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Three-Dimensional Model of the Saturn Accelerator Water Tri-plate Transmission Line Connection to the Vacuum Insulator Stack

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I will discuss improvements to the load region modeling of the Saturn Accelerator

Necessary for accurate determination of voltages at the vacuum insulator for the Saturn rebuild in the face of inadequate voltage measurements

A quick review of the electrical design of the Saturn Accelerator

Significance of the “bottles” for coupling power to the vacuum diodes

3D calculation to determine bottle impedance

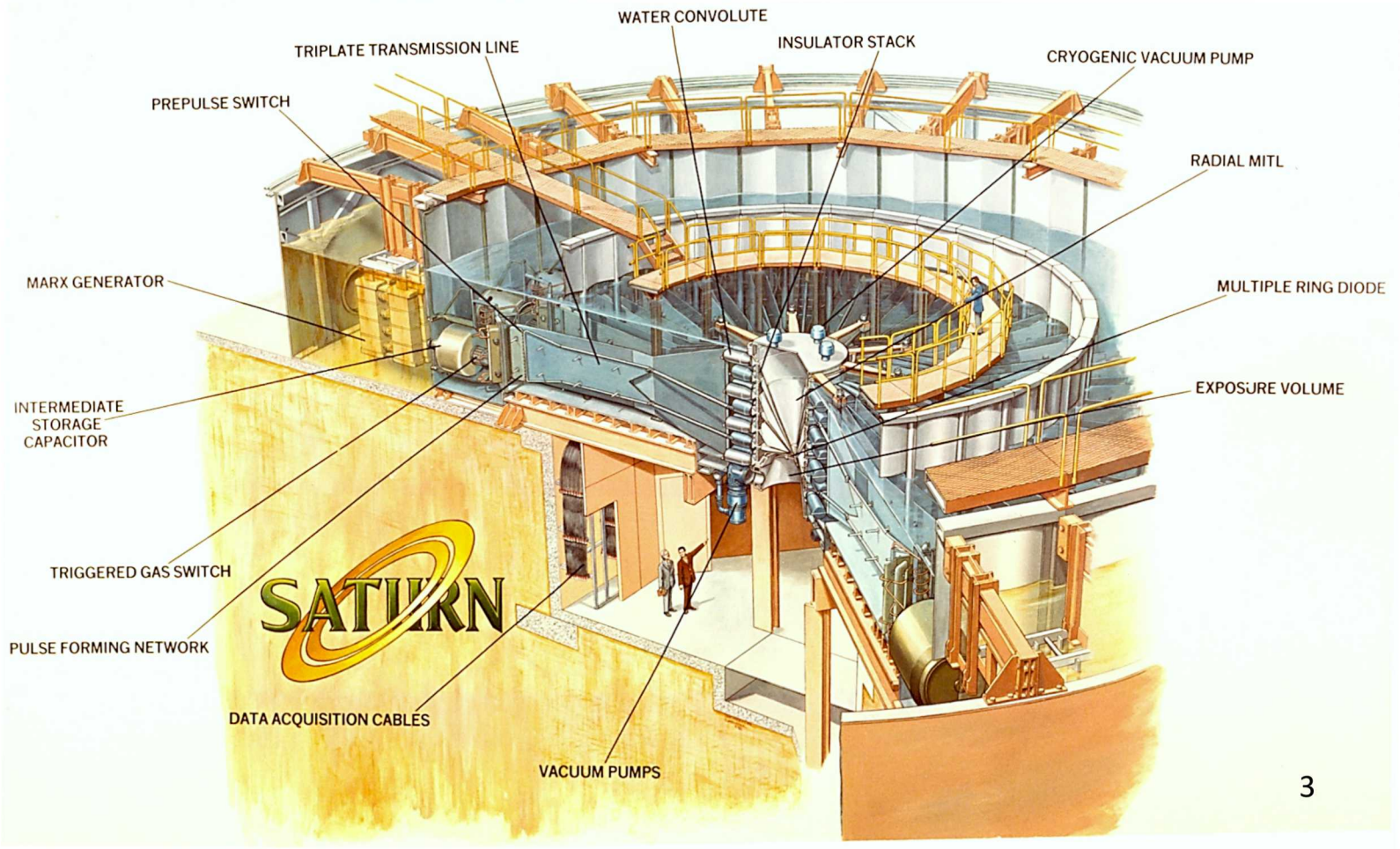
2 D representation using the Transmission Line Matrix method

A 2D model for each of the three cathode levels of the vacuum section

Comparison to measurements

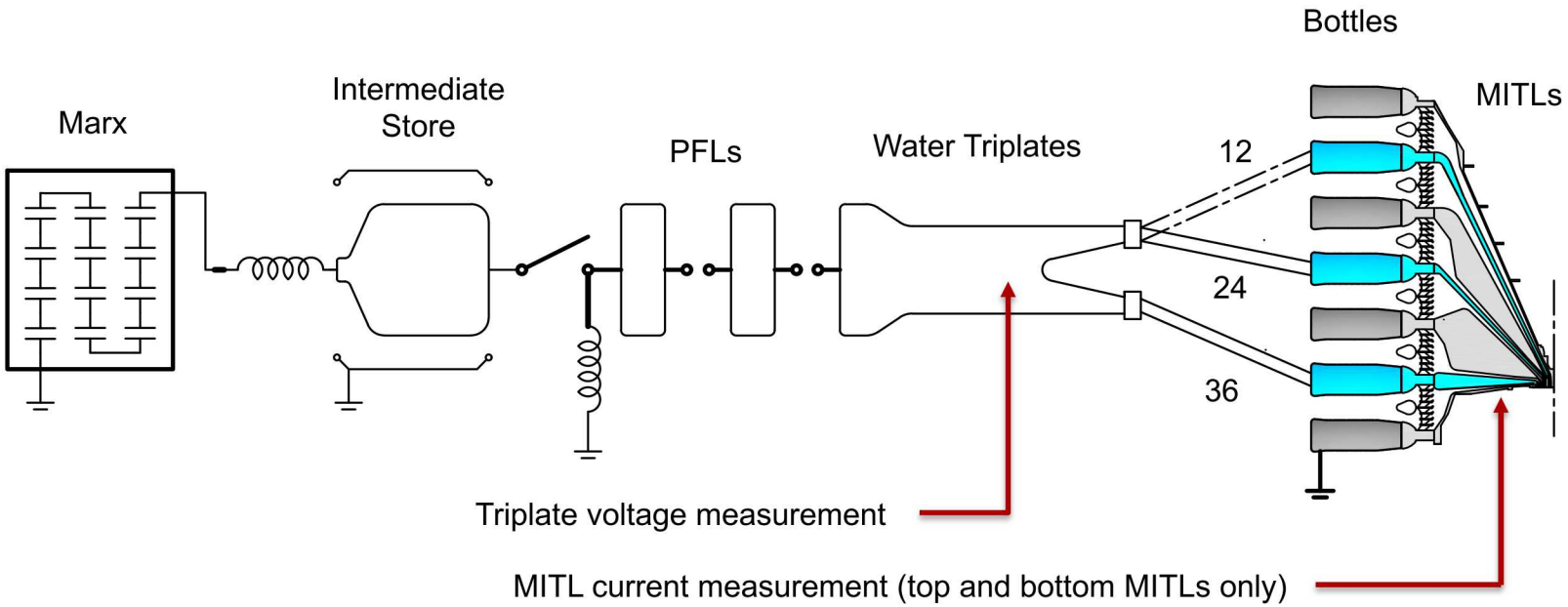
Saturn has 36 Marx banks and water PFLs that drive 3 “independent” Bremsstrahlung radiation loads

Nominally 10 MA, 1.6 MV, 40 ns power pulse, 5×10^{12} rad/s (Si) at 1 MeV



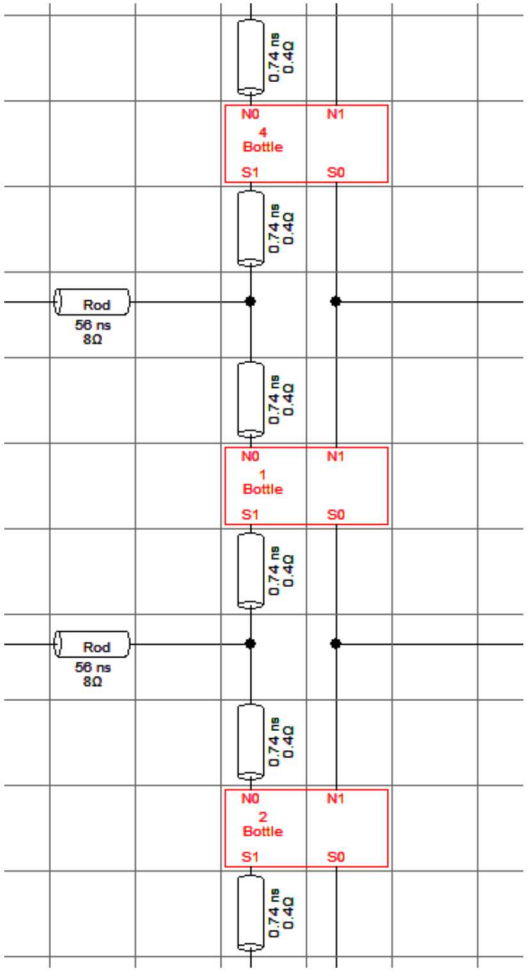
We use the Bertha[1] code for a 2D circuit model of each cathode level of the vacuum MITLs from a measured voltage in the water triplates to a measured current in the MITLs

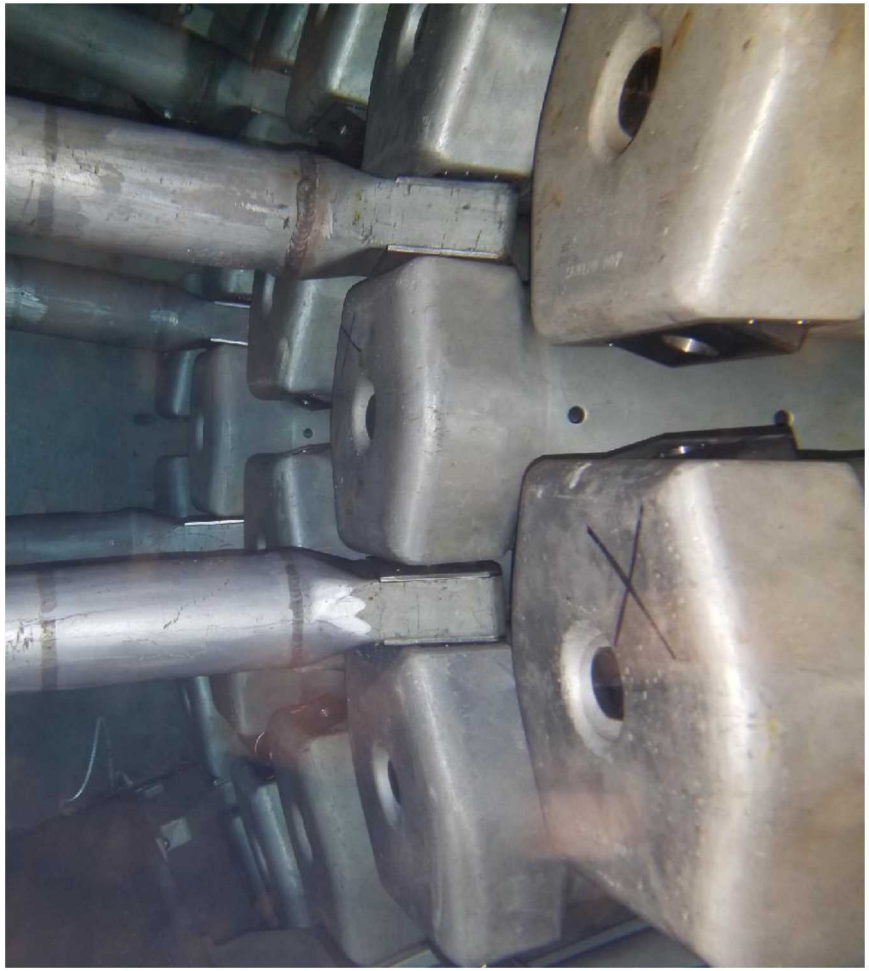
Block Diagram of the Saturn Pulsed power configuration (1 of 36 parallel lines)



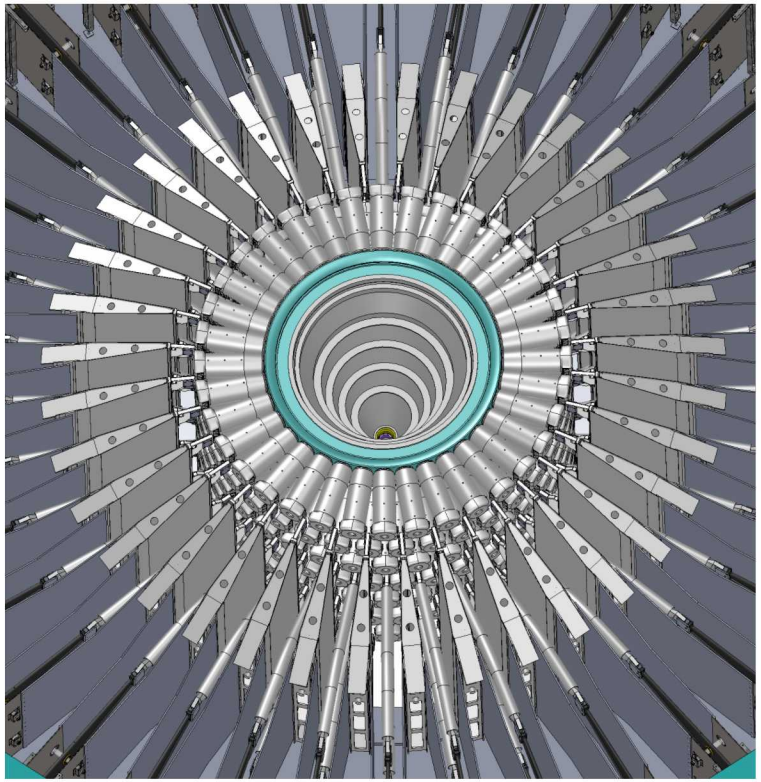
[1]Bertha, a transmission-line circuit code developed by NRL

An important part of the circuit is the rod and bottle connection that delivers energy from the triplate transmission lines to the vacuum MITLs

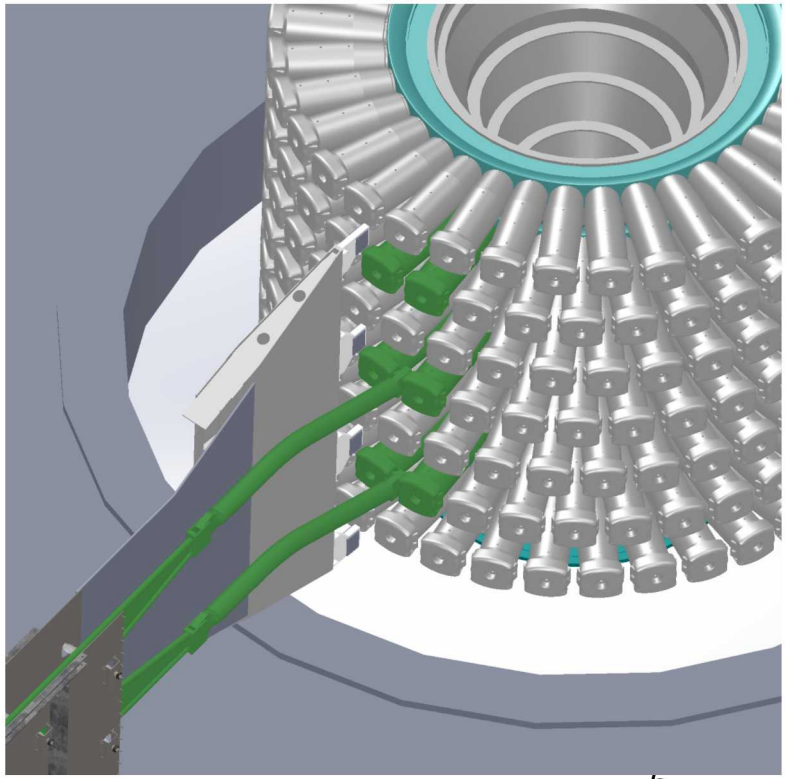




The flexibility in the design is that lines can be easily reconfigured to different cathodes

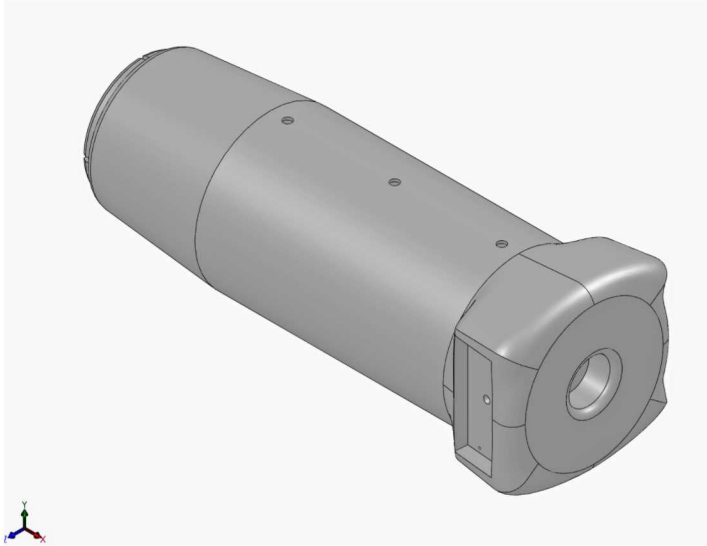


Stack connections, all 36 lines

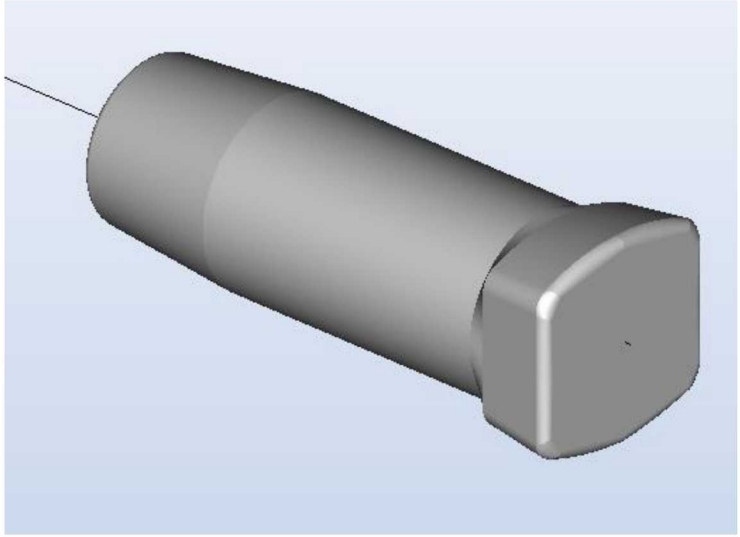


One line connection

The impedance of the bottle was previously not well known. We have used the Coulomb[2] code to calculate capacitance between layers to determine impedance



SolidWorks Model



Coulomb Model

The SolidWorks drawing for the bottle was redrawn within the Coulomb code maintaining gross dimensions but eliminating minor connection details.

[2]Coulomb, a 3D electrostatic Green's functions Laplace equation solver by Integrated Engineering Software, Winnipeg, Canada.

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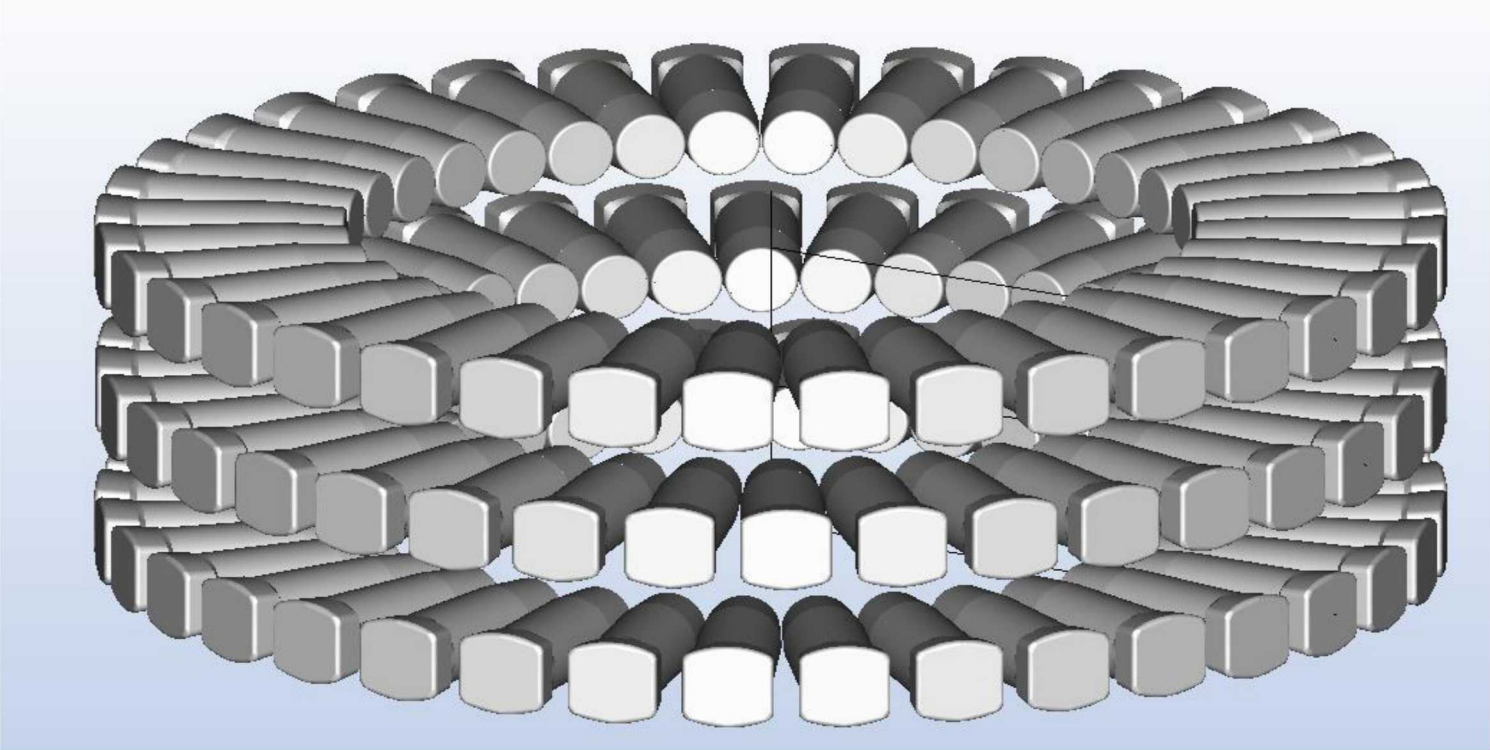
One bottle was then duplicated 108 times to represent one cathode level of the stack.

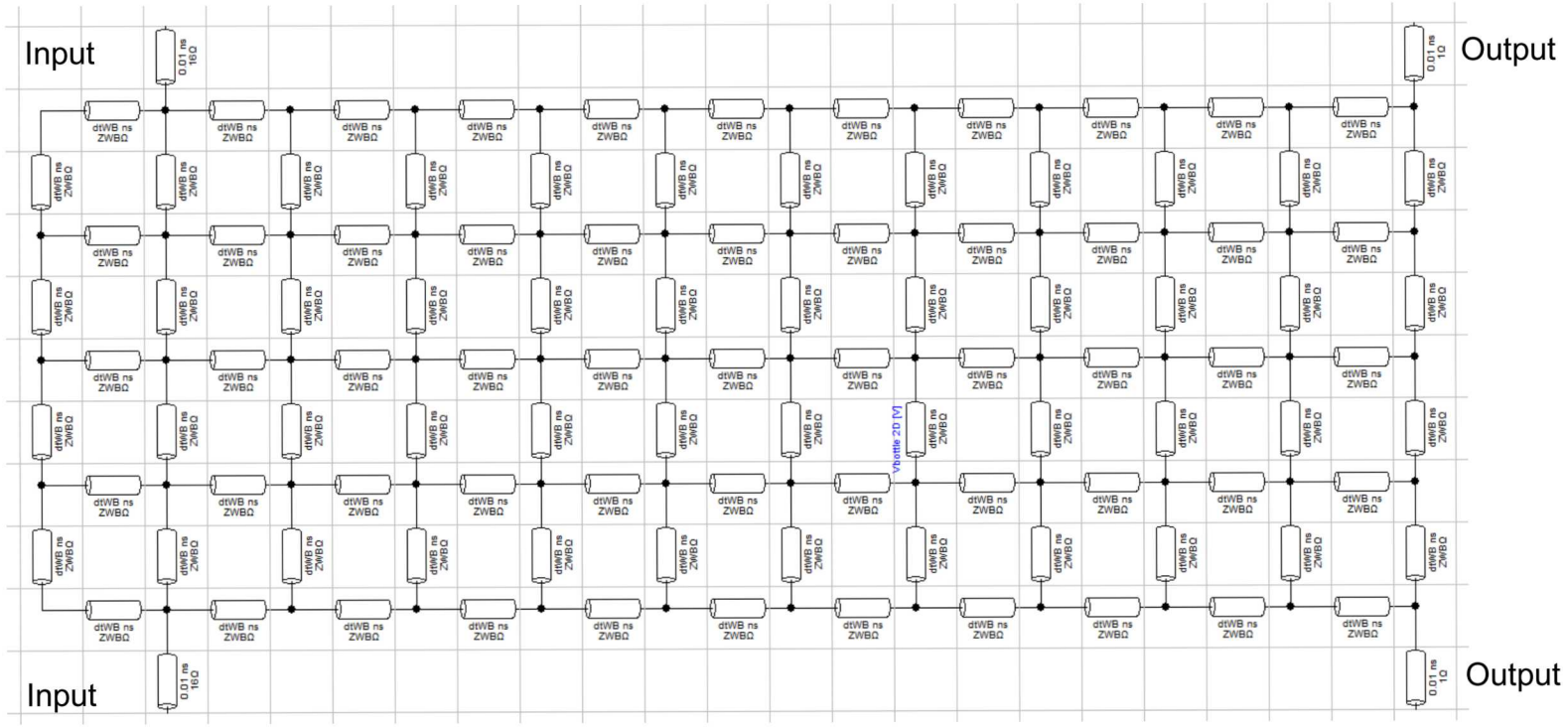


The result is a capacitance of 56.3 nF between the cathode row and the two adjacent anode rows

- The length of the bottle is 26.5”, or 20.2 ns in water, assuming $\varepsilon_r = 81$
- Thus the impedance Z = 20.2 ns / 56.3 nF = 0.359 Ω
- The impedance of one bottle is 12.9 Ω
- This value is 30% lower than previously used
- This calculation could be improved by splitting the model into axial segments to provide an impedance versus distance

From this we constructed a 2D transmission line matrix model of the bottle to simulate its non-axial current flow and delays

This block used 36 times for each of the three cathode levels

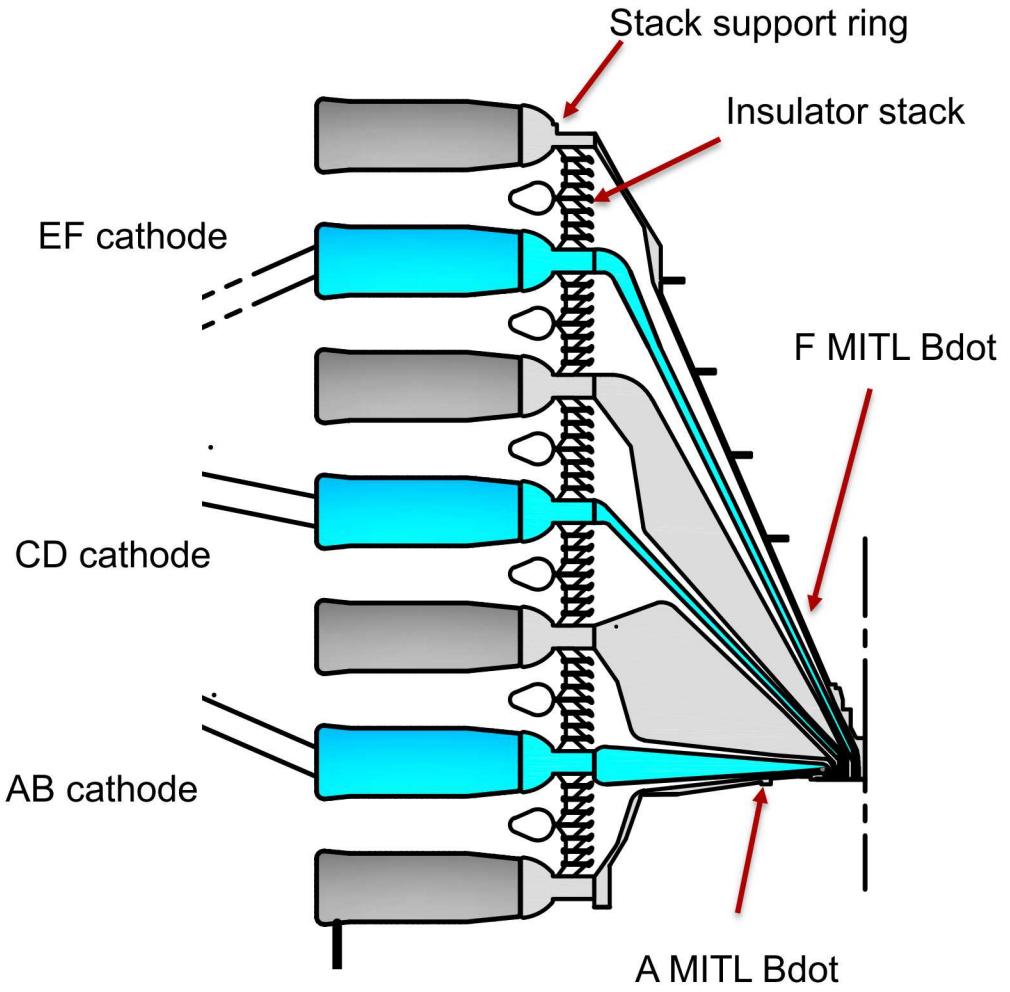


ZWB = 86.3 Ω, dtWB = 1.43 ns

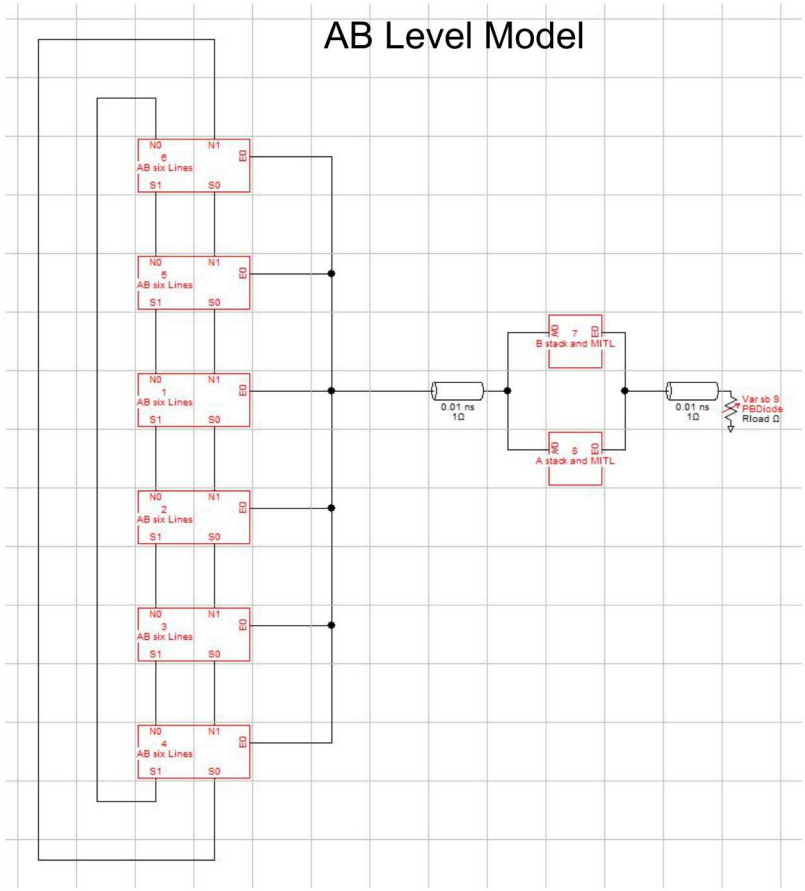
Equivalent length and impedance are 20.2 ns and 12.9 Ω

Even with a common drive each of the three cathode levels can be treated independently

- The output pulse is 40 to 50 ns
- The 3 diode rings do not connect
- The roundtrip time between diodes is 240 ns

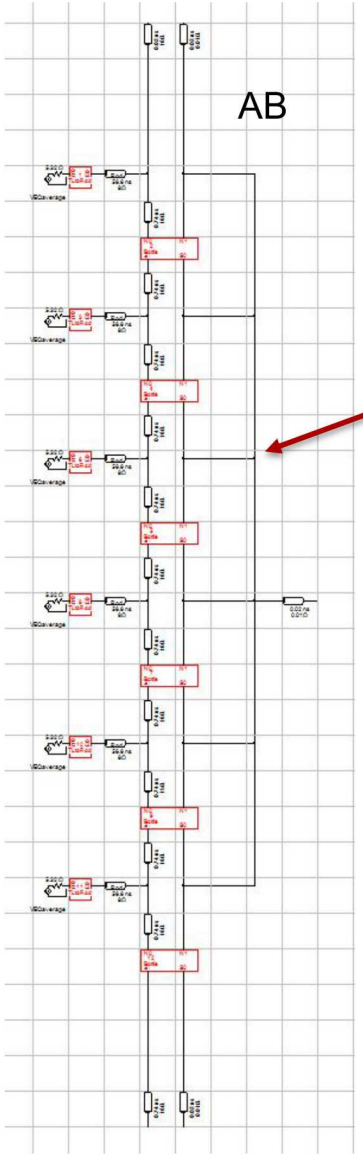


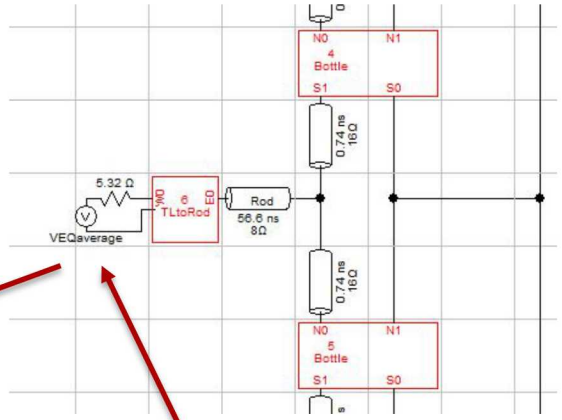
The top level of the model relies on machine symmetry to divide the circuit into six identical modules for each of the three cathode levels

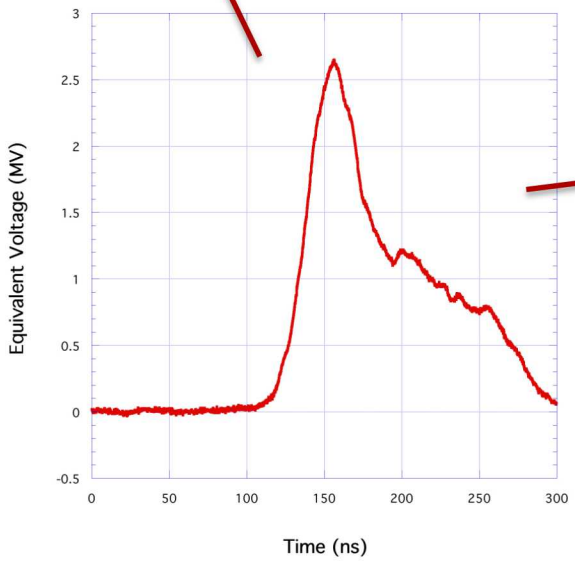


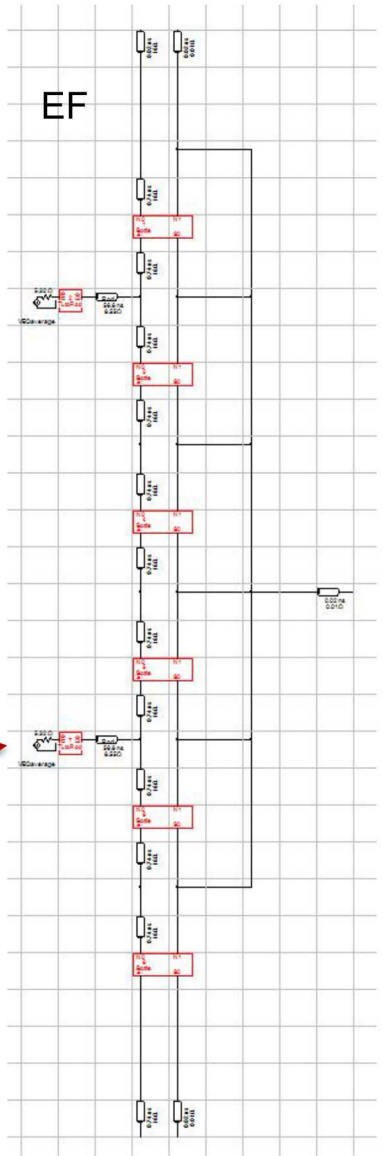
- Each level drives two parallel MITLs
- CD and EF levels have same structure but different modules
- Each module has six lines that are independently driven
- This represents a 2D to 1D transformation of the model at the insulator stack support ring
- Further improvement would be to extend the 2D configuration to the inside of the stack

AB and EF six-line-module configurations





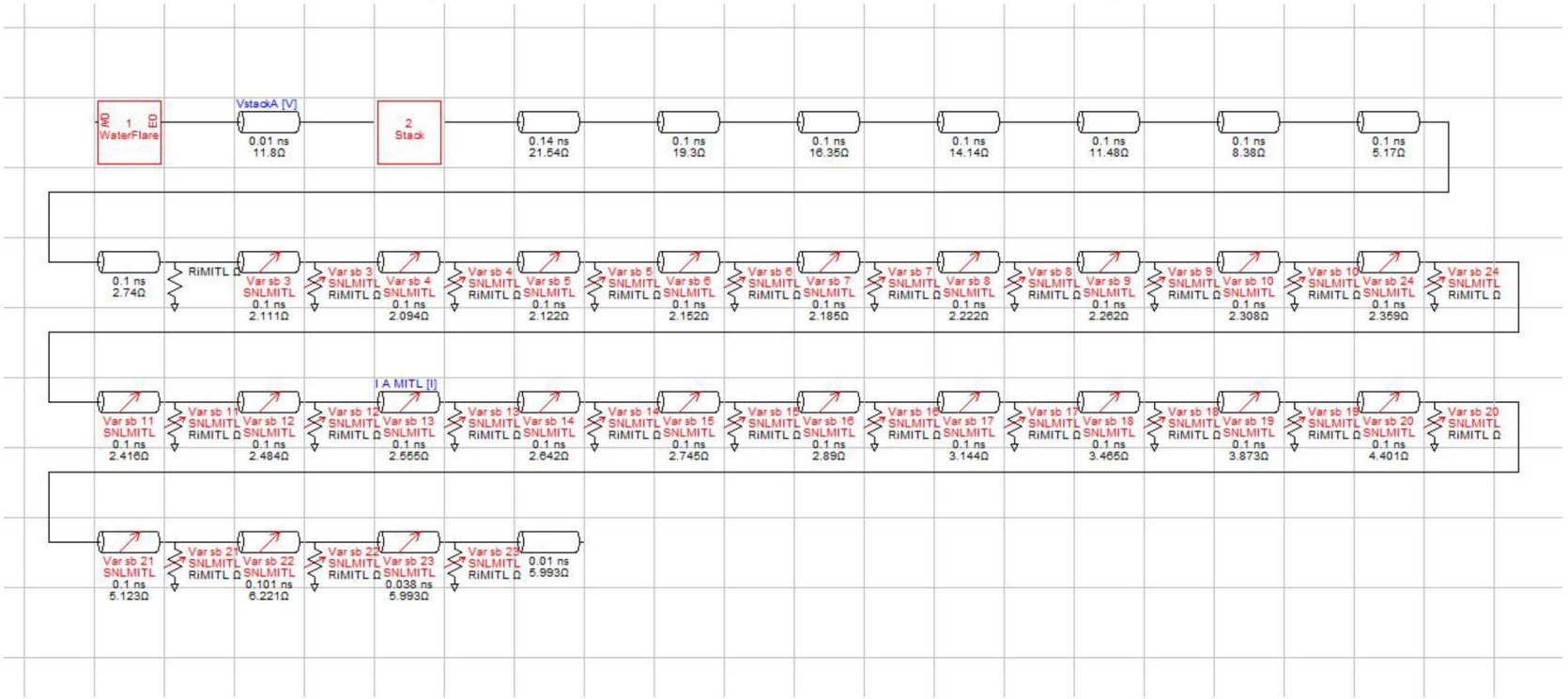




Each stack and vacuum transmission line is treated as a lossy MITL with 0.1 ns increments

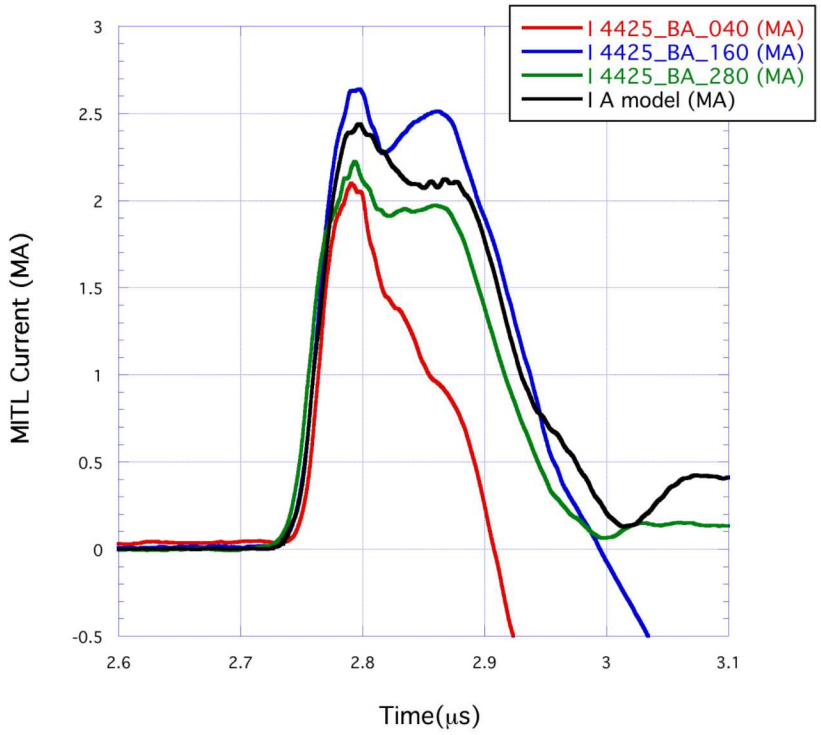
A stack and MITL module

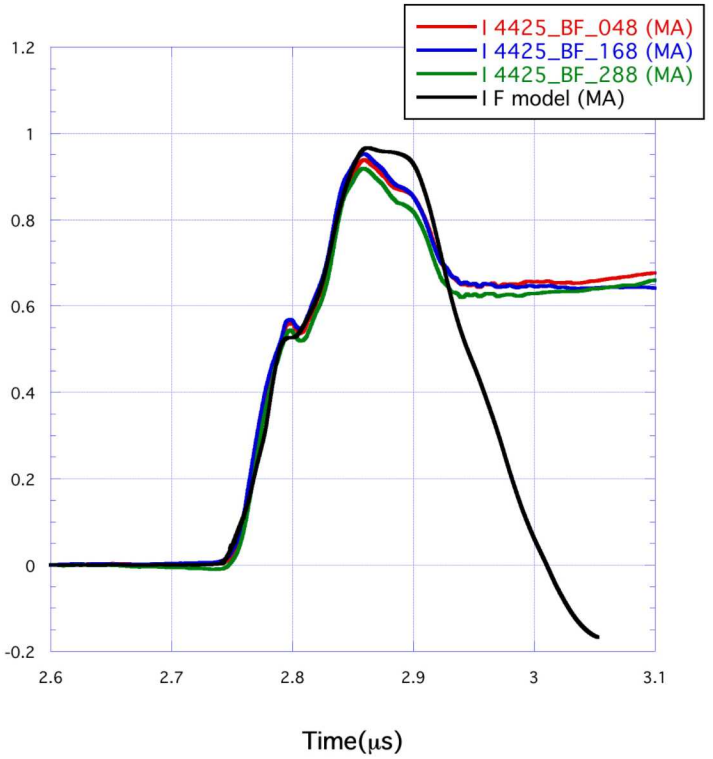
(Values derived from stack and MITL drawings)



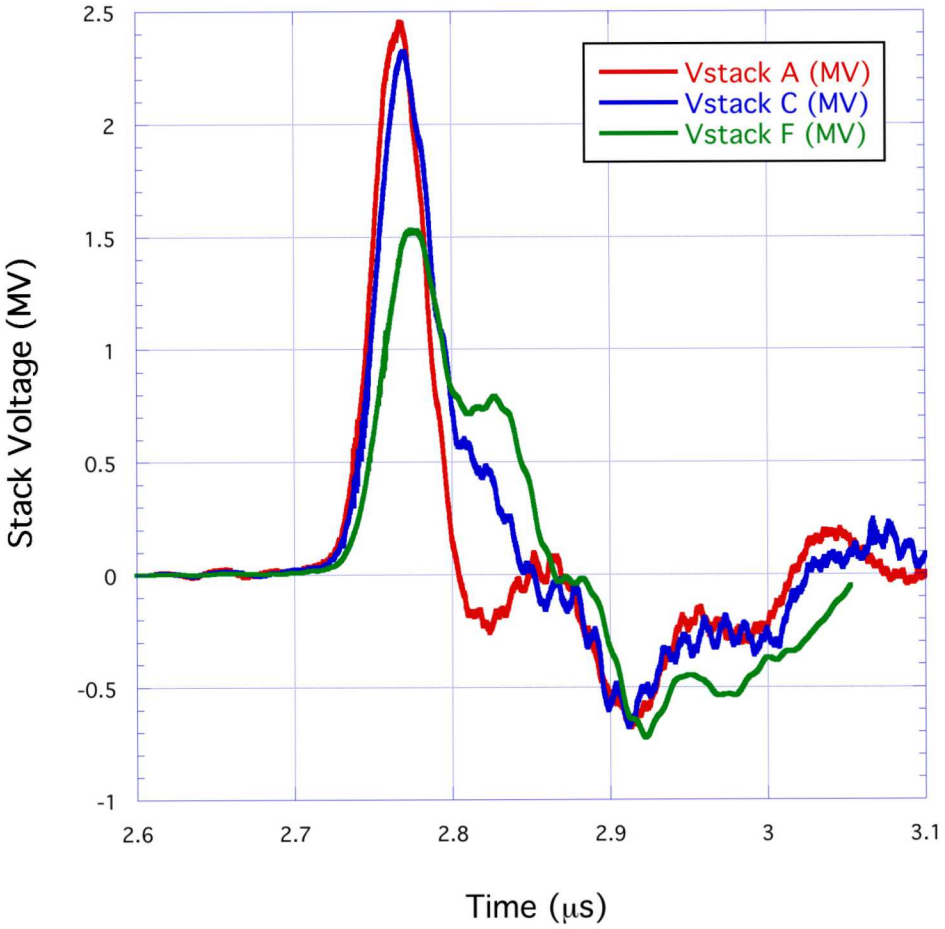
Each pair of MITLs is terminated in the Bertha Ring Diode model

Comparison of model with measured current





Model-predicted stack voltage



Summary

- We have developed a 36-line 2D circuit model of the load region of Saturn based on a measured voltage in the triplate transmission lines
  - Uses results of a 3D impedance calculation
  - Predictions in close agreement with measurements
  - Provides the capability for investigating effects of timing spread
  - Provides stack voltage estimates which are needed for redesign
  - Provides a tool for diode redesign studies
- Further improvements are possible to extend the 2D configuration into the vacuum section to provide higher fidelity in evaluating asymmetrical drive effects
- Based on these voltage estimates we believe we have room for designing a much less inductive stack and MITL configuration