Studying power flow in a coupled conical/coaxial magnetically insulated transmission line

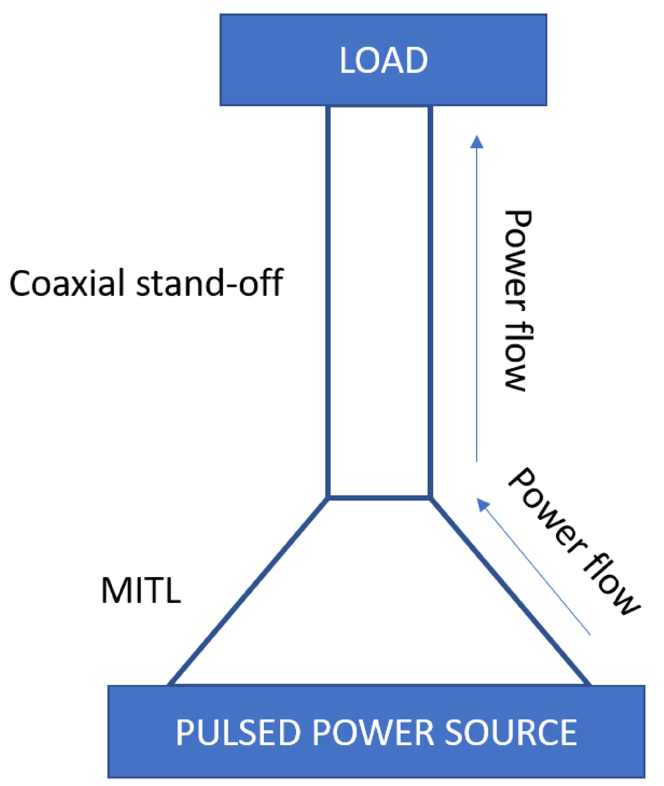
A. Fierro, K. Faris, J. Lehr
Electrical and Computer Engineering, University of New Mexico

ELECTRICAL & COMPUTER ENGINEERING

ABSTRACT

Power loss in magnetically insulated transmission lines (MITL) at high voltages and currents is still an on-going research topic. Different topologies for MITL design can be utilized for delivering high current with efficient power transfer from an input source to a target load. Often, the low-impedance transmission lines required for driving large currents result in small anode-cathode gap distances leading to large electric fields in the vacuum gap. The combination of increasing current density and large electric fields could ultimately lead to plasma formation which decreases power transmission efficiency of the transmission line. To this end, the simulation tool EMPIRE is used to construct an impedance matched conical to coaxial magnetically insulated transmission line. Specifically, geometric optimization of a conical transmission line coupled to a coaxial line is made to produce minimal electric fields in the vacuum gap. Furthermore, parallel combinations of several transmission lines are used to increase the effective anode-cathode gap distances but maintain the same driving impedance. Space charge limited emission of electrons across the cathode surface is included to examine regions where magnetic insulation is not maintained.

CONCEPT and APPROACH



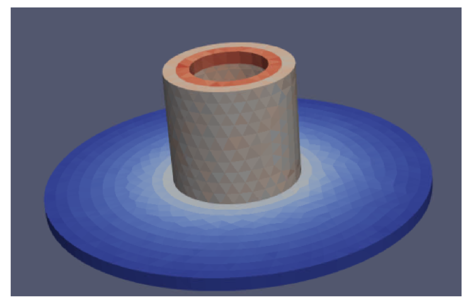
The transition from a conical to coaxial transmission line requires

- Impedance matching at the transition
- In high power systems, the reduction of electric fields in the transition to reduce field emission of electrons potentially leading to plasma formation.

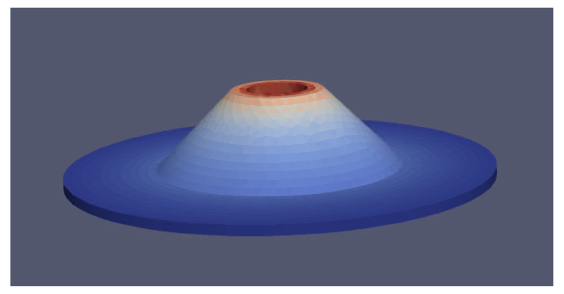
Approach: Utilize a three-dimensional electromagnetic simulation to study the conical-to-coaxial transition and compare with other equivalent lumped element models.

This work utilizes the commercial software package CST and the EMPIRE code developed at Sandia National Laboratories and uses the particle-in-cell (PIC) method for field effects on particles and direct simulation Monte Carlo (DSMC) for binary particle collisions.

Radial to coaxial transition



Radial to conical transition



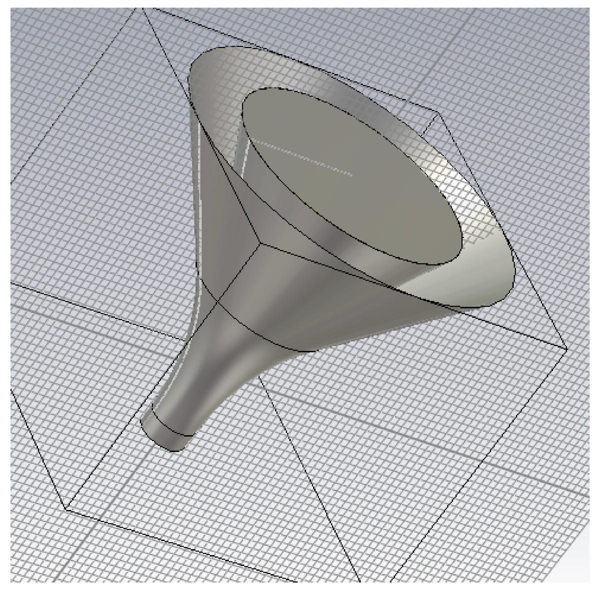
Colors indicate magnitude of magnetic field

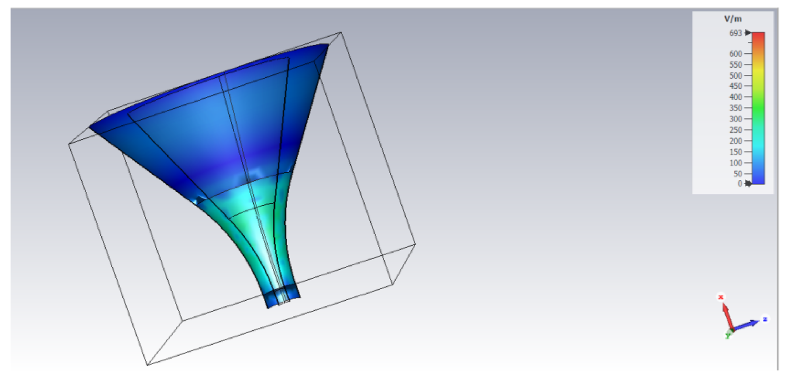
Steps:

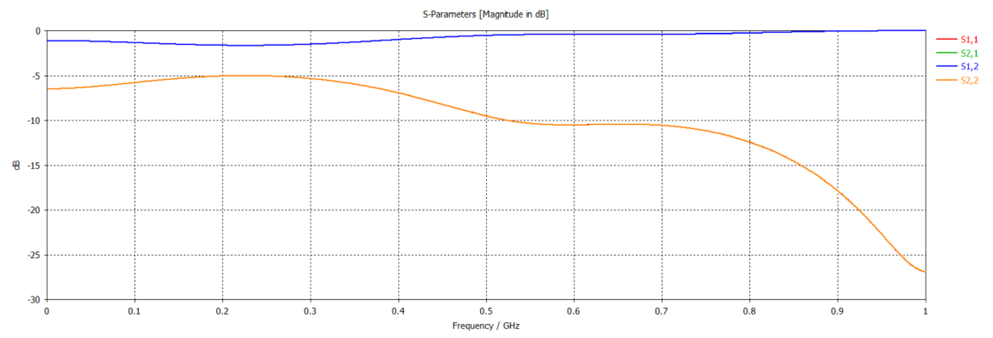
1) Analyze conical to coaxial transition in electromagnetic only simulations
2) Add field emission of electrons from cathode

CST MODEL

Using CST to analyze small scale behavior, look at S-parameter space and implement a smooth transition from the conical to coaxial section to reduce electric fields.

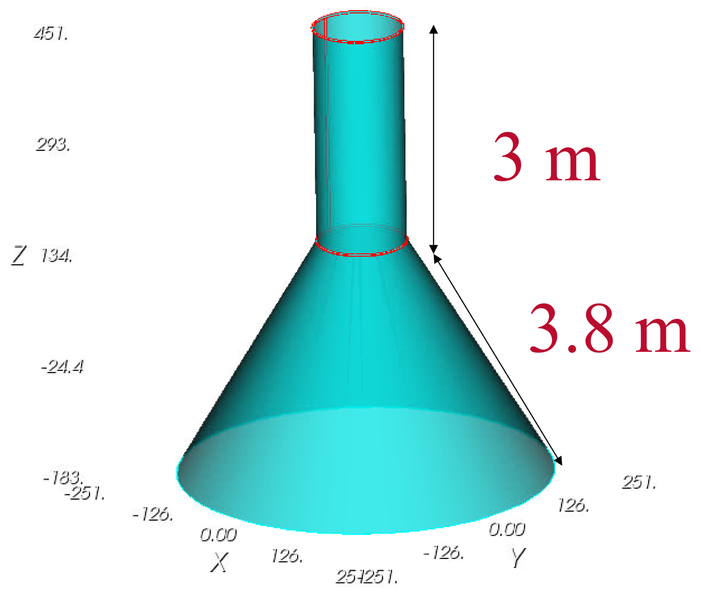






A circular profile is applied at the conical to coaxial transition that reduces the electric field but maintains transmission of power over the frequency band from 0.1 GHz to 1 GHz

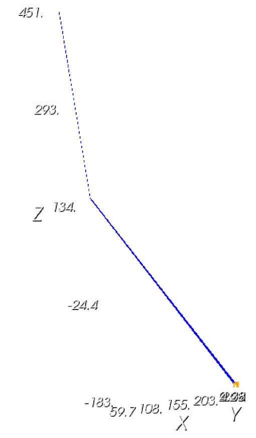
EMPIRE MODEL



Also interested in simulating realistic sized geometries with realistic input waveforms. This requires a time-domain simulations and a large amount of computational power: EMPIRE

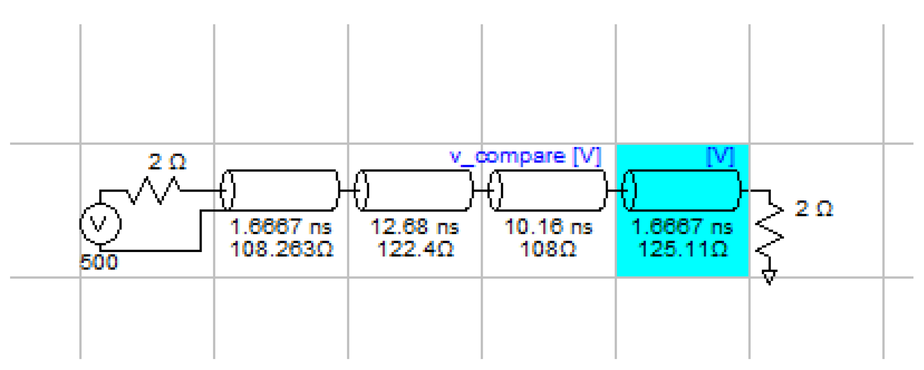
A full 360 degree domain at meter sized geometries is still computationally difficult so the total angle simulated was only chosen to be 1 degree.

A 1 degree wedge of the entire simulation domain still results in ~9.5 million elements with a 1 mm mesh resolution. The conical and coaxial lines are designed to have a 0.3 Ω impedance leading to roughly 2-3 mm gap sizes.

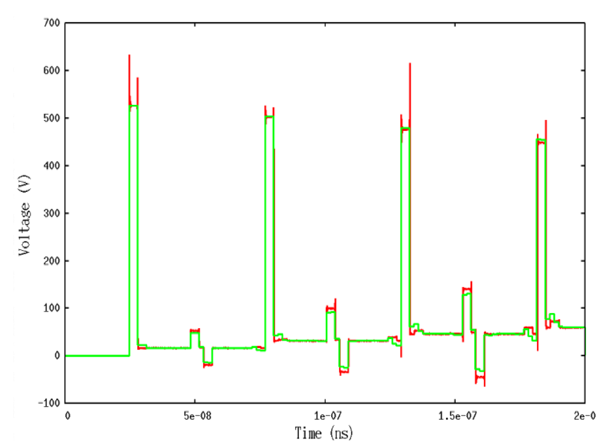


EMPIRE RESULTS

Comparison between EMPIRE results and an equivalent Bertha circuit model show results that agree reasonably well for voltage at the load. Oscillations in the EMPIRE signal are observed because of the instantaneously voltage pulsed applied which leads to numerical ringing.



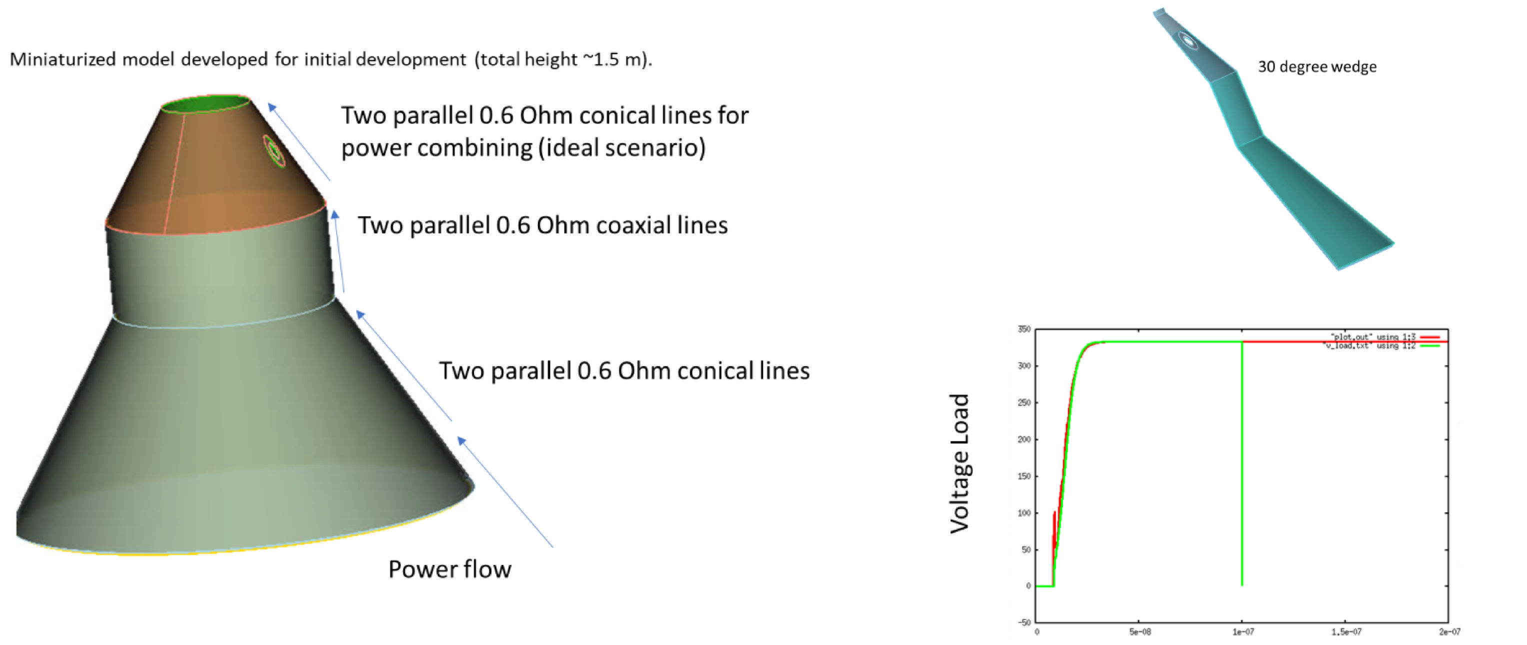
Red = EMPIRE, Green = Bertha



As noted, the gap distances for this design are on the order of 2-3 mm which leads to large electric fields.

PARALLEL TRANSMISSION LINES

A series of parallel transmission lines could increase the gap distance while providing the same power flow performance



Initial results show expected behavior for voltage at the load that agrees with lumped element circuit models.

CONCLUSIONS AND REFERENCES

- Developed a fully three-dimensional electromagnetic model for the conical to coaxial transmission line in EMPIRE and CST.
- EMPIRE electromagnetic results agree well with the results from a lumped element circuit code, Bertha.
- Parallel combinations of transmission lines lead to increase in gap distances, lowering the electric field, and maintain power flow performance.
- Will optimize the transition by looking at electric fields and power flow transmission.

[1] van der Walt, P, "A novel matched conical line to coaxial line transition," 1998.
[2] Creedon, J, "Relativistic Brillouin flow in a high v/γ diode", 1975.

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