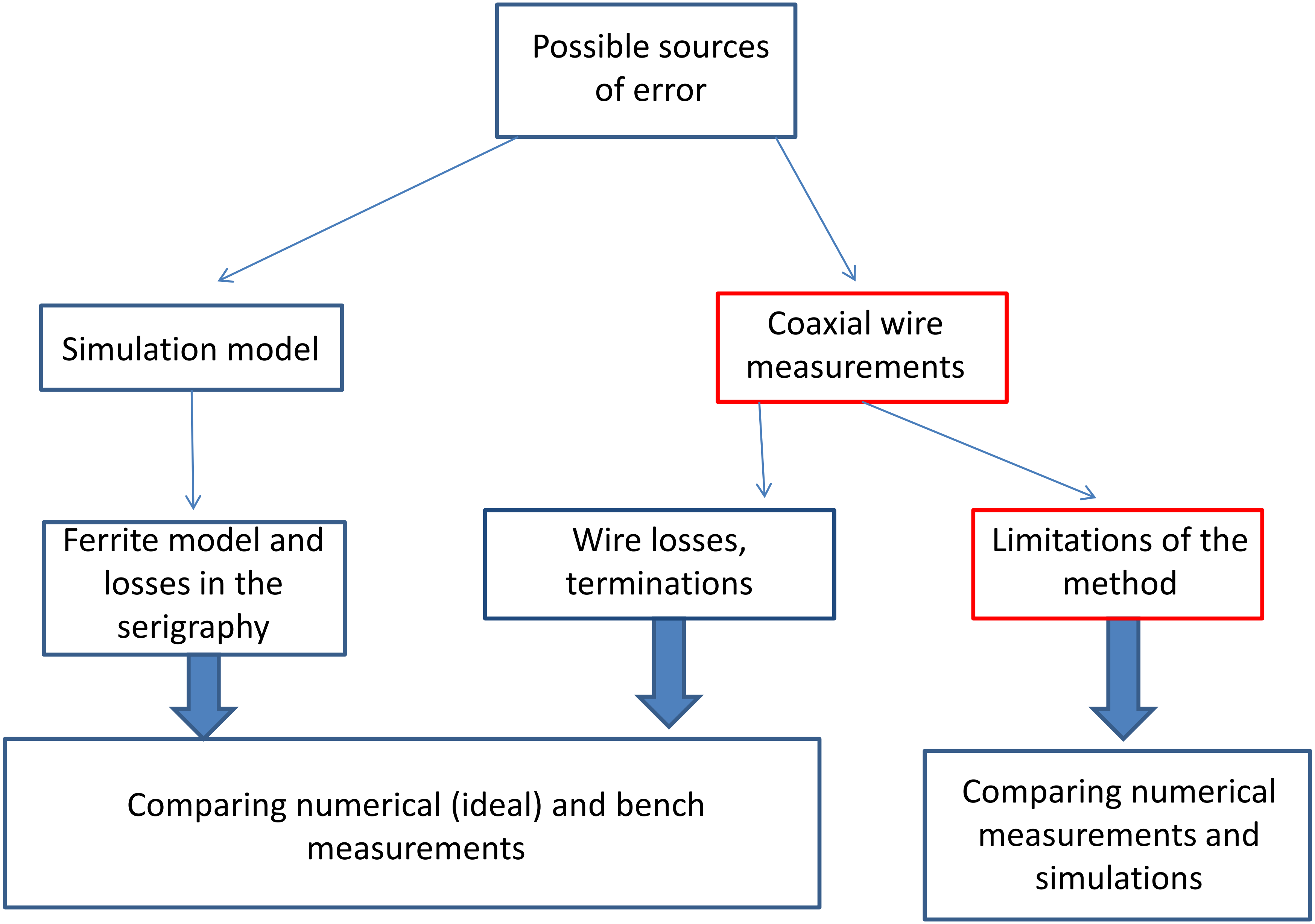


Good agreement except a difference on the low frequency resonance

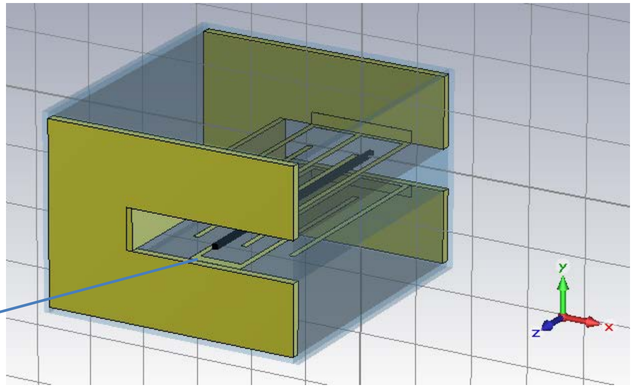
Investigation of the low frequency discrepancy



Investigation of the low frequency discrepancy



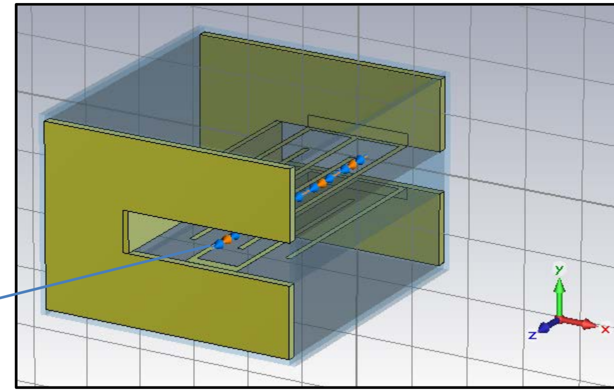
Comparing numerical measurements and simulations



wire

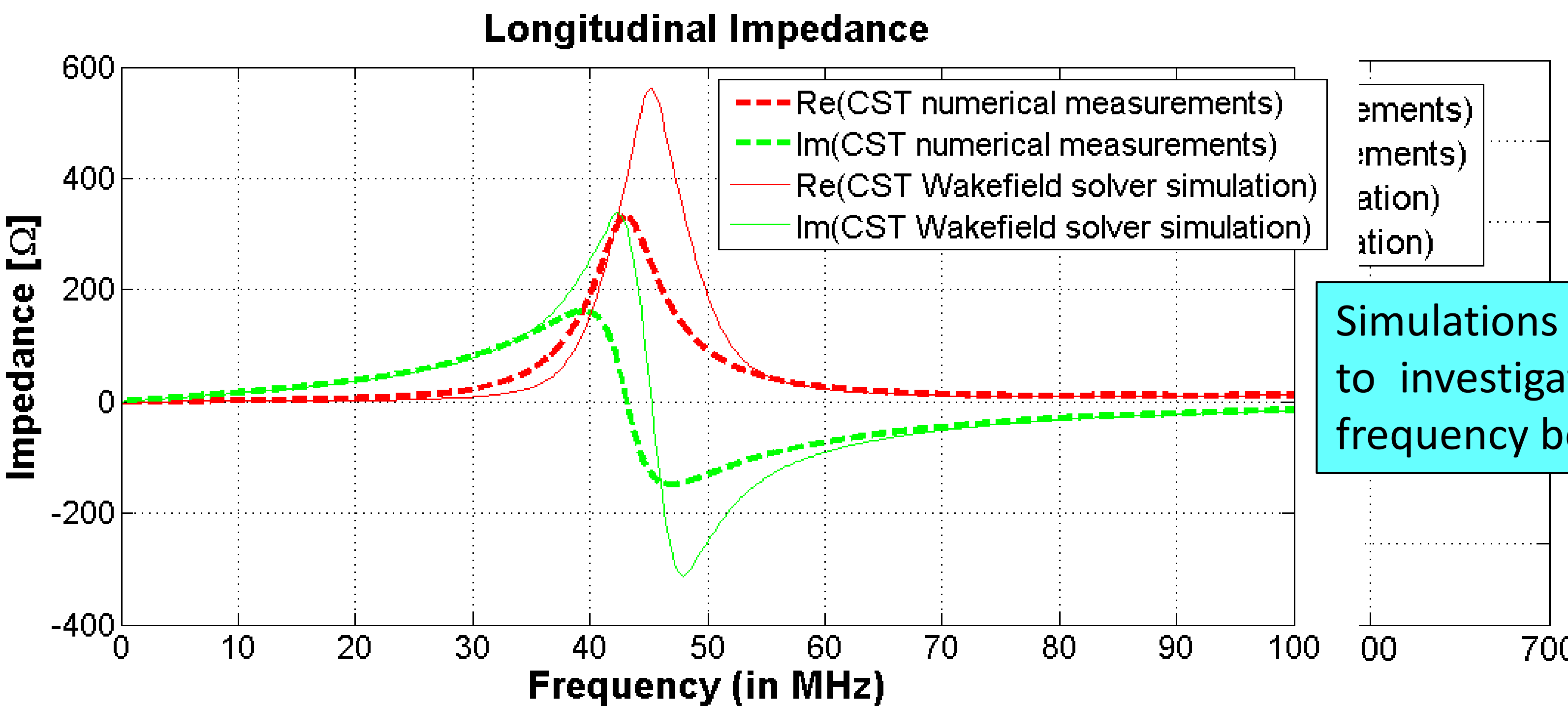
Simulation output: S21 and Zch

$$Z_{||} = -2Z_{ch}\,log\left(\frac{S_{21}}{S_{REF}}\right) \qquad S_{REF} = e^{-j\frac{2\pi fL}{c}}$$



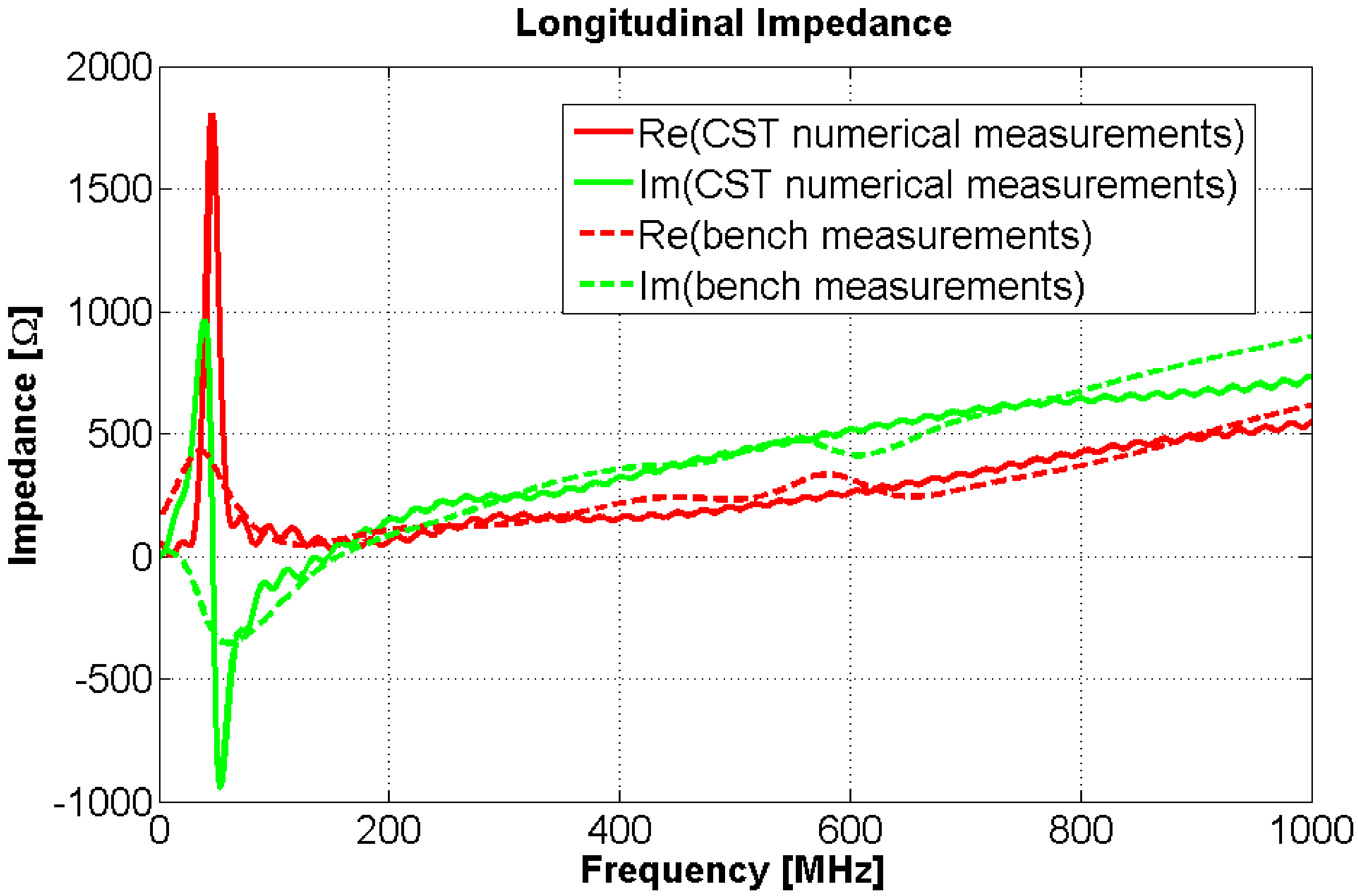
beam

Simulation output: Impedance



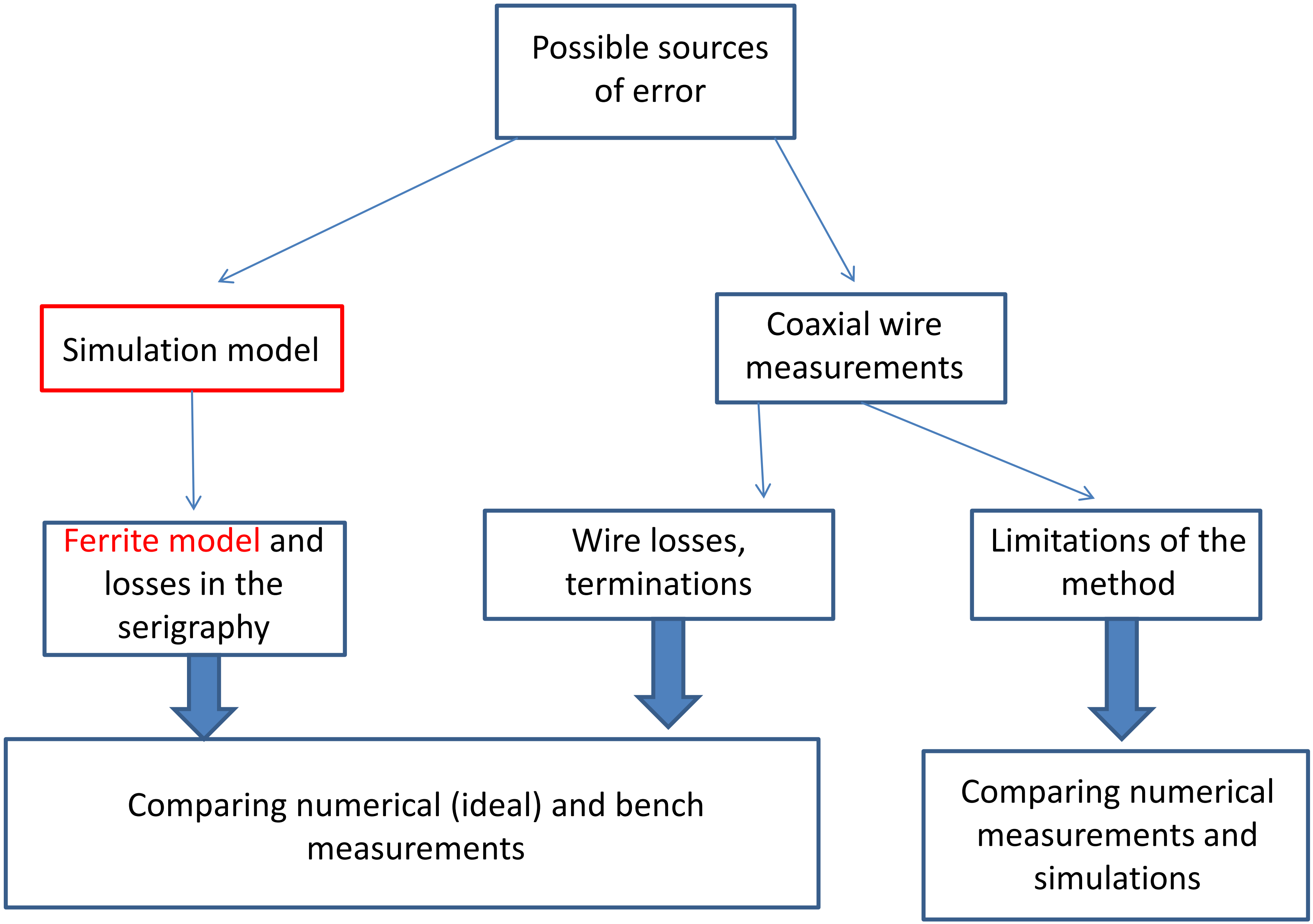
Simulations optimized to investigate the low frequency behaviour

Comparing numerical and bench measurements

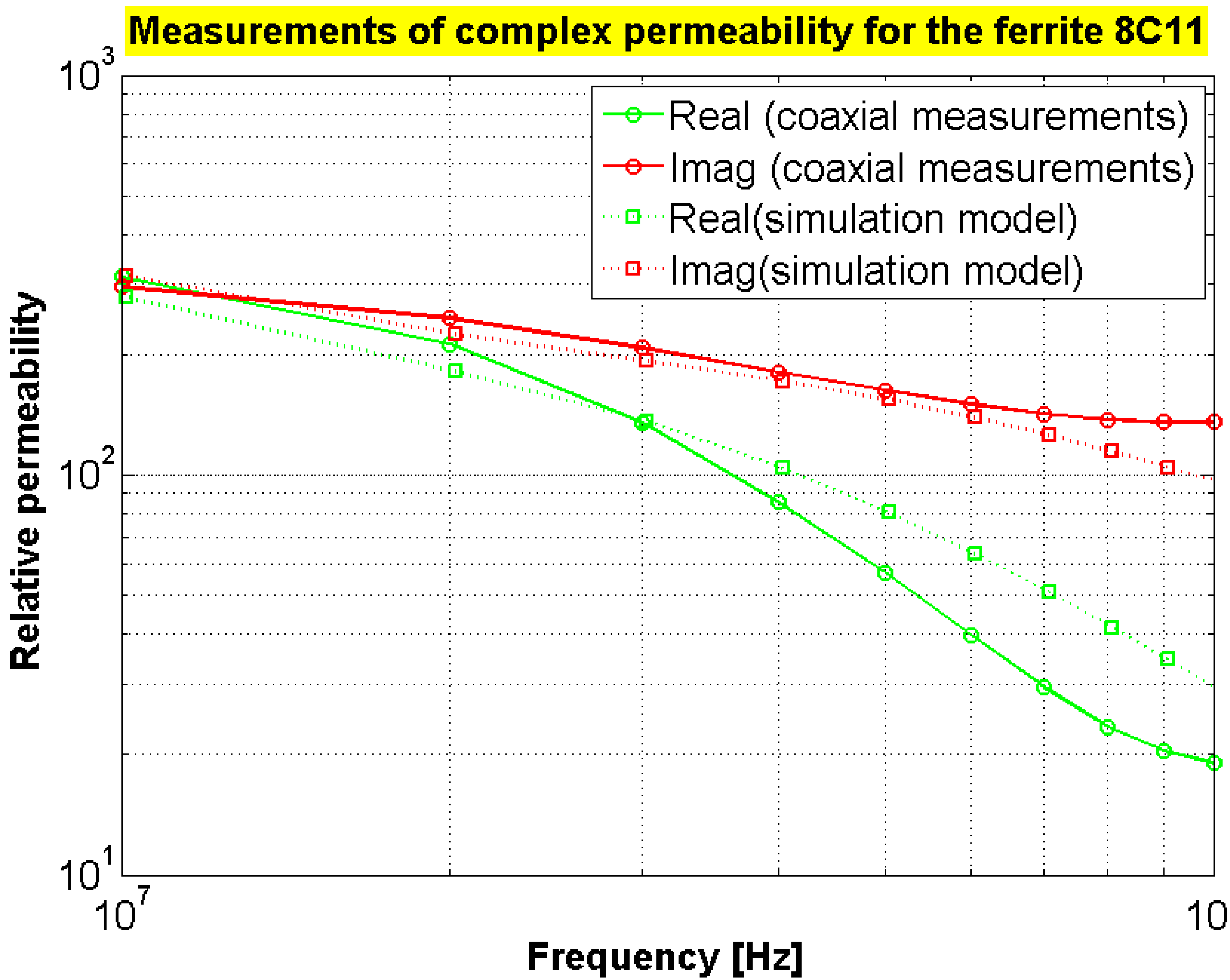


Bench and numerical measurements show a good agreement above a certain frequency but are quite different in the low frequency peak probably due to additional losses in the real setup

Investigation of the low frequency discrepancy



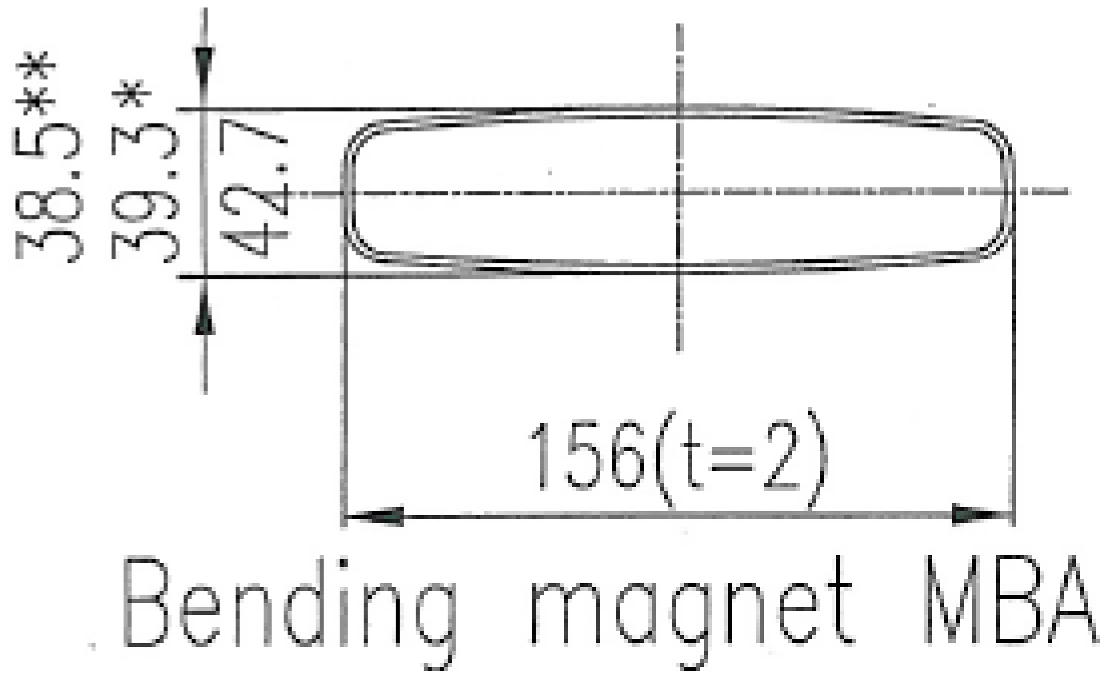
Ferrite permeability model



Overview

- Status of the SPS impedance model
- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

Status of the SPS wall Impedance

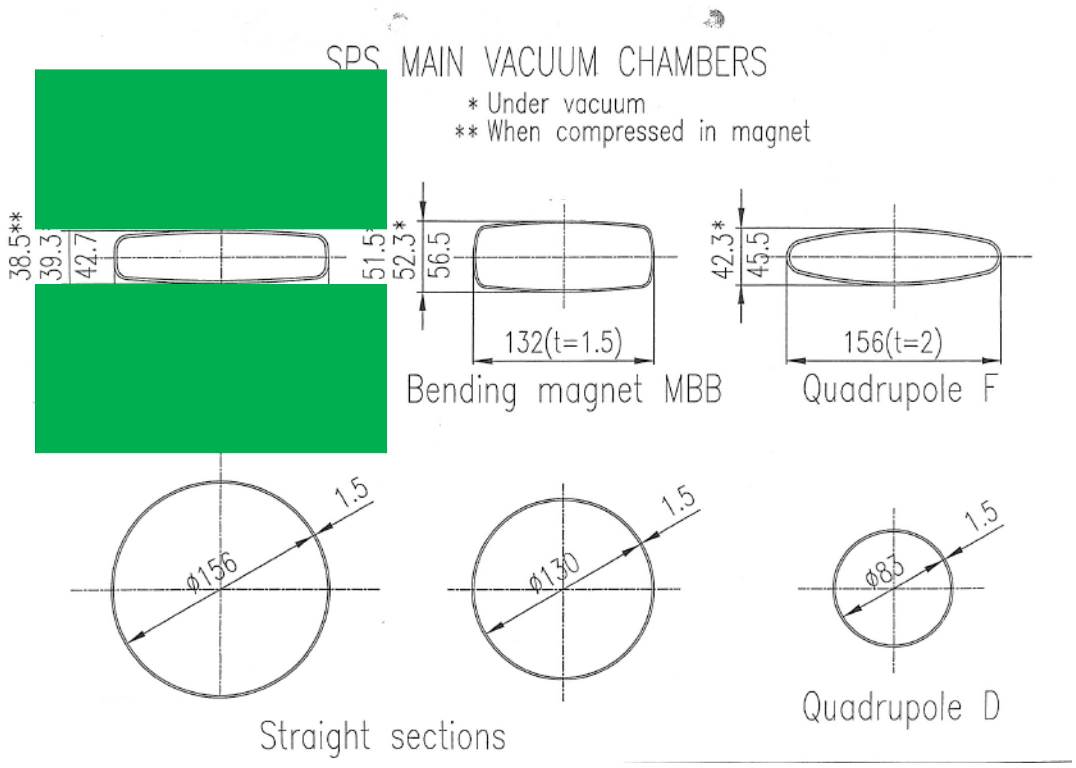


6.911 km beam pipe (Zotter/Metral analytical calculations for a round pipe of 20mm radius including indirect space charge, transformed with Yokoya factor)

Overview

- Status of the SPS impedance model
- Improvement of the model
  - Kicker impedance model
    - Status of the SPS kicker impedance model
    - Improvement of the model
      - C-Magnet model
      - Realistic models
      - Comparisons with bench impedance measurements
  - Resistive wall impedance
    - Status of the SPS wall impedance model
    - A more realistic model

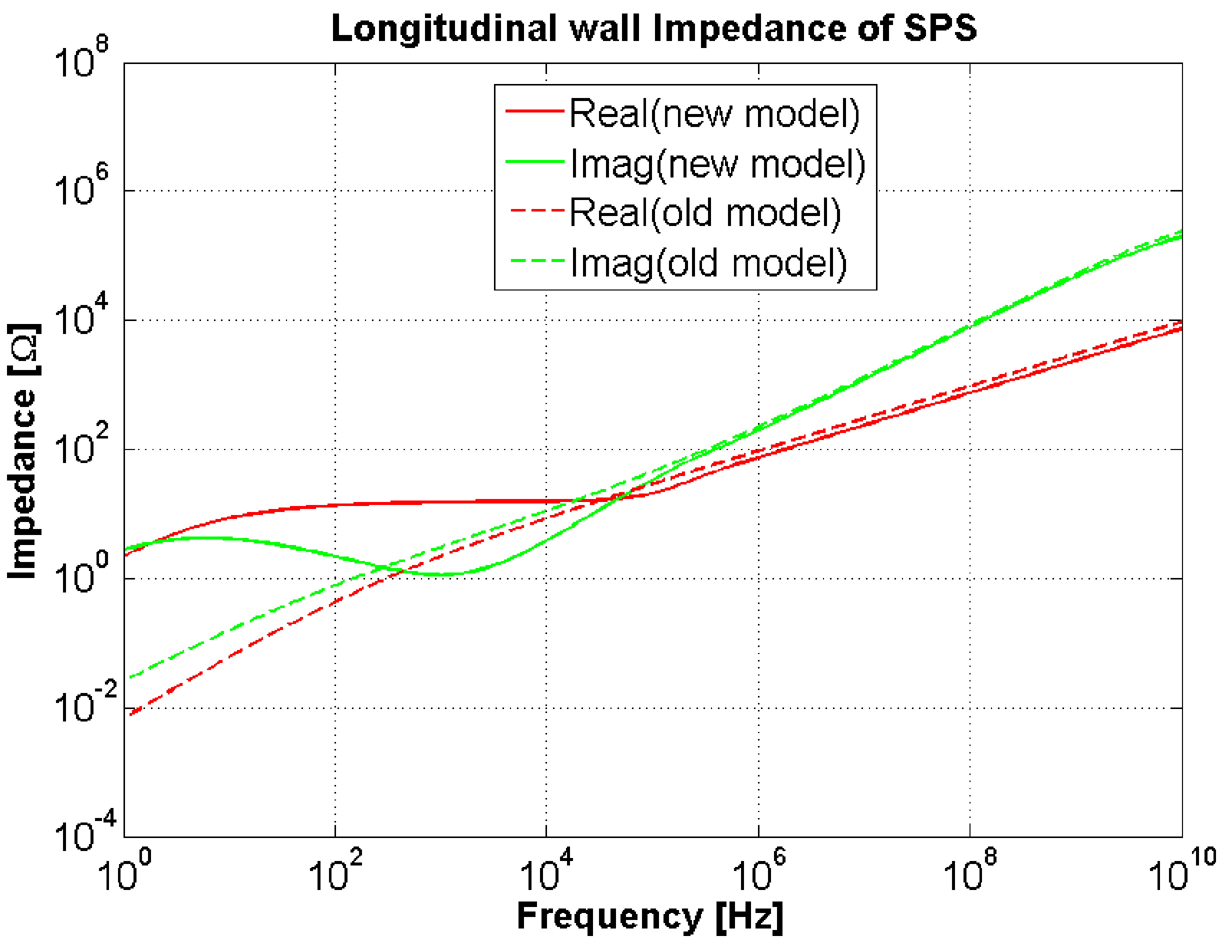
Improvement of the model



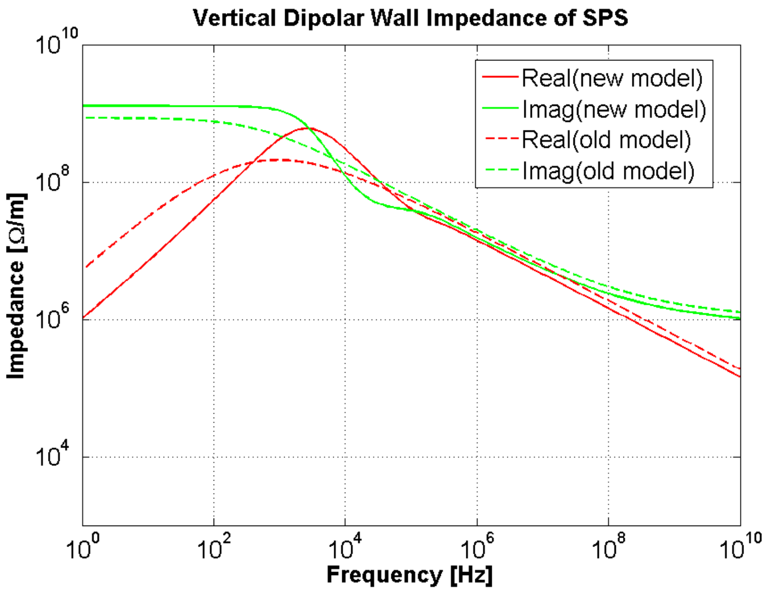
$$Z_x = \frac{1}{\langle \beta_x \rangle} \sum_{i=1}^{6} Z_{xi} L_i \langle \beta_{xi} \rangle \qquad Z_y = \frac{1}{\langle \beta_y \rangle} \sum_{i=1}^{6} Z_{yi} L_i \langle \beta_{yi} \rangle \qquad Z_l = \sum_{i=1}^{6} Z_{li} L_i$$

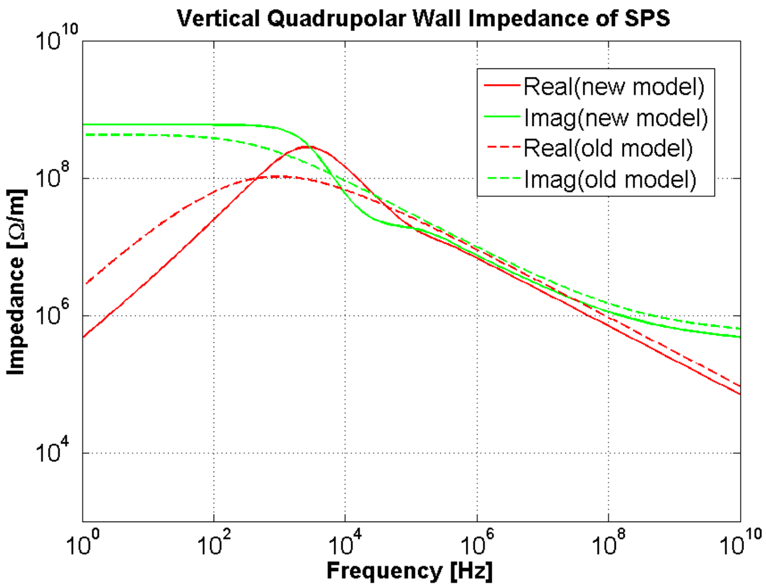
1. Different vacuum chambers weighted by the respective length and beta function
2. The iron in the magnets is also taken into account

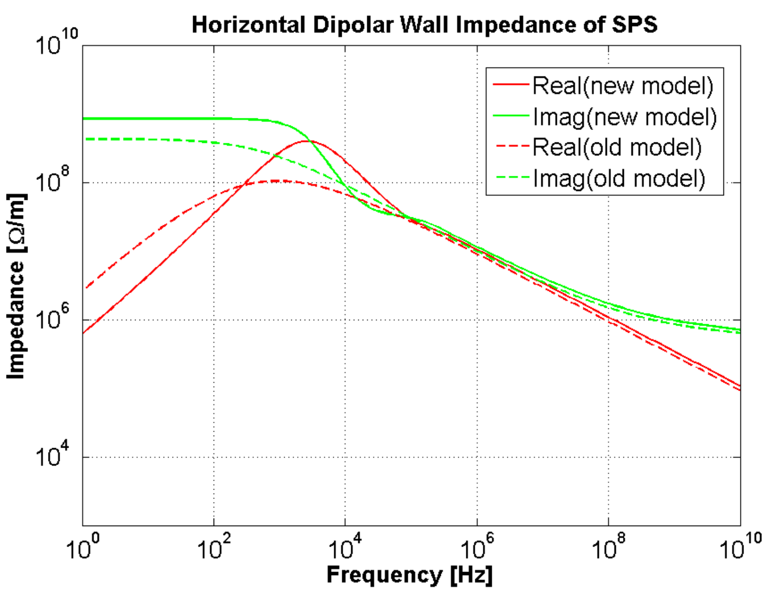
Longitudinal Impedance

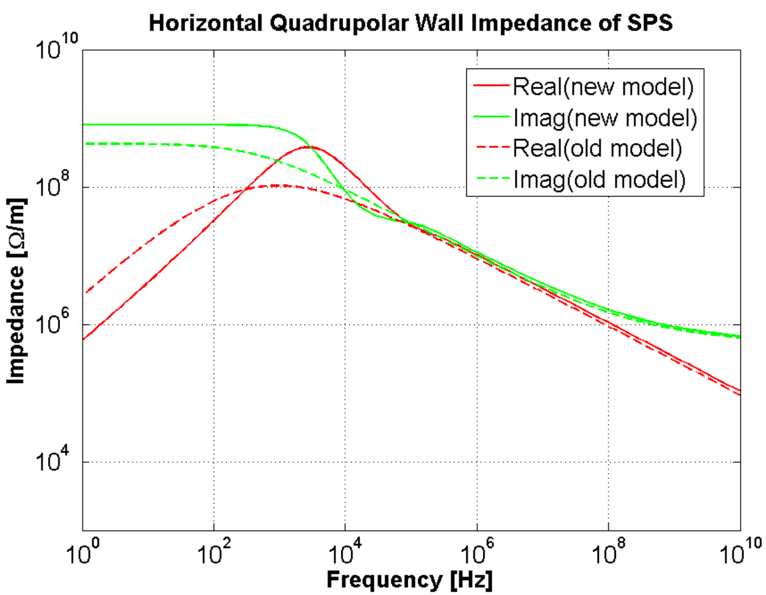


Transverse Impedance: Q26 Optics





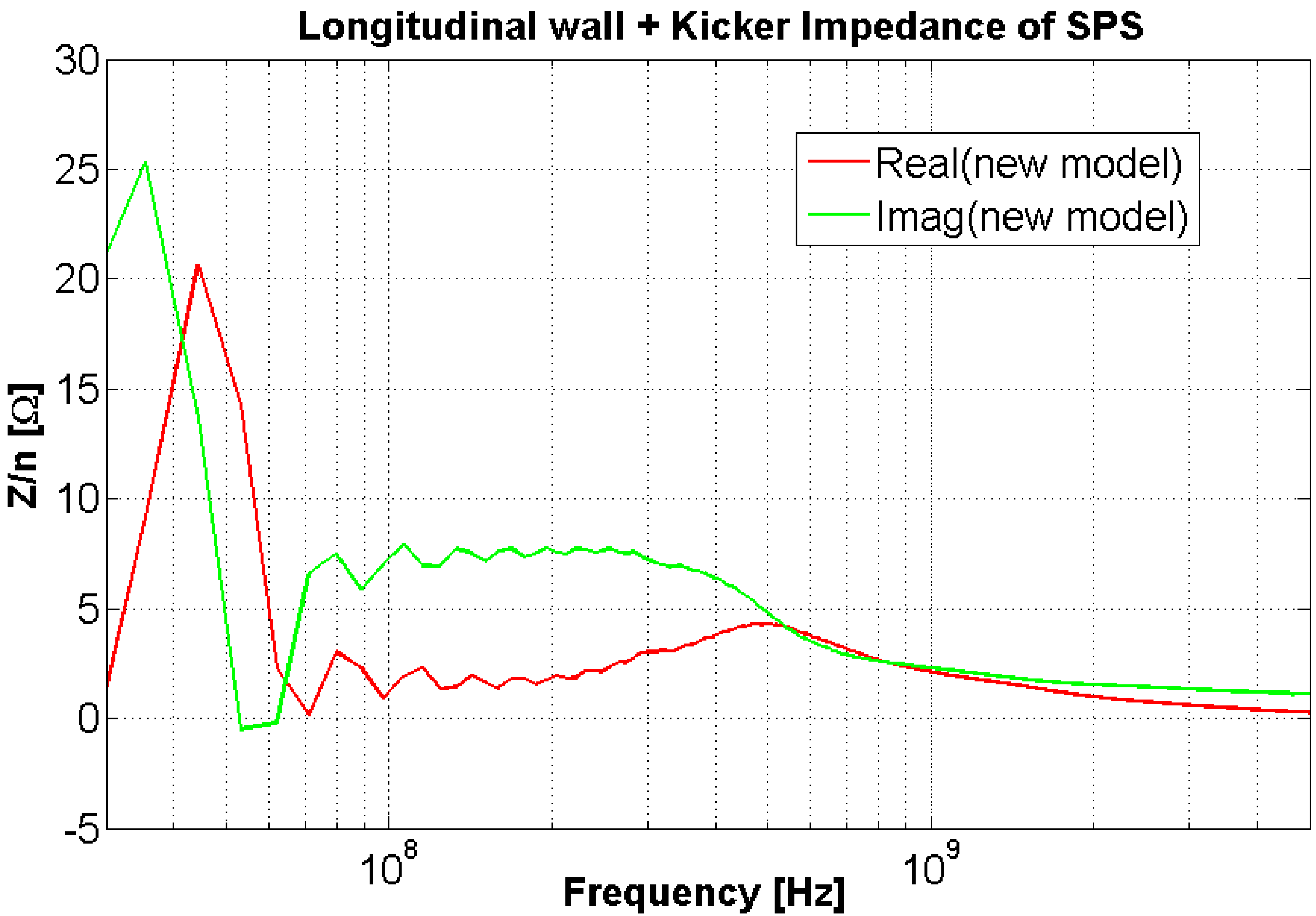




Conclusions

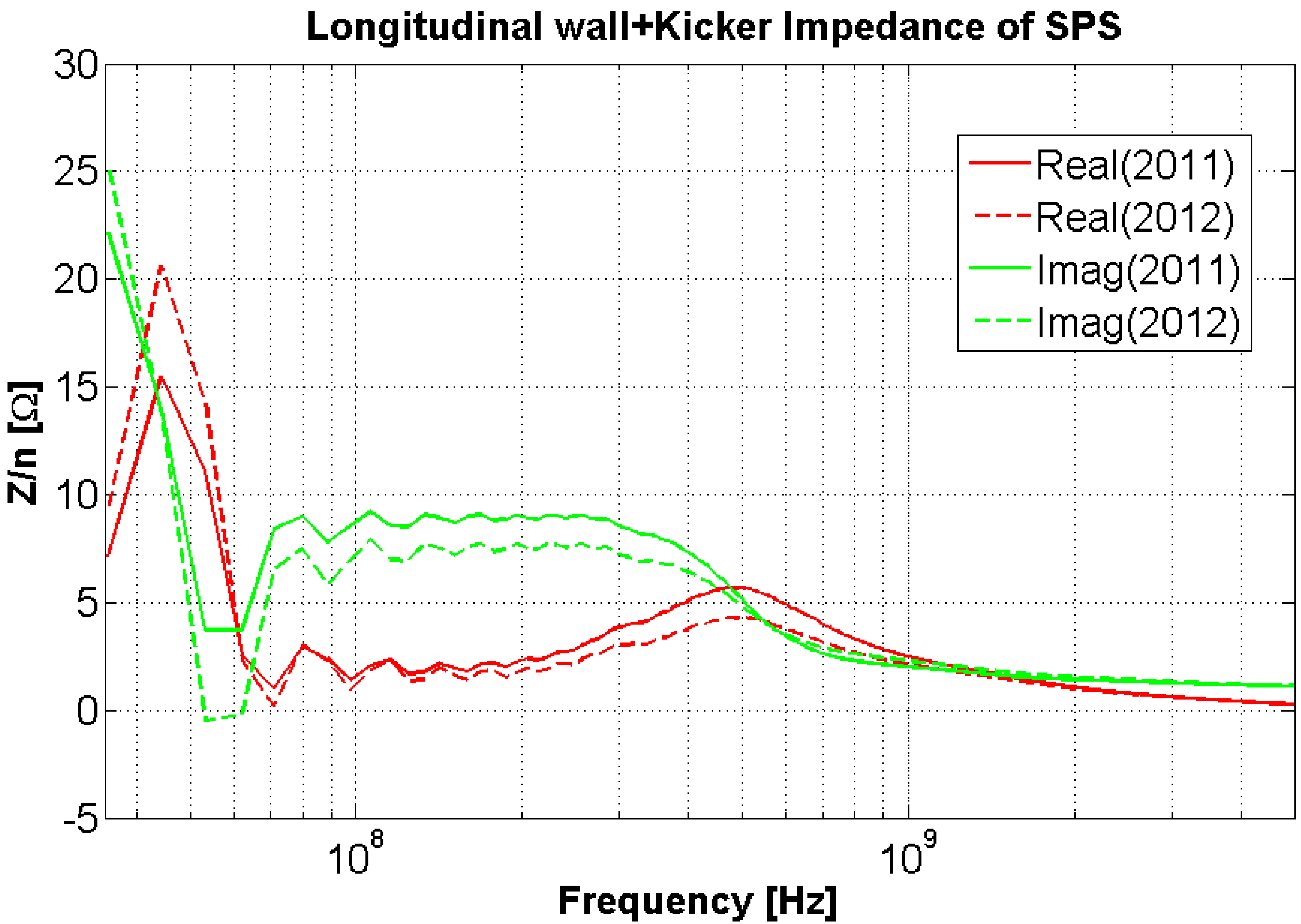
- The SPS kicker model was improved for a more accurate estimation of this relevant impedance contribution.
- The limitations of the coaxial wire method for impedance measurements are being investigated.
- Ferrite measurements were performed to validate the complex permeability model used in CST 3D EM simulations
- The SPS wall impedance model was improved accounting for the different vacuum chambers and the iron of the magnets

Longitudinal SPS Impedance model



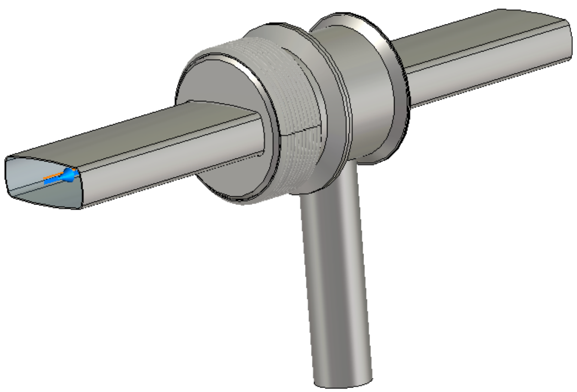
To be discussed with the RF team (possible sources, multi-bunch only single bunch etc.)

Longitudinal SPS Impedance model

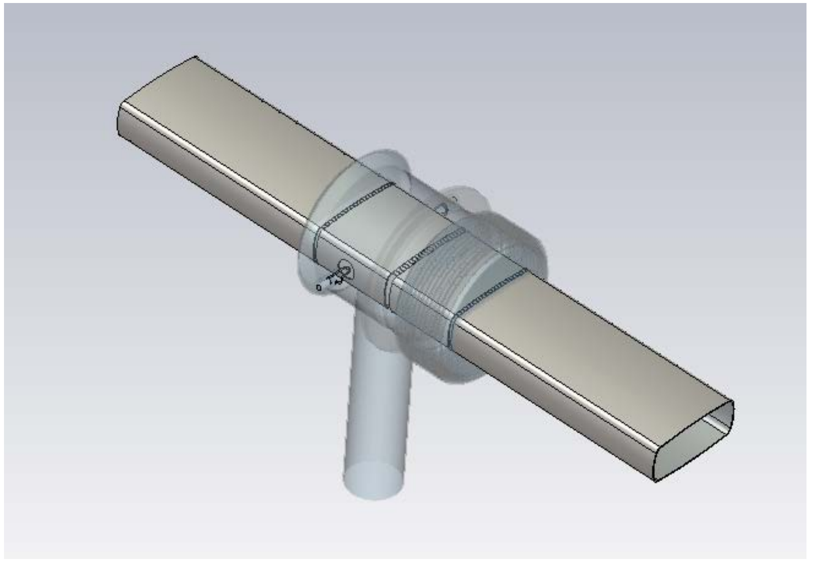


To be discussed with the RF team (possible sources, multi-bunch only single bunch etc.)

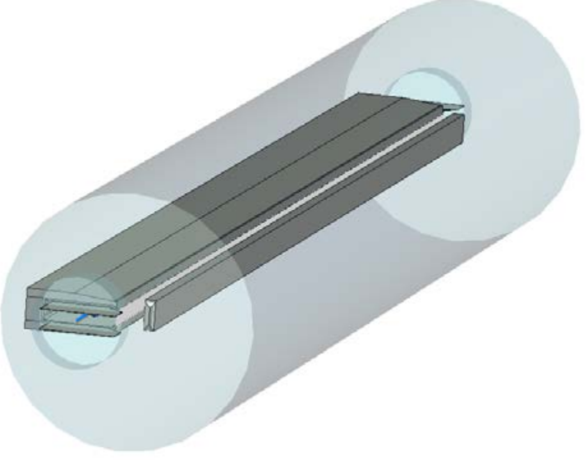
Other devices that are not yet taken into account



SPS Pumping port

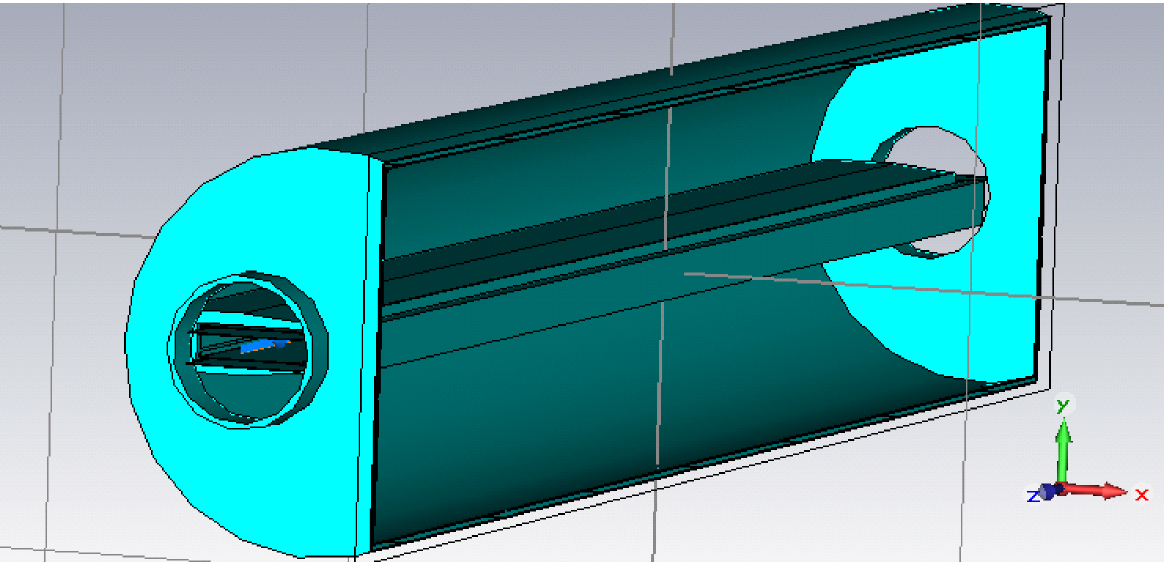


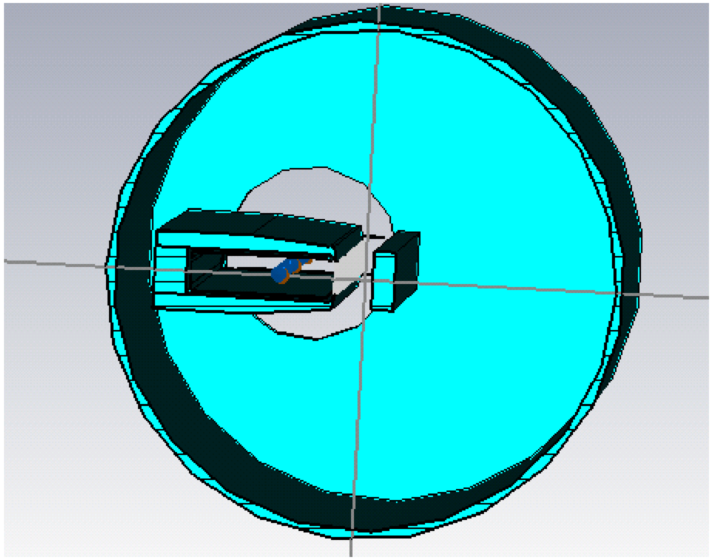
SPS Pumping port shielding and RF antenna



SPS electrostatic septum

ZS simulations with CST (B. Salvant)

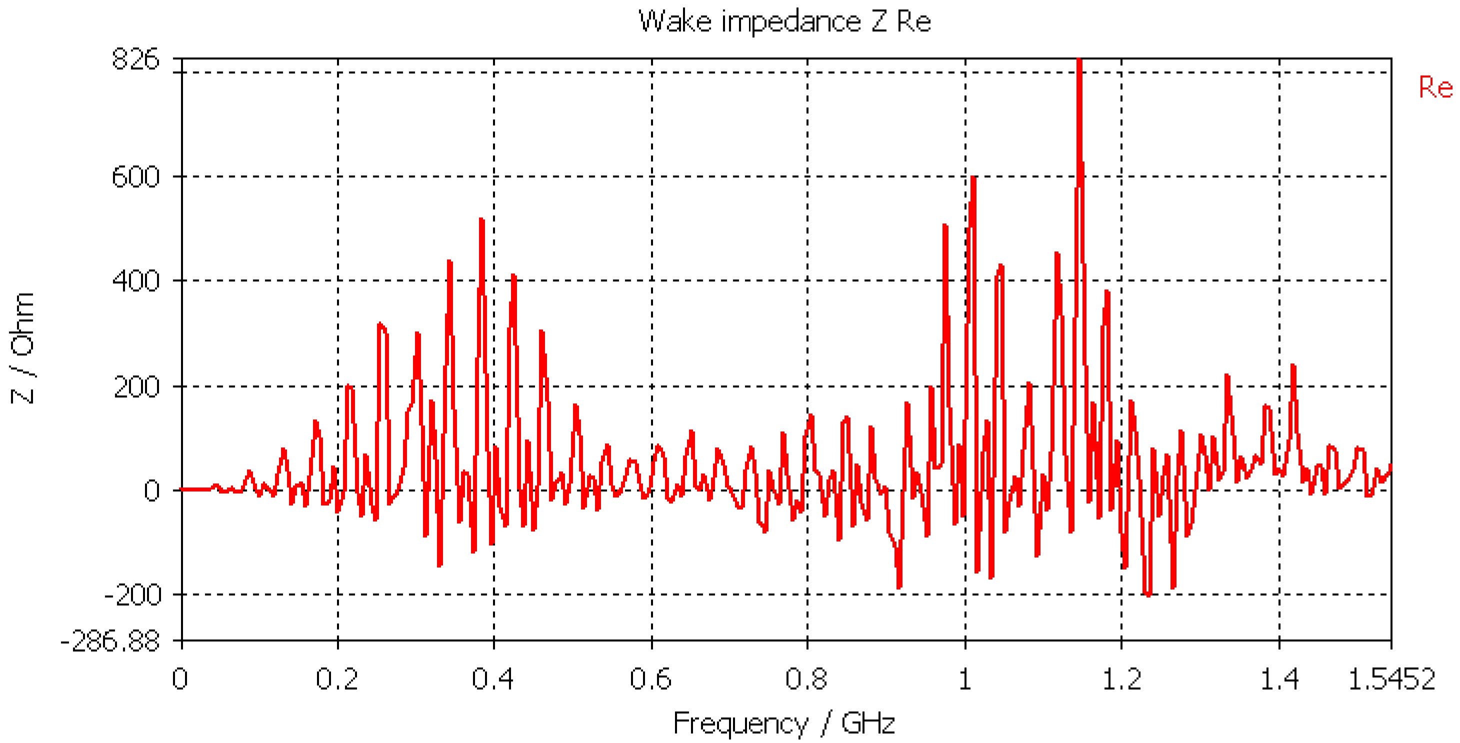




- Wires are tricky to simulate

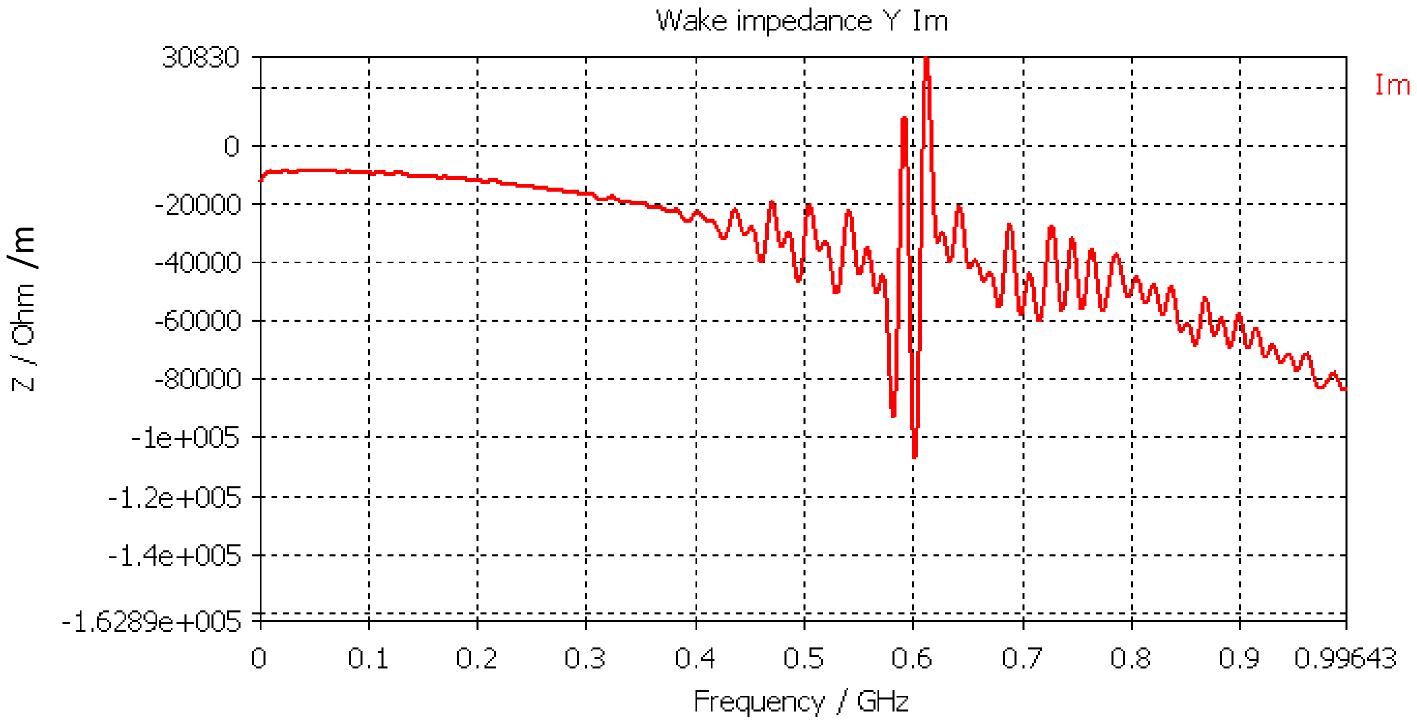
Thanks to Bruno Balhan!

Simulated longitudinal impedance



Im(Z/n)~0.02 Ohm

Vertical impedance (imaginary)



Im(Z_y)~8 kOhm/m (for 1 ZS)

Measurements of Fritz presented by Elena at Chamonix 2001

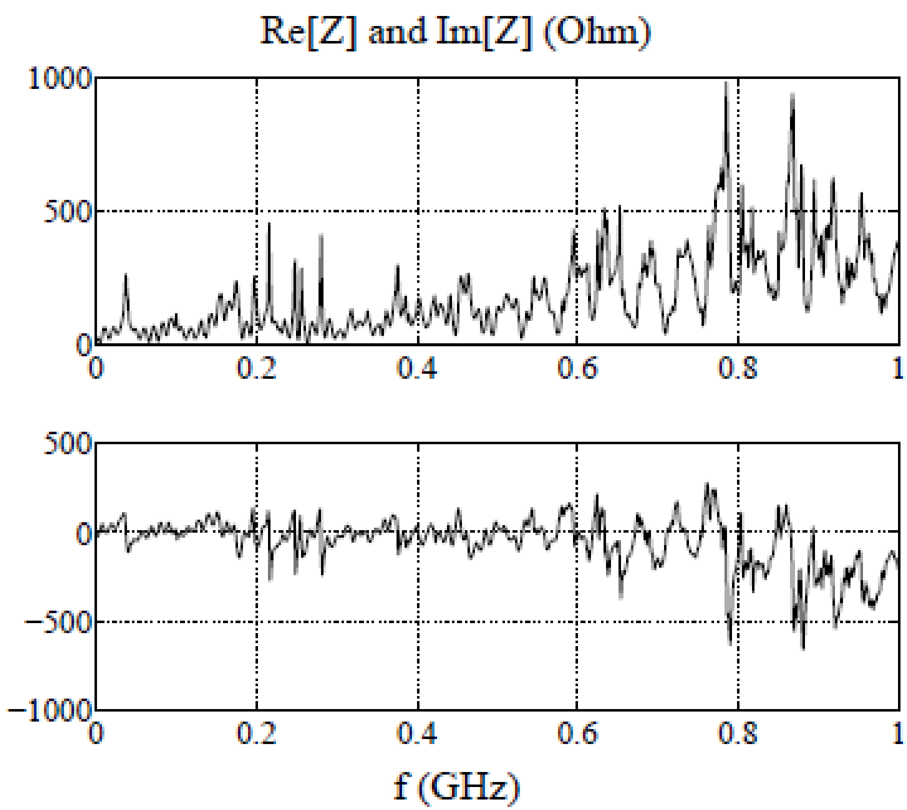
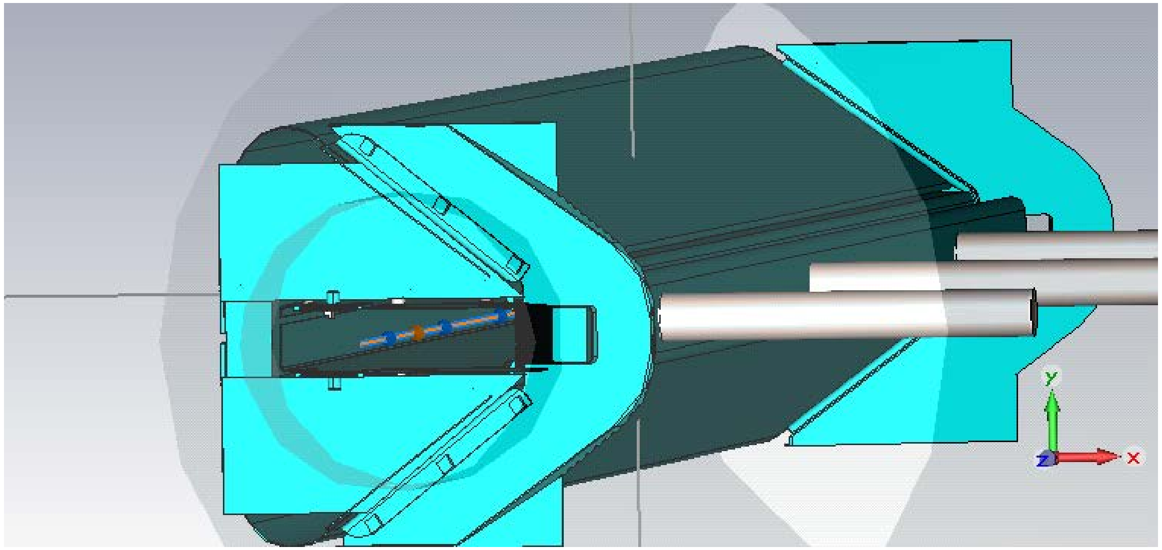
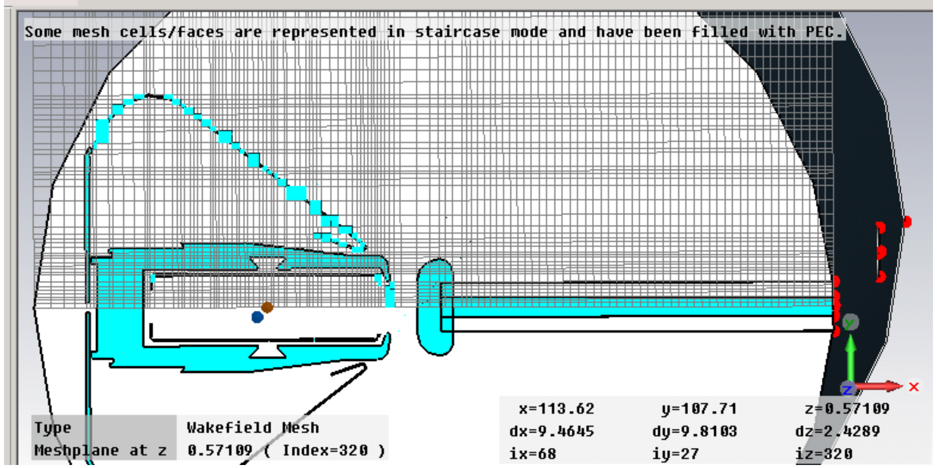


Figure 12: Real (top) and imaginary (bottom) parts of ZS impedance evaluated from the corrected values of amplitude and phase of S_{21} parameter.

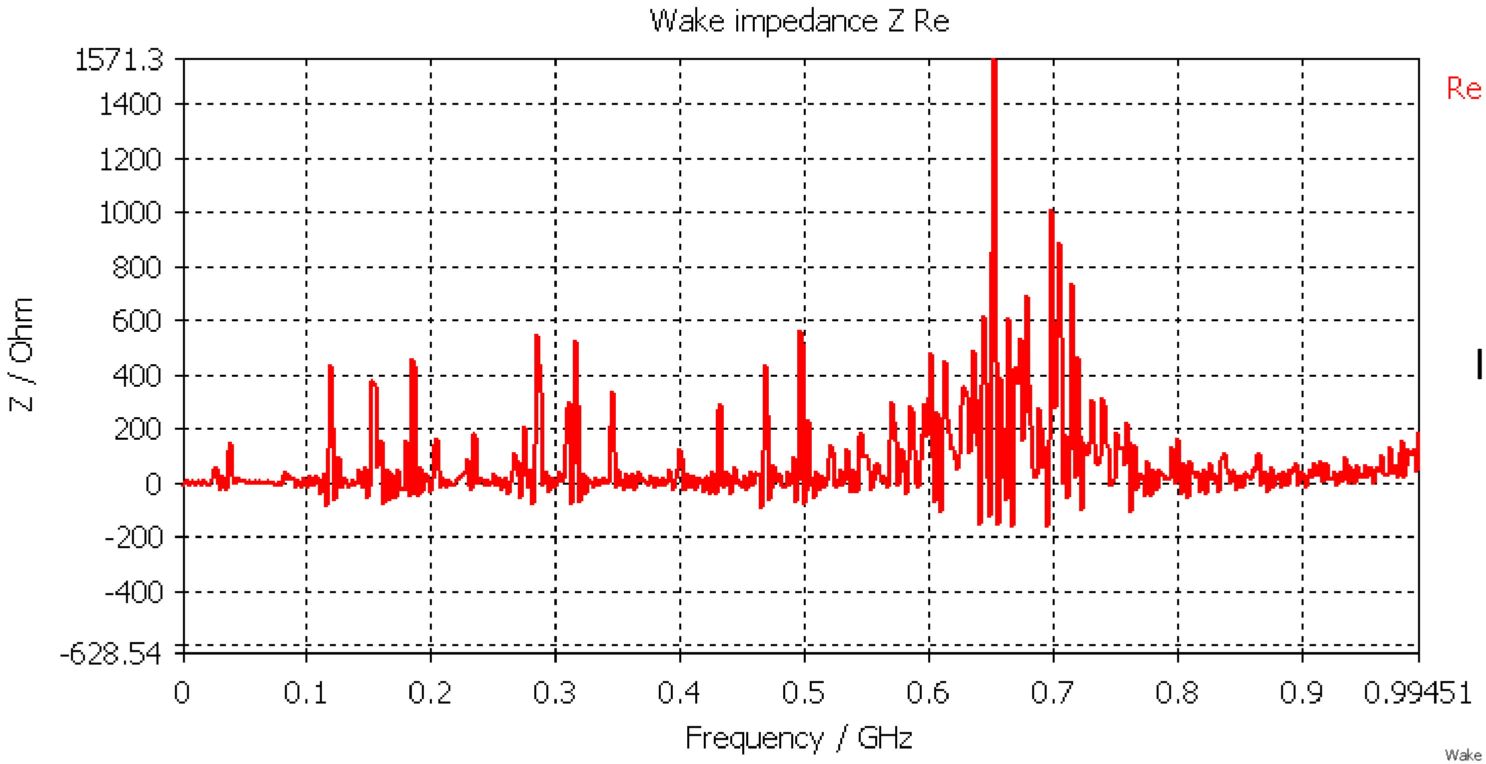
Imported structure from CATIA





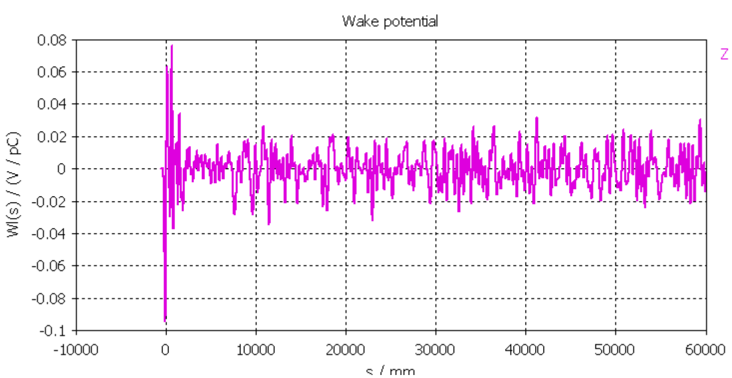
Very difficult to mesh properly,
but we could assume the
wires do not let the fields go through.

Preliminary longitudinal impedance results with 60 m wake



Im(Z/n)~0.04 Ohm

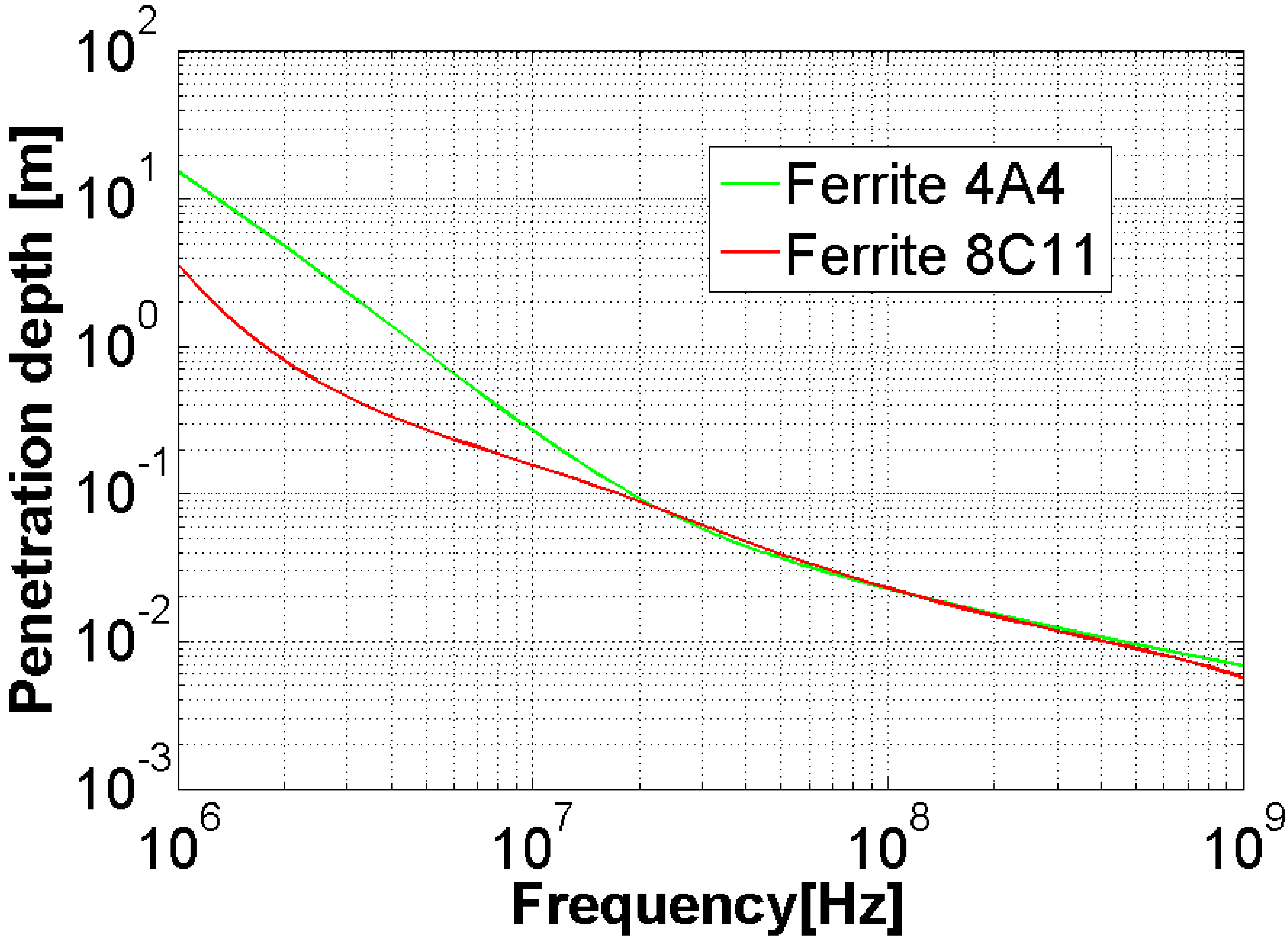
The height of the peak is underestimated →
Are these peaks an issue?



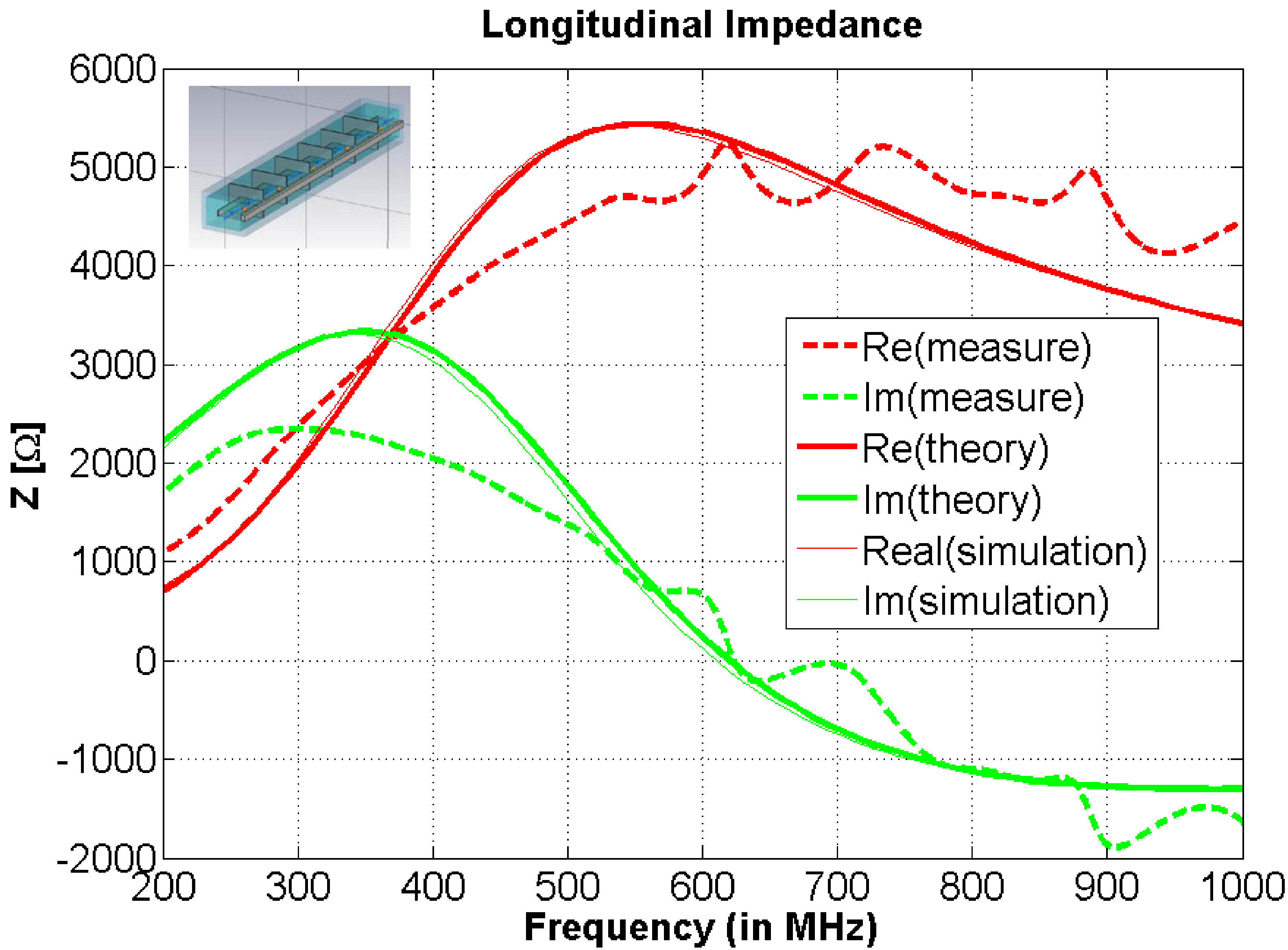
Thank you for your attention

Appendix

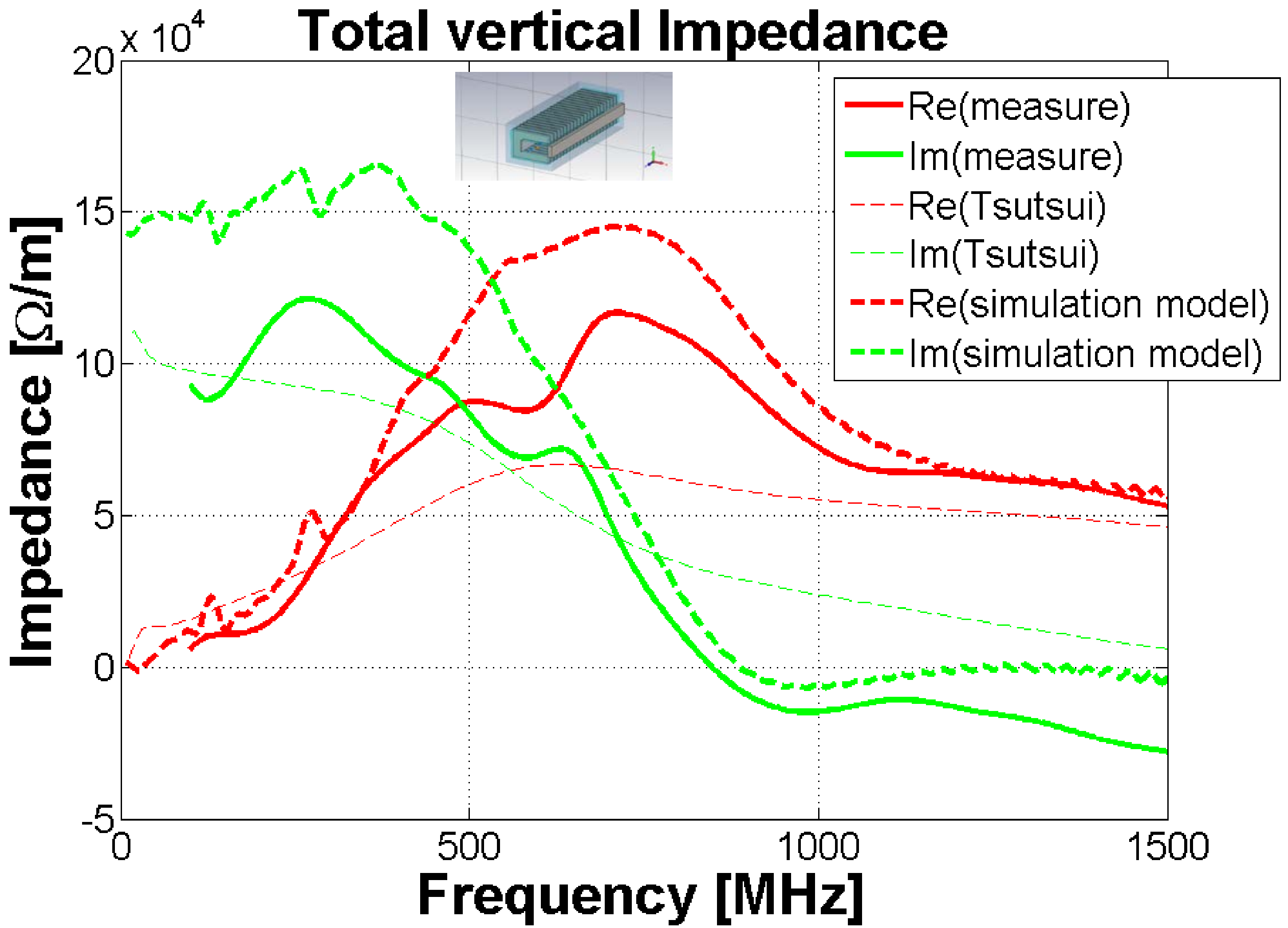
Penetration depth in ferrite



Comparing longitudinal impedance: MKE-S

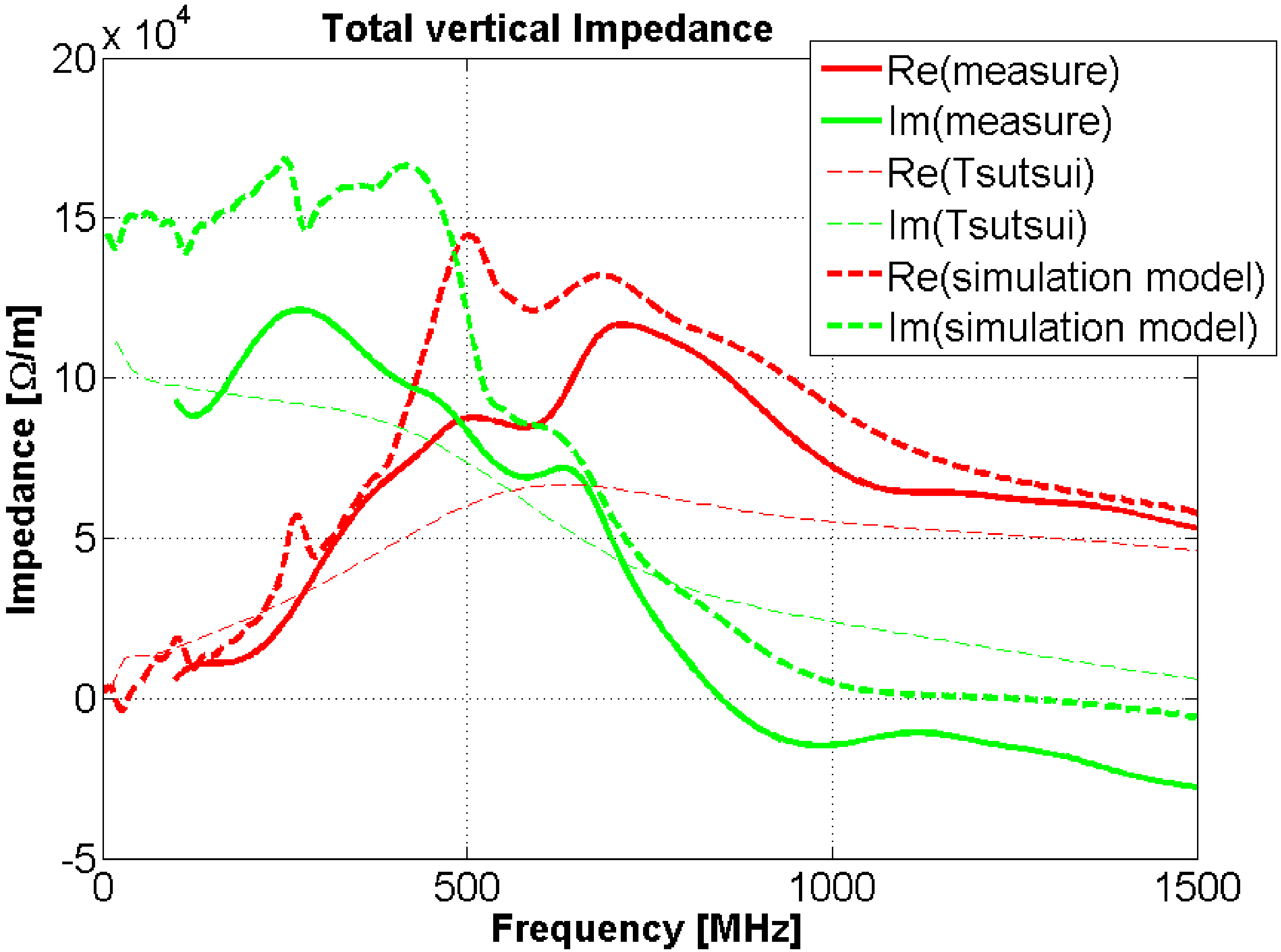


Comparing total transverse impedance: MKP-L



Parasitic inductance of 100nH in parallel with the cell capacitance of 668 pF

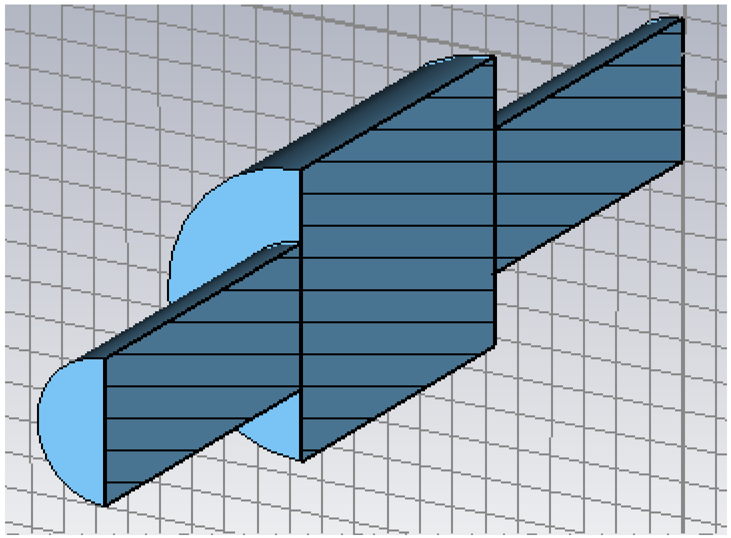
Comparing total transverse impedance: MKP-L



Parasitic inductance of 100nH in series with the cell capacitance of 668pF

Measurements of the coupling impedance using the coaxial wire method

The measured quantity is the transmission S21



cut-off frequency ≠0
cut-off frequency =0

TEM ⟹ Propagation losses

Measured Losses = True Losses + Propagation losses

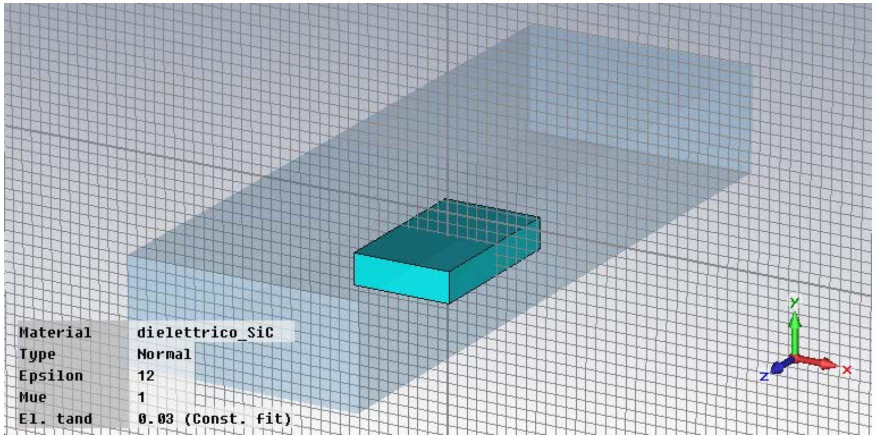
For resonant structures:

$$\frac{1}{Q_m} = \frac{1}{Q_{true}} + \frac{1}{Q_{prop}}$$

Due to the additional power transported by the wire the resonance should shift to lower frequency

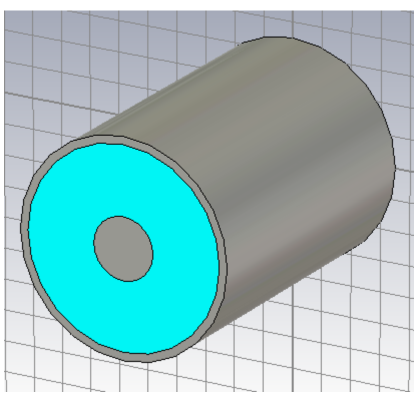
Electromagnetic characterization of materials

We characterize the material at high frequency using the waveguide method



$$S21 = G(\varepsilon', \varepsilon'')$$

Coaxial line method

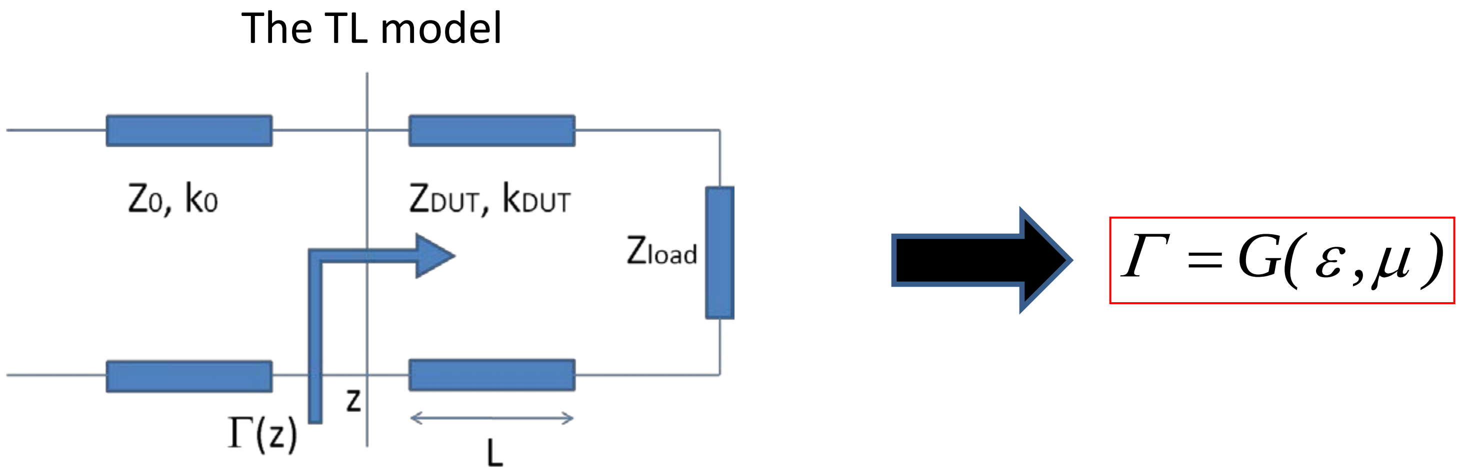


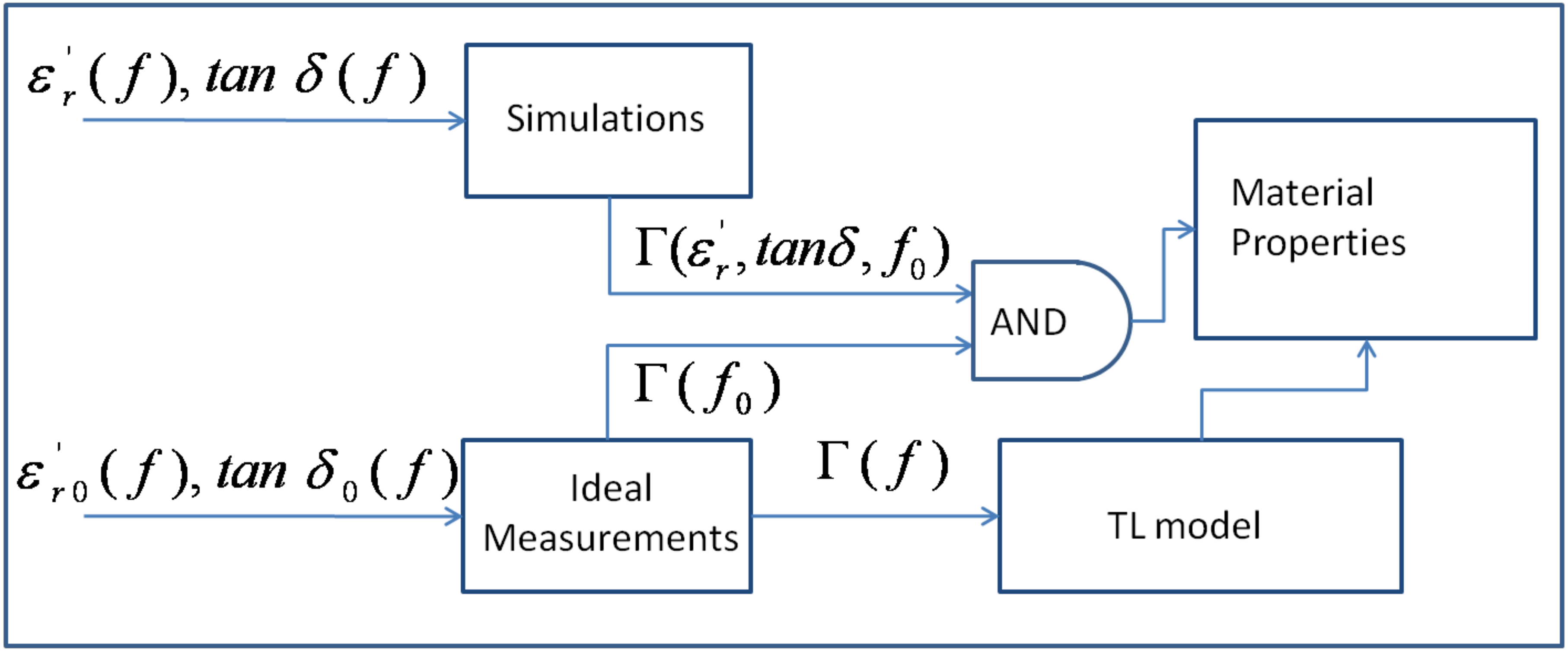
$$(\varepsilon, \mu)$$

$$\Gamma = G(\varepsilon, \mu)$$

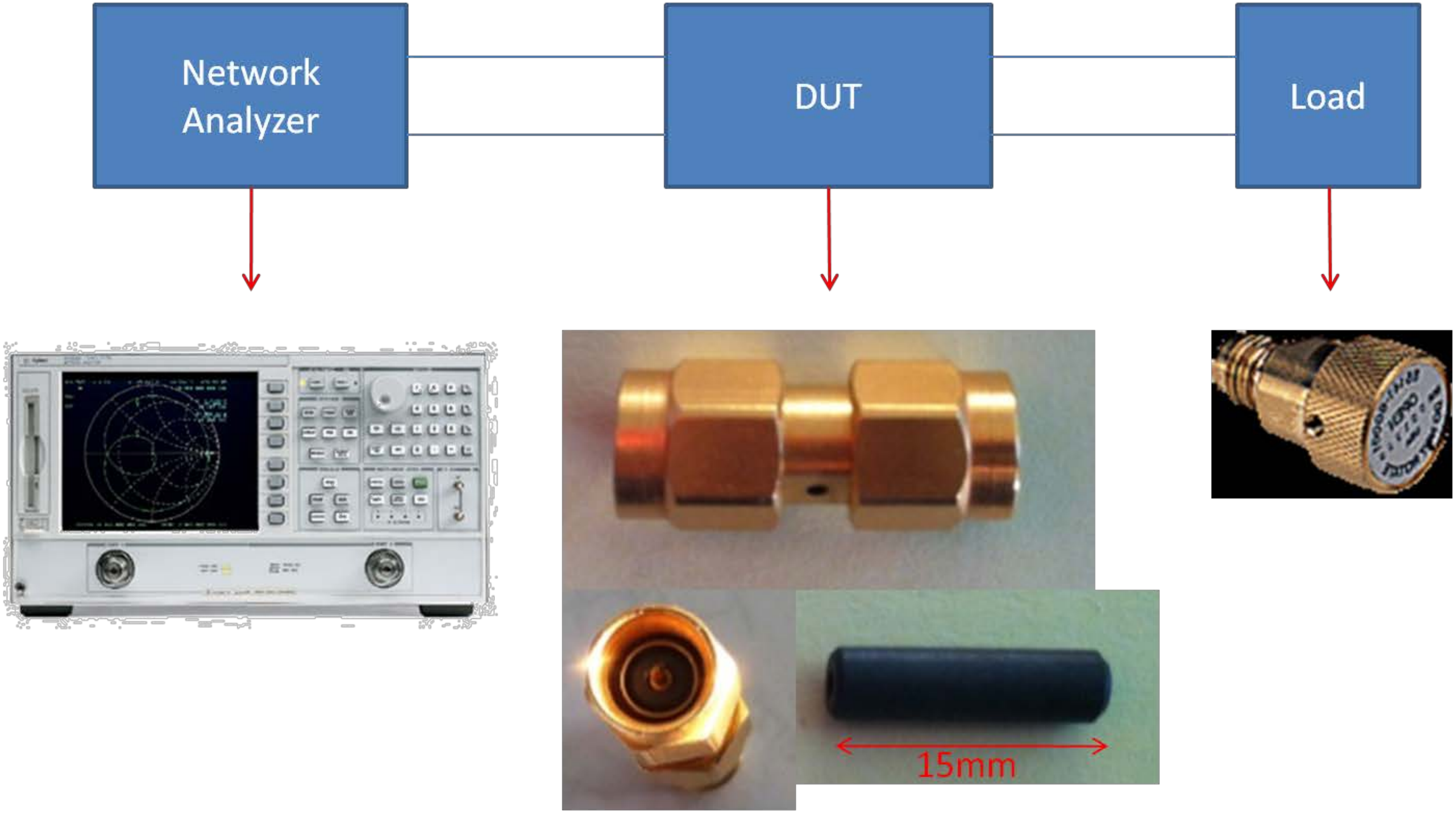
$$(\varepsilon, \mu)$$

The coaxial line method



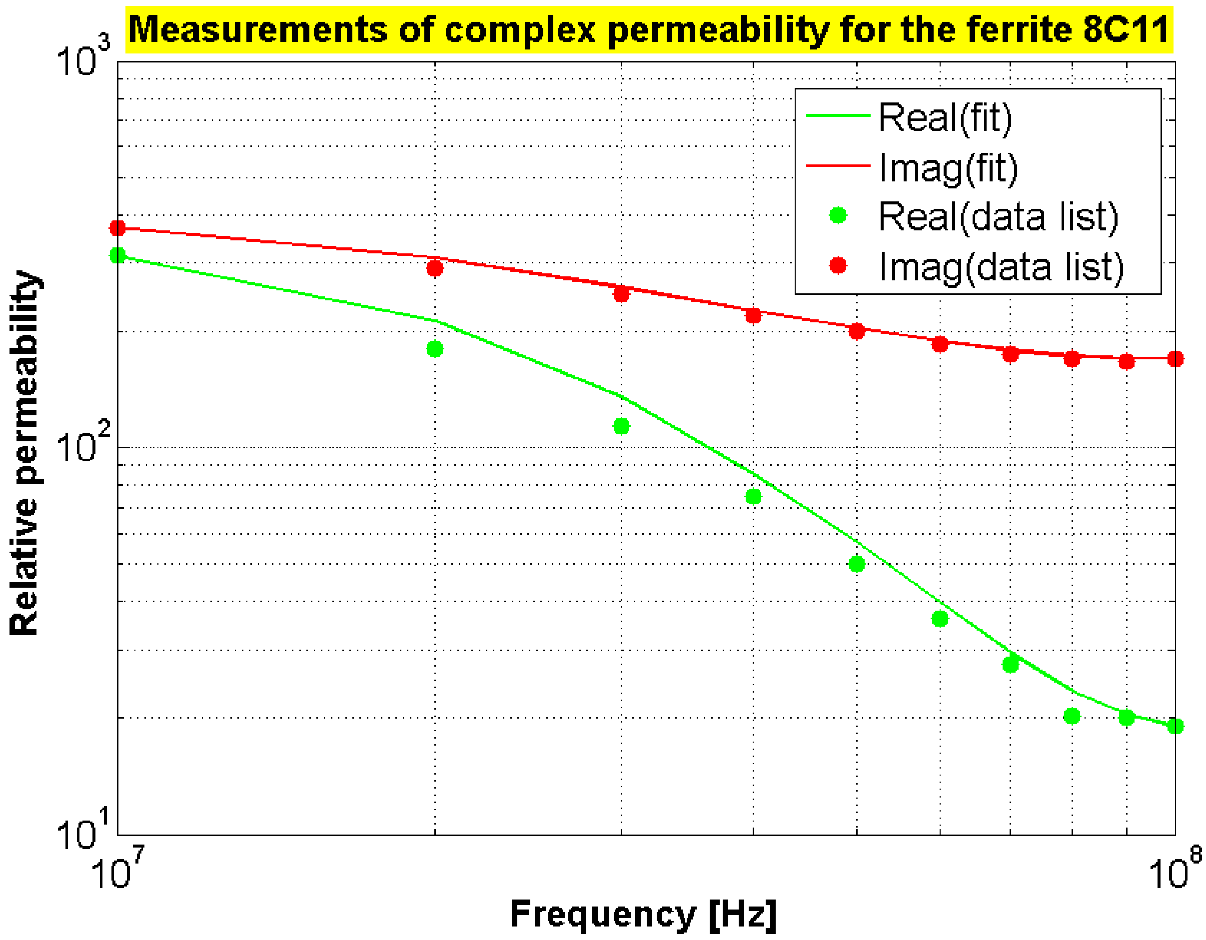


Measurement setup



We did measurements for some SiC in the ranges 10 MHz-2GHz and 8 - 40 GHz and for the ferrite 8C11 in the range 10MHz-10GHz.

Permeability measurements



The effect of the iron (silicon steel)

Iron (silicon steel) electromagnetic model

$$\mu = \mu_0 \cdot \mu_r = \mu_0 \left(1 + \frac{\mu_i}{1 + jf2\pi\tau} \right) \qquad \varepsilon = \varepsilon_0 \cdot \varepsilon_r = \varepsilon_0 \left(\varepsilon' - \frac{j\sigma}{2\pi f \varepsilon_0} \right)$$

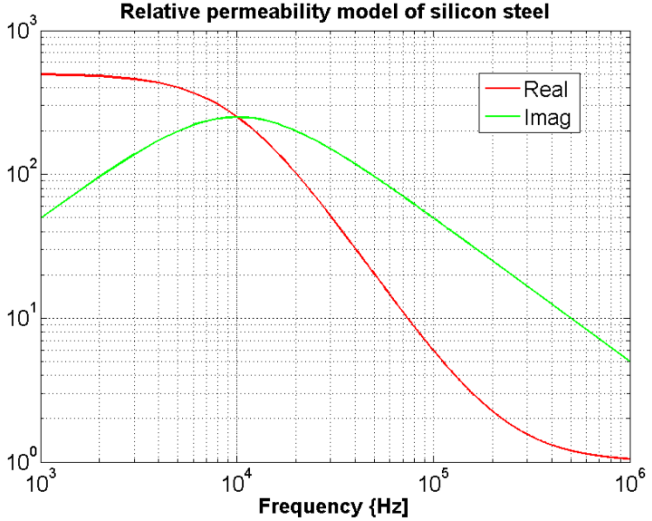
$$f_r = (2\pi\tau)^{-1} = 10KHz$$

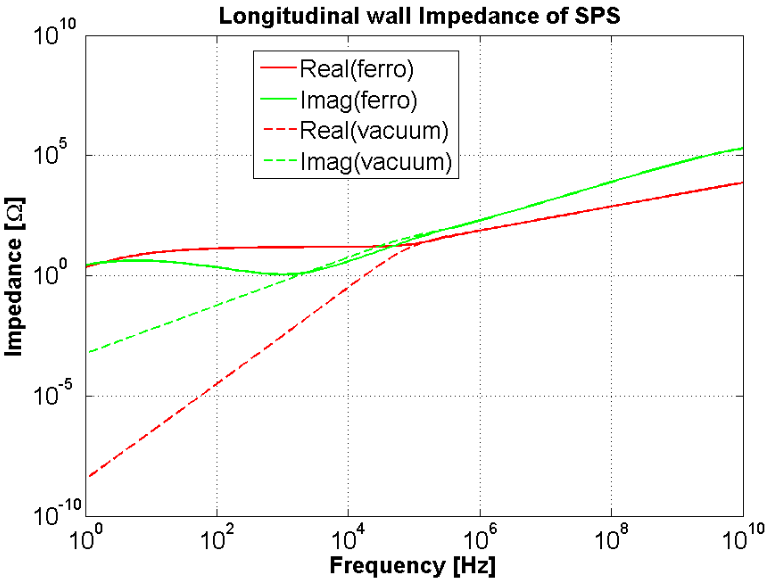
$$\mu_i(Injection) = 500$$

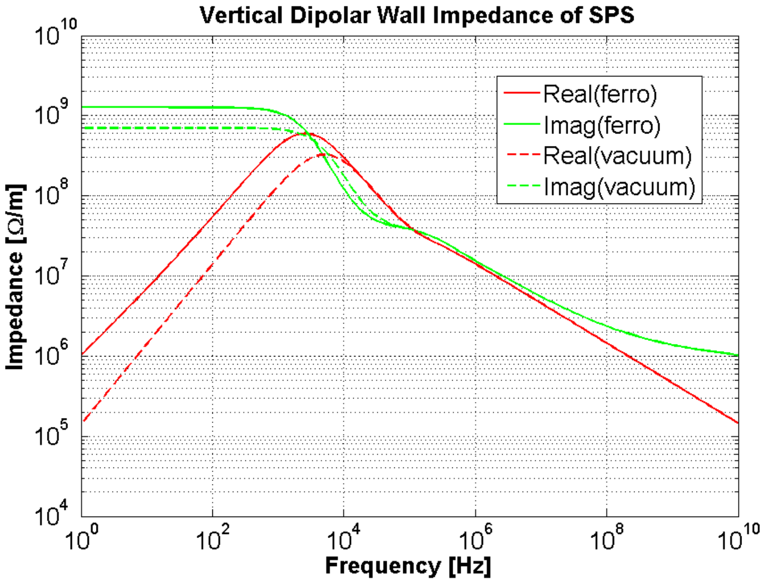
$$\mu_i(Extraction) = 33$$

$$\sigma = 10^5 [\Omega \cdot m]$$

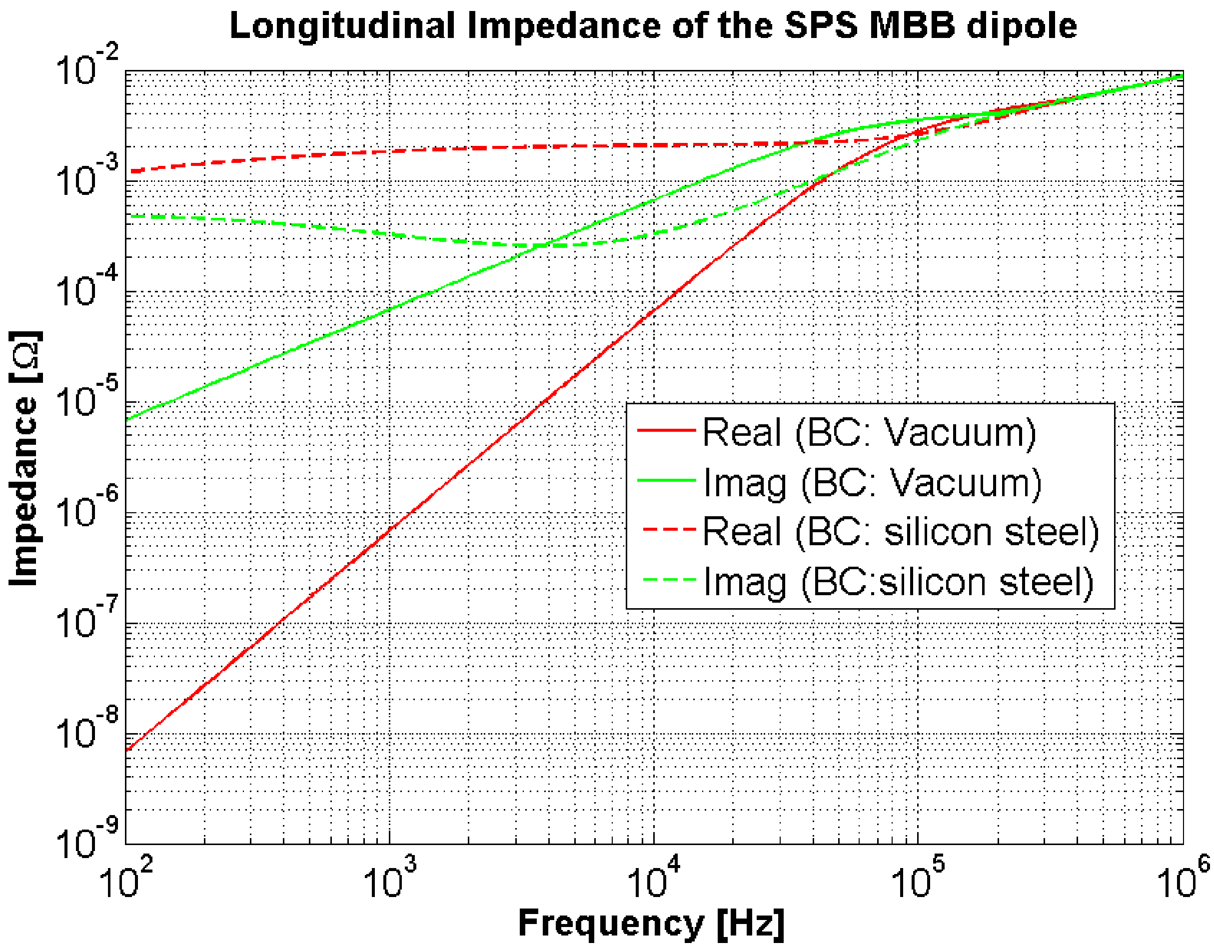
$$\varepsilon' = 1$$

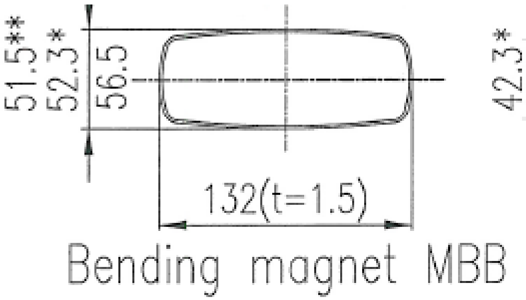






Comparing SPS vacuum chamber with Vacuum and silicon-steel boundary





At low frequency the real part of the longitudinal impedance is much larger with silicon steel boundary