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TRANSMISSION LINE AND ELECTROMAGNETIC MODELS OF THE MYKONOS-2 ACCELERATOR*

E. A. Madrid[x], C. L. Miller, D. V. Rose, D. R. Welch, R. E. Clark, C. B. Mostrom
Voss Scientific

W. A. Stygar, M. E. Savage
Sandia National Laboratories

D. D. Hinshelwood
Naval Research Laboratories

K. R. LeChien
National Nuclear Security Administration

Voss Scientific, LLC
418 Washington Street SE
Albuquerque NM 87108
(505) 255-4201

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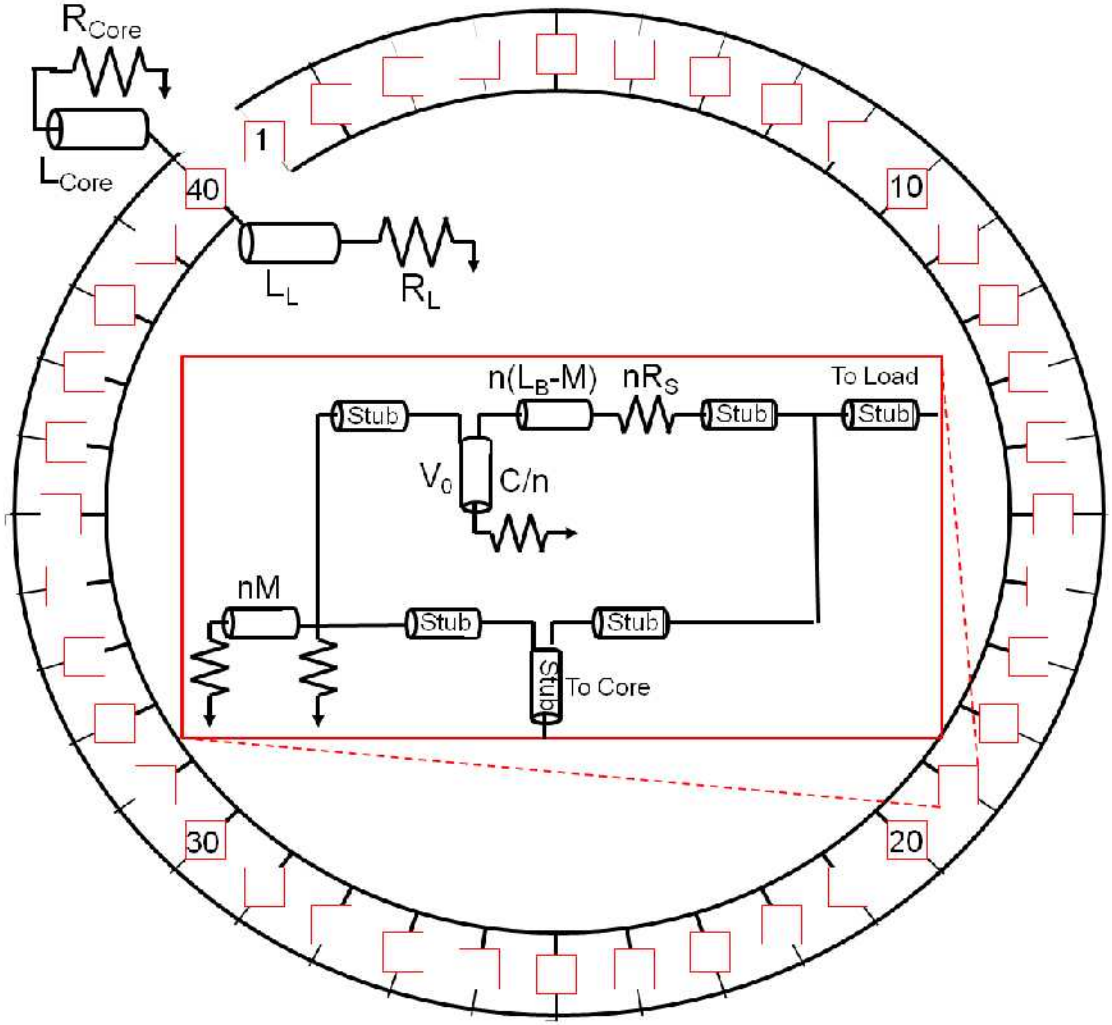
Abstract

Mykonos is a linear transformer driver (LTD) pulsed power accelerator currently undergoing testing at Sandia National Laboratories. Mykonos-2, the initial configuration, includes two 1-MA, 200-kV LTD cavities driving a water-filled transmission line terminated by a resistive load. Transmission line and 3D electromagnetic (EM) simulation models of high-current LTD cavities have been developed [D.V. Rose *et al*. Phys. Rev. ST Accel. Beams **13**, 90401 (2010)]. These models have been used to develop an equivalent two-cavity transmission line model of Mykonos-2 using the BERTHA transmission line code. The model explicitly includes 40 bricks per cavity and detailed representations of the water-filled transmission line and resistive load. (A brick consists of two capacitors and a switch connected in series.) This model is compared to 3D EM simulations of the entire accelerator including detailed representations of the individual capacitors and switches in each cavity. Good agreement is obtained between the two simulation models and both models are in good agreement with preliminary electrical data from Mykonos-2.

Single Cavity Circuit Schematic

Circuit schematic of a single 40-brick LTD cavity.

Each brick contains a representative capacitor, switch, and mutual inductance.



n = number of bricks, in this case n = 40.

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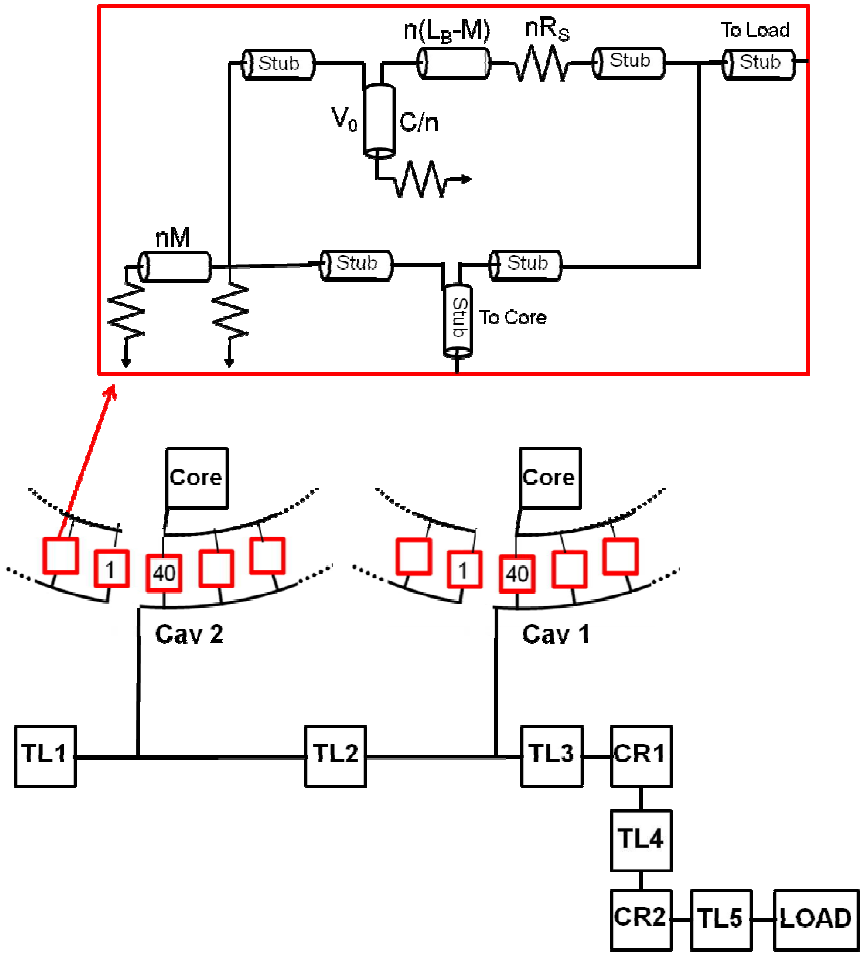
Transmission Line Model of Mykonos-2



Circuit schematic of two LTD cavities driving a common water-filled coaxial transmission line terminated by a resistive load.

D.V. Rose et al., "Circuit models and three-dimensional electromagnetic simulations of a 1-MA linear transformer driver stage," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 13, pp. 90401-1 – 90401-11, 2010.

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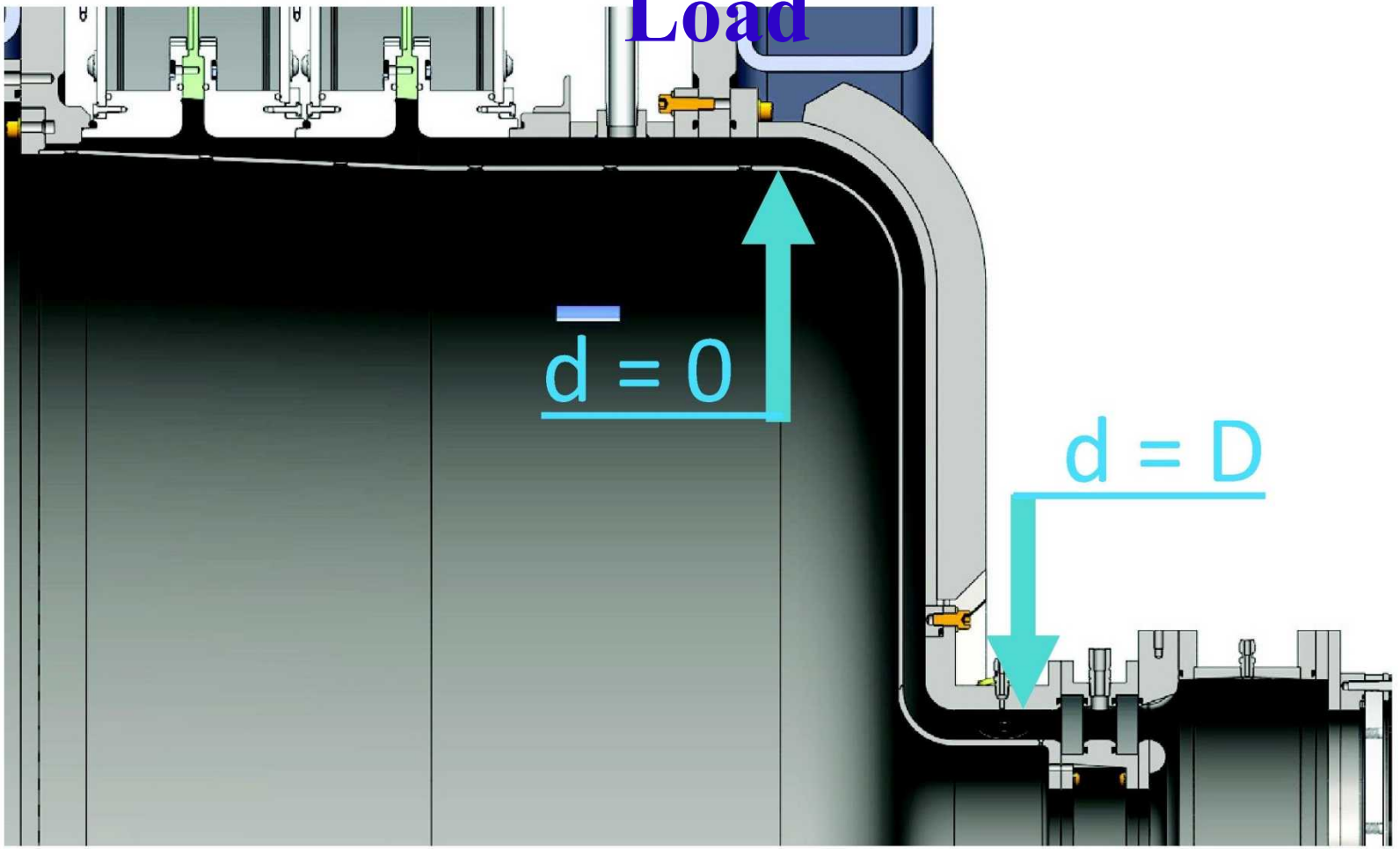
Mykonos 2-cavity Transmission Line and Load



The transmission line and load geometry for the Mykonos-2. Detailed modeling of the load is necessary to accurately produce reflections for the transmission line field structure.

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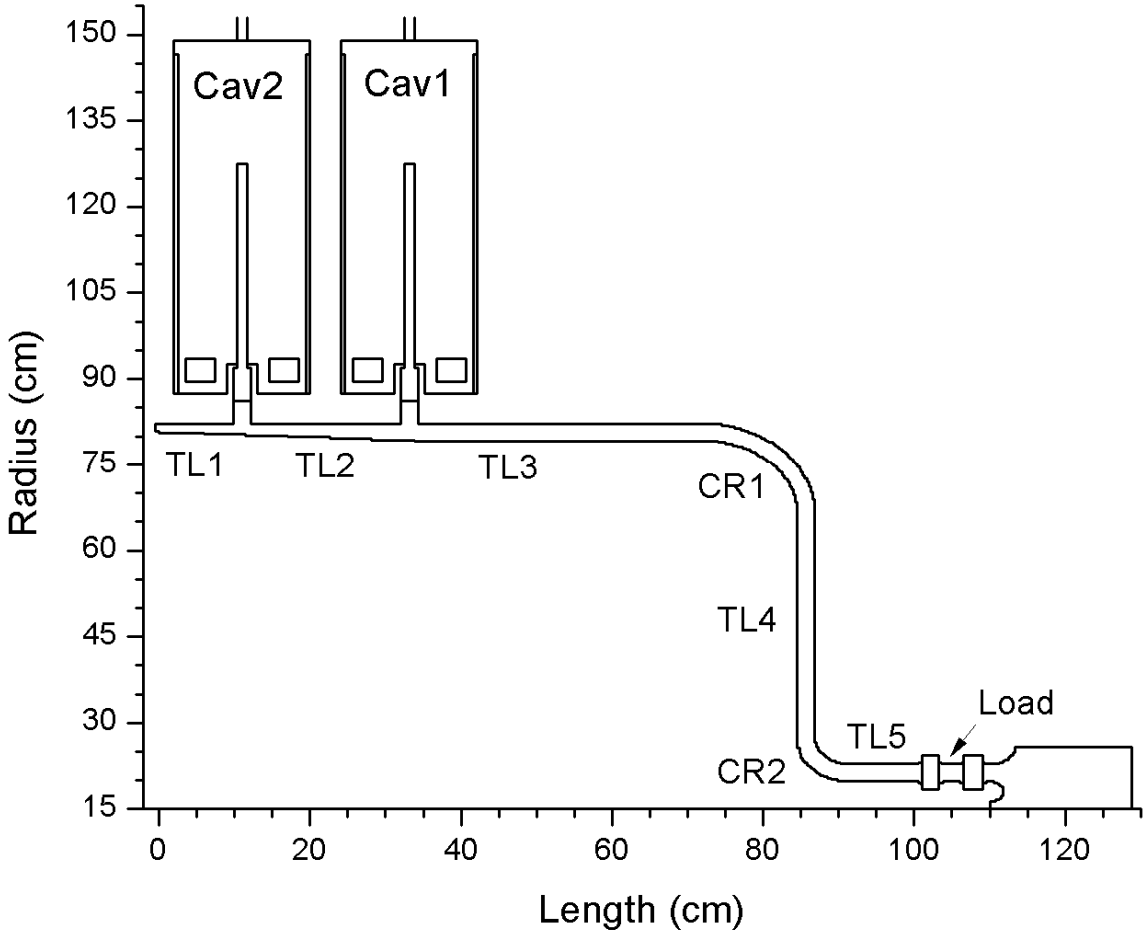
Cross-Sectional Simulation Model of 2-Cavity System



Cross-sectional view of a 2-cavity system model in Lsp. Such a model can be used to study field stresses in the Mykonos-2 accelerator.

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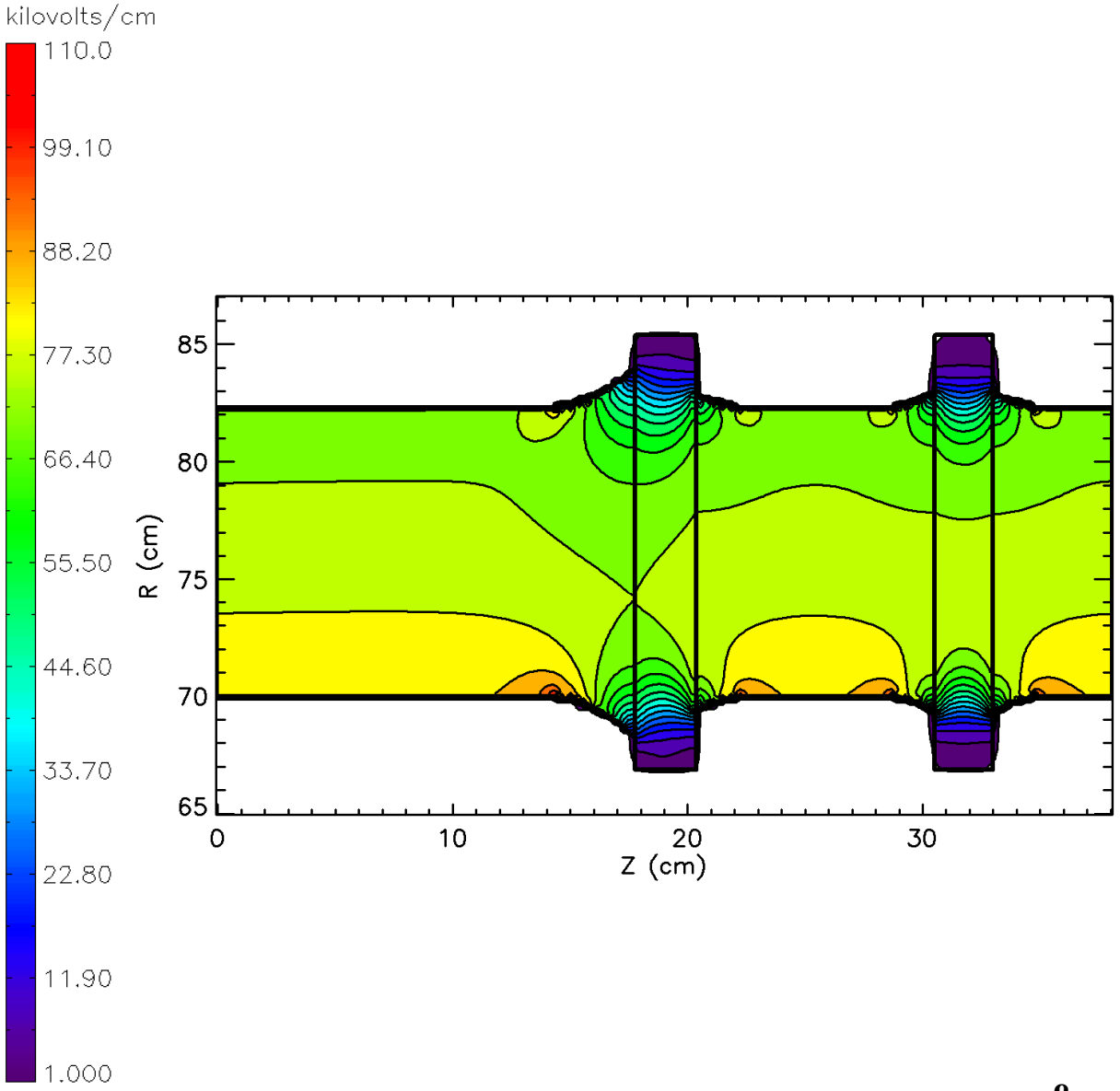
Lsp Model Components

Mykonos Load Design

LSP is used with an azimuthally-symmetric model of the load. Reflections are minimized when the geometric resistance matches the transmission line impedance. Length is not a factor and is minimized to reduce inductive effects. The full 2-cavity transmission line, including the details of the LTD cavities, is also modeled to ensure electric field levels remained below design thresholds, as the cavity-to-load transit time is small compared to the pulse width. The electric field in a 4-inch load near peak power remains below ~110 kV/cm.



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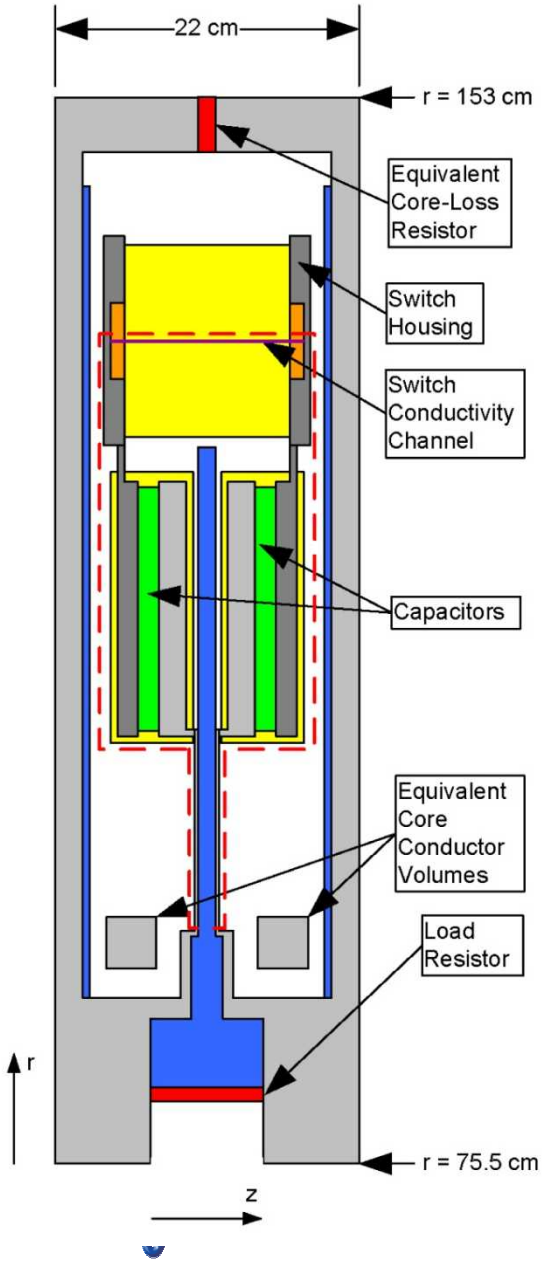
LSP Simulation Description



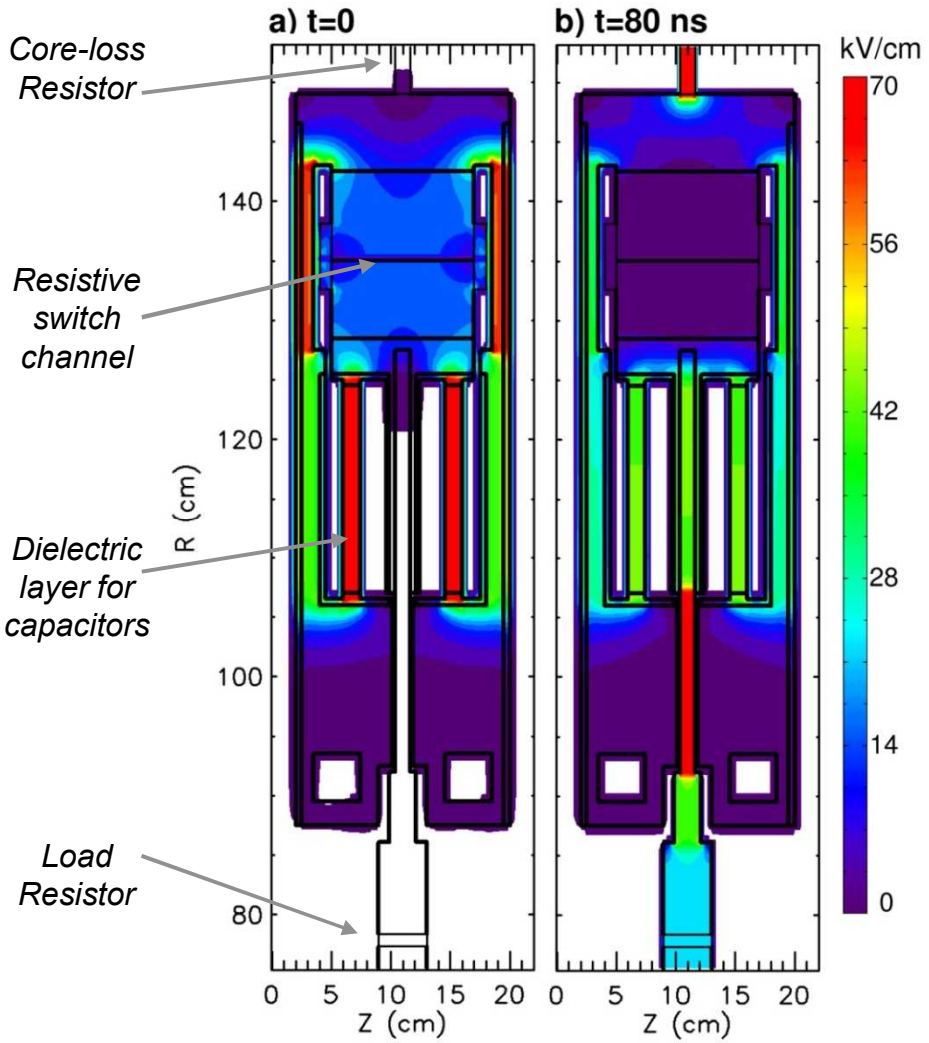
A single LTD brick consists of two capacitors connected in series by a low-inductance switch. Forty bricks inside a low-inductance cavity, connected to a load and including ferromagnetic cores, comprise a single LTD cavity.

Circuit simulations successfully model LTD cavity output. Electromagnetic models compliment these circuit models and hold information about field stresses and non-linear behavior.

LSP simulations use a fully electromagnetic treatment in 3D cylindrical coordinates (r, θ, z). The 40-fold azimuthally periodic brick arrangement intrinsic to the LTD design simplifies the simulations, requiring only 1/40th of a cavity to be modeled. Additional bricks or cavities can be modeled as necessary.

Single-Brick 3D Model

- *A Poisson electrostatic solver initializes the simulation by setting a 100 kV potential across the simplified capacitors. The switch, a time-dependent conductivity channel spanning the switch housings, triggers the discharge of the capacitors. Here, the core losses are modeled using a resistor set at high-R.*
- *Cell sizes vary from 0.25 to 0.5 cm in R, 0.15° to 0.45° in theta, and 0.125 to 0.576 cm in Z. Over 360 thousand cells for 1 brick, and nearly 1.5 million cells for 1 cavity comprised of 40 bricks.*
- *Single-cavity, single-brick simulations (0 – 300 ns) run in 6 hours on 4 processors.*
- *2-cavity, 40-brick model runs in 12 hours on 320 processors.*



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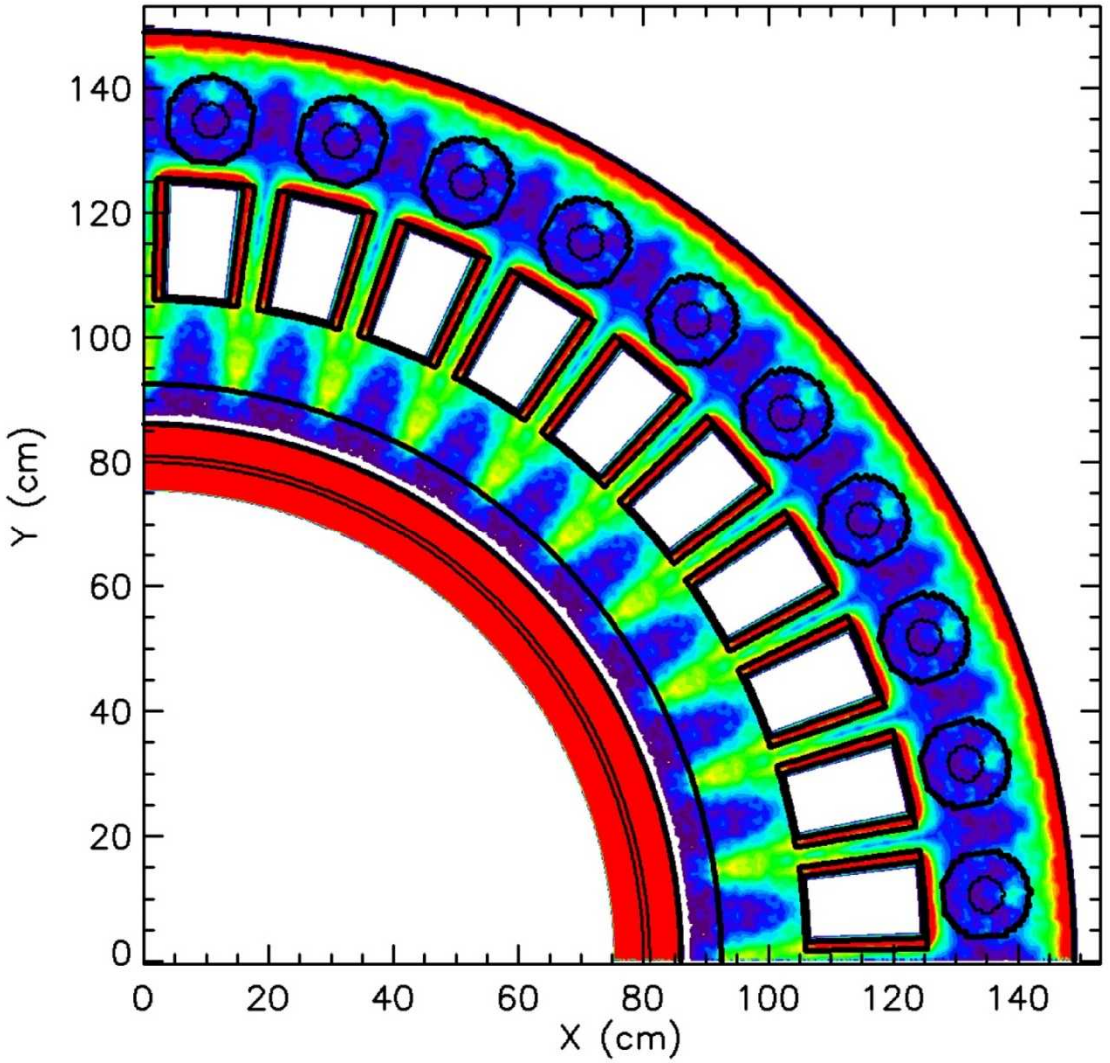
C. L. Miller et al., "3D electromagnetic and transmissionline models of a 1-MA linear transformer driver cavity for high-current z pinch accelerators," in 37th IEEE International Conference of Plasma Science, 2010.

40-brick 3D Model

Multiple brick simulation models can be used to understand inter-brick field stresses on critical components for failure mode analysis.



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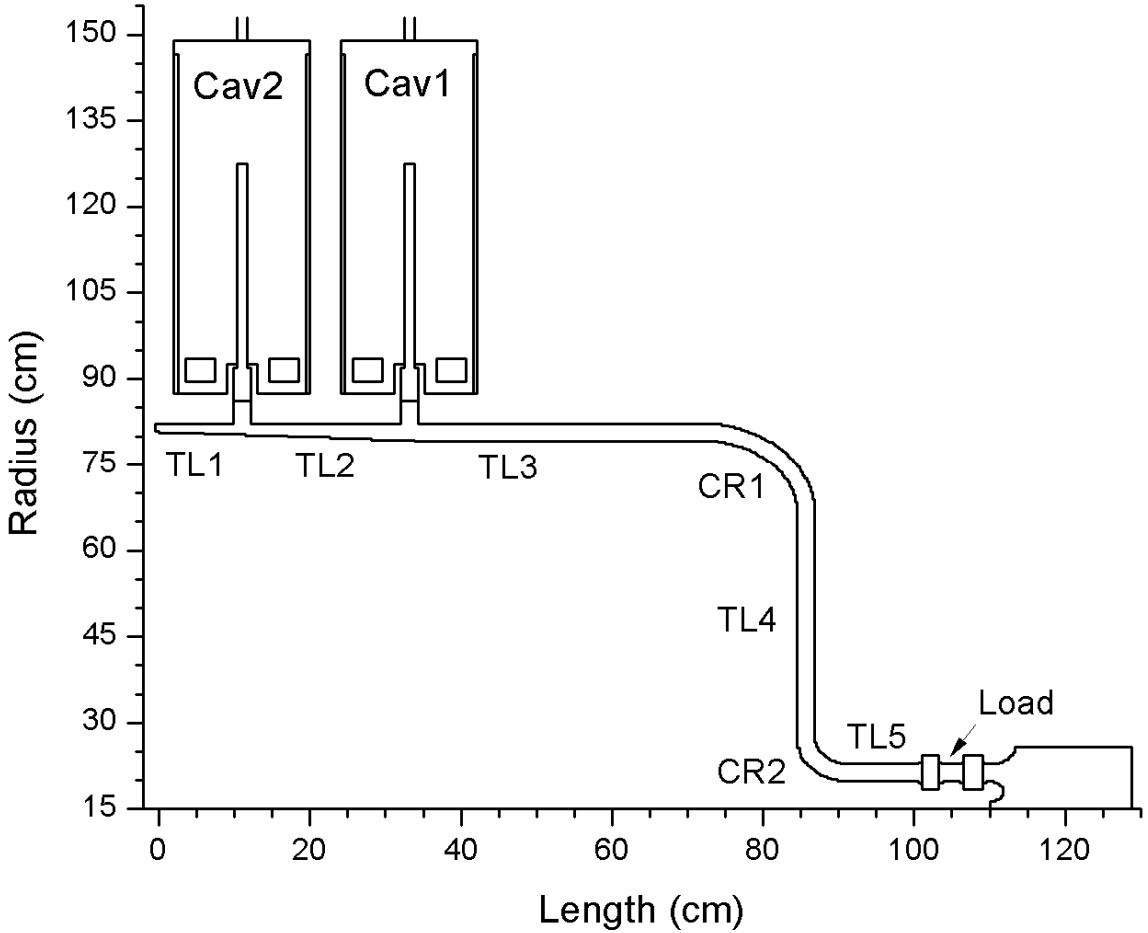
D.V. Rose et al., "Circuit models and three-dimensional electromagnetic simulations of a 1-MA linear transformer driver stage," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 13, pp. 90401-1 – 90401-11, 2010.

Cross-Sectional View of 2-Cavity System



Cross-sectional view of a 2-cavity system model in Lsp. Such a model can be used to study field stresses in the Mykonos-2 accelerator.

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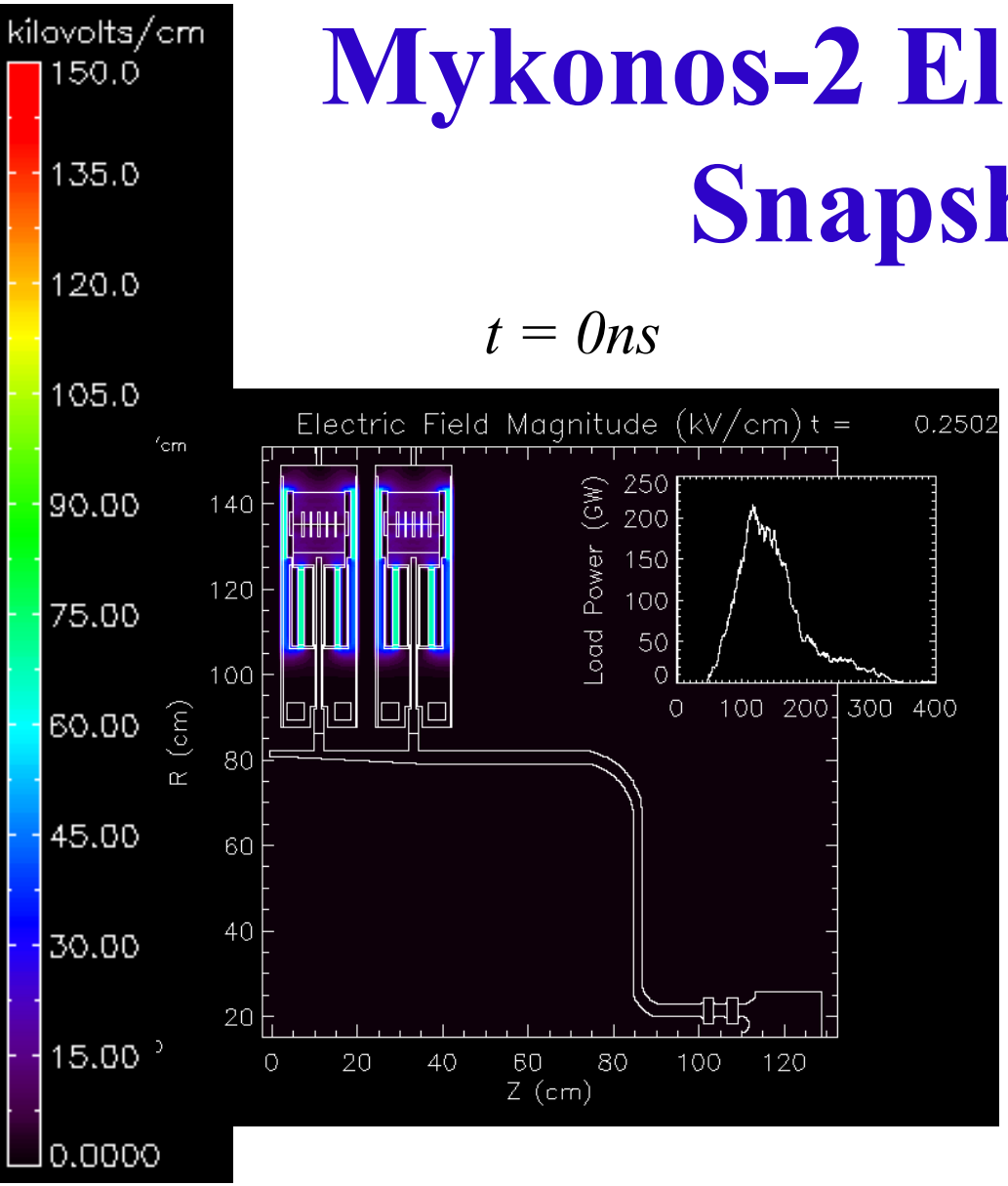
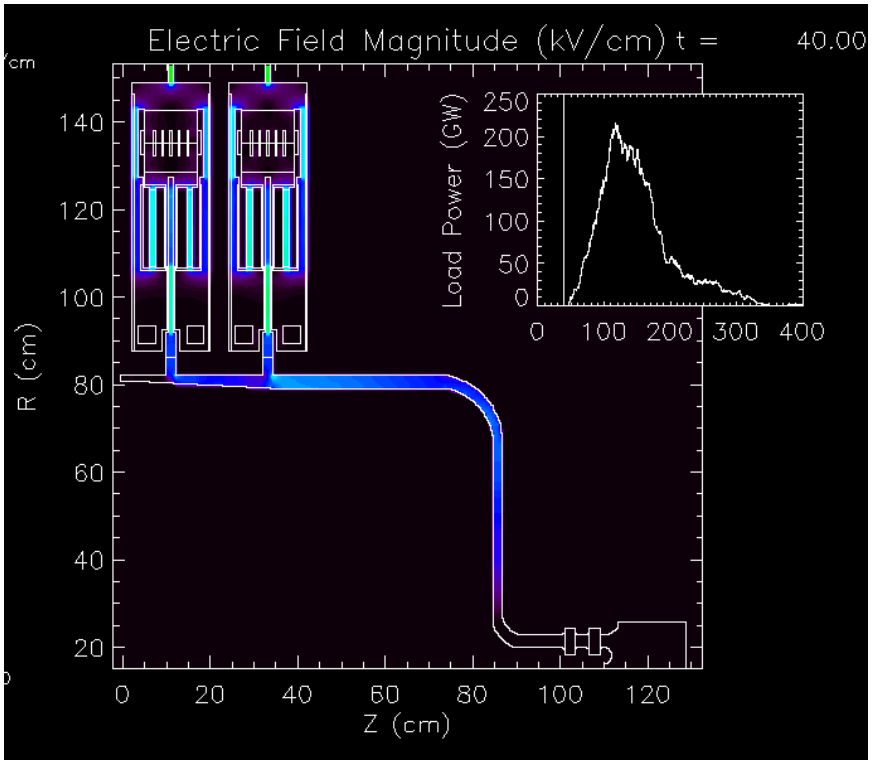
Mykonos-2 Electric Field Snapshots

t = 0ns



t = 40ns



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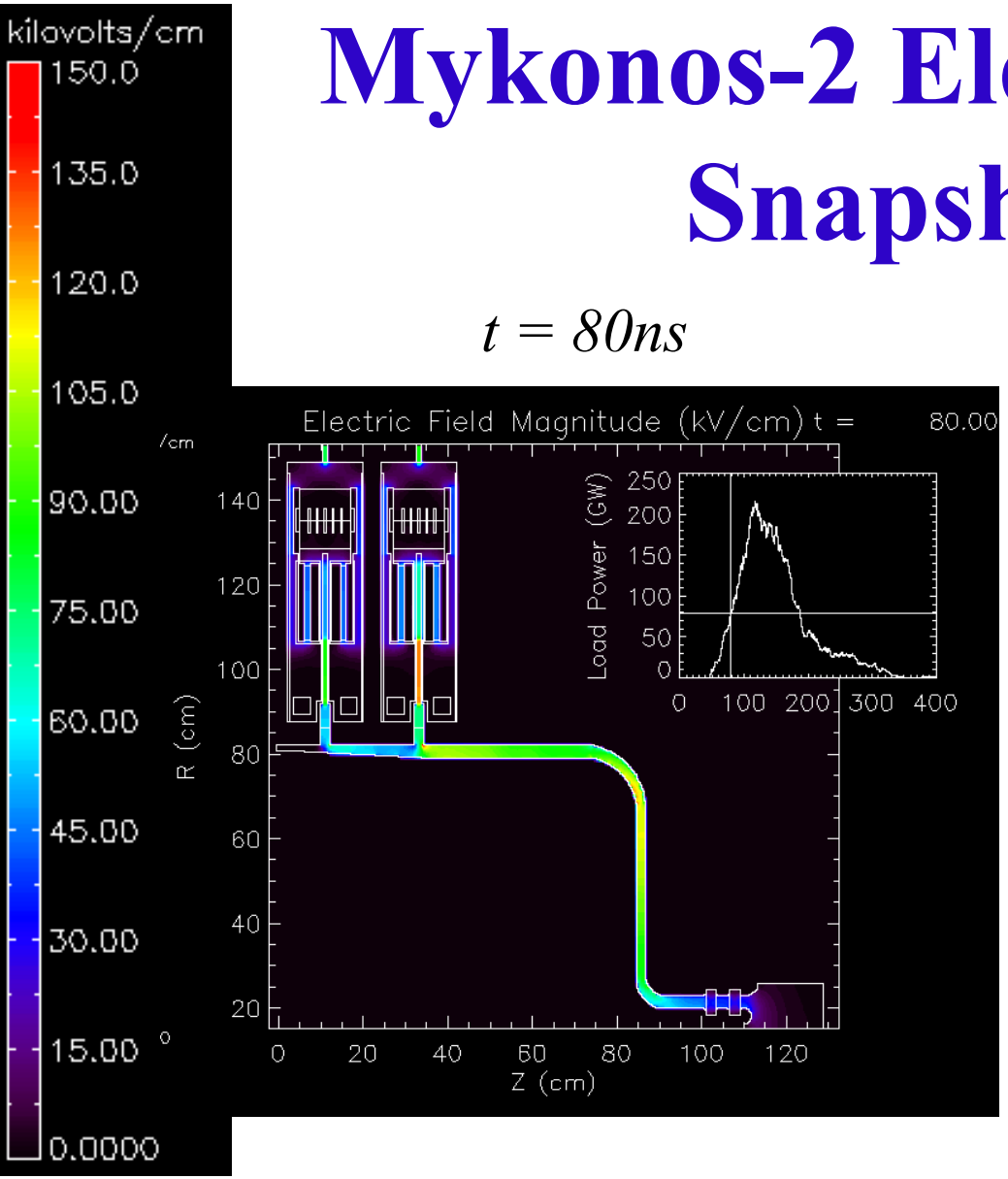
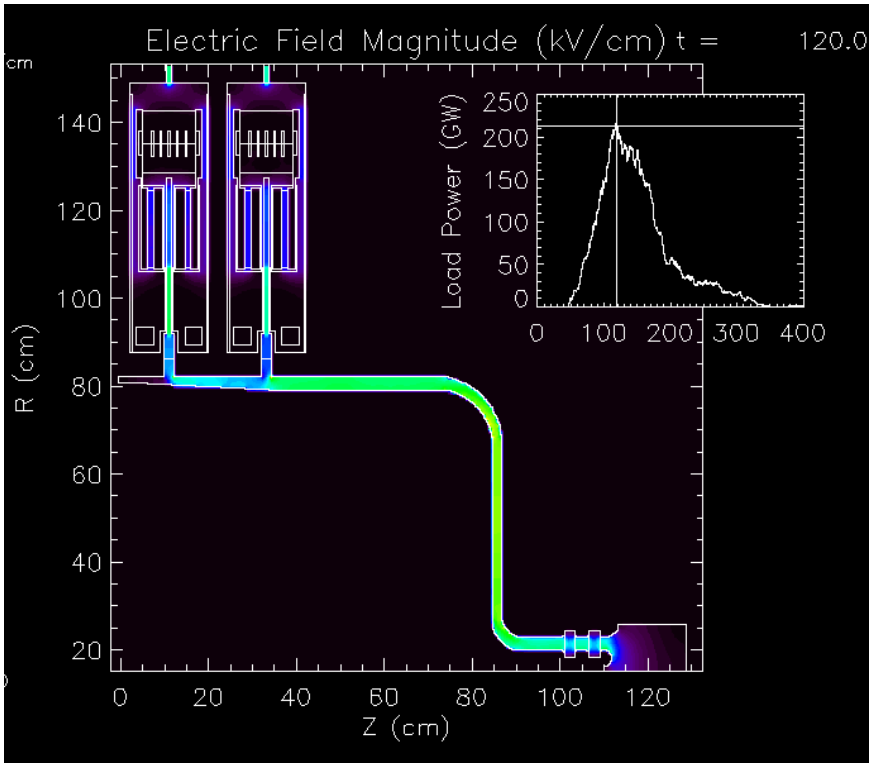
Mykonos-2 Electric Field Snapshots

t = 80ns



t = 120ns



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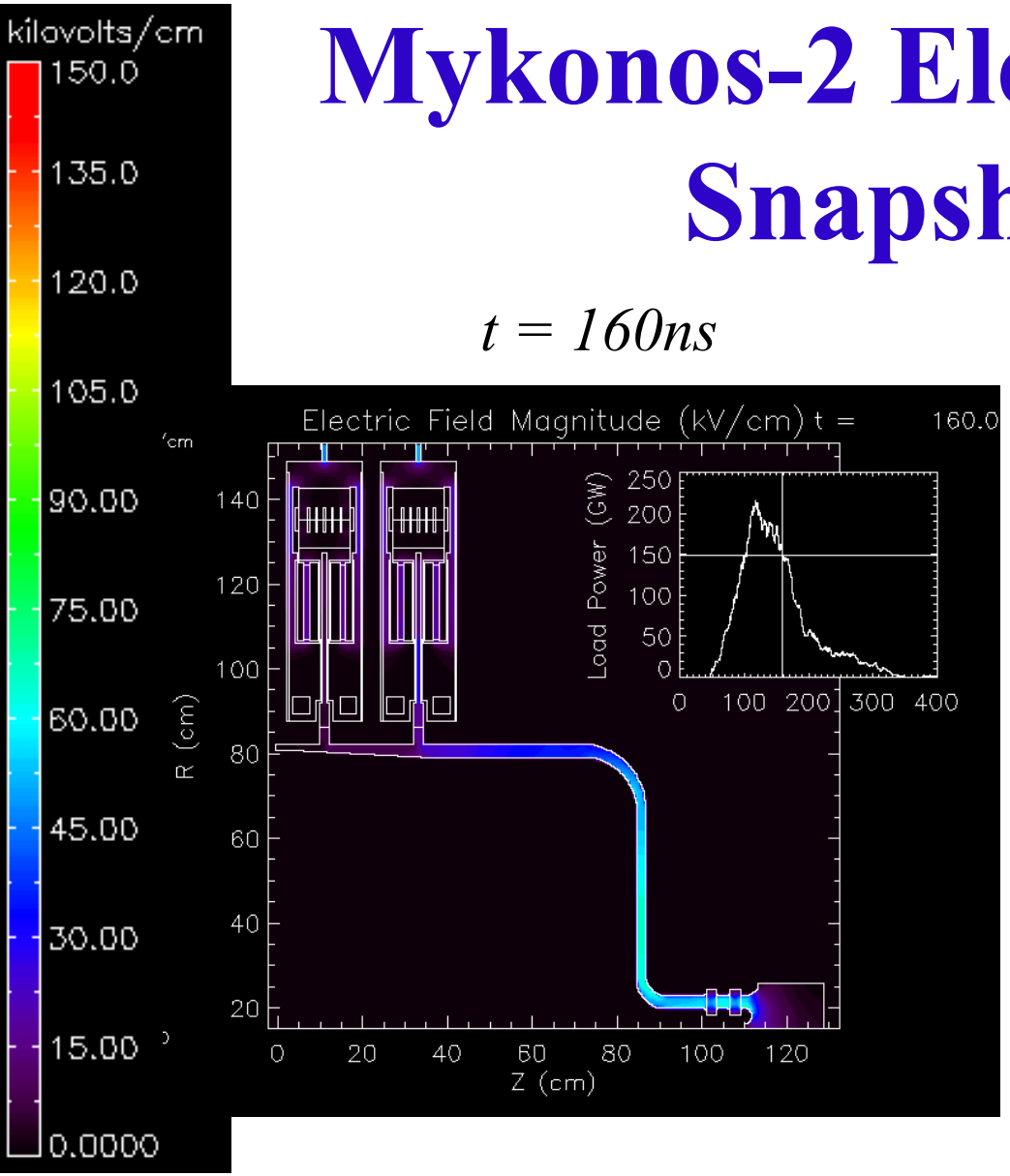
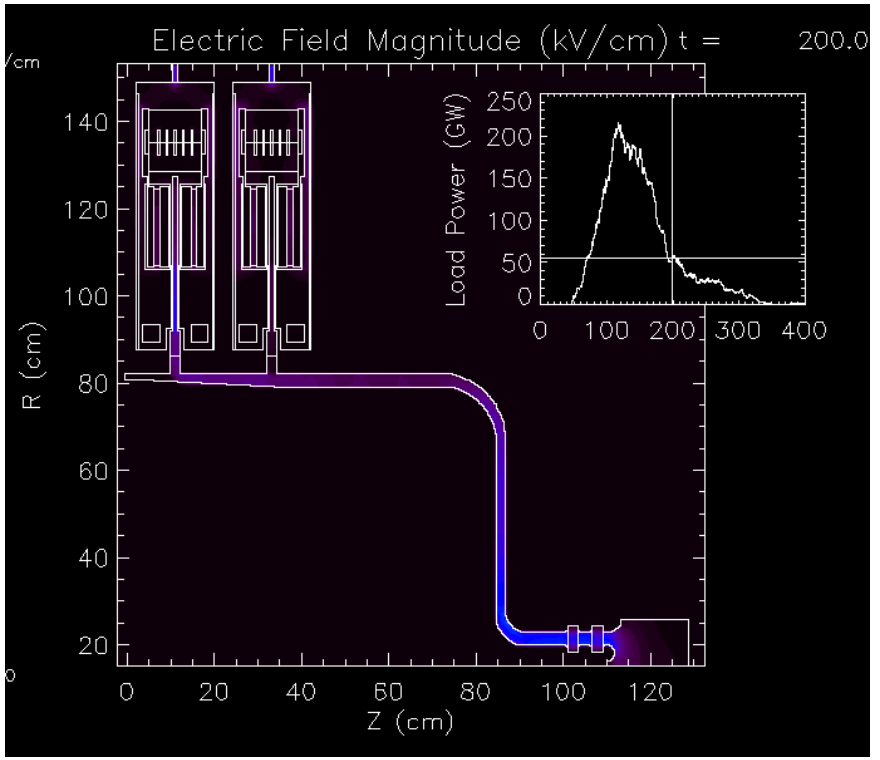
Mykonos-2 Electric Field Snapshots

t = 160ns



t = 200ns



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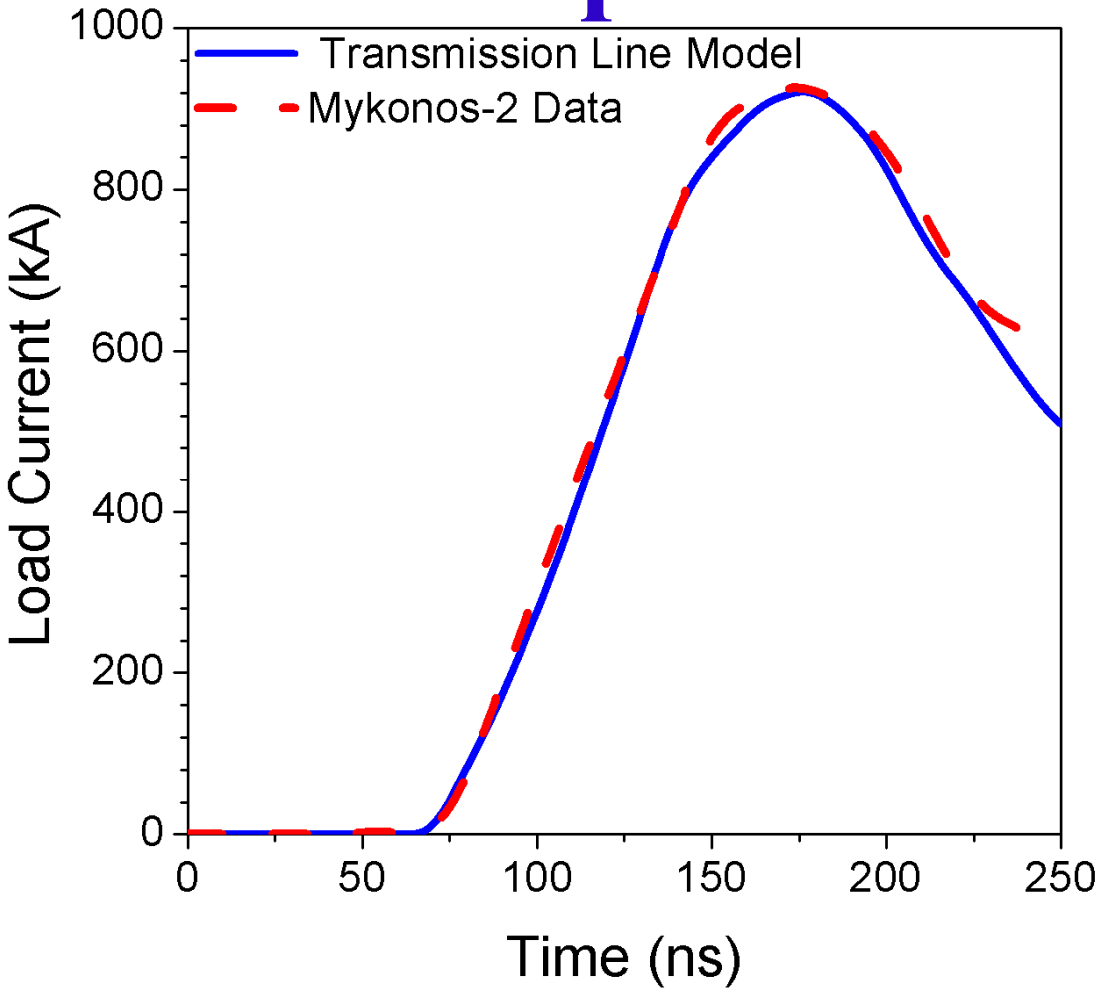
Synchronous Shot Analysis

Comparison of Load Currents Demonstrates Model precision

These load current traces are from a synchronous shot configuration, all 40 switches in each of the two cavities break down simultaneously.

The transmission line model predicts a 67.5ns 10-90% rise-time pulse with a peak value of 925kA, which is in excellent agreement with experimental data.



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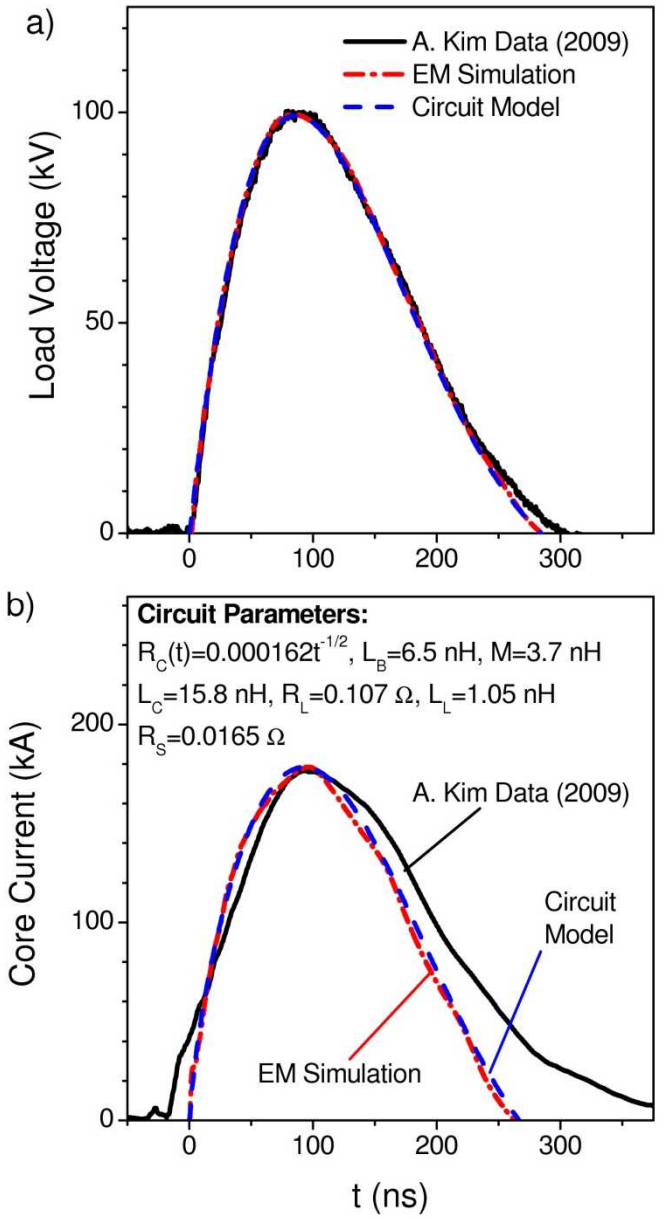
Sample Comparison Between Transmission Line and EM Models and Data –Ref paper from 2010

A three-way comparison was made between Kim's published data, the transmission line model, and the LSP EM model in order to validate the latter two.

- *Circuit representation of the mutual inductance between the core and brick current paths is essential to obtain the agreement shown.*
- *LSP self-consistently includes this inductance.*
- *A time-dependent core-loss model has been developed that can be used in both the 3D simulations and the transmission line models.*
- *Good agreement with the core-loss current is obtained over the rising portion of the pulse.*



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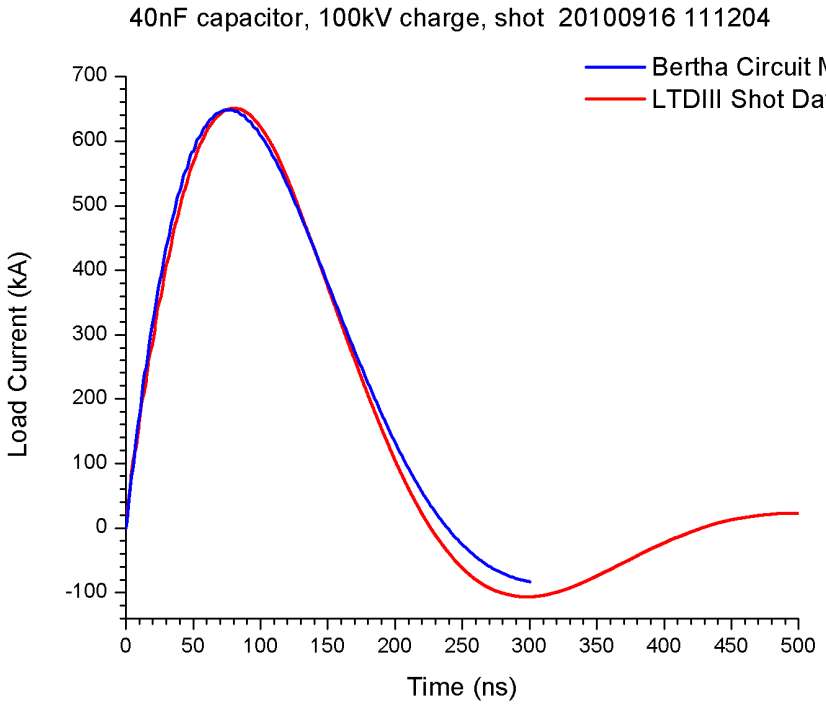
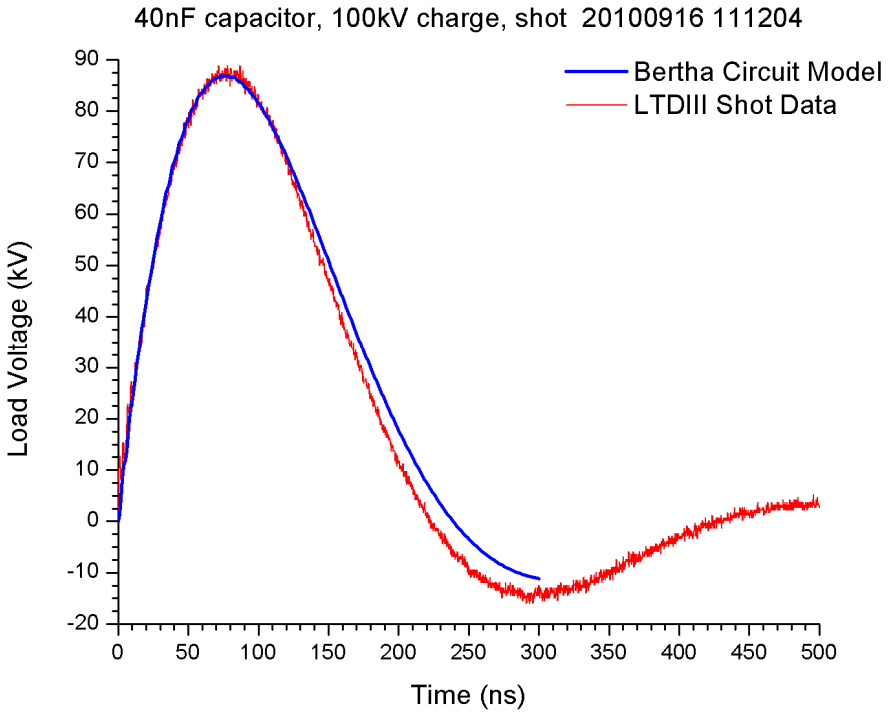
LTD-III Data Comparison

Transmission line model comparison with published LTDIII shot data. The model agrees very well with experimental results well beyond peak power.





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[1] M. G. Mazarakis et al., "High current, 0.5-MA, fast, 100-ns, linear transformer driver experiments," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 12, pp. 050401-1 – 050401-10, 2009.

[2] K. LeChien et al., "A 1-MV, 0.1-Hz linear transformer driver utilizing an internal water transmission line," in 17th IEEE International Pulsed Power Conference, 2009, p. 1186.

[3] M. G. Mazarakis et al., "Linear transformer driver (LTD) development at sandia national laboratory," in 17th IEEE International Pulsed Power Conference, 2009, p. 138.

[4] W. A. Stygar et al., "Shaping the output pulse of a linear-transformer-driver module," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 12, pp. 030402-1 – 030402-11, 2009.

[5] A. A. Kim et al., "Development and tests of fast 1-MA linear transformer driver stages," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 12, pp. 050402-1 – 050402-10, 2009.

[6] D. V. Rose et al., "Electromagnetic and circuit models of the Mykonos-2 accelerator," Voss Scientific., Albuquerque, NM, Tech. Rep. VSL-1027, Sept. 2010.

[7] D.V. Rose *et al*., "Circuit models and three-dimensional electromagnetic simulations of a 1-MA linear transformer driver stage," Phys. Rev. Spec. Top. Accel. and Beams. Vol. 13, pp. 90401-1 – 90401-11, 2010.

[8] D. D. Hinshelwood, "BERTHA – a versatile transmission line and circuit code," Naval Research Laboratory Memorandum Report 5185, November 21, 1983.

Refrences

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[12] J. R. Woodworth et al., "New low inductance gas switches for linear transformer drivers," Phys. Rev. Spec. Top. Accel. and Beams. Vol 13, pp.080401-1 – 080401-9, 2010.

[13] J. R. Woodworth et al., "Compact 810 kA linear transformer driver cavity," Phys. Rev. Spec. Top. Accel. and Beams. Vol 14. Pp. 040401-1-040401-7, 2011.