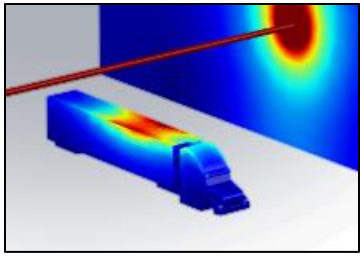
COMSOL CONFERENCE
BOSTON
2012

October 3-5, 2012
Boston Marriott Newton
Newton, MA, USA



Quasielectrostatic Induction on Stationary Vehicles under High Voltage Power Lines

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POWER ENGINEERS

Excerpt from the Proceedings of the 2012 COMSOL Conference in Boston

INTRODUCTION

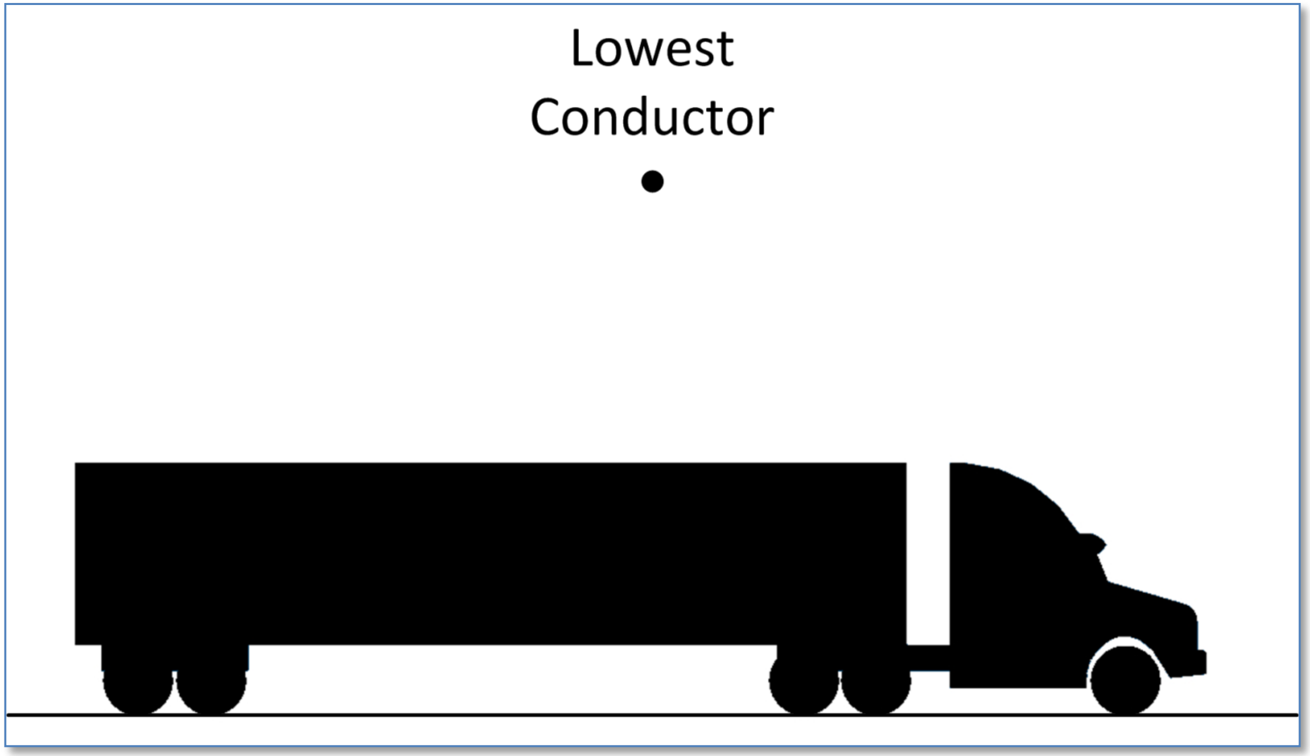
INTRODUCTION

The National Electrical Safety Code ® states:

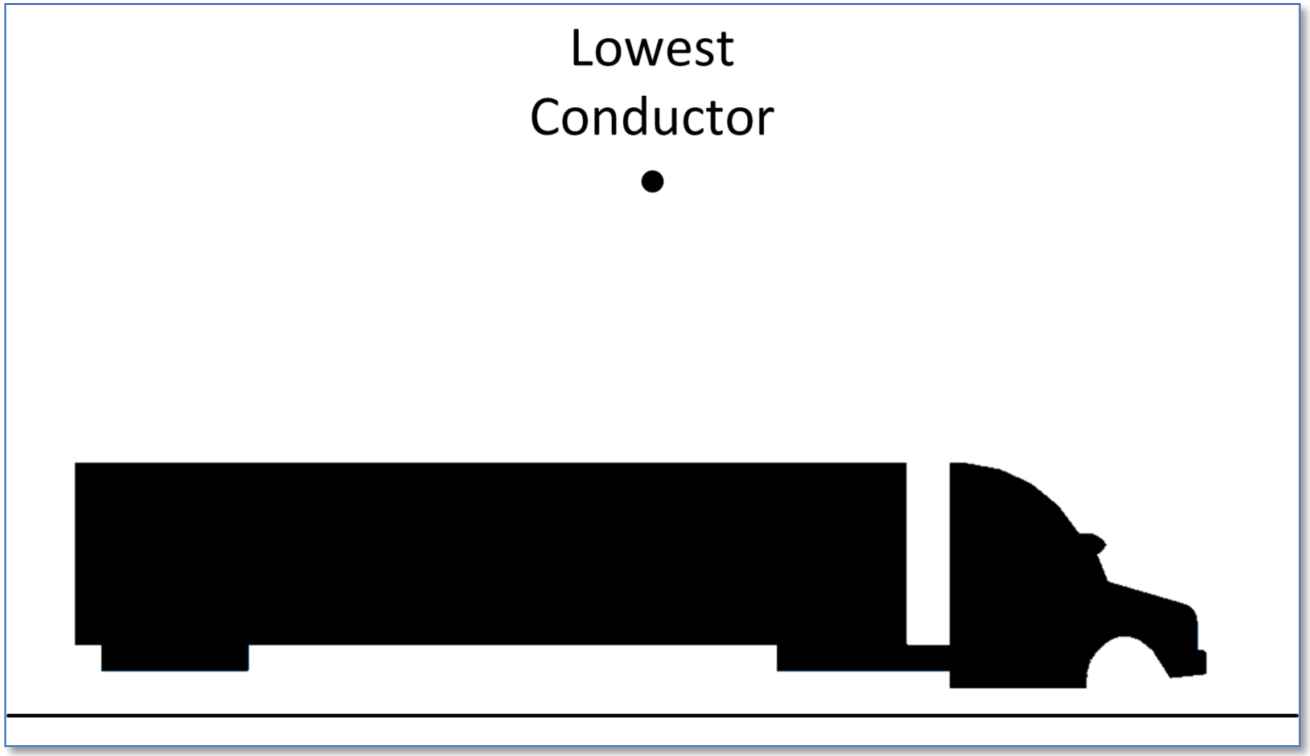
"For voltages exceeding 98 kV ac to ground, either the clearances shall be increased or the electric field, or the effects thereof, shall be reduced by other means as required to ***limit the steady-state current due to electrostatic effects to 5 mA*** *if the largest anticipated truck, vehicle, or equipment under the line were short-circuited to ground."*

Current (60 Hz)	Physiological Effect
0.5-1 mA	Threshold of perception
10-20 mA	Sustained muscular contraction
>100 mA	Ventricular fibrillation

INTRODUCTION



INTRODUCTION



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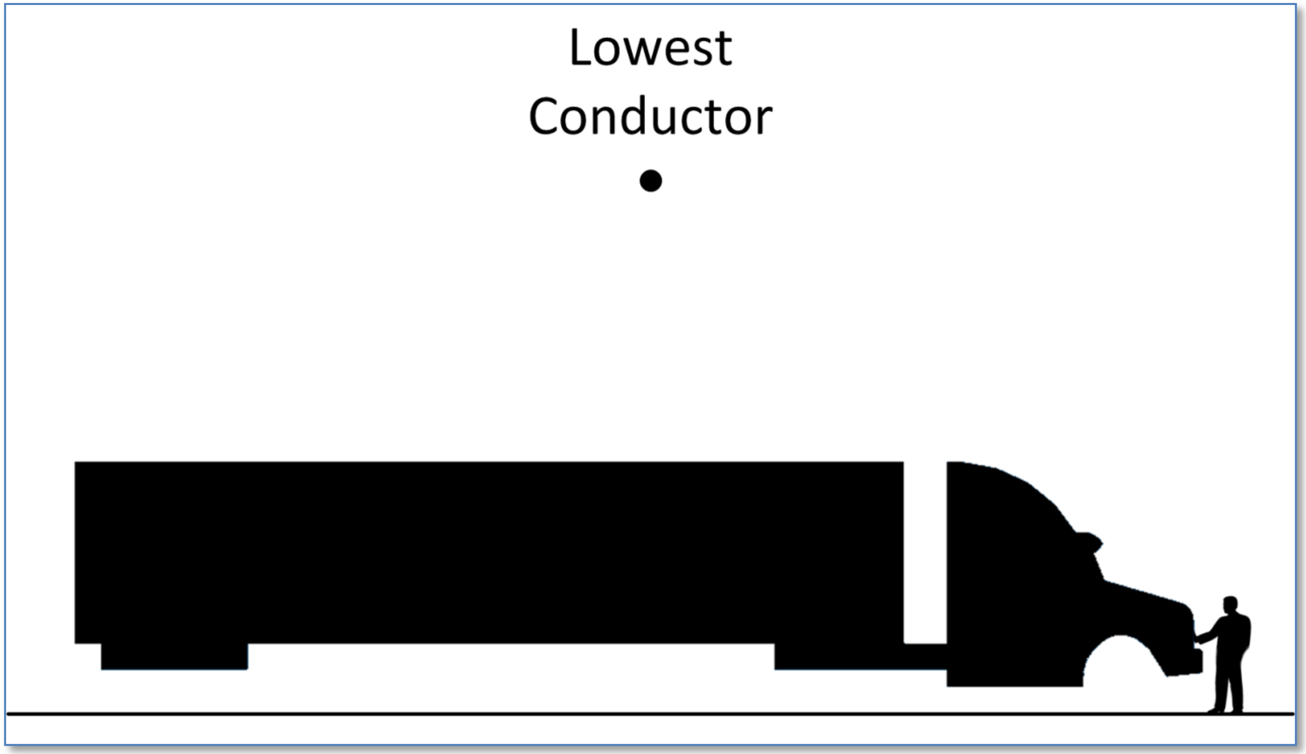
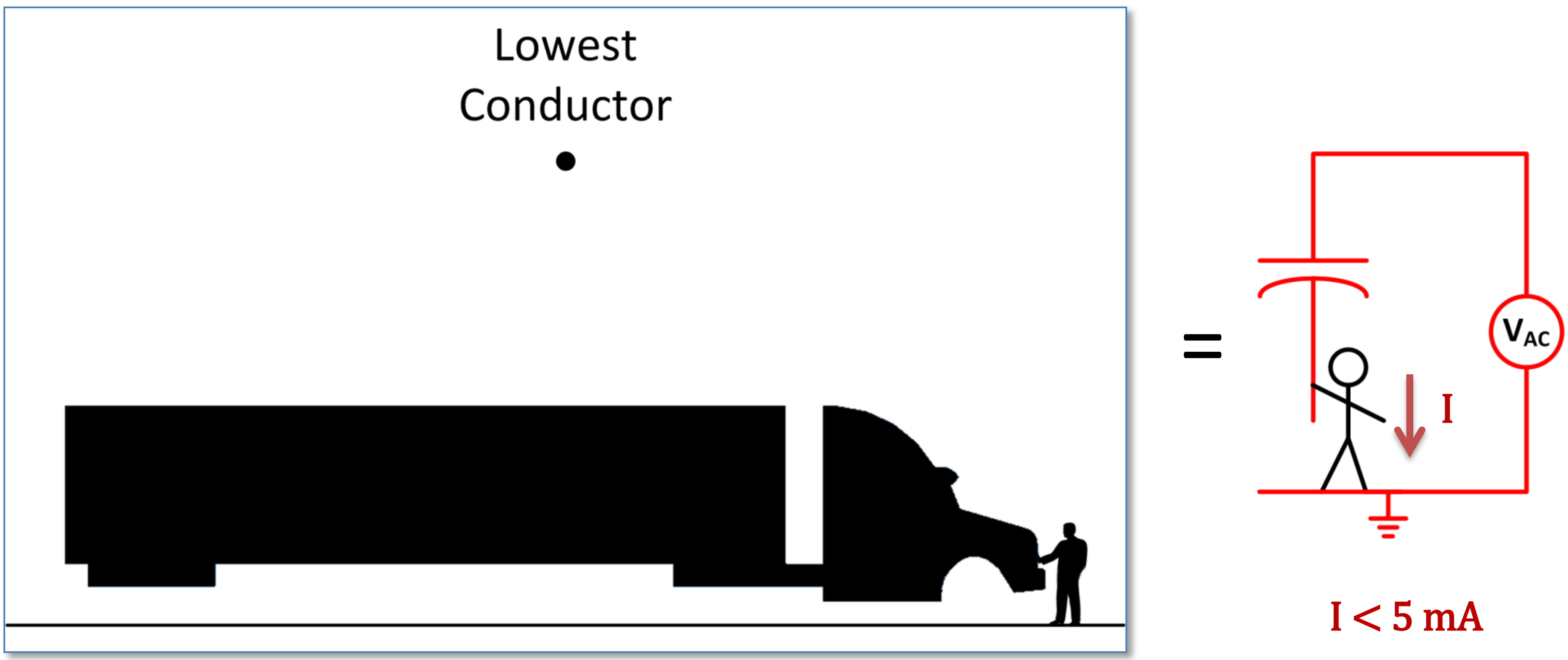
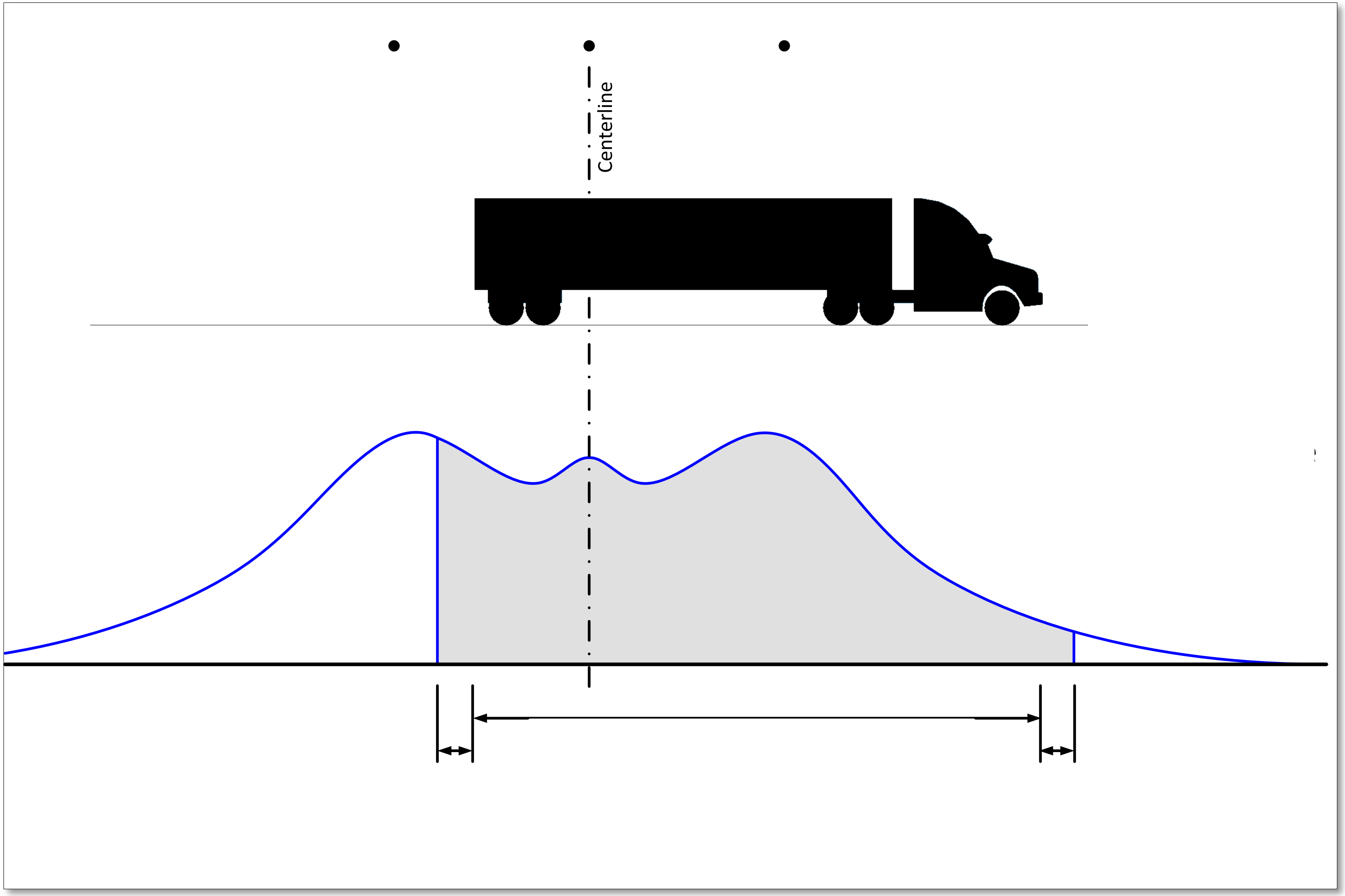


INTRODUCTION



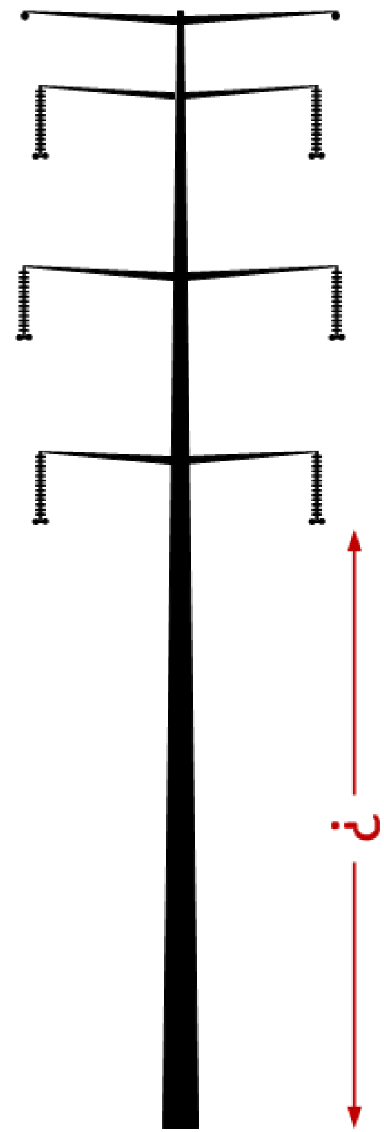
SEMI-EMPIRICAL APPROACH



THE PROBLEM

Cost vs. Electrical Clearances

Need to understand assumptions in order to optimize the design!



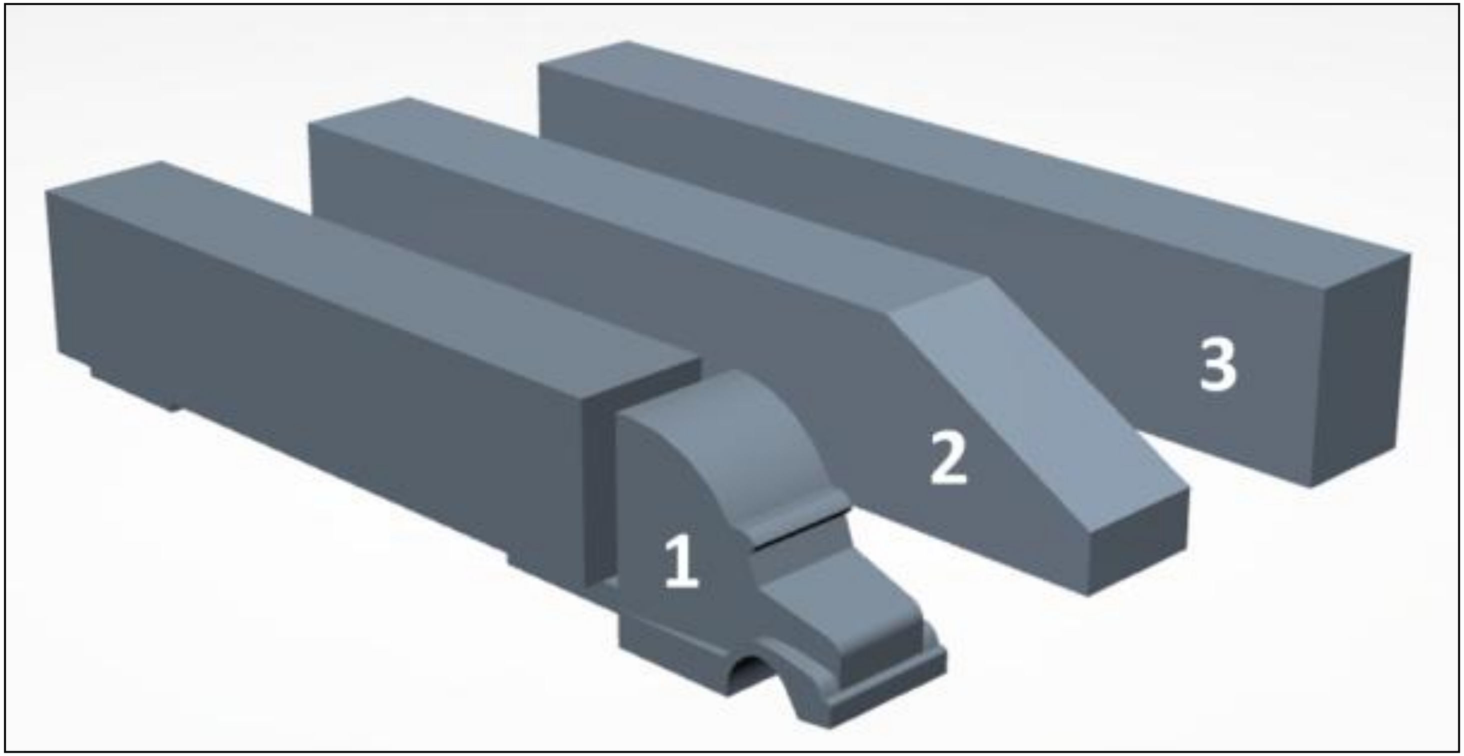
PHYSICS of the STUDY

Key Characteristics:

1. Transmission line allows 2D analysis, but vehicle requires 3D
2. ELF AC voltages and currents => Electric Currents Interface
3. Steady state 60 Hz => Frequency domain
4. Ground and vehicle body are assumed to be very good conductors with charge relaxation times much smaller than a 60 Hz period (hence classification as quasistatic).

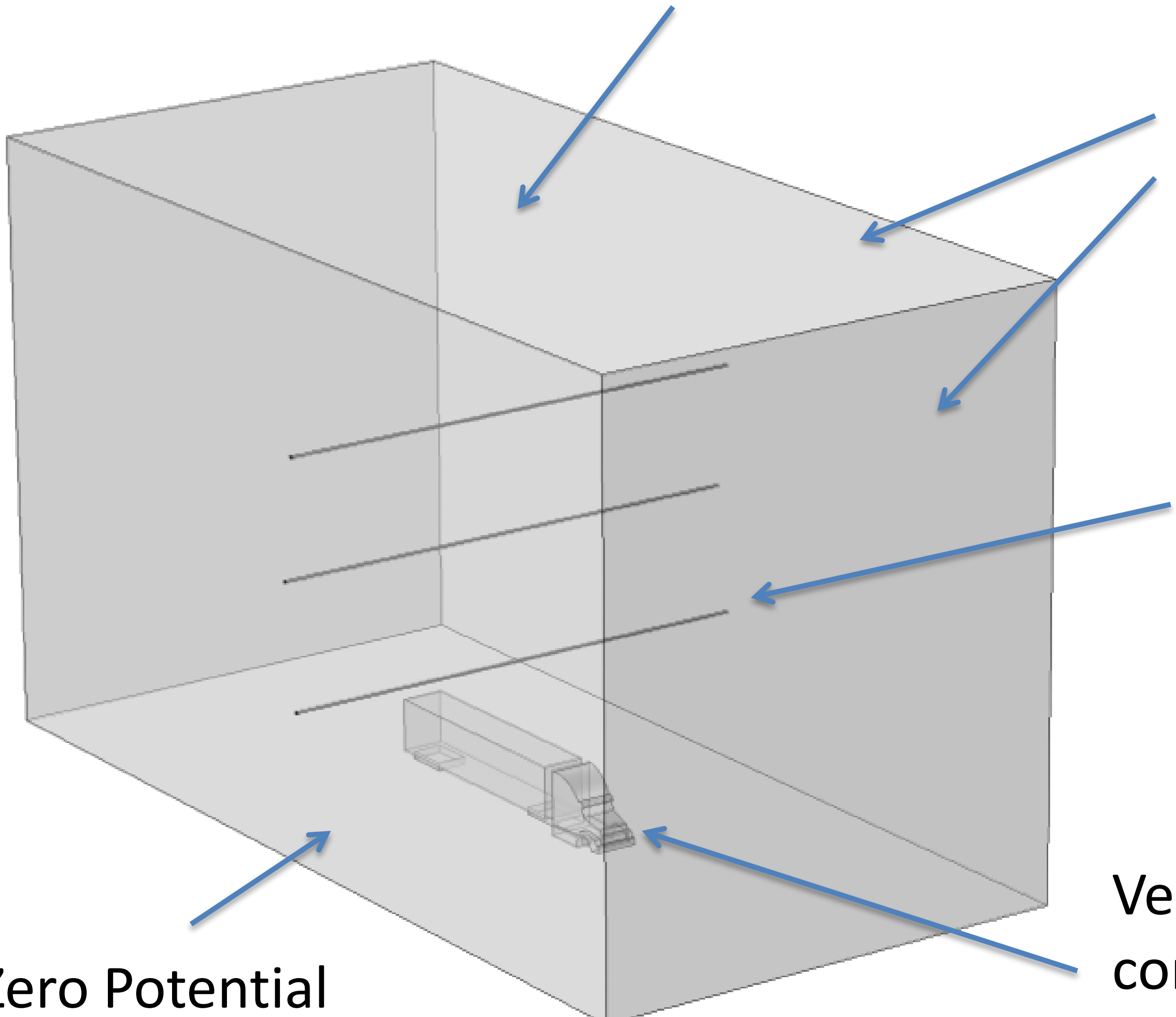
Equation	Summary
$\boldsymbol{E} = -\nabla \boldsymbol{V}$	Relationship between electric potential and electric fields
$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$	Gauss' Law: Electric flux through a surface is proportional to the enclosed charge
$\mathbf{n} \cdot (\varepsilon_0 \boldsymbol{E^a} - \varepsilon_0 \boldsymbol{E^b}) = \sigma_s$	Relationship between surface charge density and electric field at the surface boundaries
$\nabla \cdot \boldsymbol{J} = -\frac{\partial \rho}{\partial t}$	Law of conservation of charge: Current in or out of a volume is equal to the rate of change of charge
$\boldsymbol{J} = \sigma \boldsymbol{E} + j\omega \boldsymbol{D} + \boldsymbol{J_e}$	Equation for current density given a steady-state frequency domain problem

COMSOL MODEL



CAD Model of Vehicle Imported into COMSOL

COMSOL MODEL



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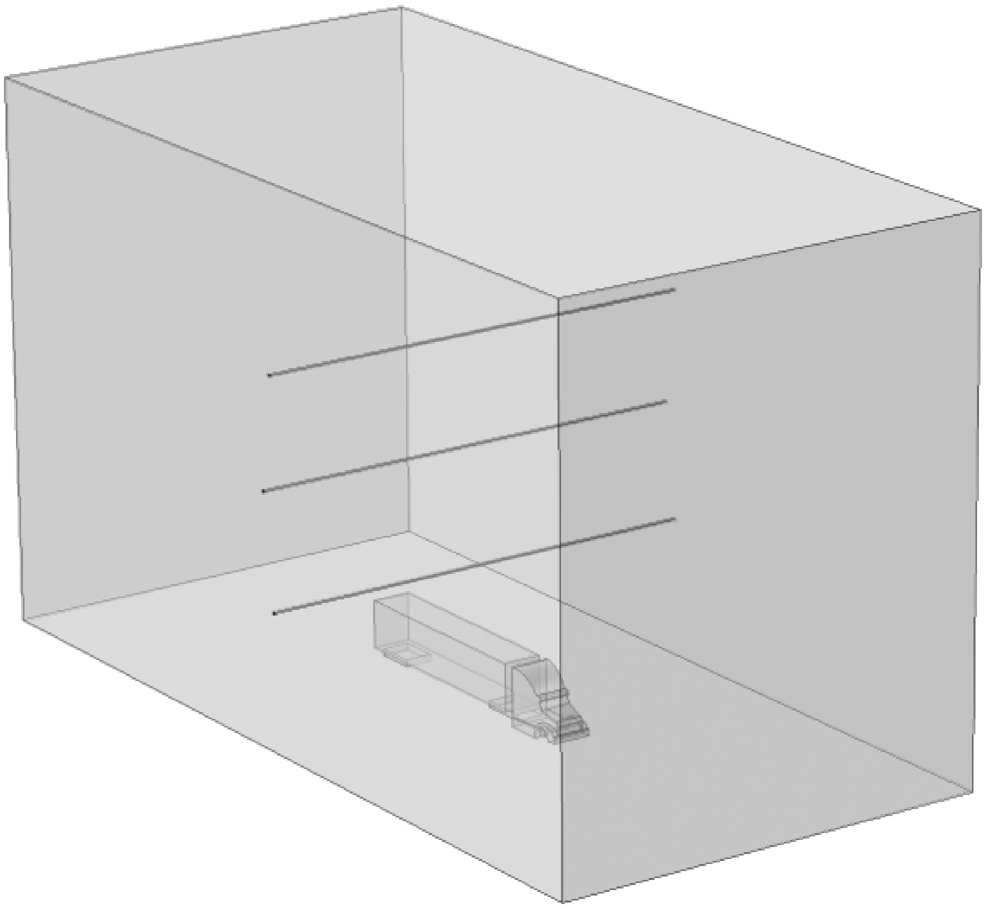

Largest dimension in space = 200 ft
Conductor diameter = 1 inch

=> 2400:1

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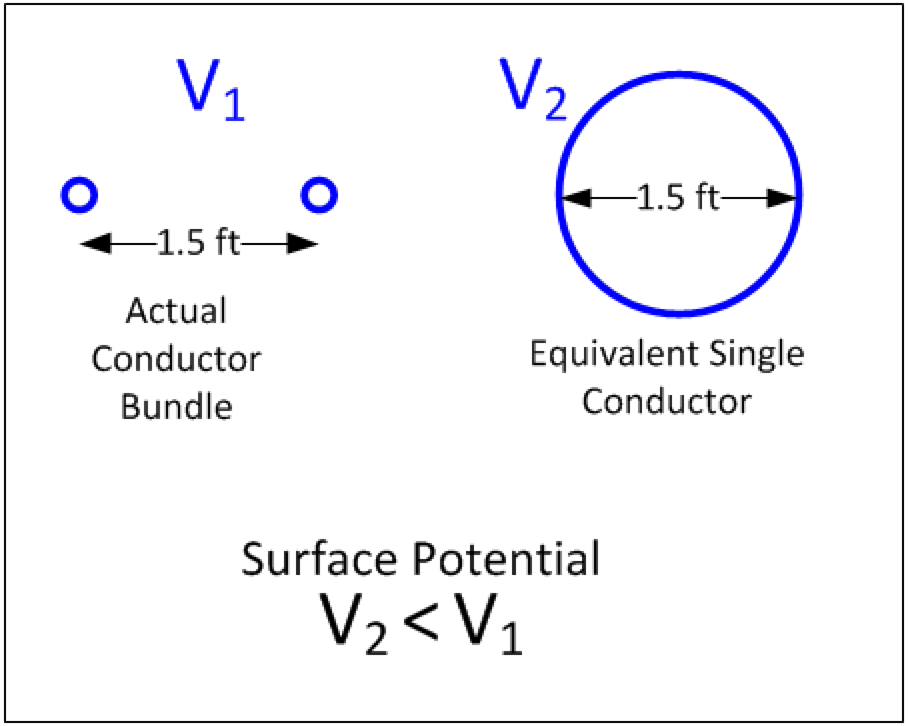

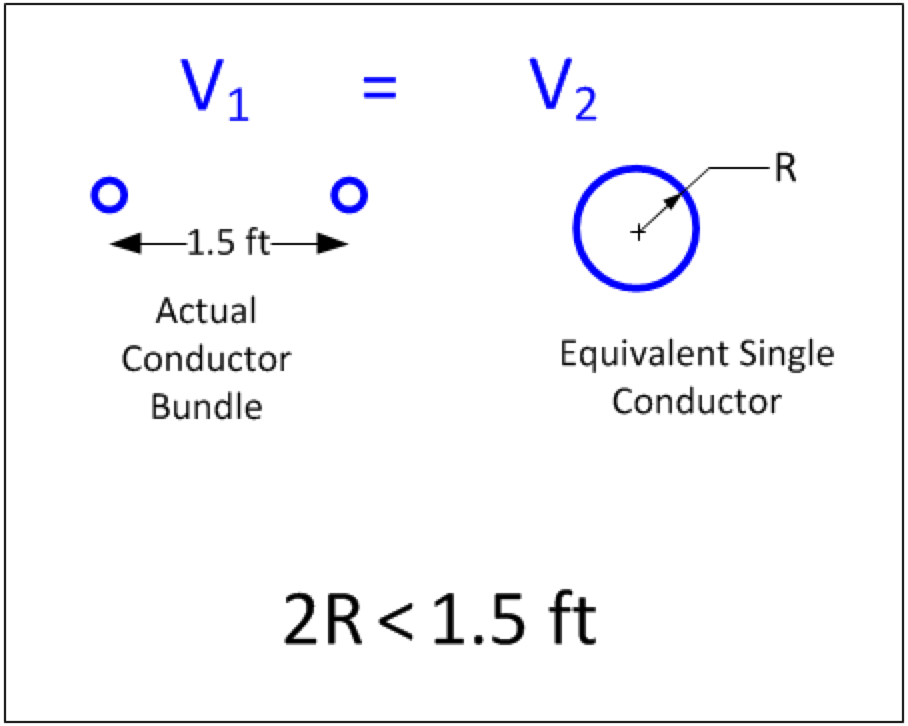

Perform parametric sweep of V_2

133:1

Perform parametric sweep of R

400:1

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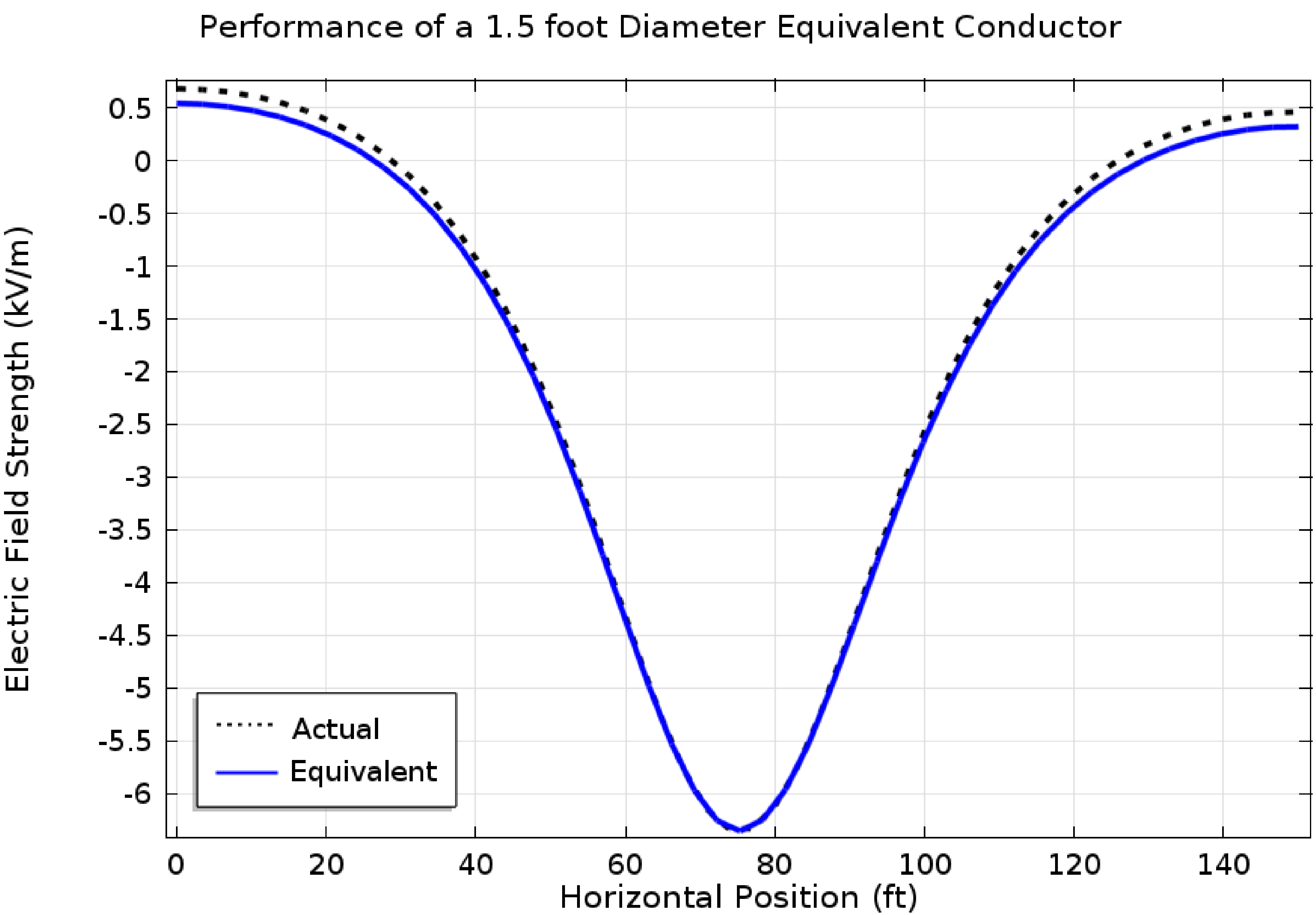

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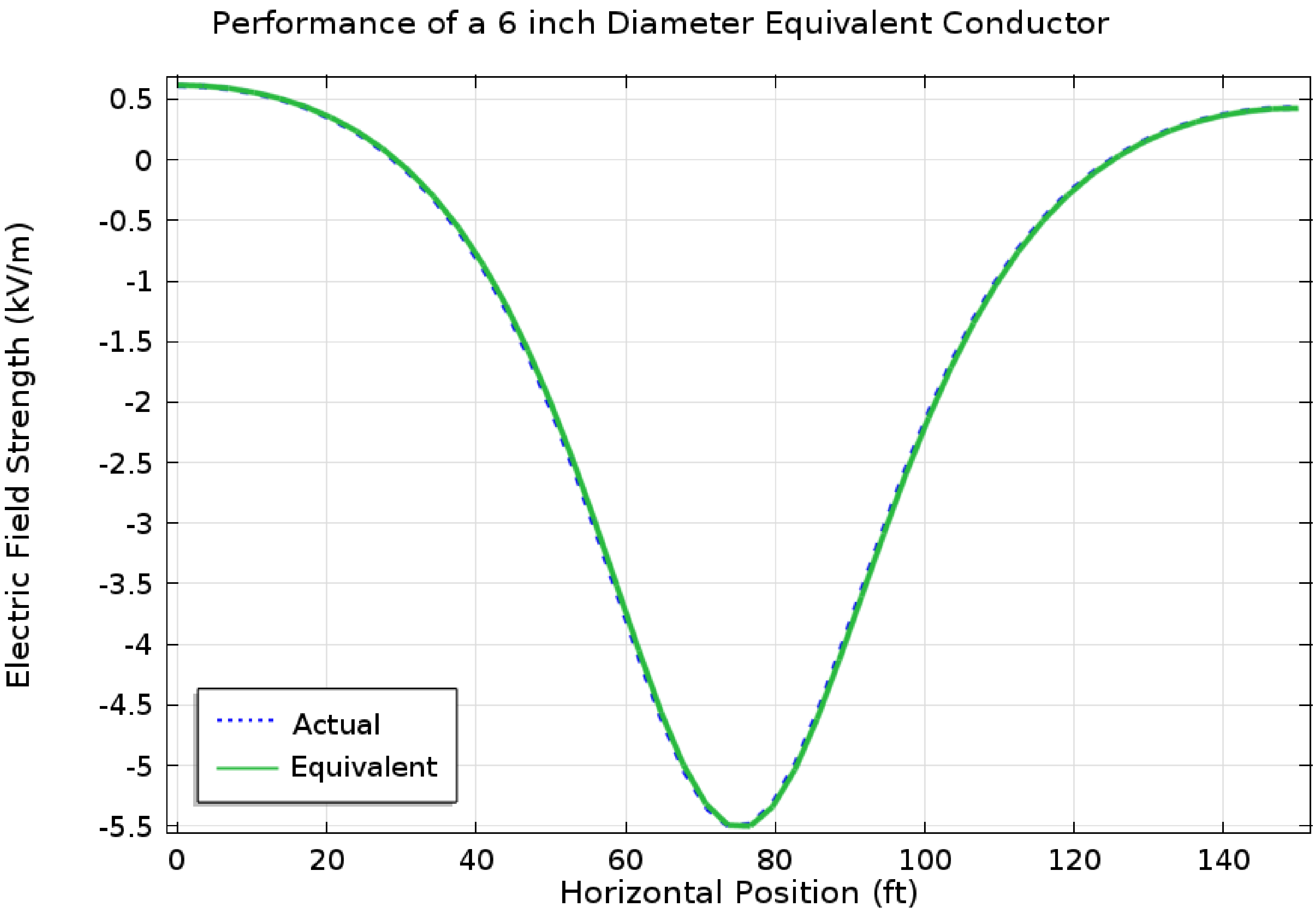

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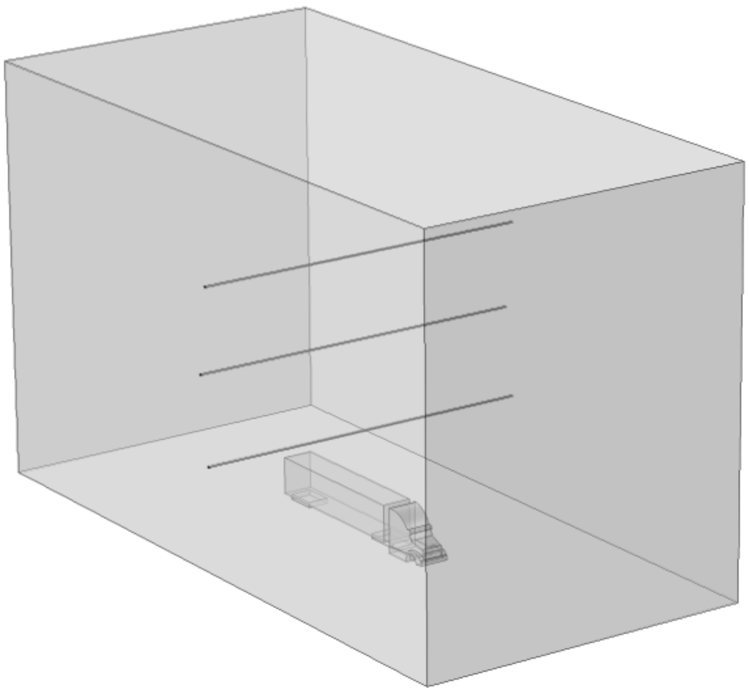

Approach 1:

- Electric Currents Interface with iterative solver => easily handled about 1.2M DoF
- Truck volume meshed and included in solution space
- Conducting cylinder connects vehicle to ground

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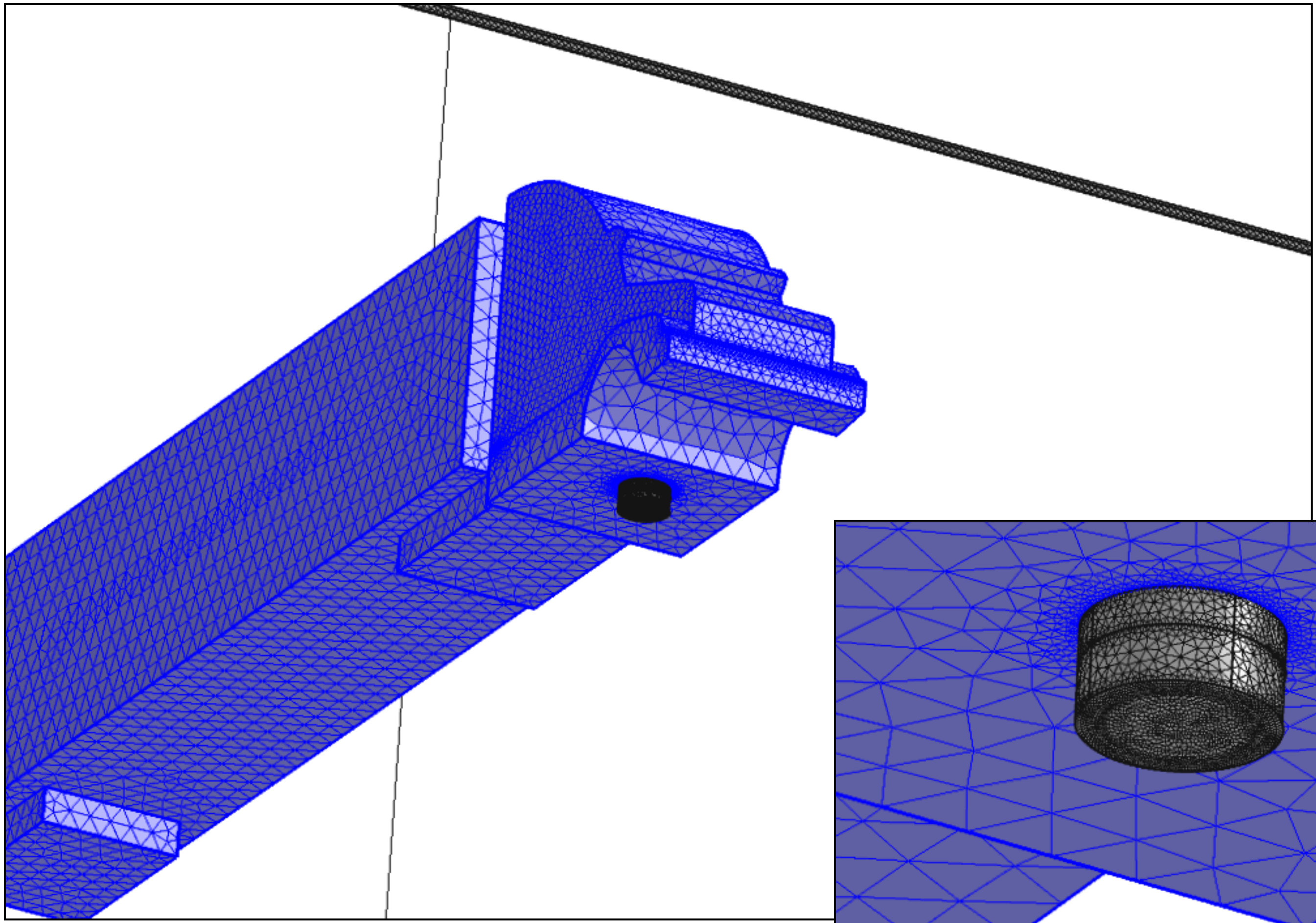

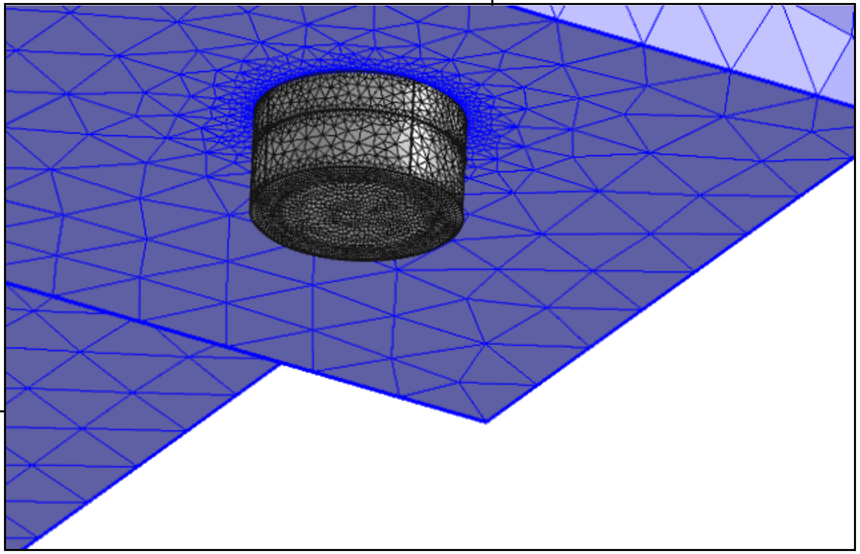

Approach 1

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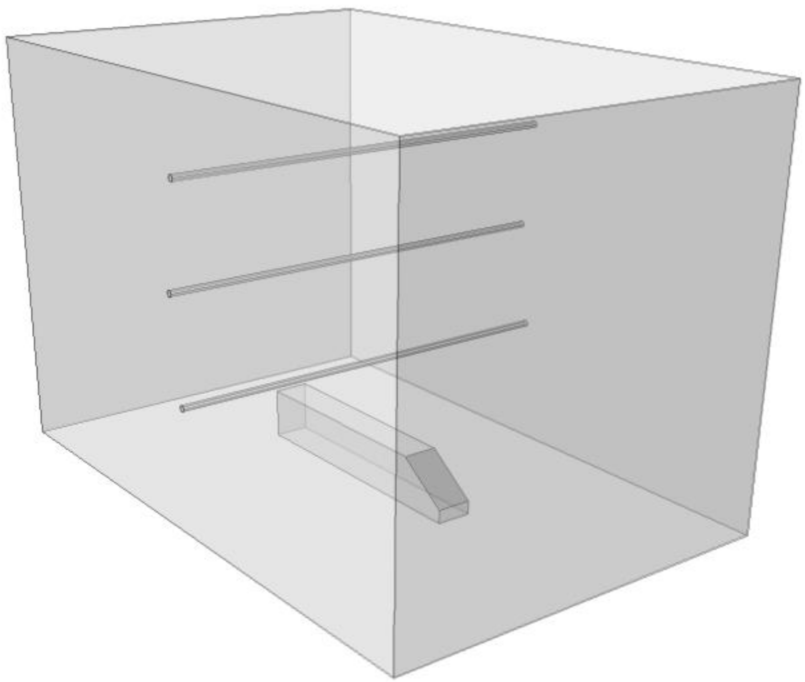

Approach 2:

- Electric Currents Interface and Electrical Circuits Interface with direct solver => could only handle about 200K DoF
- Truck volume not meshed and not included in solution space
- Electric Shielding element with conducting properties used on vehicle surfaces

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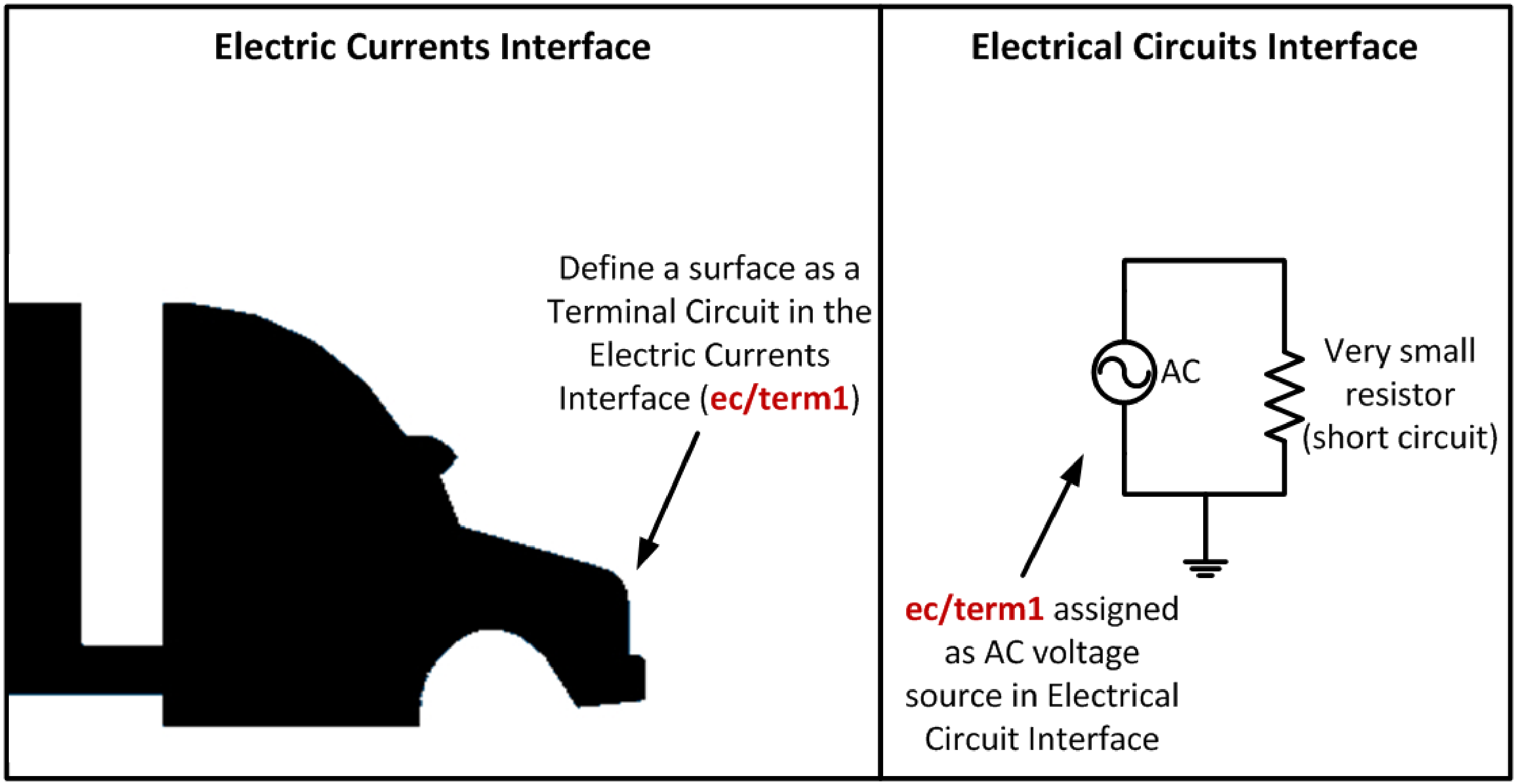
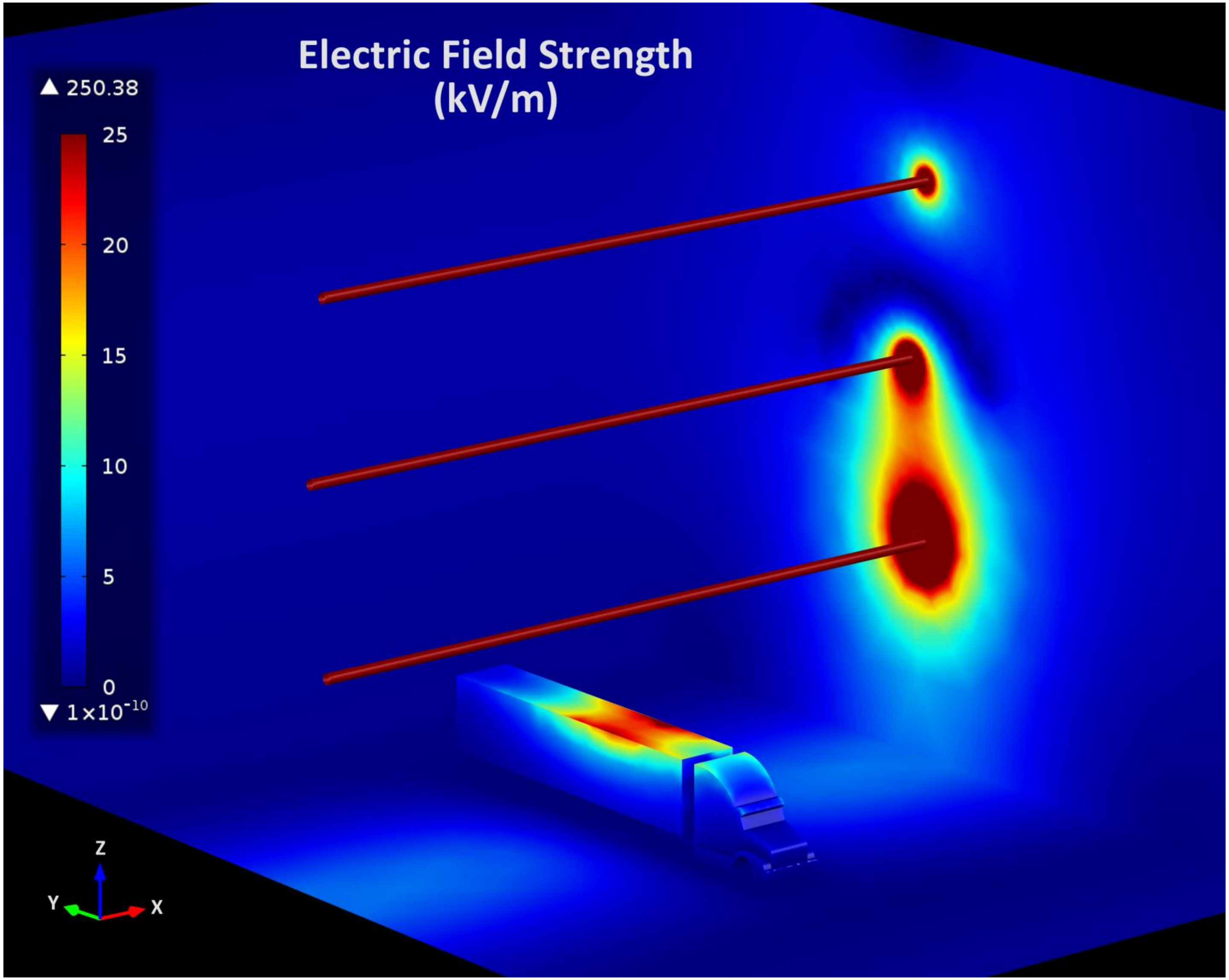
Approach 2



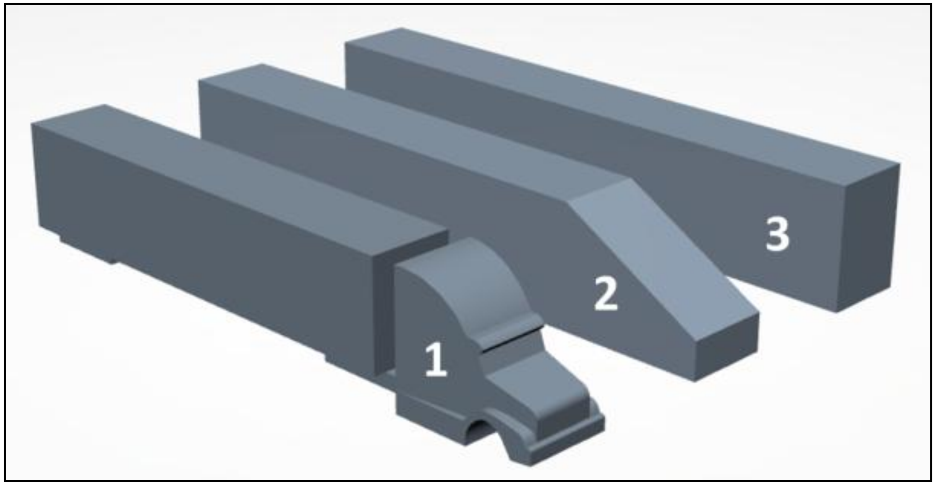
RESULTS



RESULTS

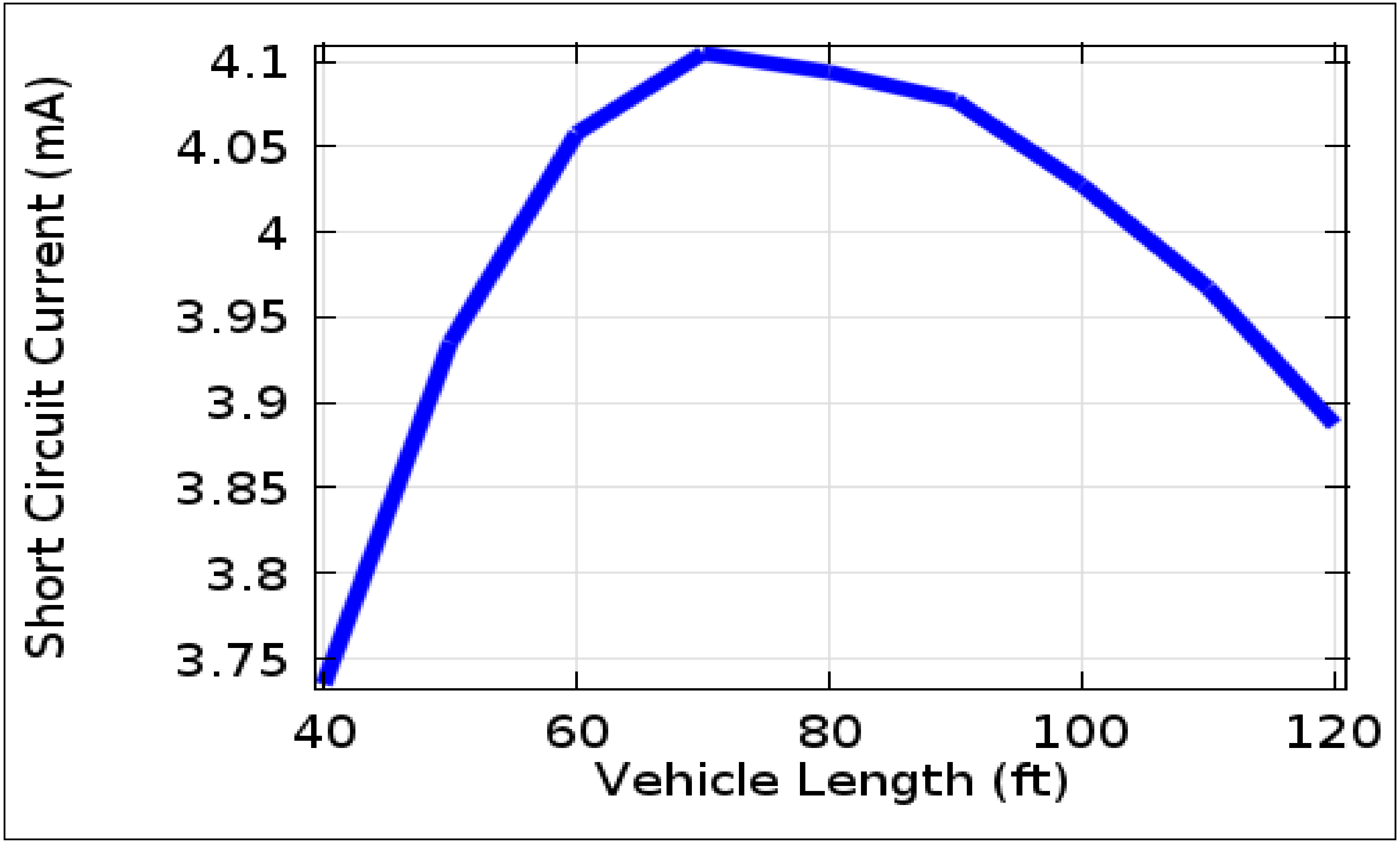
Short Circuit Current

Approach	Short Circuit Current		
	Truck 1	Truck 2	Truck 3
Semi-empirical	n/a	n/a	4.2 mA
COMSOL approach 1	3.8 mA	4.1 mA	4.2 mA
COMSOL approach 2	4.0 mA	4.0 mA	4.1 mA
CDEGS	n/a	4.1 mA	4.2 mA



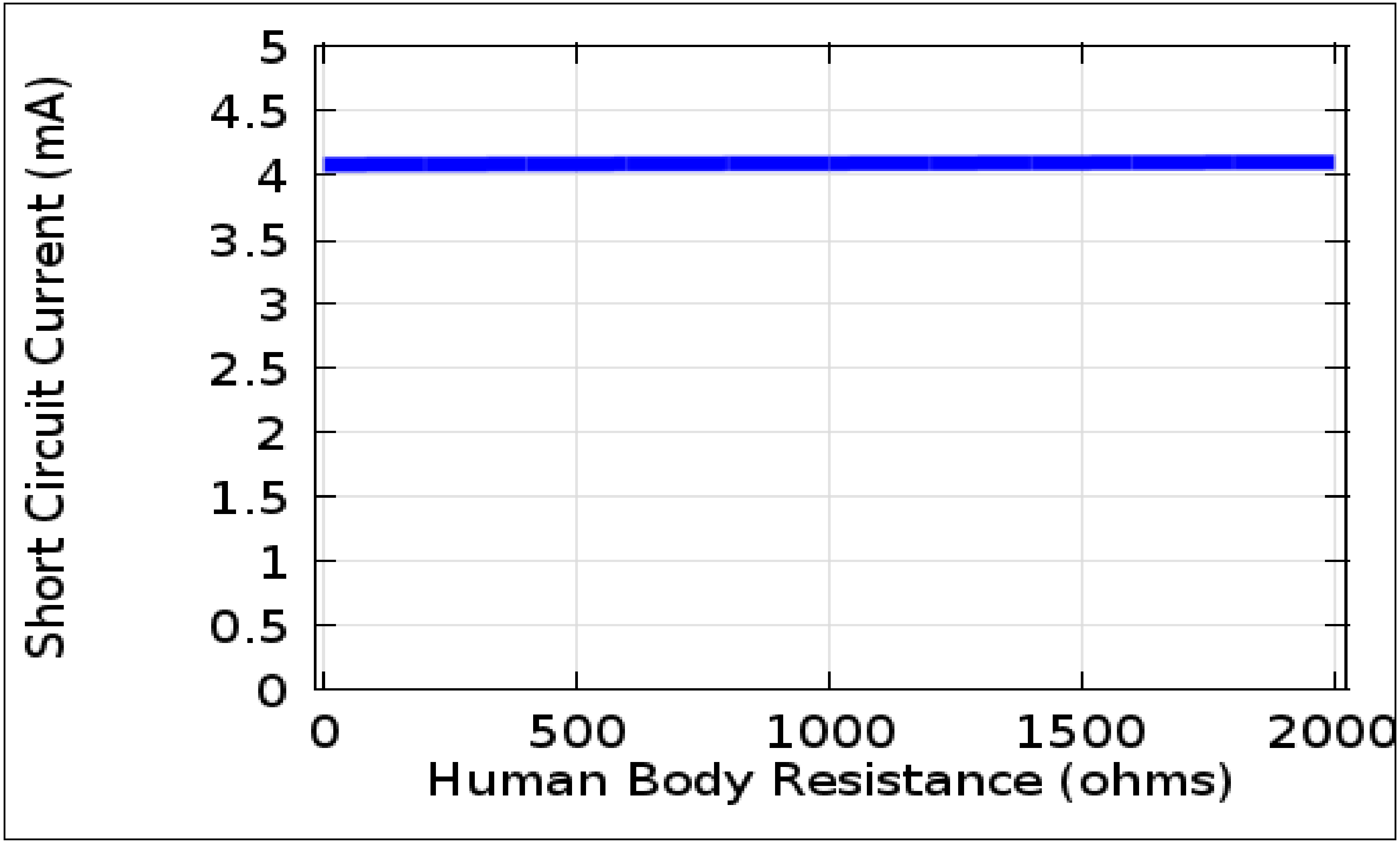
RESULTS

Parametric Sweep of Vehicle Length



RESULTS

Parametric Sweep of Body Resistance



CONCLUSIONS

For The Case Studied:

1. The semi-empirical approach with geometric simplifications provides reasonably accurate results and is biased appropriately on the side of safety
2. The “largest anticipated vehicle” is not necessarily the controlling case for electrical clearances
3. Resistances in the range of that of the human body have negligible effect on the flow of current to/from the vehicle

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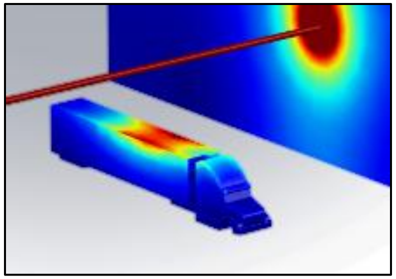

QUESTIONS?

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