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# Pulsed Power Engineering Engineering Simulations

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# Engineering Simulations in Pulsed Power Systems



- Uses of engineering simulation
- Tools
- Typical methodology
- Analytical estimates of electric field



# Pulsed Power Engineering Simulations

- Differential equations govern many processes of interest to pulsed power engineers.
  - Ex. Heat flow, stress/strain, electric and magnetic field intensities
- Simulations provide a straightforward method to solve these equations for complex geometries and non-linear conditions.
- Some Types of Simulations Used
  - Finite Element Method (FEM)
    - Very common method; used for transient and non-linear problems
  - Boundary Value Method (BVM)
    - Good for odd aspect-ratio problems with open spaces; quick simulation times
  - Particle in Cell (PIC)
    - For particle trajectory problems and plasma simulation



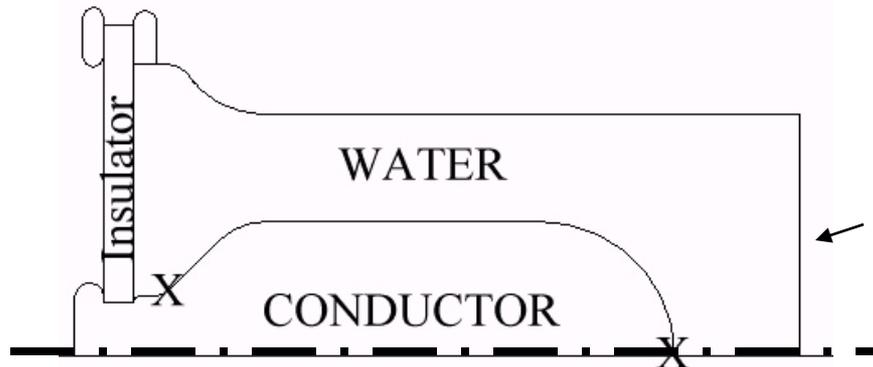
# Types of Simulations

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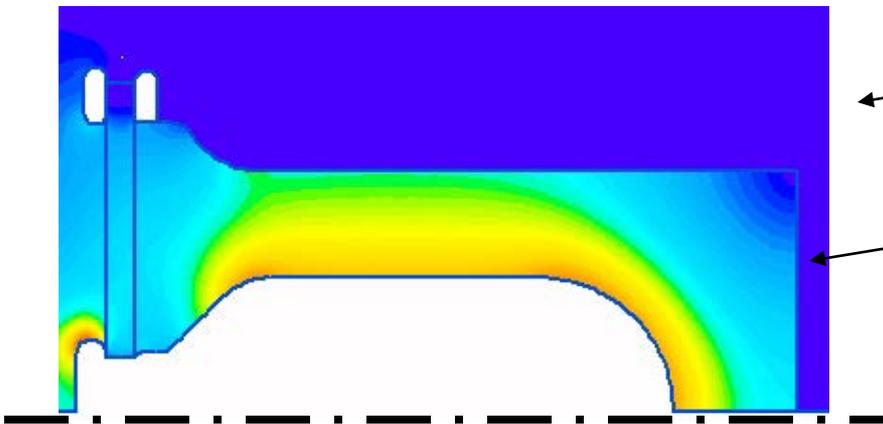
- Electrostatic/Magnetostatic
  - Electro, Maxwell 2D (free)/3D, Quickfield
- Multi-physics
  - ANSYS, ATILA (free)
- Capacitance/Inductance Solvers
  - FastHenry (free), FastCap (free)
- Electromagnetic Solver
  - HFSS, Singula
- Particle-in-Cell
  - XOOPIC (free), LSP

# Electric Field Stress

- What is the electric field stress for a certain geometry and voltage?
- Shown is a rotationally symmetric capacitor.



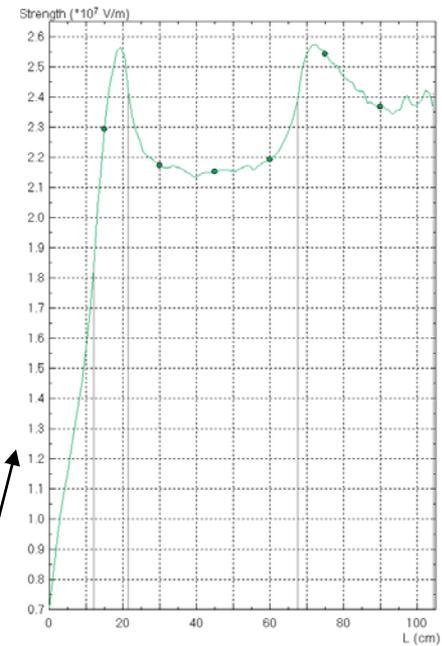
CAD Drawing of Water Capacitor (azimuthally symmetric)



Electric Field Magnitude Plots

Open Space

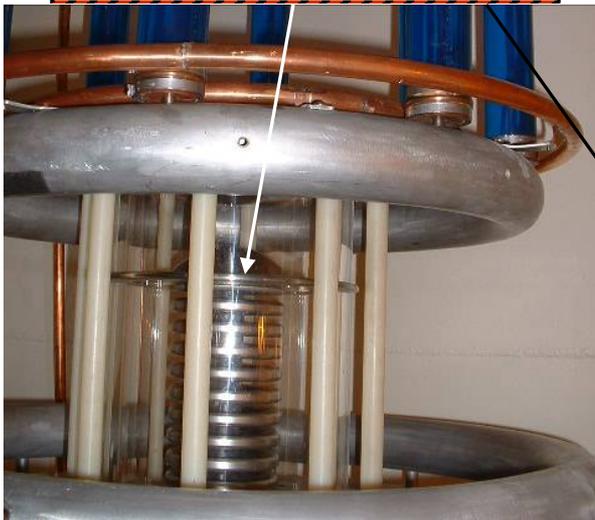
Along a Measurement Line



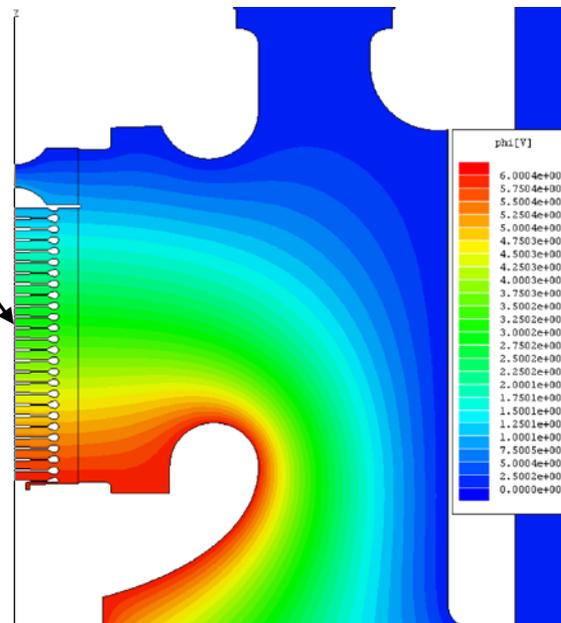
# Electric Field Grading

- Where should field shapers be placed to evenly grade the electric field along an insulator?
- Field response to geometry changes can be modeled.

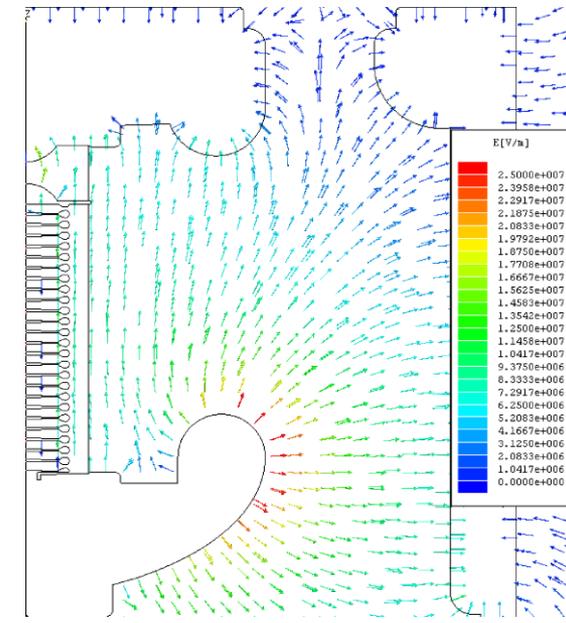
Floating Conductors in a Gas Discharge Switch



Equipotentials

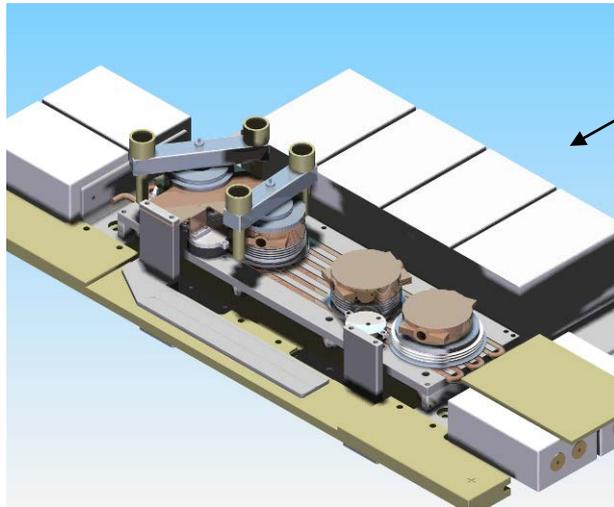


Electric Field Vectors





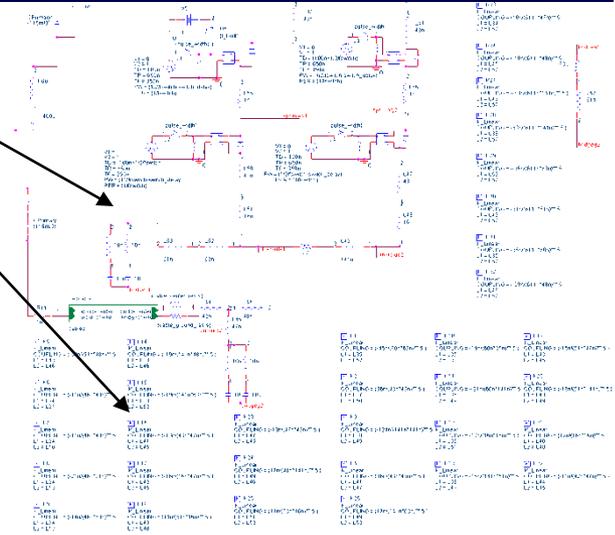
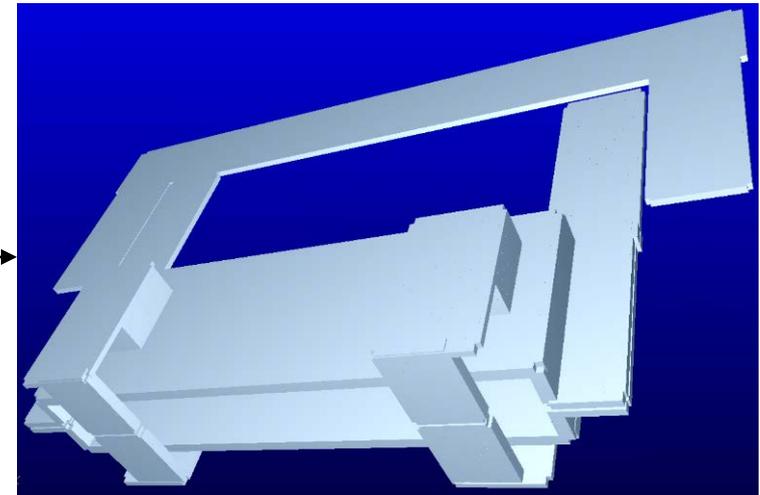
# Inductance Matrices



CAD Drawing

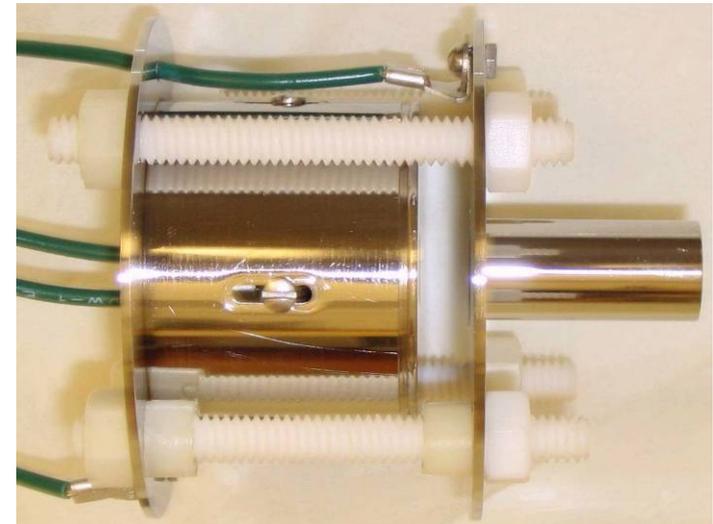
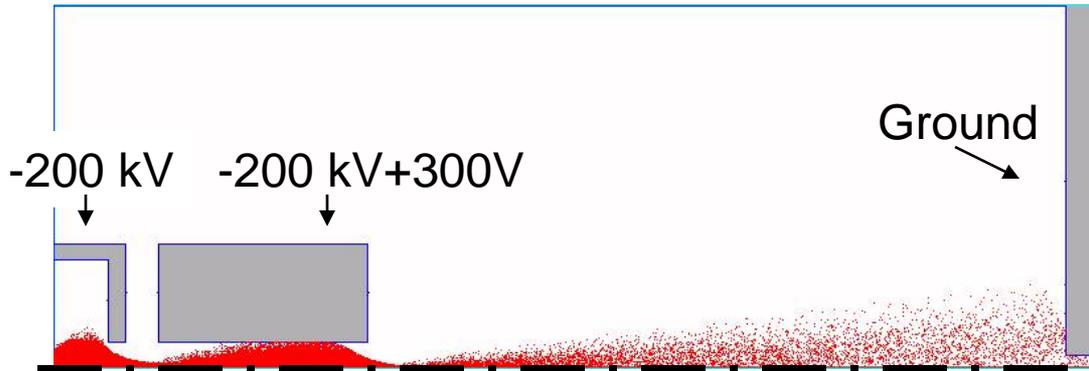
Simplified Representation

Inductance Matrix



- Simplified representations are in many time necessary and appropriate for simulating complex geometries.
- Self- and mutual- inductance matrices can be generated.

# PIC Cathode Design

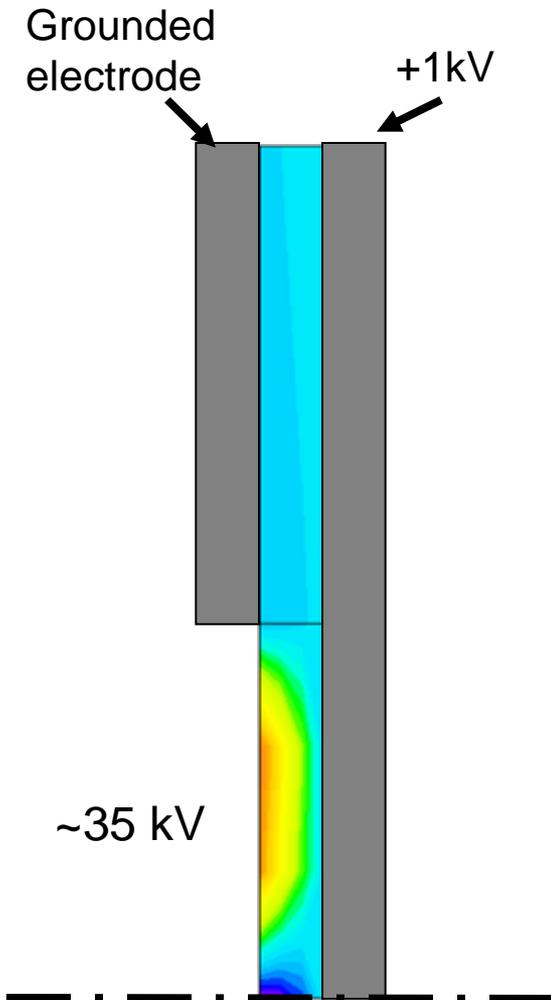


- Some PIC codes can self-consistently model E&M systems.
- Above is a cathode design showing the effect of external fields and self-fields from electrons.



# Multi-Physics Design

- In some cases, several systems interact. E.g. mechanical, electrical, and thermal.
- For example, left is a simulation of a piezoelectric transformer. Coupled mechanical and electrical systems are simulated.
- ANSYS and ATILA (free) are two codes available.





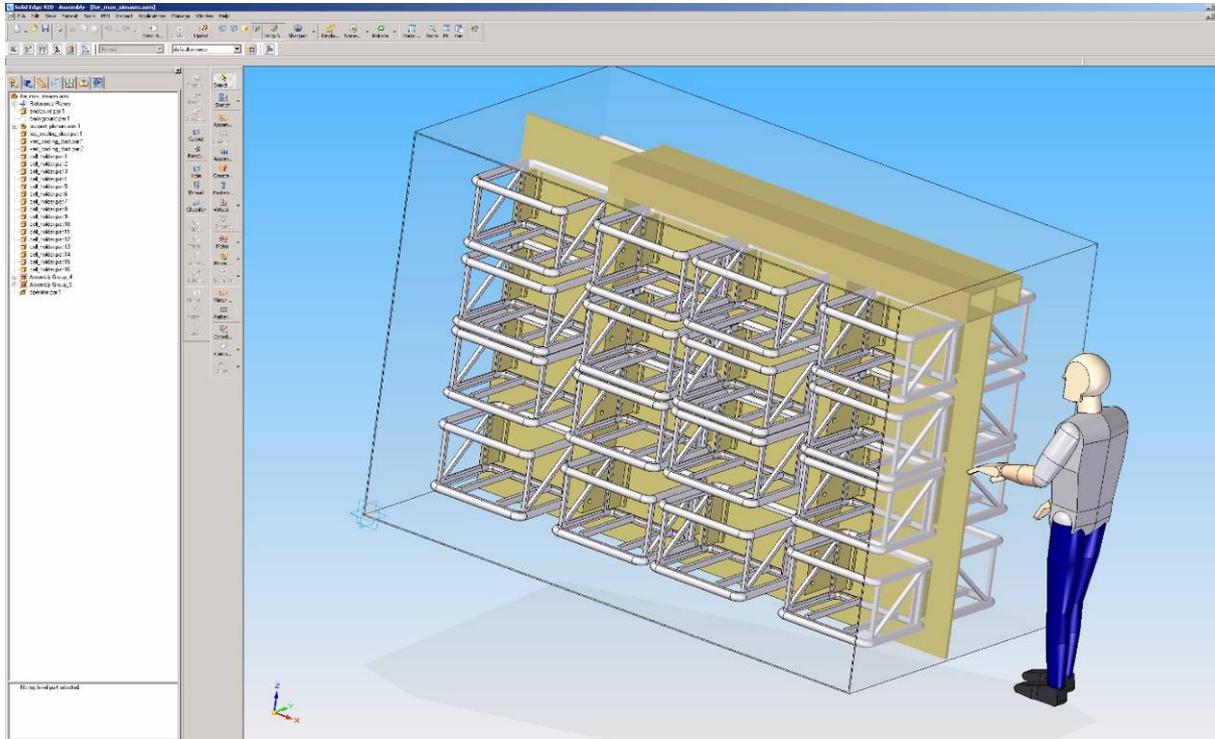
# Typical Work Flow

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- Create Geometry
  - Through external CAD program
  - Through included CAD program
  - By manually entering text coordinates
- Define Boundaries and Sources
  - Ex. Force on a surface, voltage on a conductor, or charge in a volume.
- Define Solution Type
- Create Mesh
- Simulate
- Post-Process

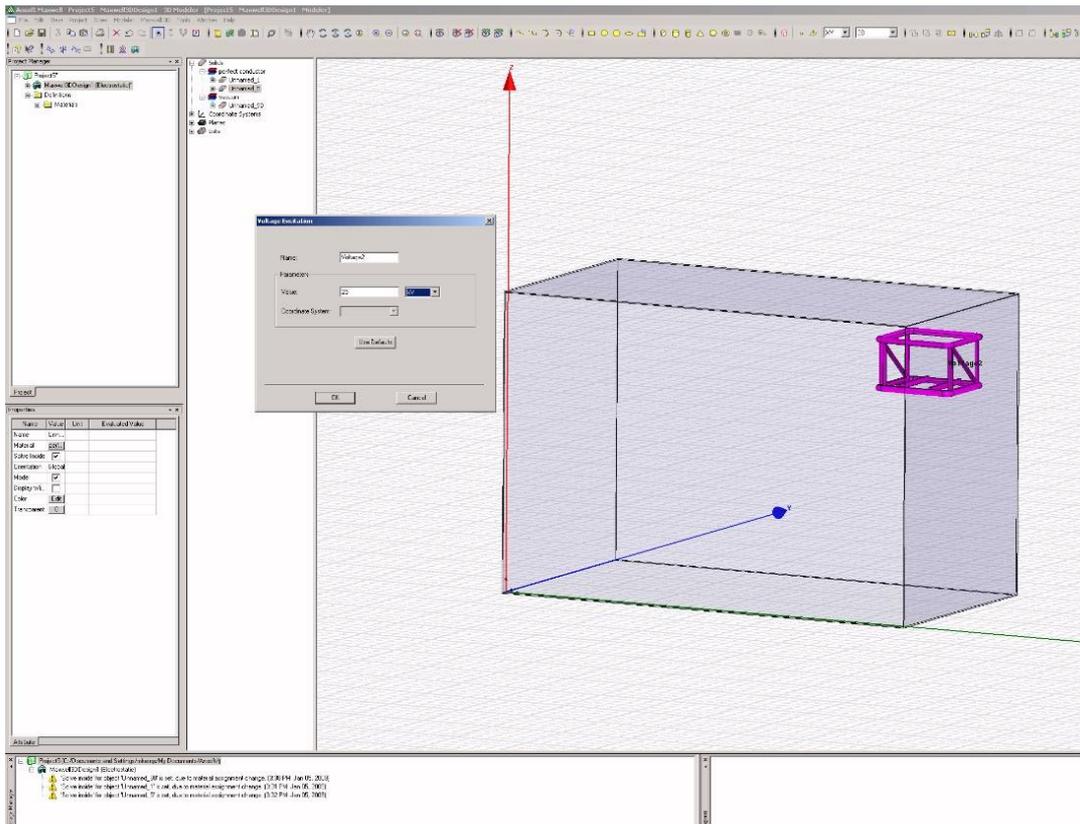
# Typical Workflow

- A complex geometry is created in a CAD program
- Can be 2D or 3D depending on the software and the nature of the problem

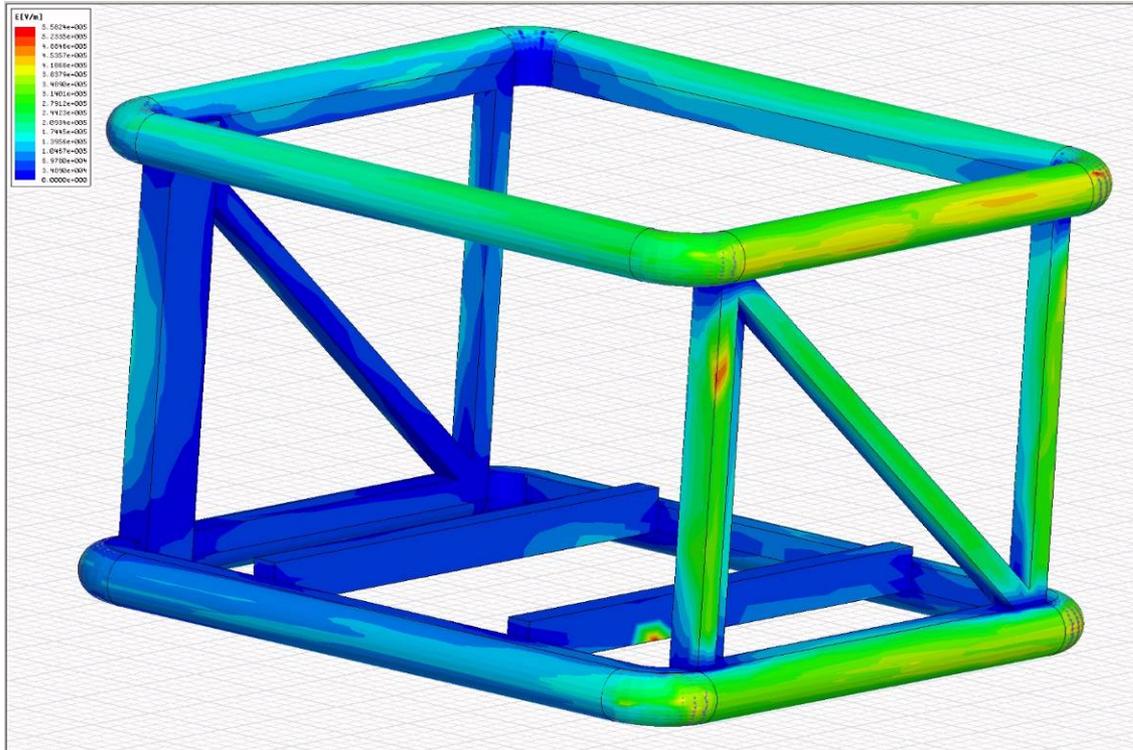


# Typical Workflow

- The specific area of interest is imported to the simulation software.
- Excitations and boundary conditions are set.
- Simulation settings are entered.

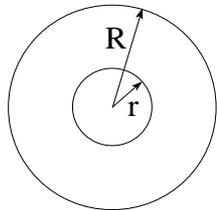


# Typical Workflow



- Once a problem has a converged solution, results can be viewed.
- Many programs have the option to view results in a post-processor program or export for processing elsewhere.

# Estimating Electric Fields



Concentric Spheres

Maximum Stress ( $E_M$ )

$$f = \frac{\text{maximum stress}}{\text{mean stress}}$$

$$E_M = \frac{VR}{r(R-r)}$$

$$f = \frac{R}{r}$$

Optimum ratio  $\frac{R}{r}$   
and corresponding  
maximum stress

$$\frac{R}{r} = 2$$

$$E_M = \frac{2V}{r} = \frac{4V}{R}$$

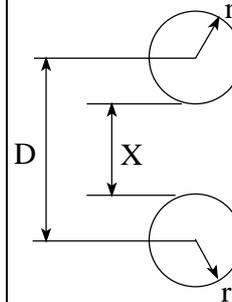
Concentric Cylinders  
(symbols as for  
concentric spheres)

$$E_M = \frac{VR}{r \ln \frac{R}{r}}$$

$$f = \frac{\frac{R}{r} - 1}{\ln \frac{R}{r}}$$

$$\frac{R}{r} = e$$

$$E_M = \frac{V}{r} = \frac{Ve}{R}$$



Equal Spheres

Maximum Stress ( $E_M$ )

$$f = \frac{\text{maximum stress}}{\text{mean stress}}$$

$$E_M = \frac{V}{X} f \cong \frac{V}{2r} \text{ for } \frac{X}{r} \gg 1$$

$$f = \frac{\frac{X}{r} + 1 + \sqrt{\left(\frac{X}{r} + 1\right)^2 + 8}}{4} \cong \frac{X}{2r} \text{ for } \frac{X}{r} \gg 1$$

Equal parallel  
Cylinders  
(symbols as for  
equal spheres)

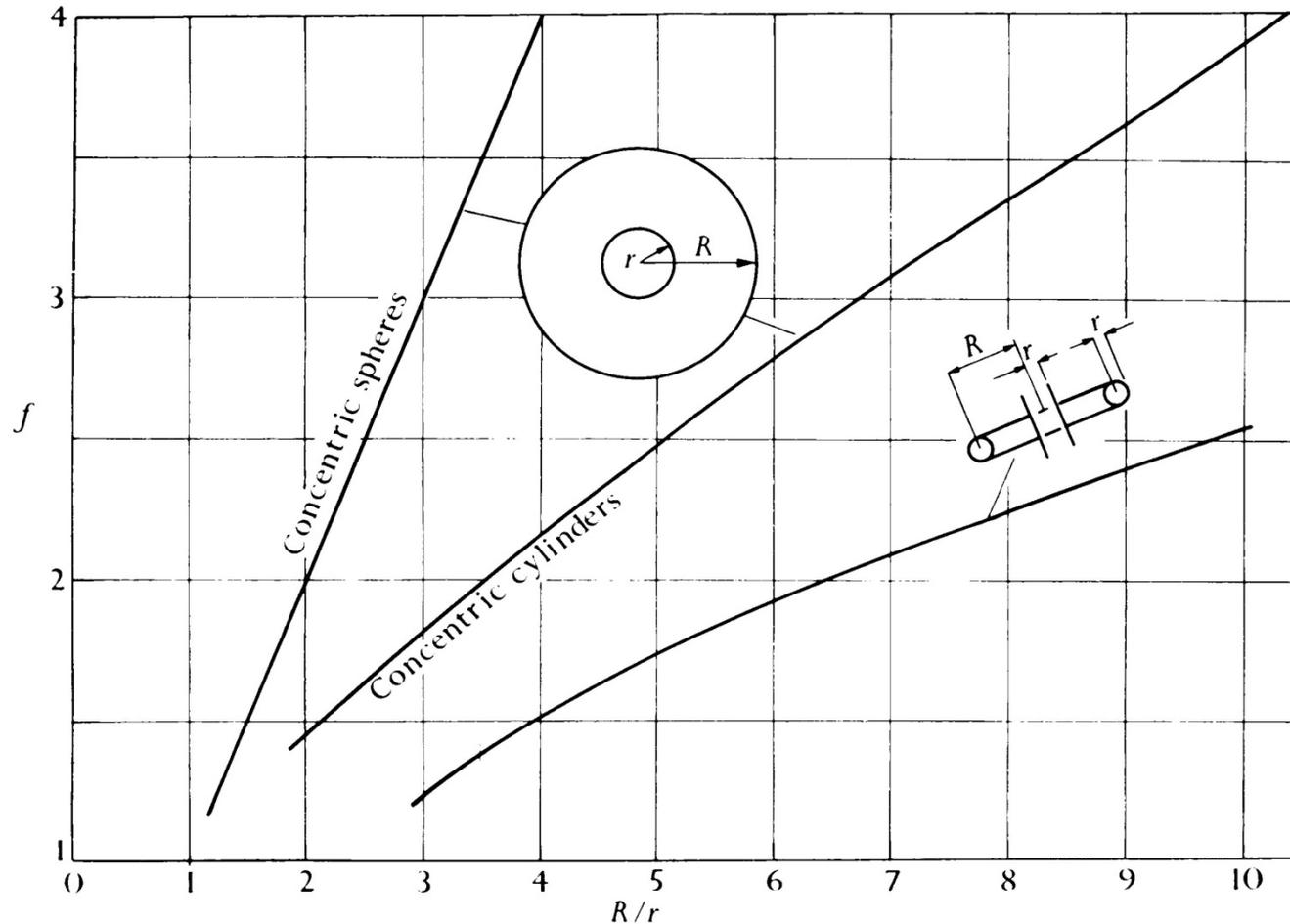
$$E_M = \frac{V \sqrt{(D^2 - 4r^2)}}{2r(D - 2r) \ln \left[ \frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1} \right]}$$

$$E_M \cong \frac{V}{2r \ln \left( \frac{D}{r} \right)} \text{ if } D \gg 2r$$

$$f = \frac{\sqrt{\left\{ \left( \frac{X}{r} \right)^2 + 4 \frac{X}{r} \right\}}}{2 \ln \left[ \frac{X}{2r} + 1 + \frac{1}{2} \sqrt{\left\{ \left( \frac{X}{r} \right)^2 + 4 \frac{X}{r} \right\}} \right]}$$

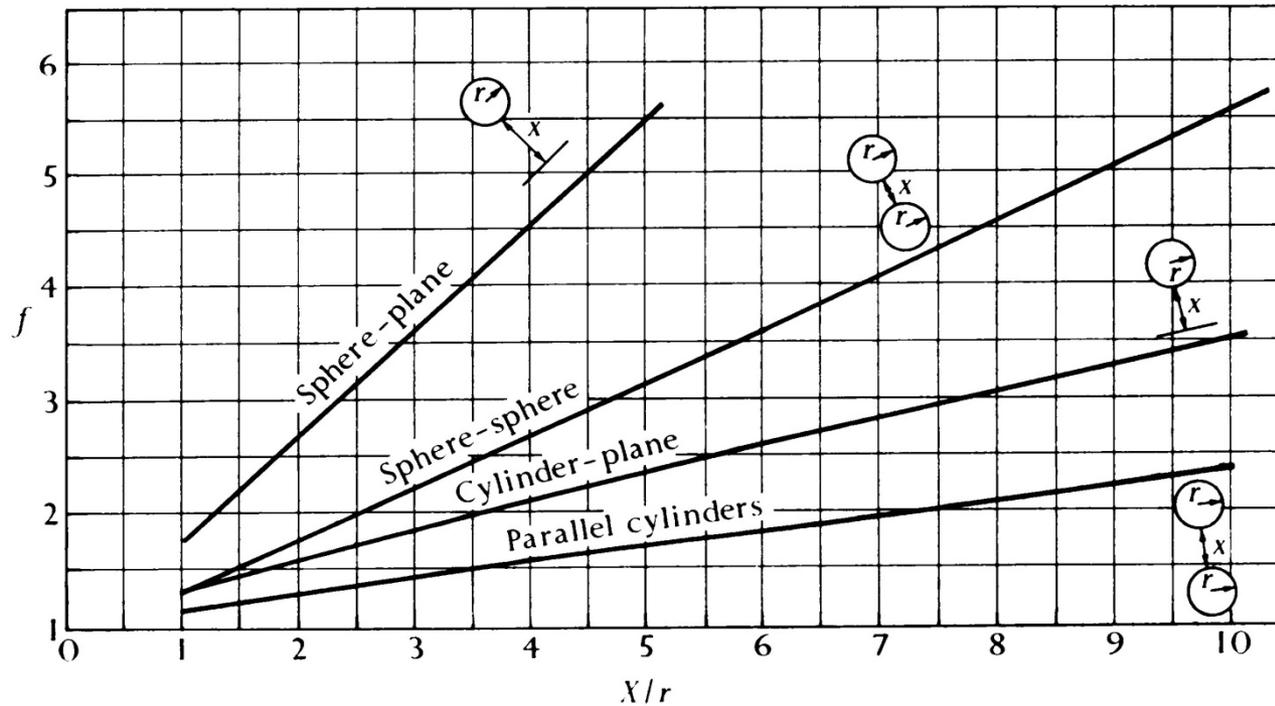
$$f \cong \frac{X}{2r \ln \frac{X}{r}} \text{ if } \frac{X}{r} \gg 4$$

# Estimating Electric Fields



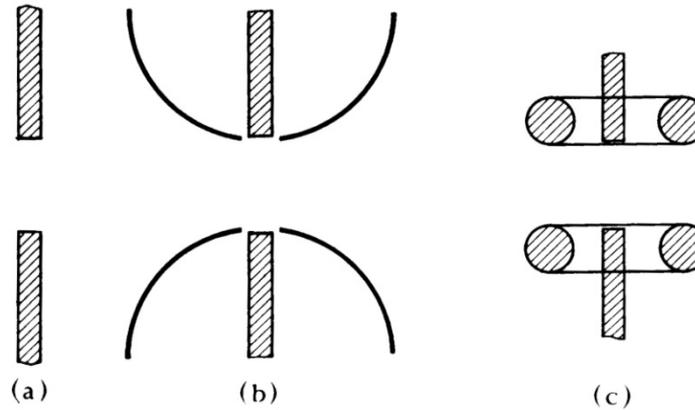
Dependence of the ratio  $f = \frac{\text{maximum stress}}{\text{mean stress}}$  on electrode geometry for concentric cylinders and spheres (calculated from stress table) and for cylinder surrounded by a torus.

# Estimating Electric Fields

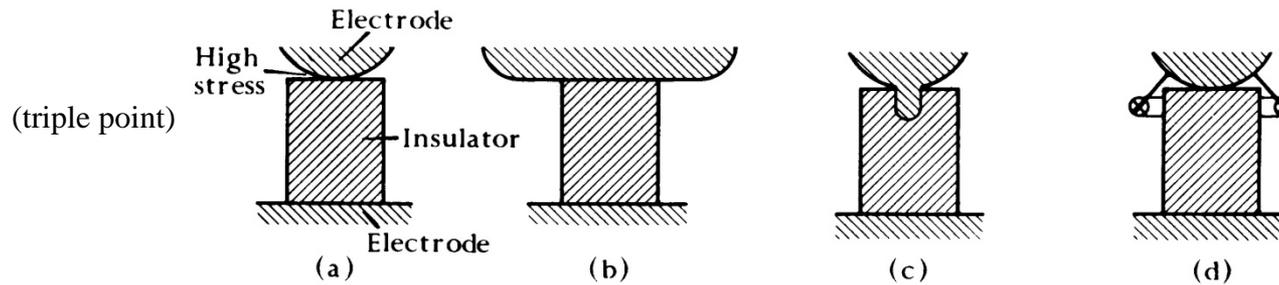


Dependence of the ratio  $f = \frac{\text{maximum stress}}{\text{mean stress}}$  on electrode geometry for separate spheres and separate cylinders (calculated from stress table) and sphere-plane and cylinder-plane assemblies

# Control of High Stress Points



Use of stress shields.



Control of stress at an electrode edge.