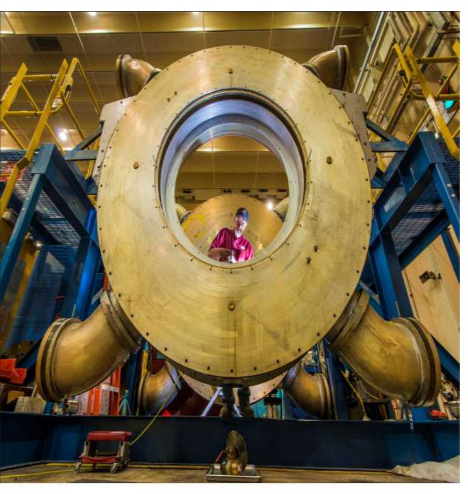

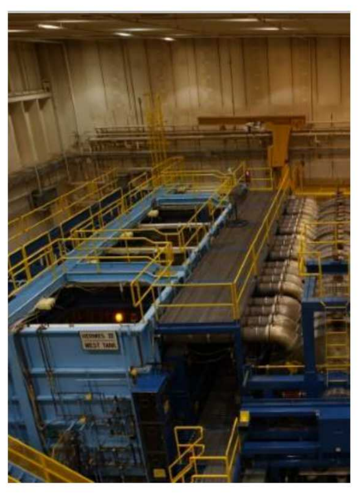

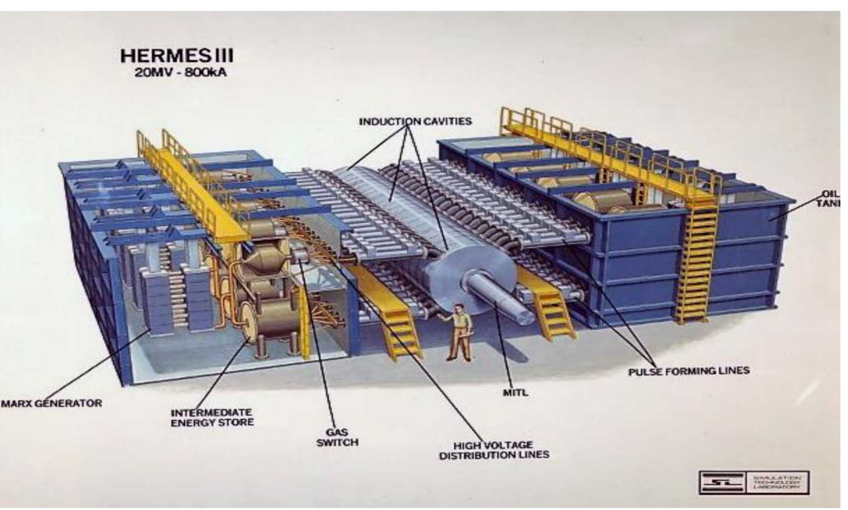

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Hermes-III Accelerator: Impedance Calculations, Bertha Modelling, and Waveforms

A. Weiseman, I. Owens, K. Struve, N. Trujillo*, and G. Tilley

Introduction

The HERMES-III Accelerator is a gamma ray simulator that has been in use at Sandia National Labs since the late 1980's.[1] The accelerator is powered by 10 Marx generators, which lead to the 20 intermediate stores, arriving at the 20 laser-triggered gas switches to be brought to 80 pulse-forming lines (PFLs). The PFLs connect to the 20 HERMES-III cavities, which combine the pulses from 4 PFLs to deliver them to the Magnetically Insulated Transmission Lines (MITL). The pulse travels through the MITL to the electron beam diode. HERMES-III has been in use for over 30 years to date, however a model of the voltage waveform has never been created, and an exact measurement of the voltage output has never been made either. The voltage produced by HERMES-III is thought to be from 18-22 MV depending on calculation methods.[2] The pulse width is believed to range from 30-50 ns depending on modifications made to the various switches. This paper describes the modelling of HERMES-III with the Stella-Bertha program combined with the related calculations used in an attempt to create this waveform.

Calculations

HERMES-III is being studied to be put into a Stella-Bertha pulsed power model and obtain an accurate and reliable waveform of the pulse throughout the system. A similar technique was done by Kenneth Struve on the SATURN Accelerator.[3] Stella-Bertha requires two main inputs for the elements: impedance (Ω) and length (ns). Because the HERMES-III elements resemble coaxial cables, impedance (Z_0) was calculated using the geometric formula:

$$Z_0 = \frac{138}{\sqrt{\varepsilon}} \log\left(\frac{R}{r}\right)$$

Where ε is the dielectric constant of the insulator, R is the radius of the insulator, and r is the radius of the inner conductor. The length of the elements were calculated using the equation:

$$\Delta t = \frac{x\sqrt{\varepsilon}}{c}$$

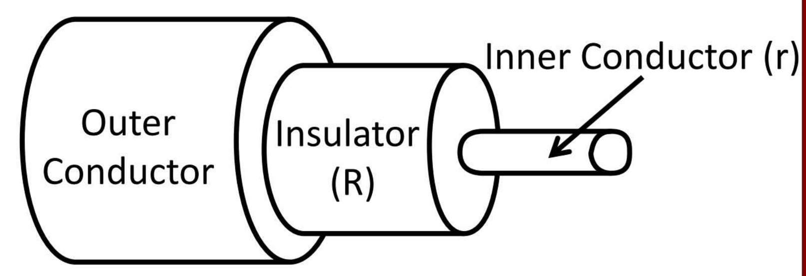

Fig. 1: Model of a coaxial cable

Where x is the distance from the start of the element to the end and c is the speed of light. The next subsections will further explain how the impedance calculations were executed for each element of HERMES-III. All impedance calculations were checked for accuracy using Electro Software.

Marx Generator

The 10 Marx generators are the only main element that cannot be modeled as a coaxial cable. However, this is not an issue as they are the power supplier, and all that is needed is the voltage (2.4 MV), capacitance (56 nF), and inductance (4.9 μH).

Intermediate Store

The intermediate store is a large cavity encased in water (ε=80), surrounded by oil (ε=2.2). Each store has two 'end caps'- one on each side. Three calculations were used, one on the large cavity and one on each end cap.

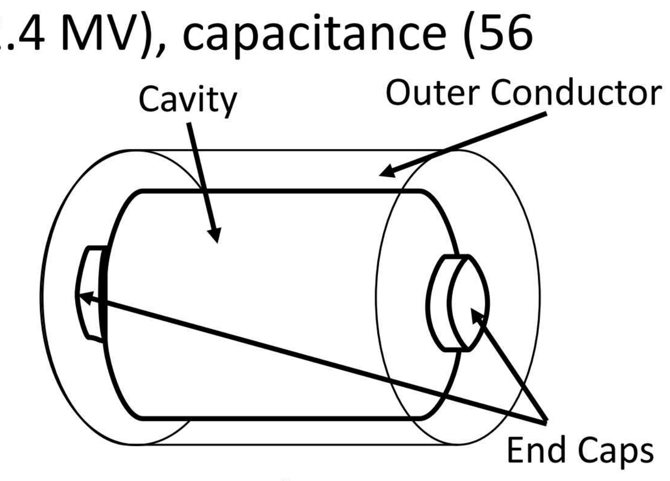

Fig. 2: Drawing of HERMES-III intermediate store

Gas Switch

The gas switch is SF-6 insulated (ε=1) and also surrounded by oil. Its composition gets a little more complicated; a laser is used to trigger the multiple diodes which are then activated to form an electrical barrier between the gaps. Because of this barrier, the gaps become blocked and the system can be thought of as one inner conductor stretched through the switch instead of multiple electrodes and gaps. The calculations were split between the laser and the gaps. The laser section was calculated in four parts while the gaps were calculated as a whole treating the gas switch as 'closed'.

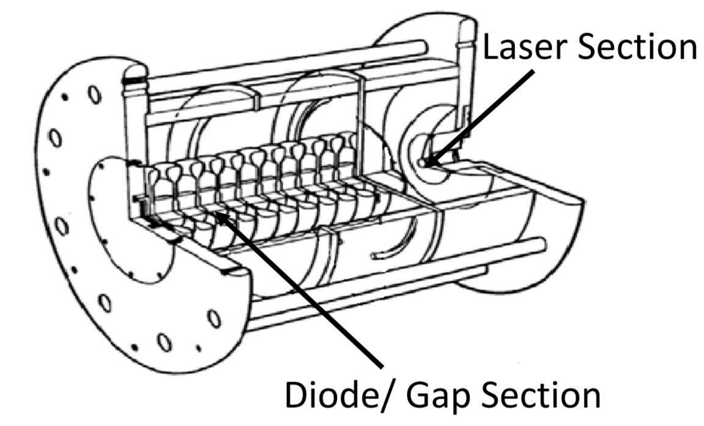

Fig. 3: Drawing of the gas switch for the HERMES-III Accelerator

Pulse-Forming Line

Water insulated PFLs contain three switches: a pulse forming switch, a pulse sharpening switch, and a crowbar switch. The PFLs were split into 15 sections with multiple subsections for most due to the curvature of the elements.

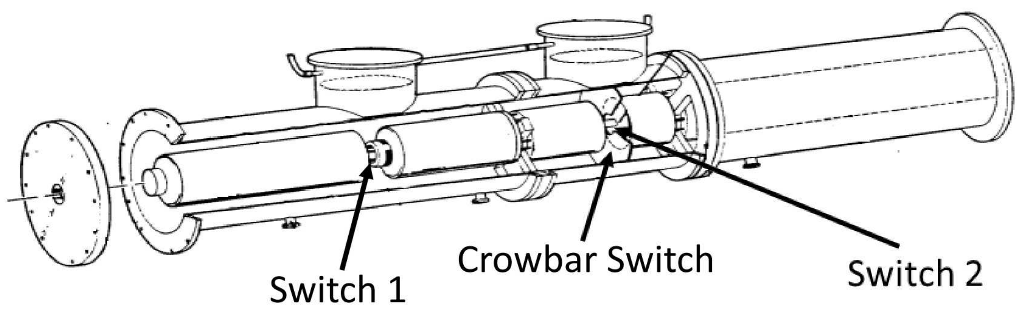

Fig. 4: Drawing of the HERMES-III PFL system

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Cavity

The cavity is the most complicated aspect of the HERMES-III accelerator in terms of impedance. It's geometry is complicated to model as a coaxial cable due to it's asymmetric elements. The cavity consists of an H.V. tab, azimuthal lines, H.V. feed, Metglas cores, and a vacuum insulator. It is oil-insulated with the exception of the vacuum area, which is of course vacuum insulated (ε=1). The *R* value for the impedance calculation is the inner radius of the cavity wall, and the *r* value is the outer radius of the specific element being evaluated.

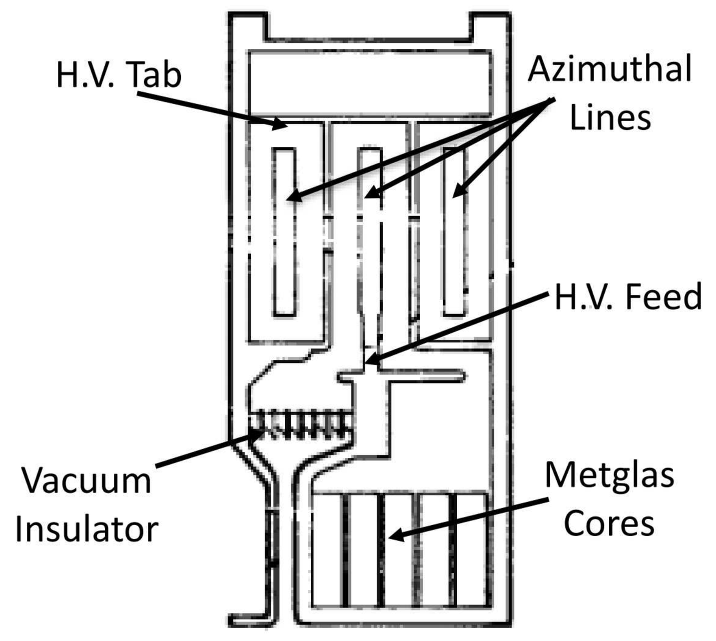

Fig. 5: Drawing of a cavity cross-section

Magnetically Insulated Transmission Line

The MITL is vacuum insulated and decreases in inner conductor radius with each cavity addition. When the MITL is operating, an electron sheath is present, effecting the characteristic impedance. [4] The nominal characteristic impedance (or vacuum impedance) is still found using the coaxial cable model. To account for the sheath's contribution to the characteristic impedance, an equation is used to relate the vacuum impedance (Z_0) with the electron sheath ($f_{MC}(V)$):

$$Z_f^{MC}(V) = Z_0 f_{MC}(V)$$

$$f_{MC}(V) = \frac{\left(\frac{gmc^2}{8eV}-1\right)+\left[\left(\frac{gmc^2}{8eV}-1\right)^2+\left(\frac{gmc^2}{2eV}-1\right)\right]^{1/2}}{\left(\frac{gmc^2}{2eV}-1\right)}$$

Where $Z_f^{MC}(V)$ is the actual characteristic impedance, m is the electron mass, c is the speed of light, e is the electron charge, V is the voltage of the region, and $g(\mathrm{V}) = 0.99565 - 0.05332\mathrm{V} + 0.0037V^2$.

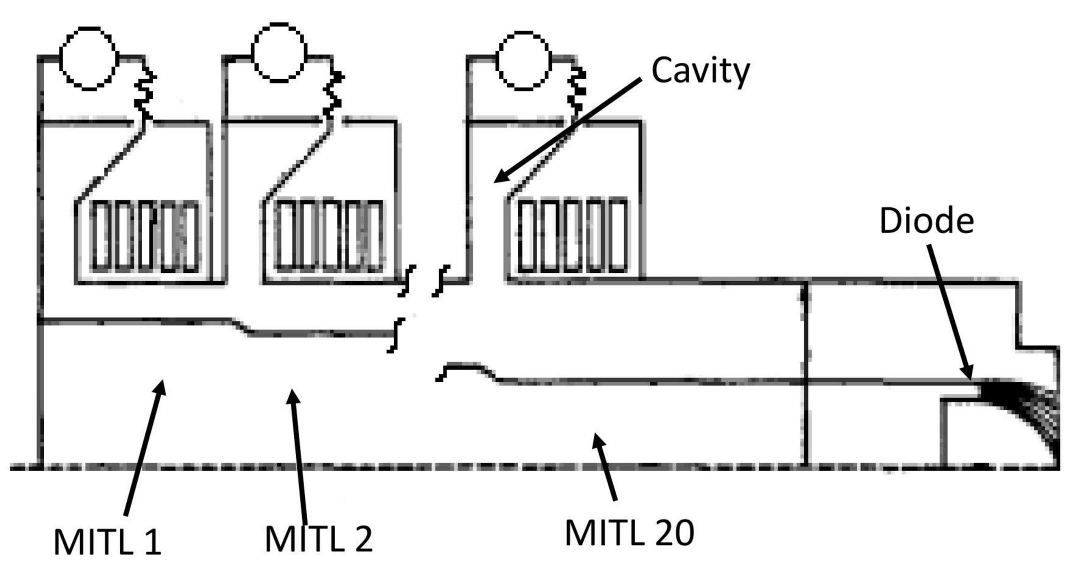

Fig. 6: Drawing of HERMES-III MITL system and diode

Diode

The vacuum insulated diode of HERMES-III uses the cathode as the inner conductor and the anode as the outer conductor, and the gap is only measured for the length.

Bertha Modelling

The impedance and length values along with the switches and resistors were inputted into the Stella-Bertha Program for pulsed power electrical models. The circuit configuration is as presented in figures 7 and 8 below. Figure 7 is the configuration of all aspects leading up to the MITL, and the red boxes contain other smaller elements that could not be displayed due to space constraints. Figure 8 contains figure 7 in each of the red modules, adding them in series. What is presented in figure 8 is then run through the program to create the effective pulse presented in the next section.

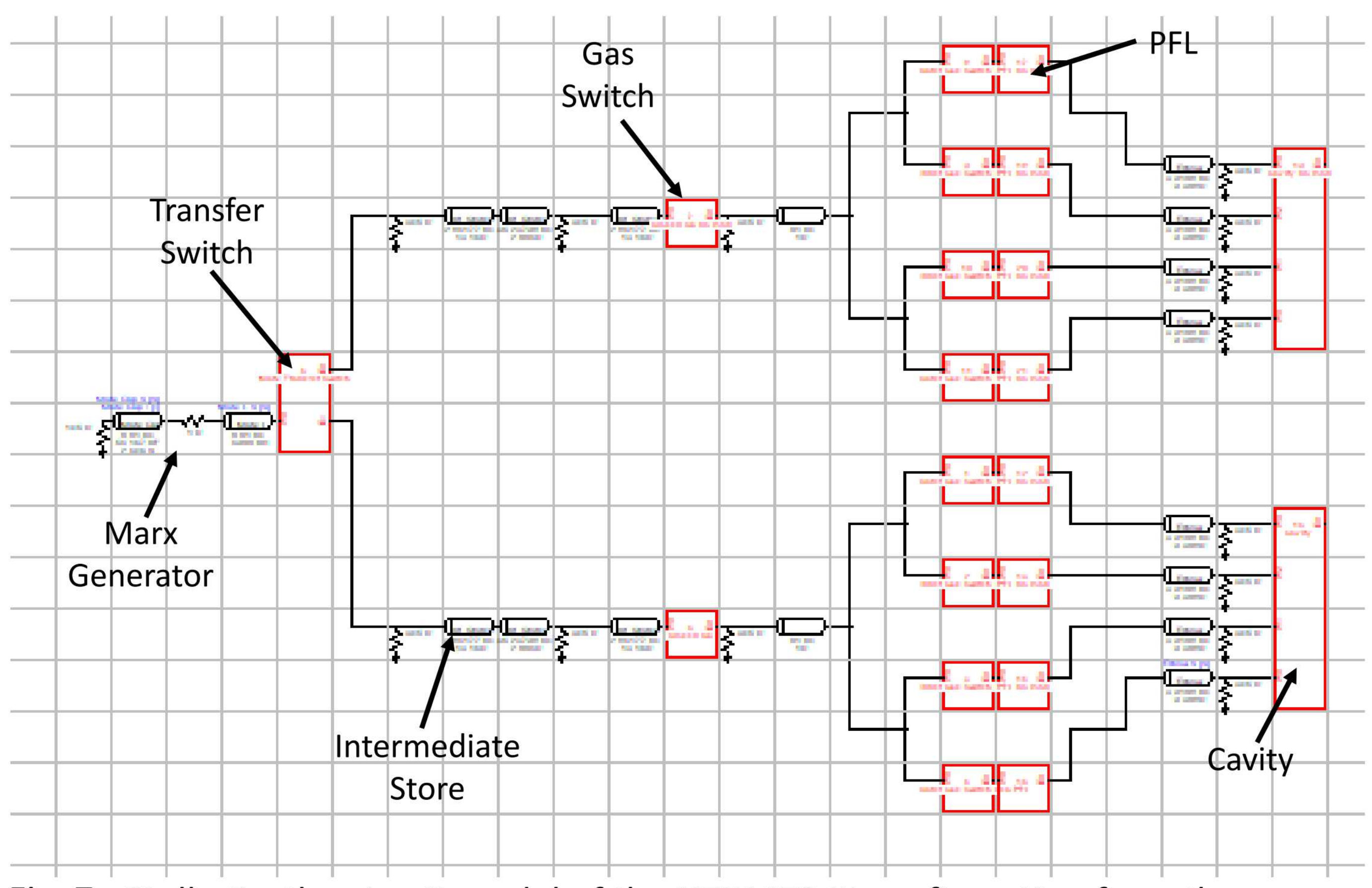

Fig. 7: Stella-Bertha circuit model of the HERMES-III configuration from the generator to the cavities

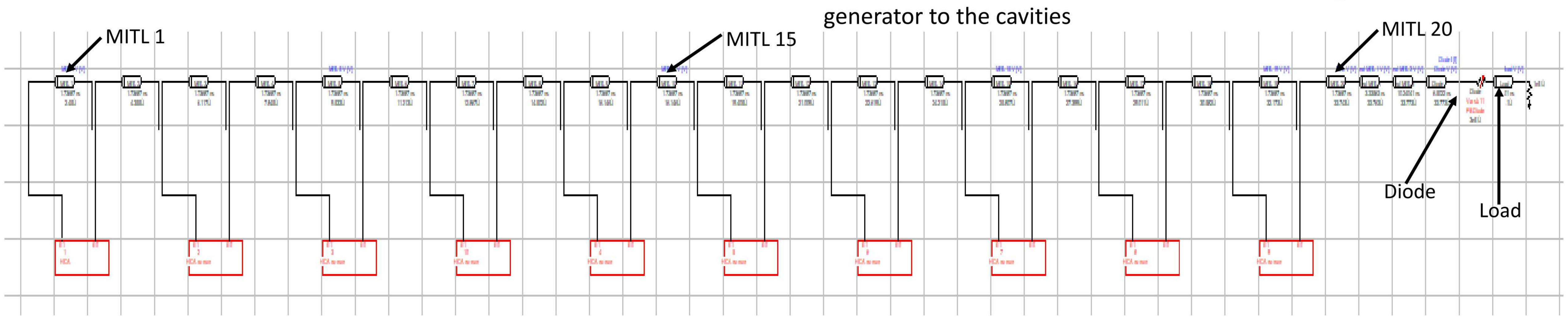

Fig. 8: Stella-Bertha circuit model of the HERMES-III MITL and diode

Results

After adjusting switch times and certain values, an accurate representation of the HERMES-III voltage was found. The pulse shape of HERMES-III is compared to a measured pulse in figure 8. The simulation's maximum voltage is slightly higher than the measured maximum voltage likely because of the slight variance in switch times for the actual machines. Effectively, HERMES-III can reach a maximum voltage of more than 20 MV, but will realistically produce voltages slightly less than 20 MV. As found previously, the average pulse width ranges from 30-50 ns.

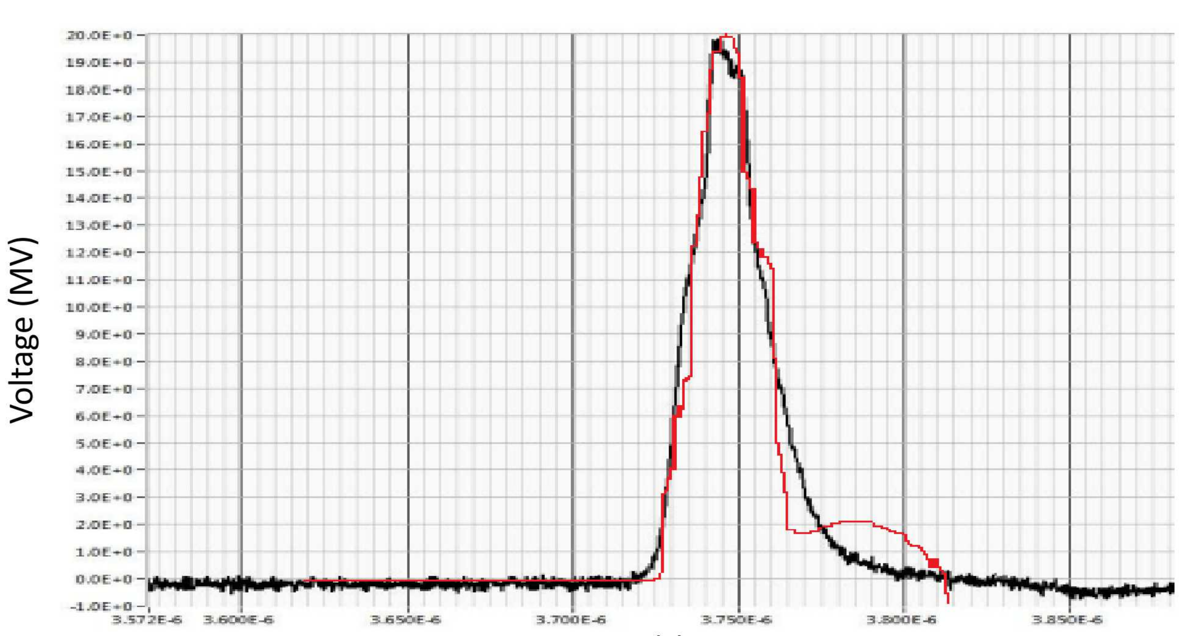

Fig. 9: Simulation (red) vs. measured (black) voltage waveform

Conclusion

A promising simulation of the HERMES-III accelerator has been created using Stella-Bertha software. Comparisons between simulated and measured waveforms prove the simulation is fairly accurate. Future applications for this simulation include modelling various design changes being made to the accelerator and adjusting PFL switch lengths to gain further understanding of how HERMES-III functions.

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