Sladjana Dordevic & Christopher Gough :: RF Section:: Paul Scherrer Institut

CST Simulation of Speed Limitations of Inductive Voltage Adder Geometry

Pulsed Power for Kickers Workshop, CERN Geneva, 12-13 March 2018

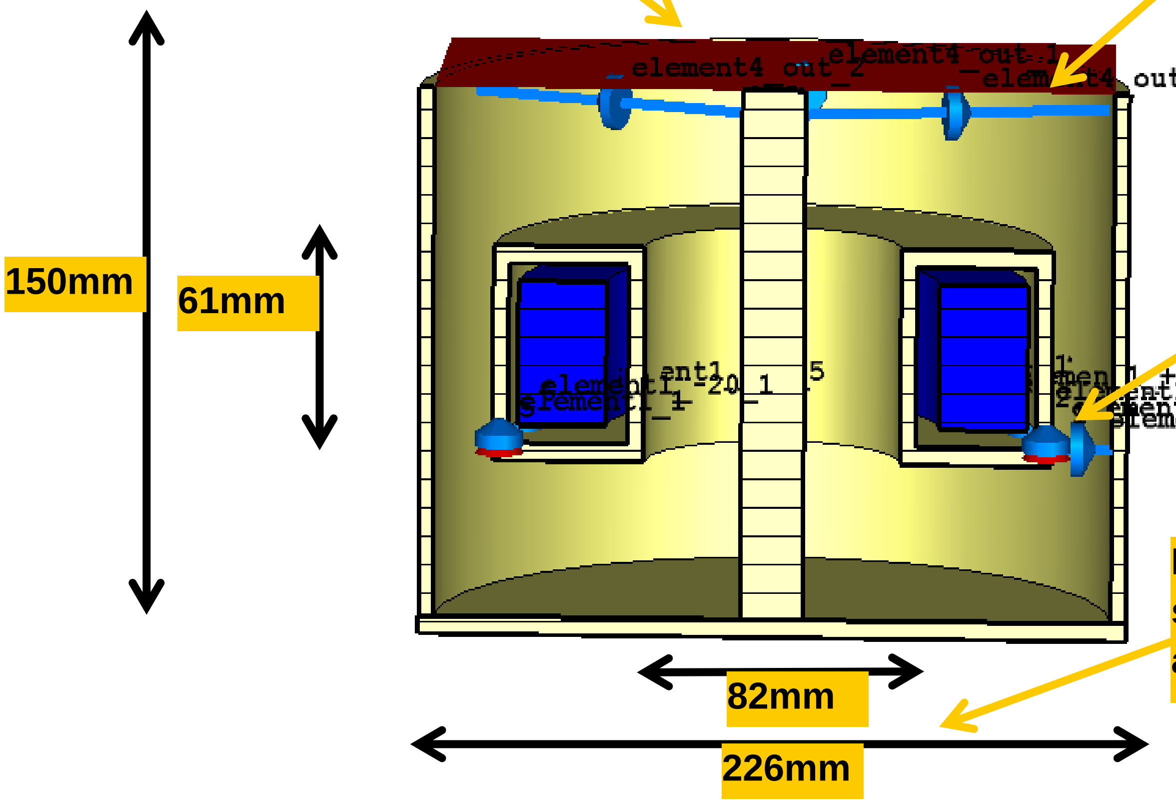
The Time Domain solver of CST Microwave Studio is used to find a preferred geometry for the fastest possible pulse from an Inductive Voltage Adder (IVA).

Introduction – typical model, one cell only

Upper surface always into infinite matched transmission line, in this case Z=143Ω

Option: Additional high Z voltage measurement

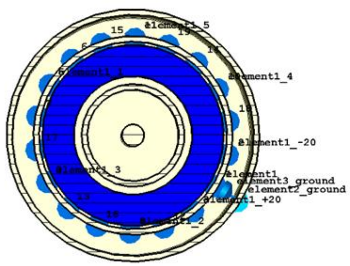
Sixteen voltage sources evenly spaced radially,
Source voltage 1V step
Source Z 3uOhm, 0nH, 1F.
(even small R and L confuses current rise time result)

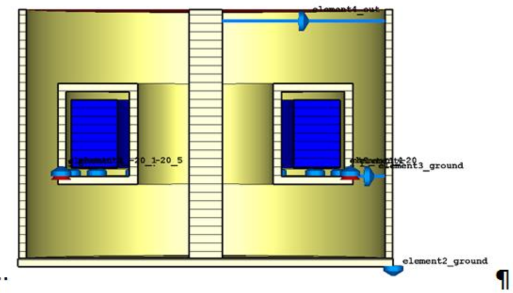


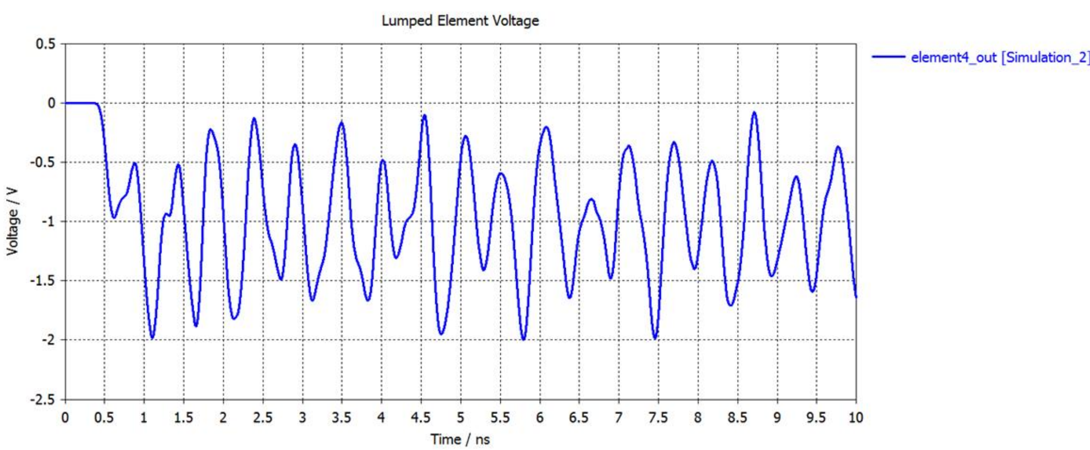
Dimensions chosen to suit several core types that are available

Source Rise Time in Simulation

Chris_model_st1_seg2_60_vol3_L0_R3uC1-lessmesh_mue15k_6seg_01ns.cst· ¶



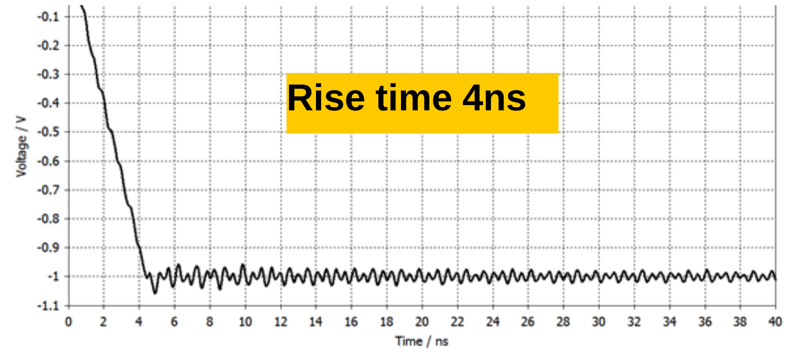




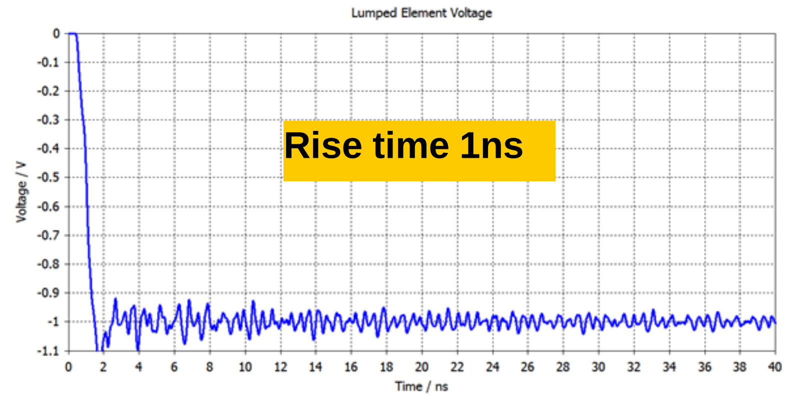
Bad luck with 0.1ns rise time. The resistive matched transmission line at the top of the model means longitudinal resonance can not exist. Transverse resonances seem possible with this period, but we did not see corresponding H and E fields to match this voltage. Result is also mesh-dependent. So this result may still be realistic but no use for the present study.

PAUL SCHERRER INSTITUT PSI

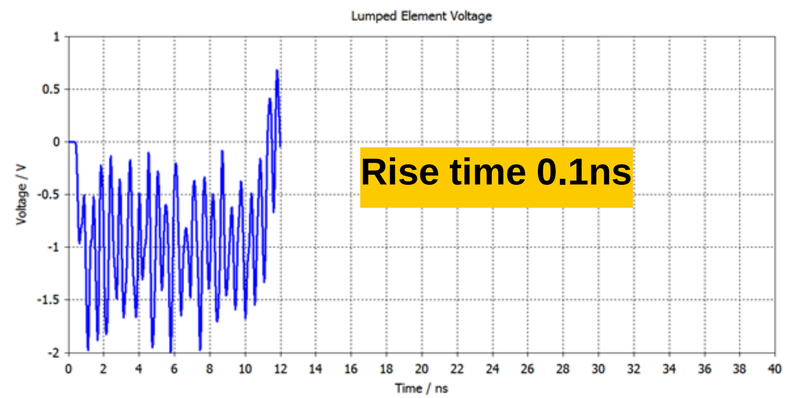
Source Rise Time in Simulation



rise time=4ns



rise time=1ns



rise time=0.1ns

Conclude:

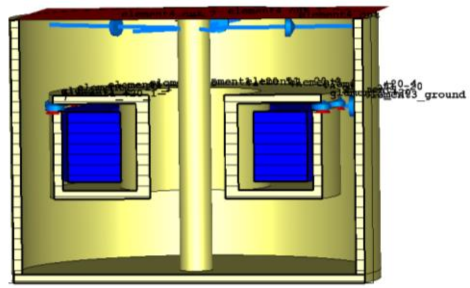
To have some chance with comparing different simulation geometry:

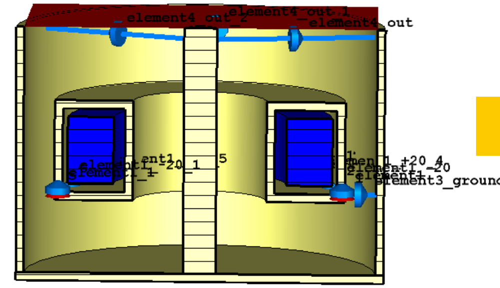
avoid rise time <4ns

avoid any source impedance which could slow current rise

Basic Geometries

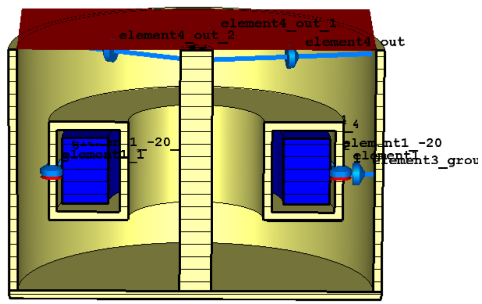
Up

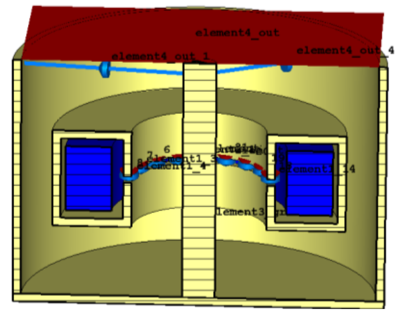




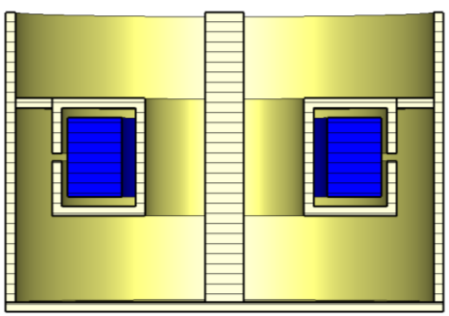
Down

Left

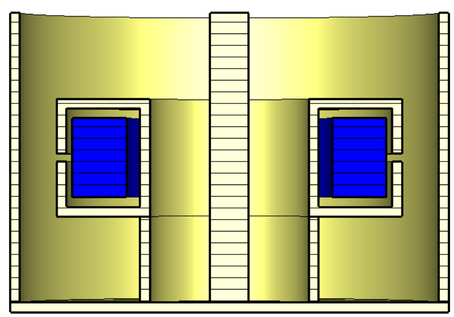




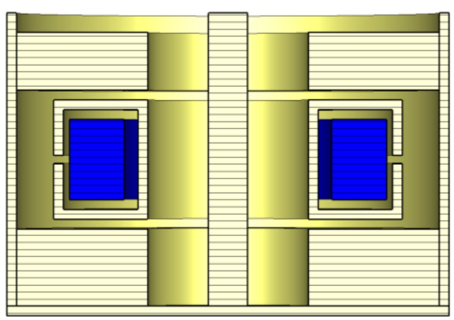
Right



Ring to the wall

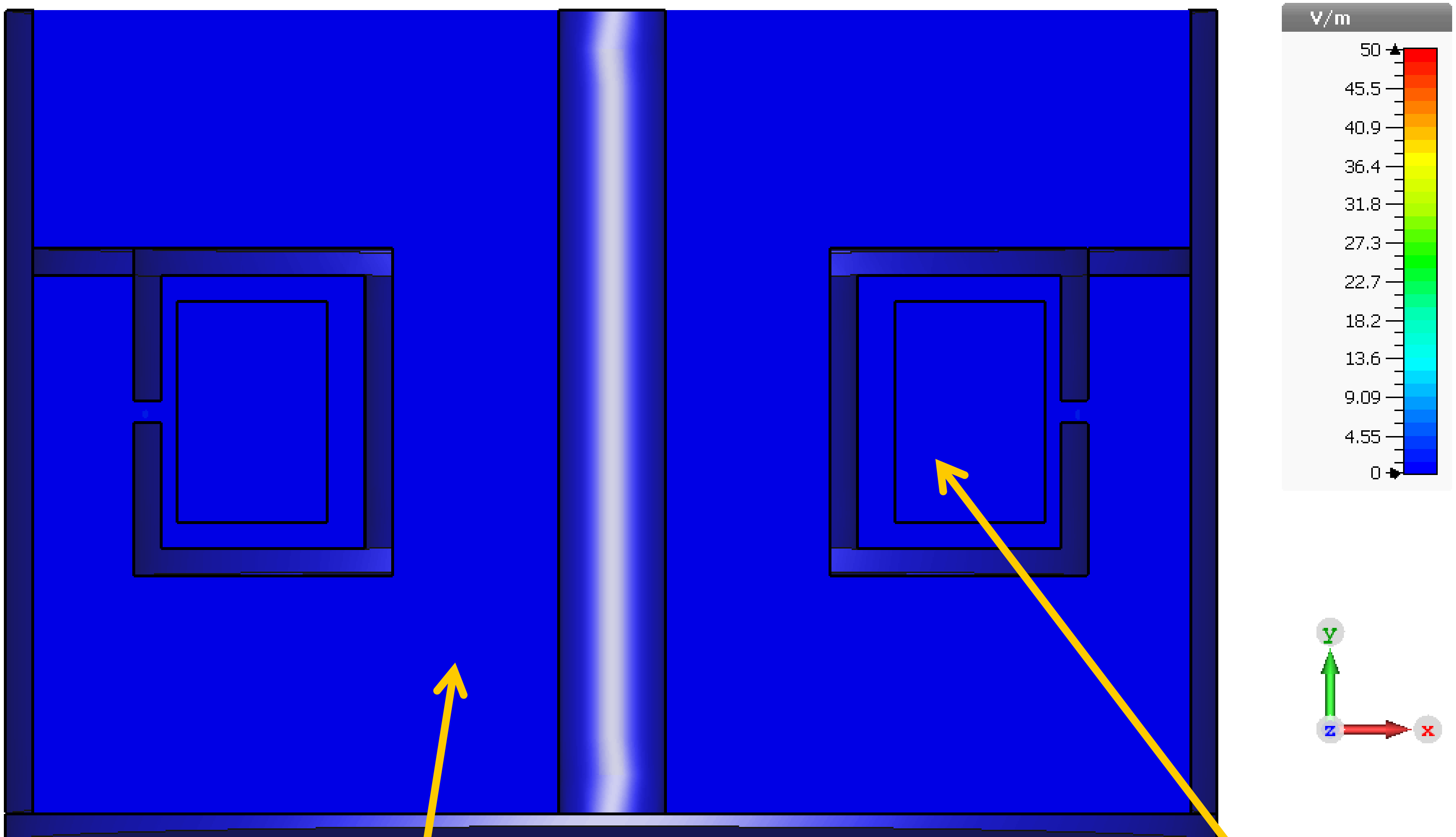


Ring to the base



Two metal rings

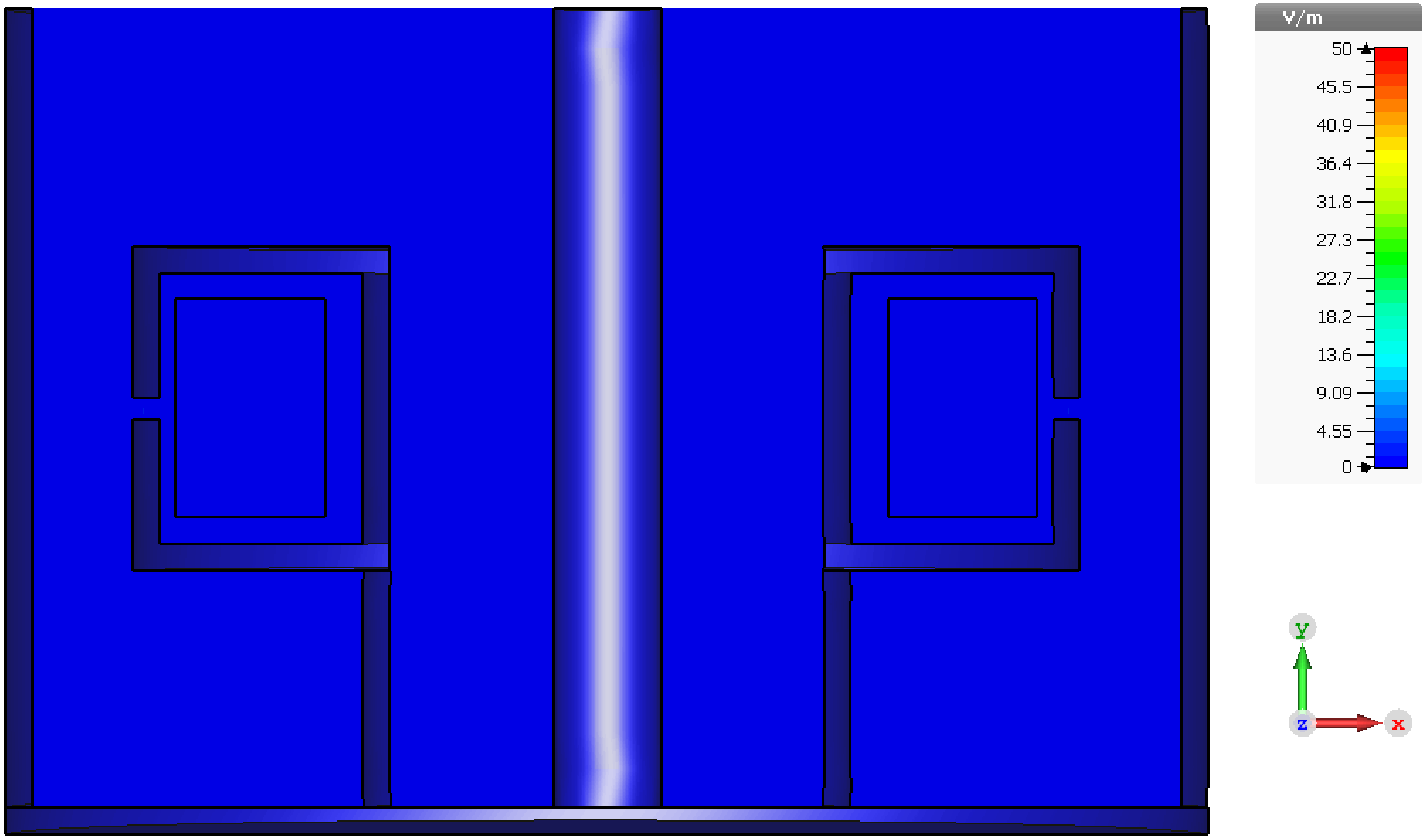
Example 1– "Ring to the Wall"



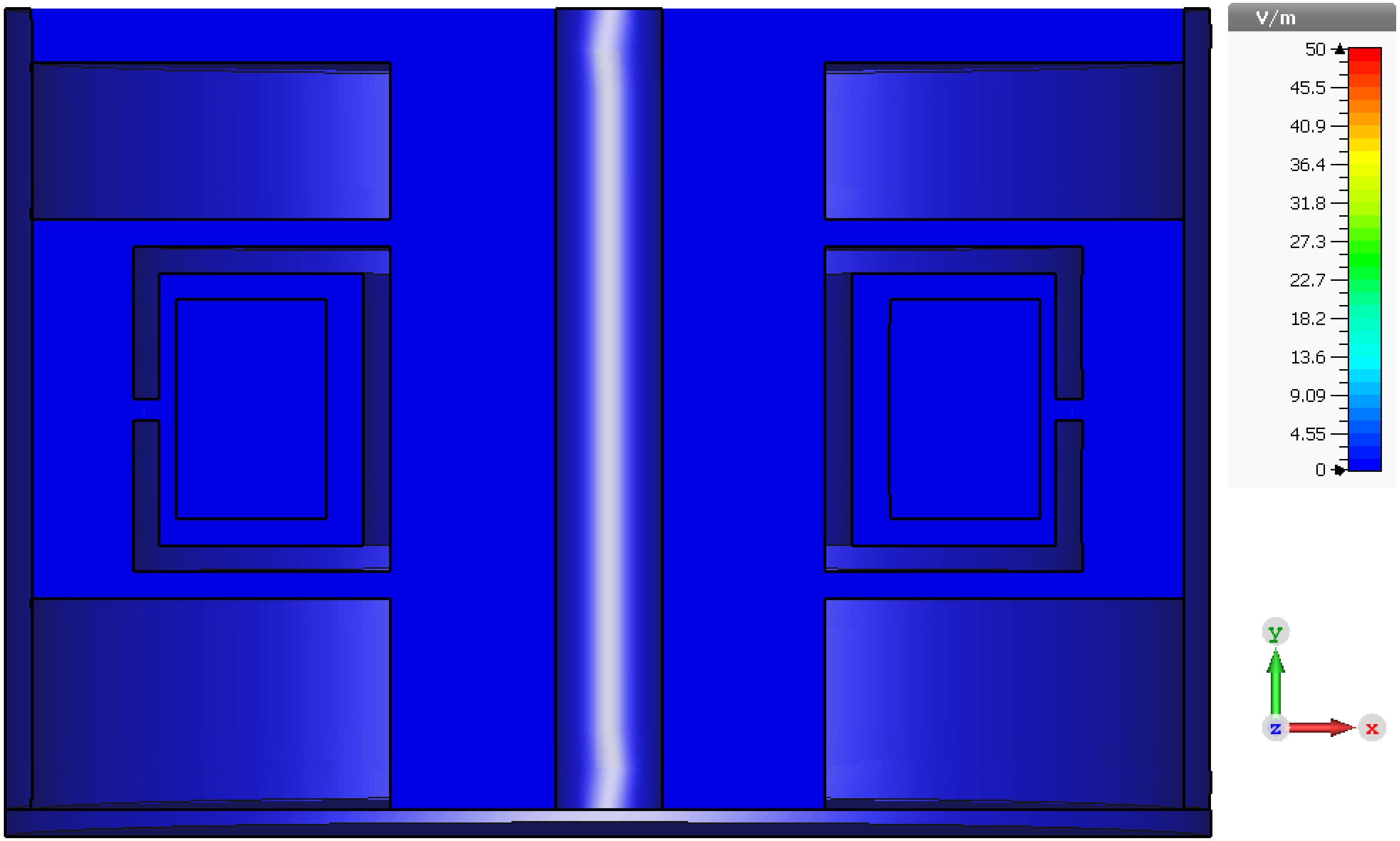
E-field at speed of light through cavity

E-field propagates at c√(15000) through core with mu=15k and ε=1

Example 2– “Ring to the Base”

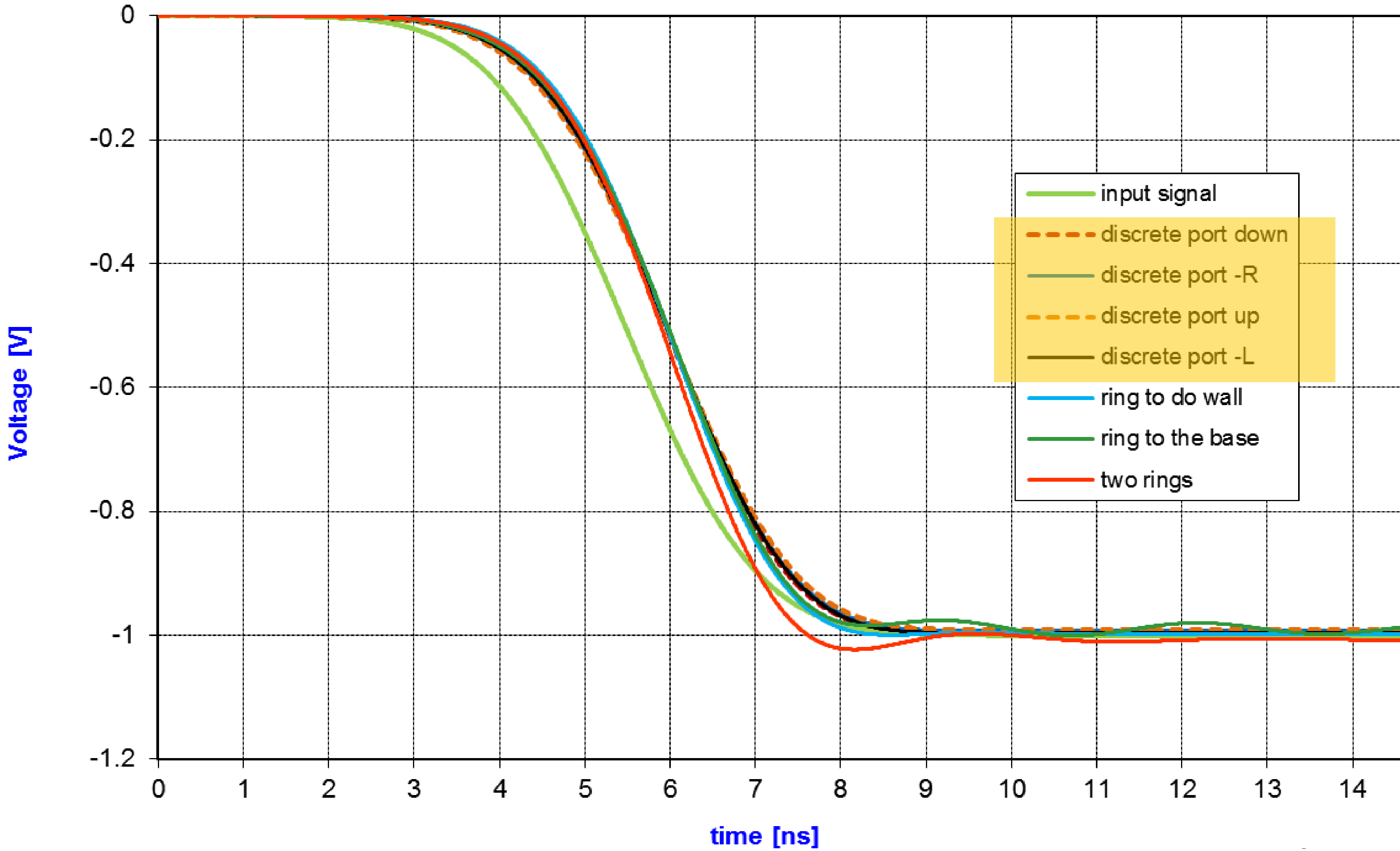


Example 3– "Two Rings"



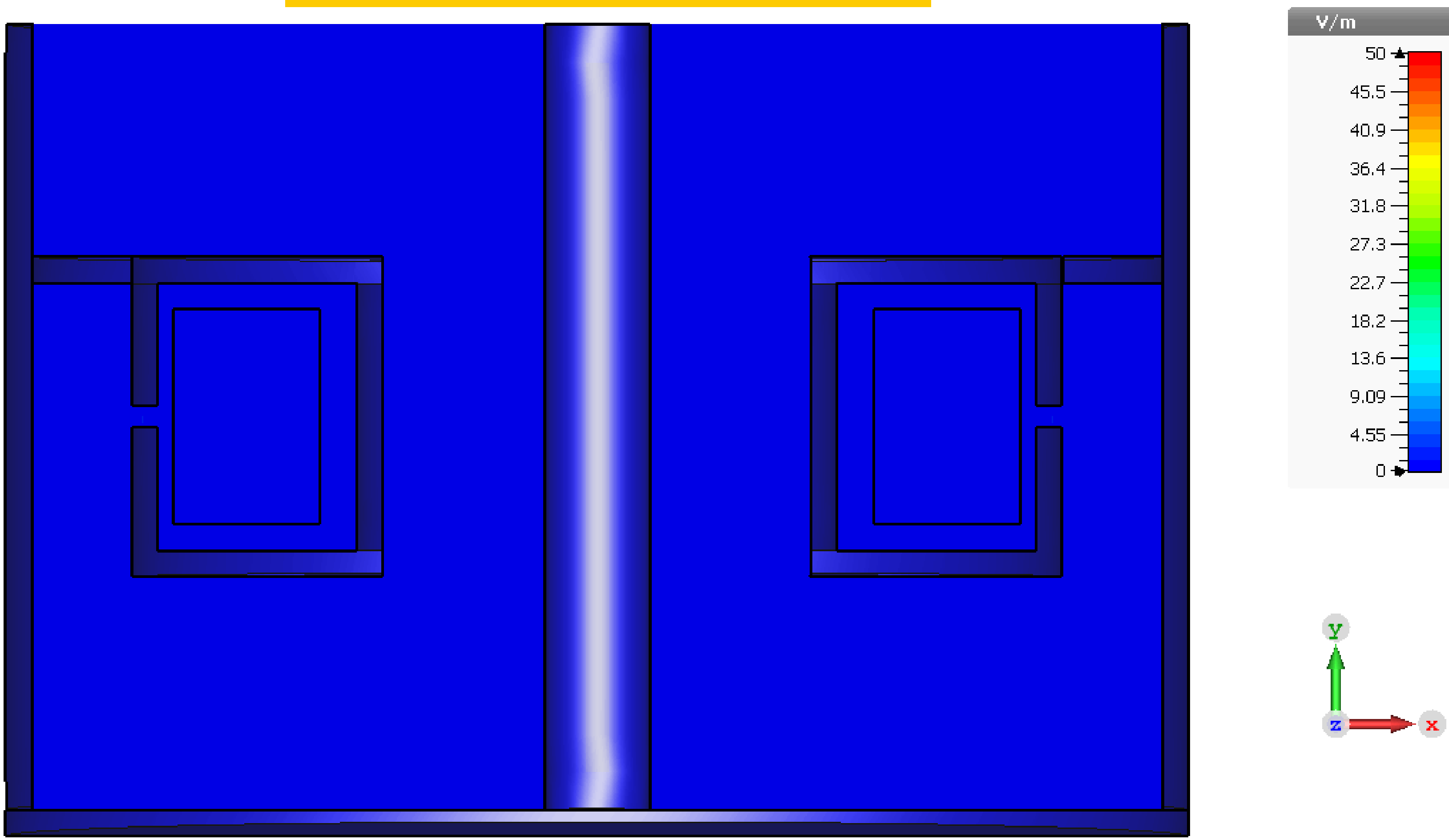
Example geometries

Output voltage at waveguide port for 4ns rise time for additiona



Try replacing magnetic material with dielectric?

Example: $\sigma=0$, **ε=15000**, $\mu=1$

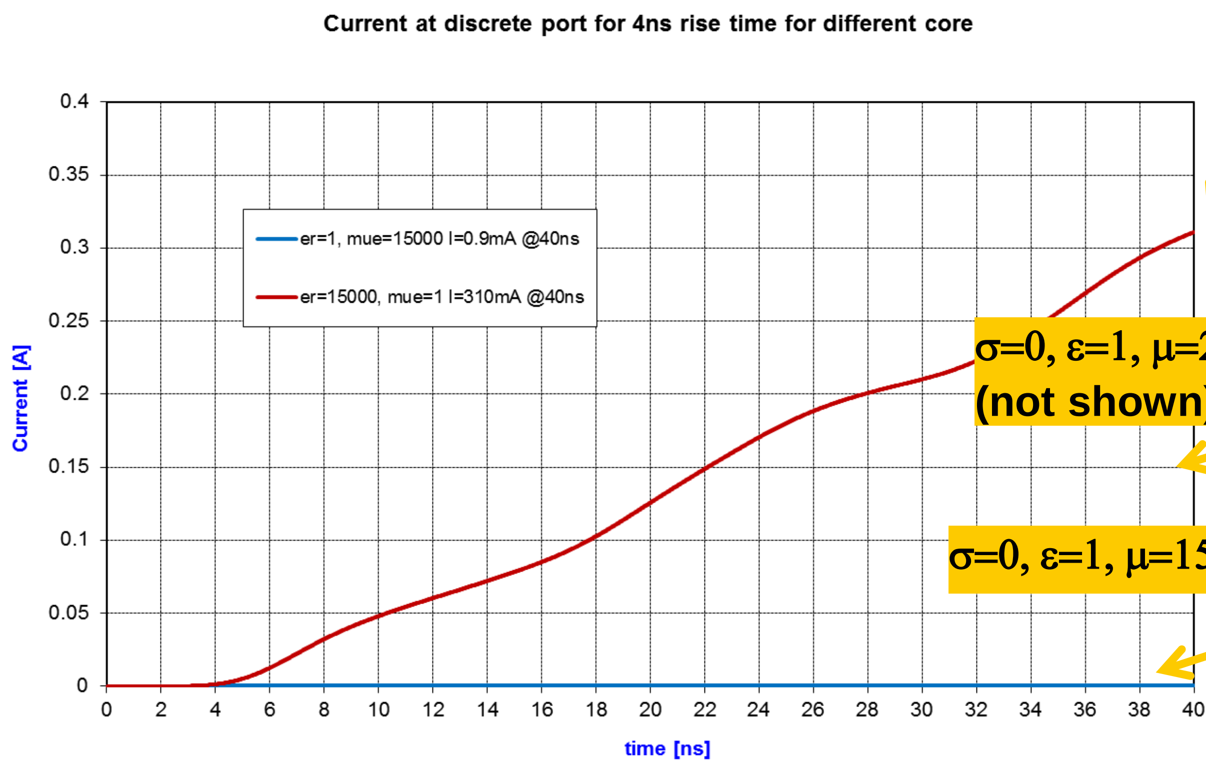


Try replacing magnetic material with dielectric?

Current in each of the sixteen radially placed voltage sources, 1V 4ns step

σ=0, ε=80, μ=20 **gives ~3A at 40ns (not shown)**

σ=0, ε=15000, μ=1 **gives 310mA at 40ns**

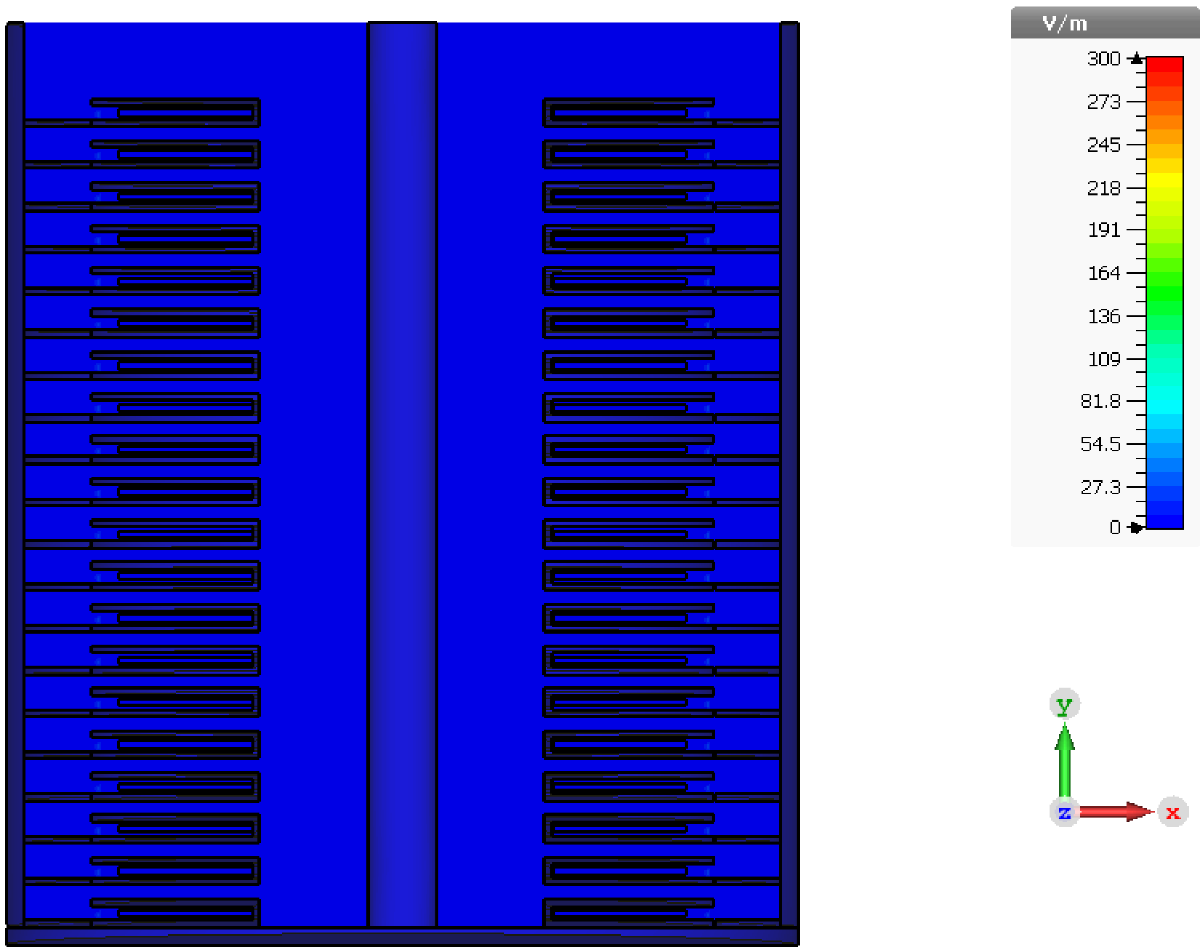


σ=0, ε=1, μ=20 **gives 150mA at 40ns (not shown)**

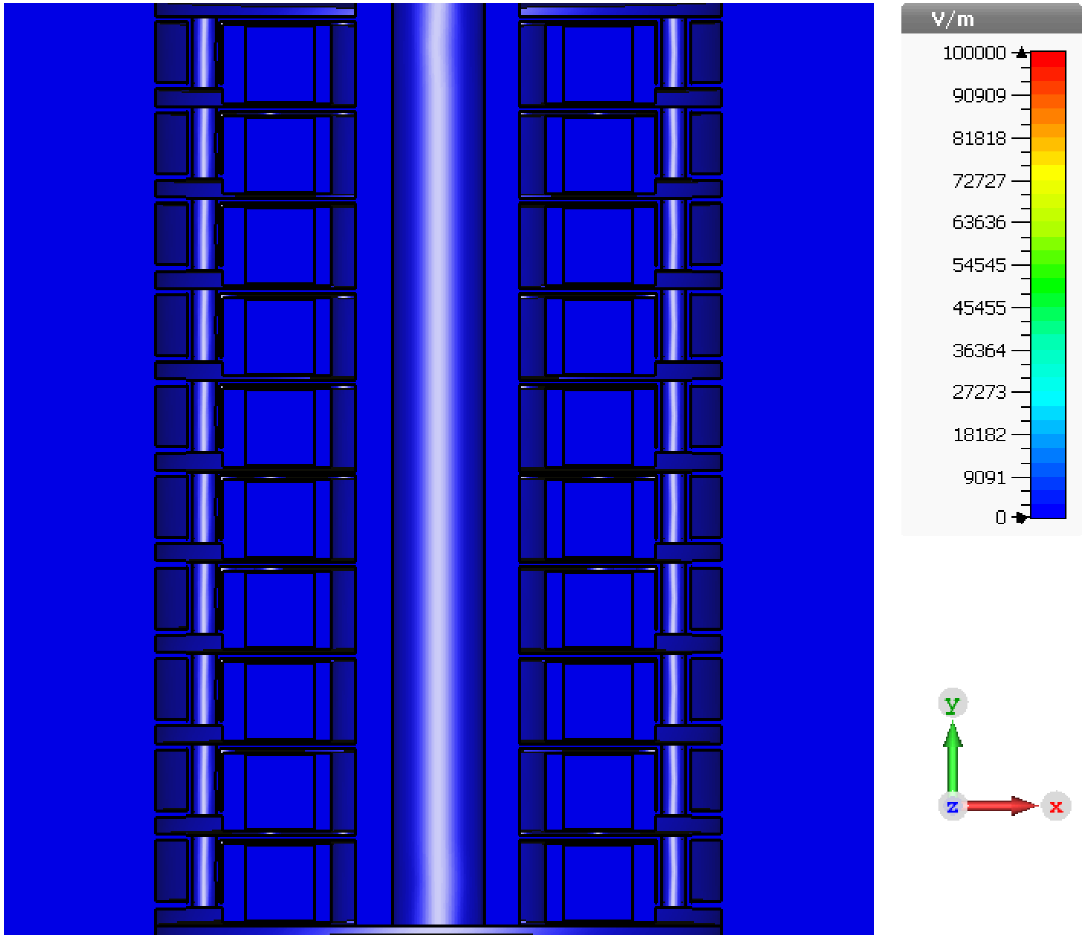
σ=0, ε=1, μ=15000 **gives 0.9mA at 40ns**

Conclude:
Most energy is magnetic so dielectric constant of core is not so important
Yes – an IVA needs magnetic material

For interest - possible high speed geometry using circuit board sandwich for minimum stage height



For interest –
what happens if only one stage is triggered?



Summary

- CST simulation is a tedious trade-off of model size, meshing parameters, etc. Expect a month's work to gain some confidence in results. Expect 4-8 hour run times.

- Use source excitation with 4ns rise time – smaller rise times tended to give excessive simulation ringing which masked usable results

- Visualising the behaviour of vector fields in 3D is really confusing. In this presentation, only scalar E-Field magnitude was shown.

- Within the IVA structure, the transients propagate longitudinally go-and-return at the speed of light, independent of geometry. So if the structure is 1 meter long, the rise time limit is around twice 3ns plus source rise time.

- In practical terms, the inductance of the primary circuit dominates rise time. For this simulation, 16 radial voltage sources are used on each stage, each source 1V with impedance R=3uOhm, L=0nH, C=1F.

- For short pulses, the primary core material is not critical because any modest permeability is enough to slow the current rise of the source to practical values

- Only homogeneous core materials like ferrite have been used in simulation. So far, not able to simulate inhomogeneous, anisotropic materials like tape cores.

References and Bibliography

[1] "*The Small-Signal Frequency Response of Ferrites", Hamilton N., High Frequency Electronics, June 2011, and the references listed within*

This reference is important !

Balcerak M High voltage pulse generation with magnetic pulse compression aee-2013-0037.pdf

Brunner N RITS IVA resonance study PhysRevSTAB.12.070401.pdf

Burdt R Magnetic Core Test Stand RevSciInst 79094703 (2008).pdf

Choi J IEEE PS 35(6) Dec 2007 Loss characteristics of Magnetic Core Kumamoto University 04381355.pdf

Cook E DAHRT IVA.pdf

Diversified Technologies NGLS Pulser PCB 2015 07287236 IEEE.pdf

Diversified Technologies NGLS Pulser PCB 2015.pdf

Gao P Plasma ignition IVA.pdf

Guo F Modelling power flow with 2D tL circuits PhysRevAccelBeams.20.020401.pdf

Jiantao L RevSciInst Distributed parameter model IVA1.5003390.pdf

Krasnyhk A Performances nanosecond core slac-pub-11853.pdf

LLNL Pockels Cell Driver IVA.pdf

Sakai Y Tokio Institute of Technology Reproducible and controllable IVA 1.4961029.pdf

Smith ID Induction Voltage Adders and the Induction Acceleraotr Family PhysRevSTAB.7.064801.pdf

Steier C Fast Kicker Systems for ALS-U mopme083.pdf

Wei H Xian Jioatong University Azimuthal Uniformity of injection _2015_Plasma_Sci._Technol._17_235.pdf

Woog D CERN 3WE09E_Inductive_Adder_Woog_16_9.pdf

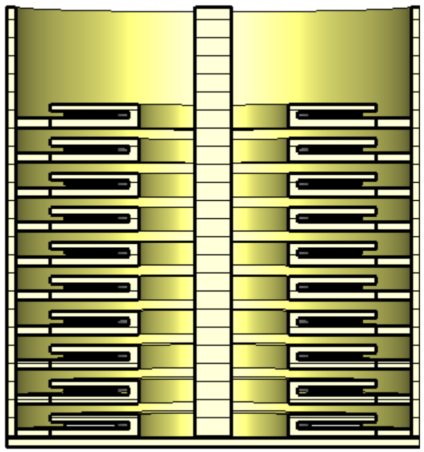
Zhang BNL simple spice circuit for IVA ADA609632.pdf

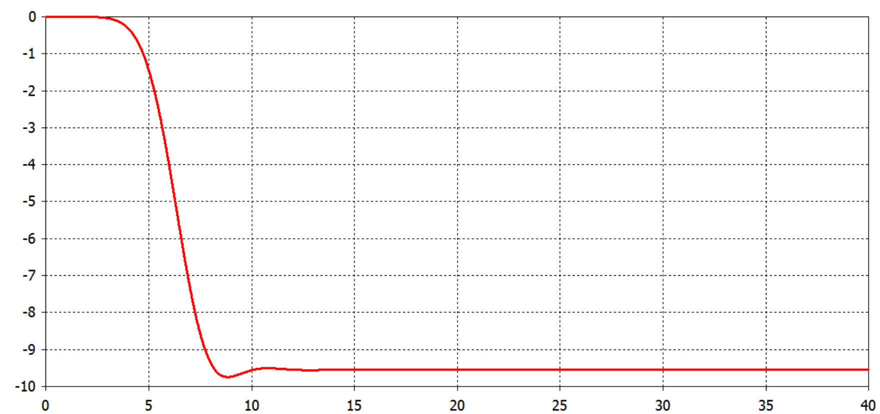
My thanks go to

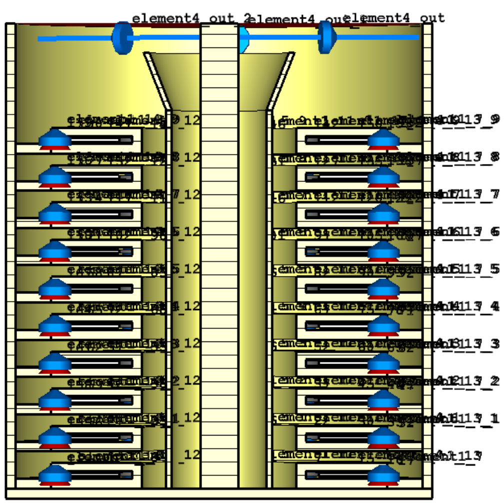
Martin Paraliev

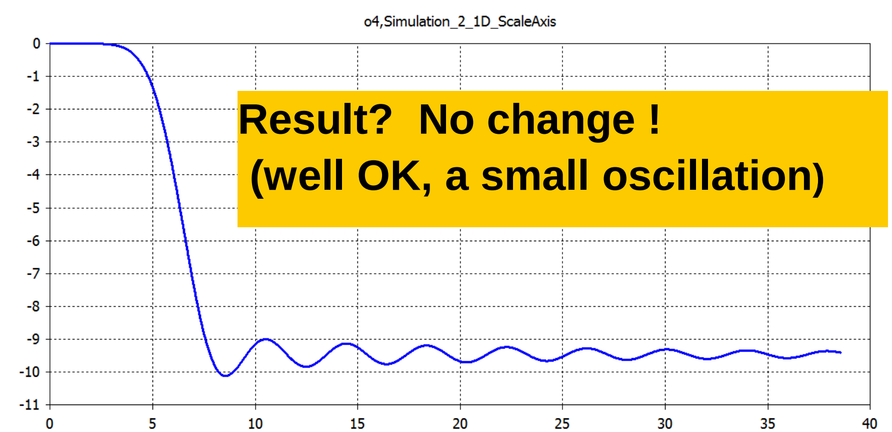
Aunt Helvetia

For fun – try adding a conducting tube to double the end-to-end propagation time



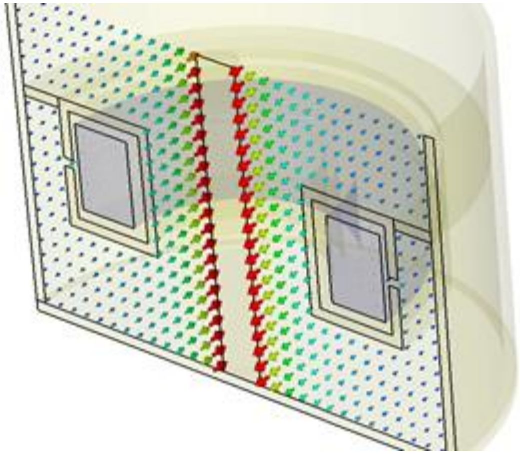




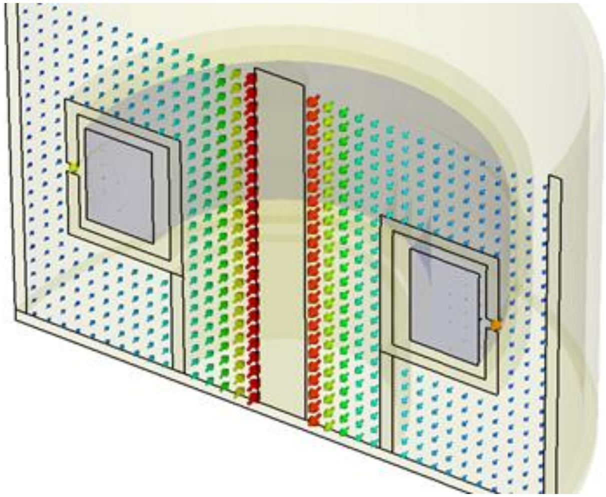


Steady-state H-field independent of geometry!

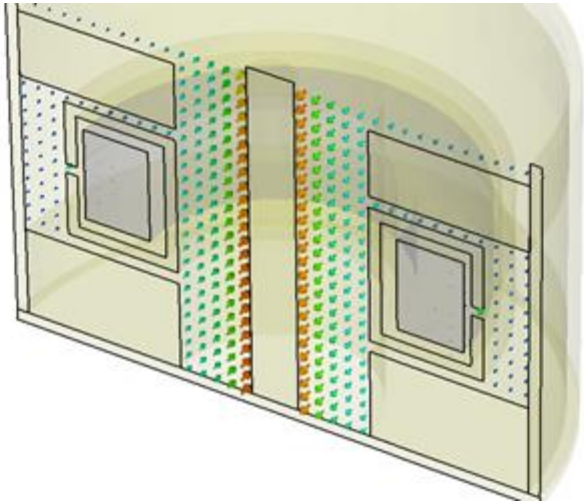
H (A/m) at 20ns



Ring to the wall

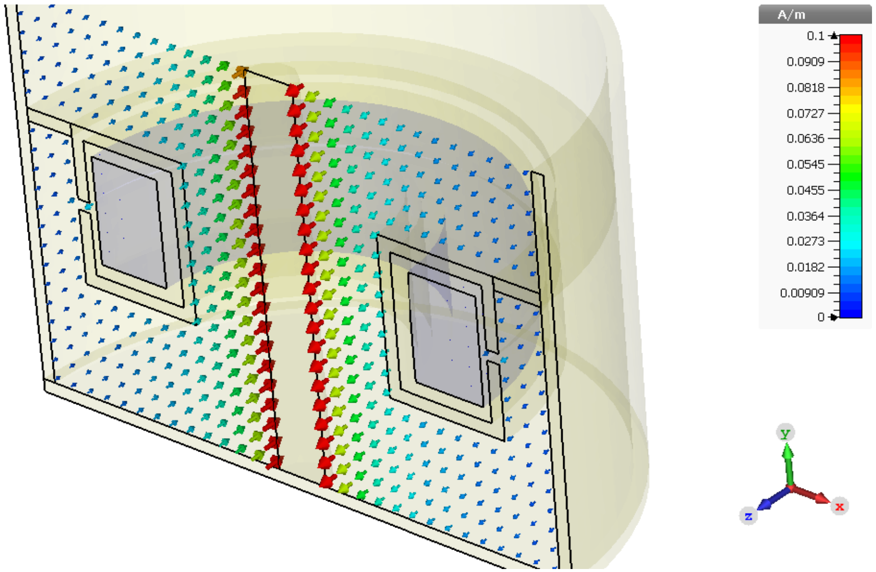


Ring to the base

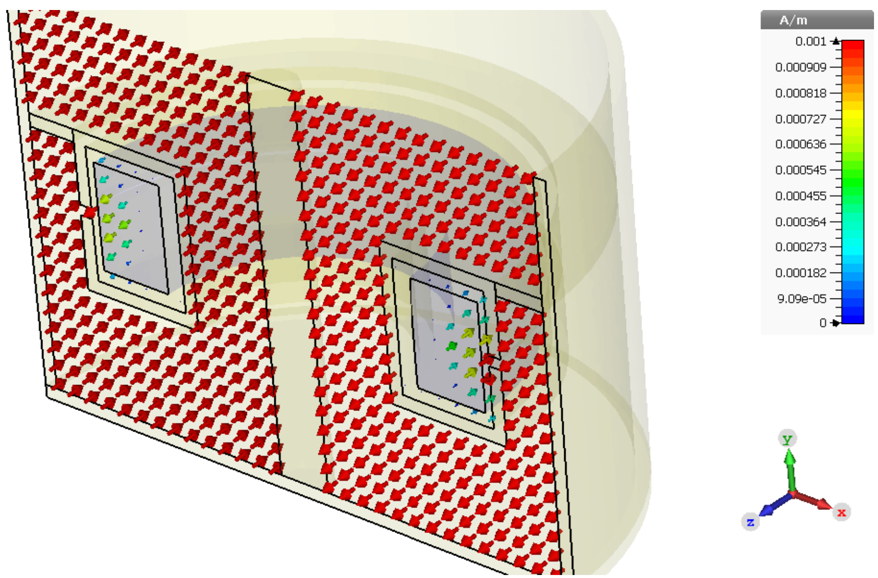


Two metal rings

Example 1– Ring to the Wall

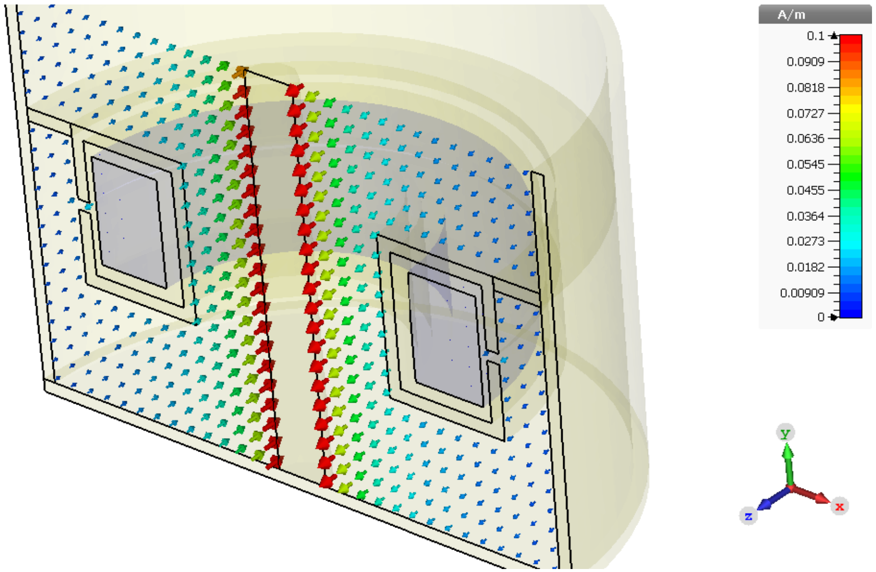


H (A/m) at 20ns

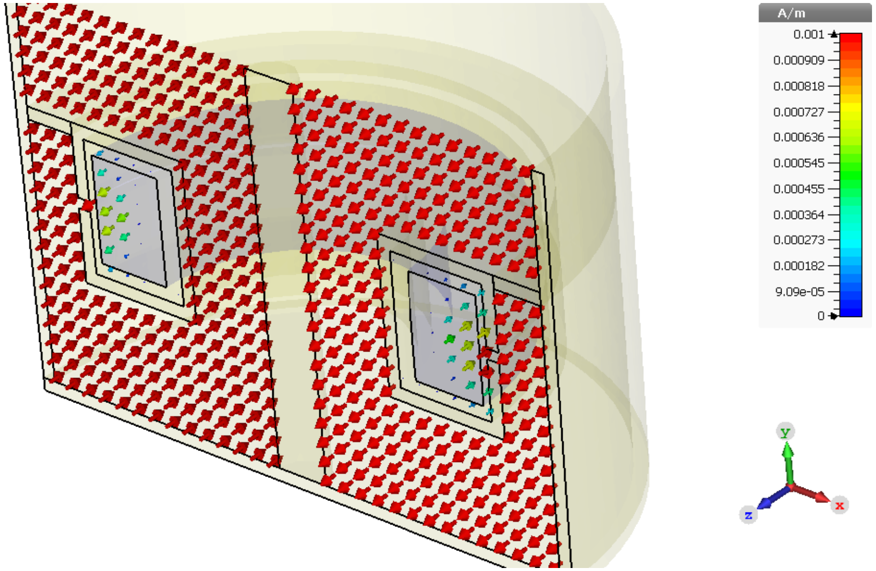


H (A/m) at 20ns,
Rescaled to see H in core

Example 1– Ring to the Wall

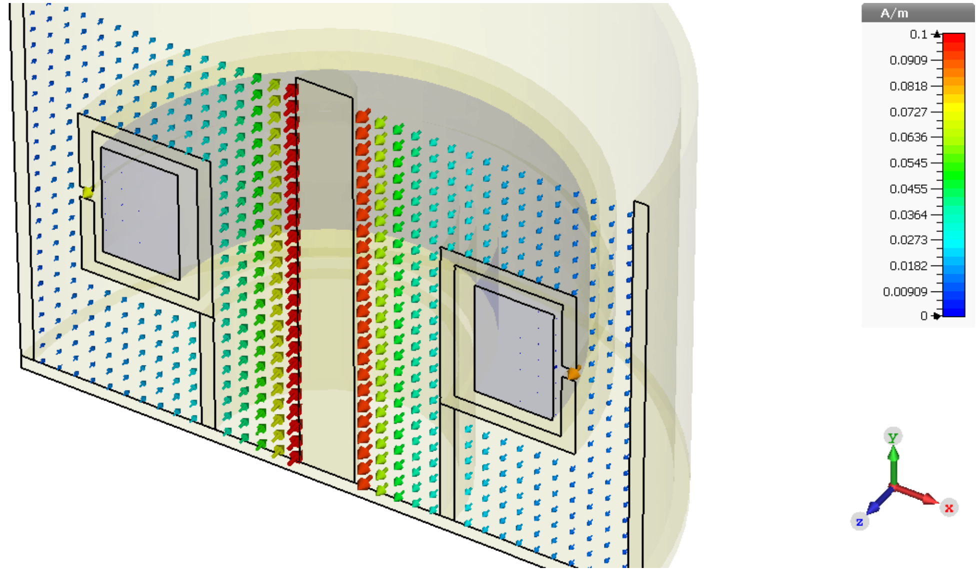


H (A/m) at 20ns

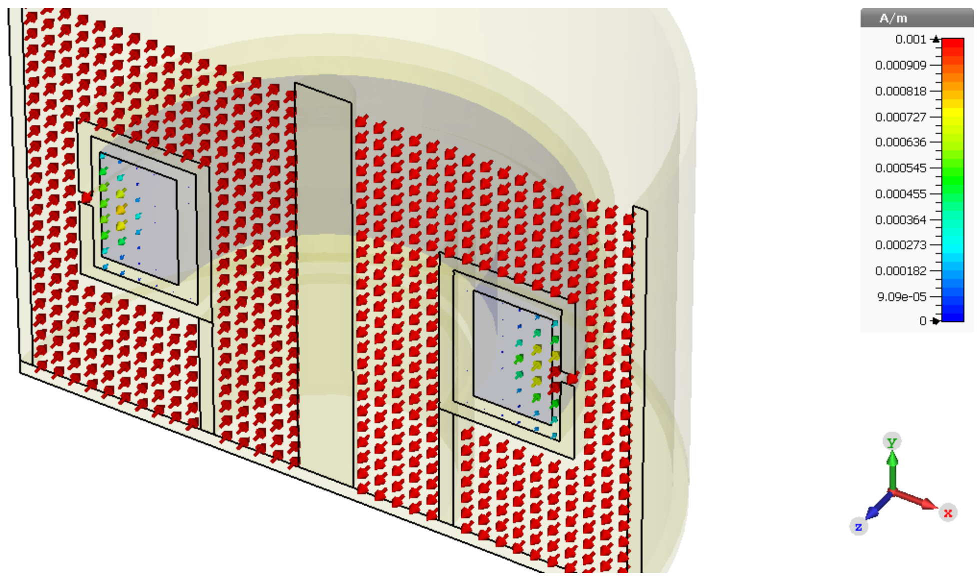


H (A/m) at 20ns,
Rescaled to see H in core

Example 2– Ring to the Base

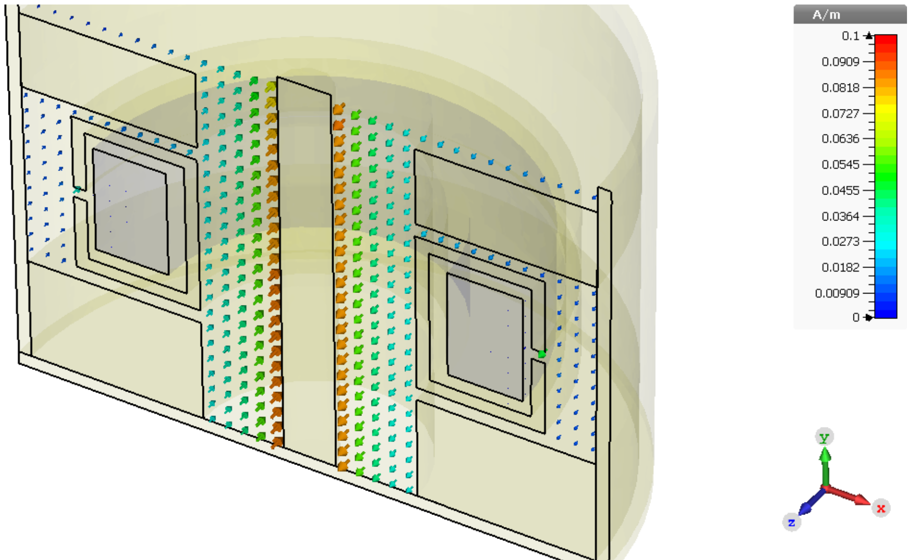


H (A/m) at 20ns

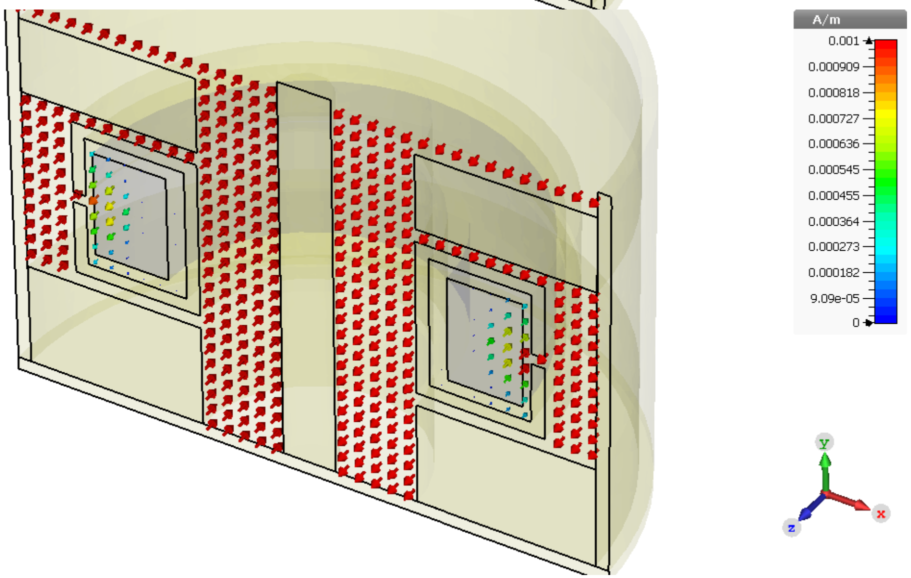


H (A/m) at 20ns,
Rescaled to see H in core

Example 3– Two Rings



H (A/m) at 20ns



H (A/m) at 20ns,
Rescaled to see H in core