# 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

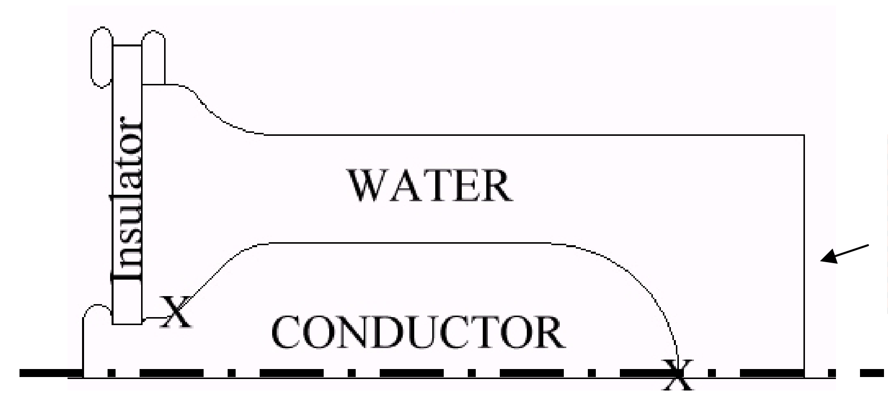
- Differential equations govern many processes of interest to pulsed power engineers.
  - Ex. Heat flow, stress/strain, electric and magnetic field intensities
- Simulations provide a straightforward method to solve these equations for complex geometries and non-linear conditions.
- Some Types of Simulations 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

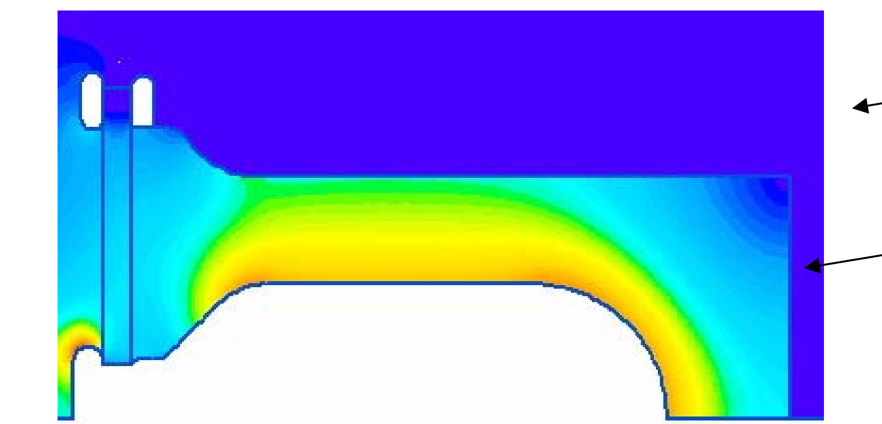
- Electrostatic/Magnetostatic
  - Electro, Maxwell 2D (free)/3D, Quickfield
- Multi-physics
  - ANSYS, ATILA (free)
- Capacitance/Inductance Solvers
  - FastHenry (free), FastCap (free)
- Electromagentic Solver
  - HFSS, Singula
- Particle-in-Cell
  - XOOPIC (free), LSP

# Electric Field Stress

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



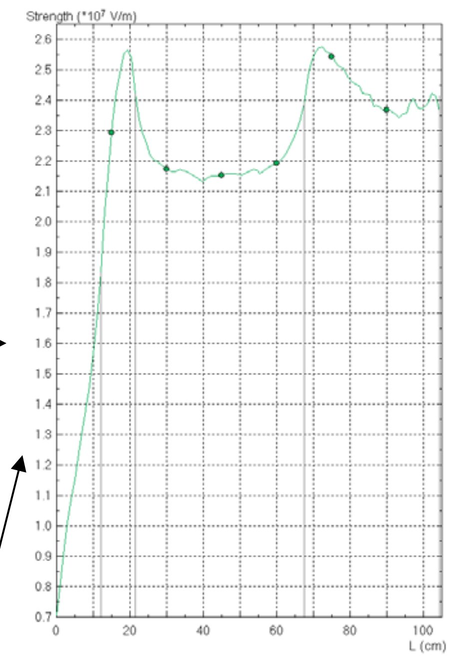

CAD Drawing of Water Capacitor (azimuthally symmetric)



Electric Field Magnitude Plots

Open Space

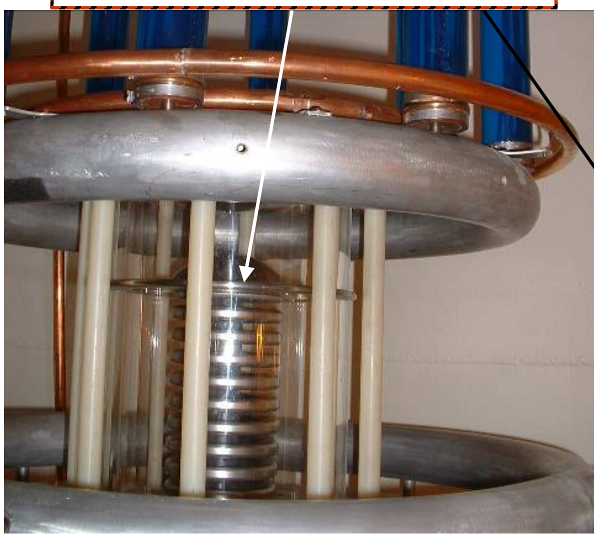
Along a Measurement Line



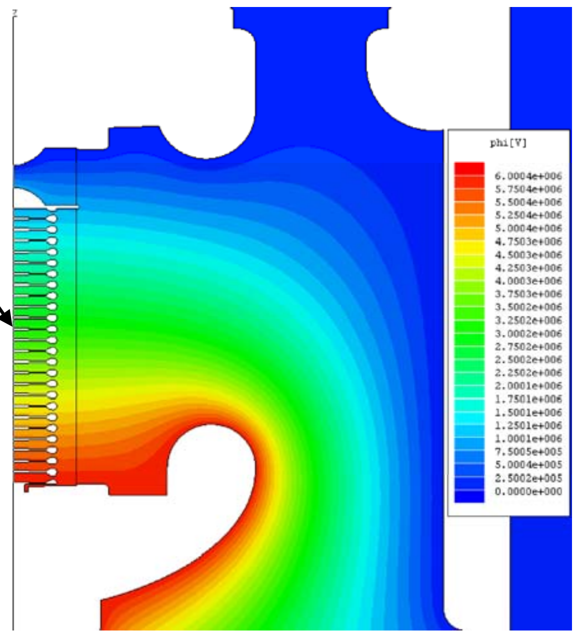
# Electric Field Grading

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

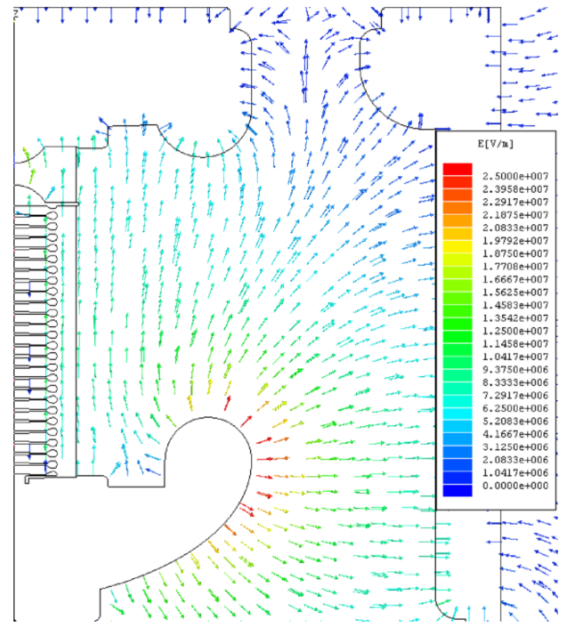
Floating Conductors in a Gas Discharge Switch



Equipotentials

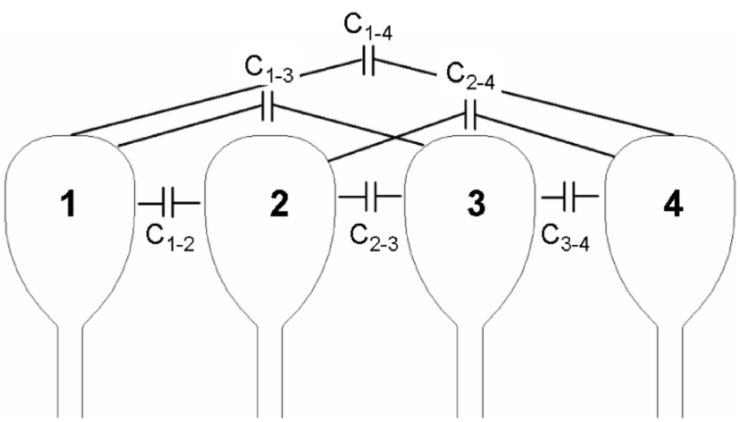


Electric Field Vectors



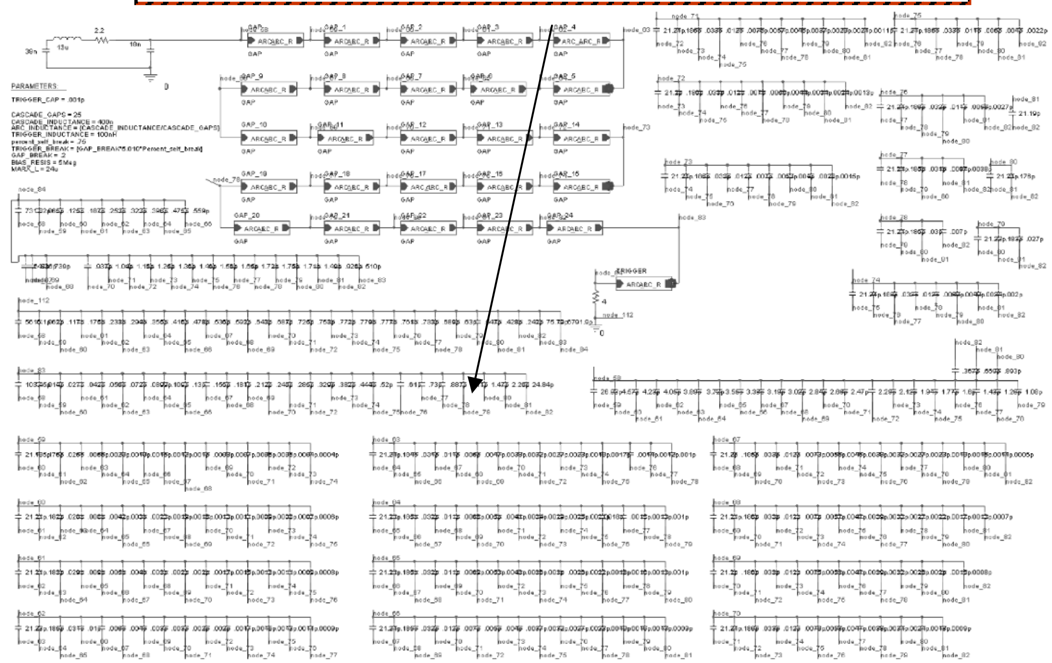
# Capacitance Matrices

- Many electrostatic codes can generate a matrix of capacitance values from element values to each other.
- These values can be exported to circuit codes for transient simulations.

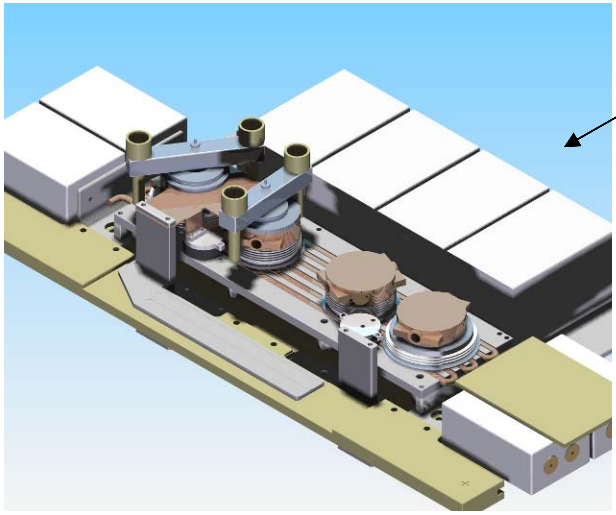



Effective Capacitance Between Isolated conductors

Simulation-Generated Capacitance Matrix



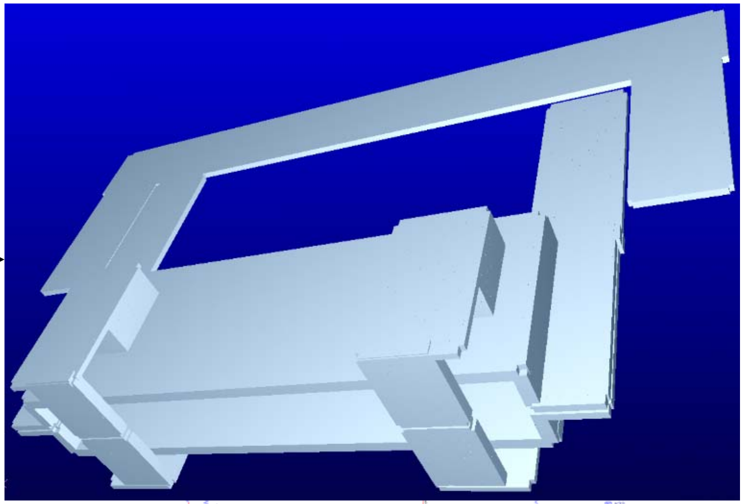
# Inductance Matrices

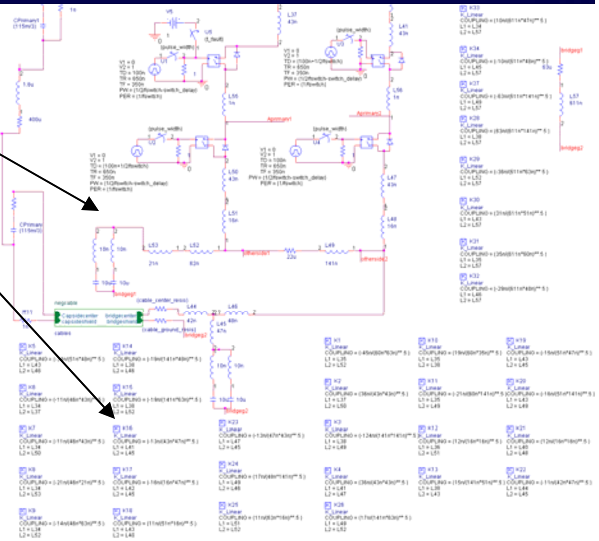


CAD Drawing

Simplified Representation

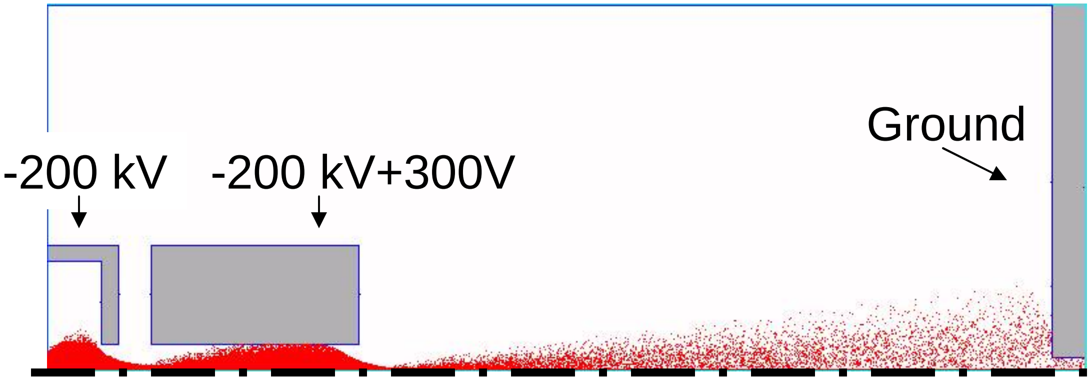
Inductance Matrix

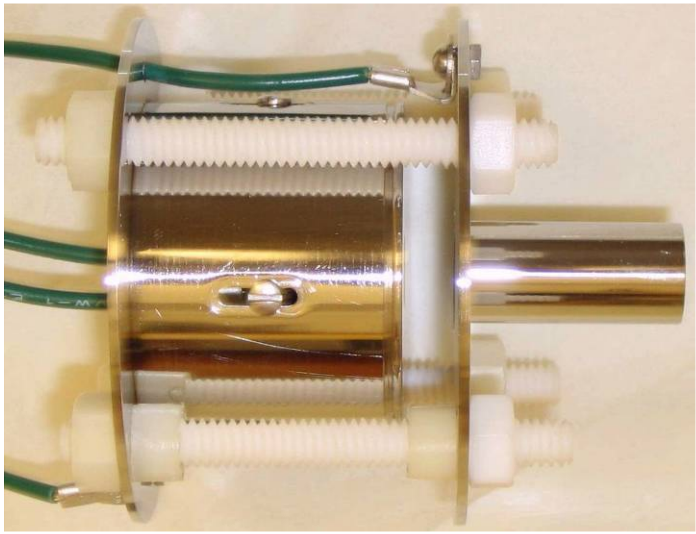




- Simplified representations are in many time necessary and appropriate for simulating complex geometries.
- Self- and mutual- inductance matrices can be generated.

# PIC Cathode Design

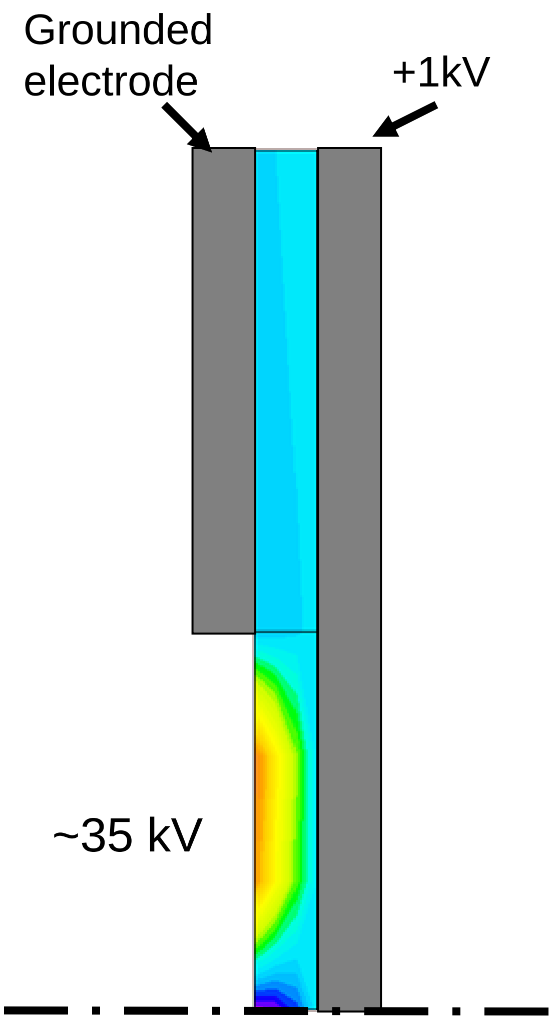


- Some PIC codes can self-consistently model E&M systems.
- Above is a cathode design showing the effect of external fields and self-fields from electrons.

# Multi-Physics Design

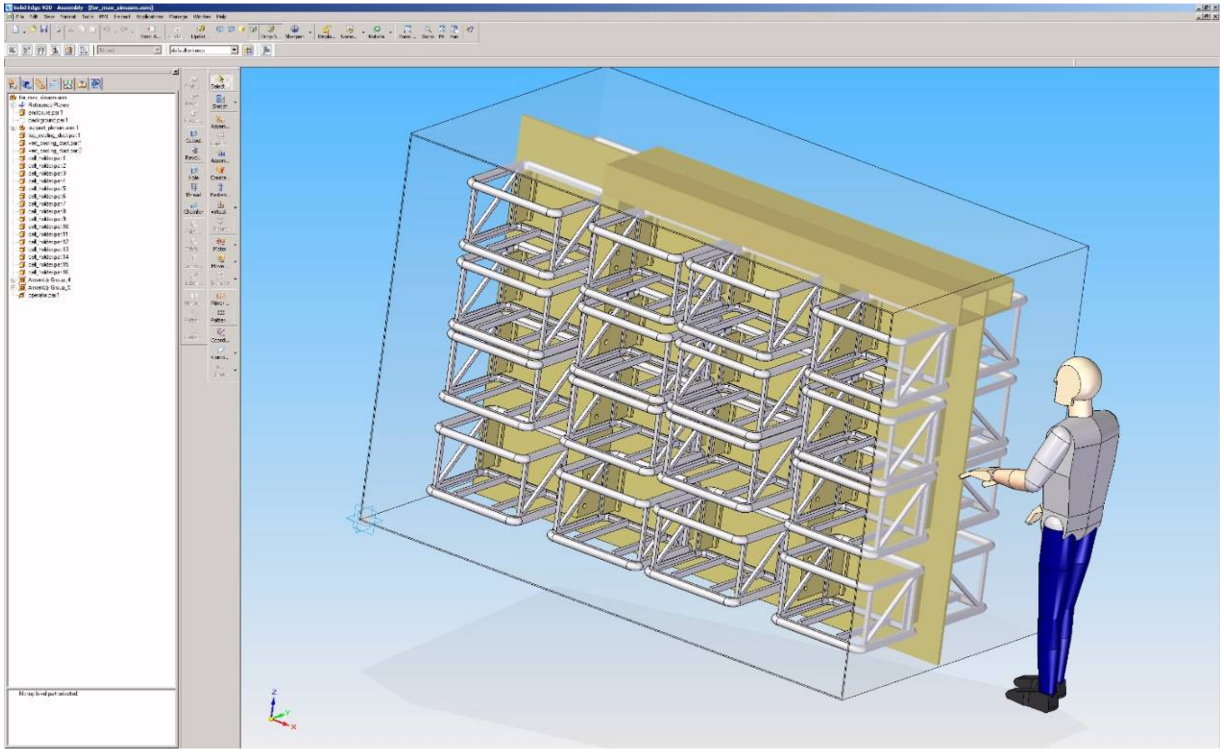
- In some cases, several systems interact. E.g. mechanical, electrical, and thermal.
- For example, left is a simulation of a piezoelectric transformer. Coupled mechanical and electrical systems are simulated.
- ANSYS and ATILA (free) are two codes available.



# Typical Work Flow

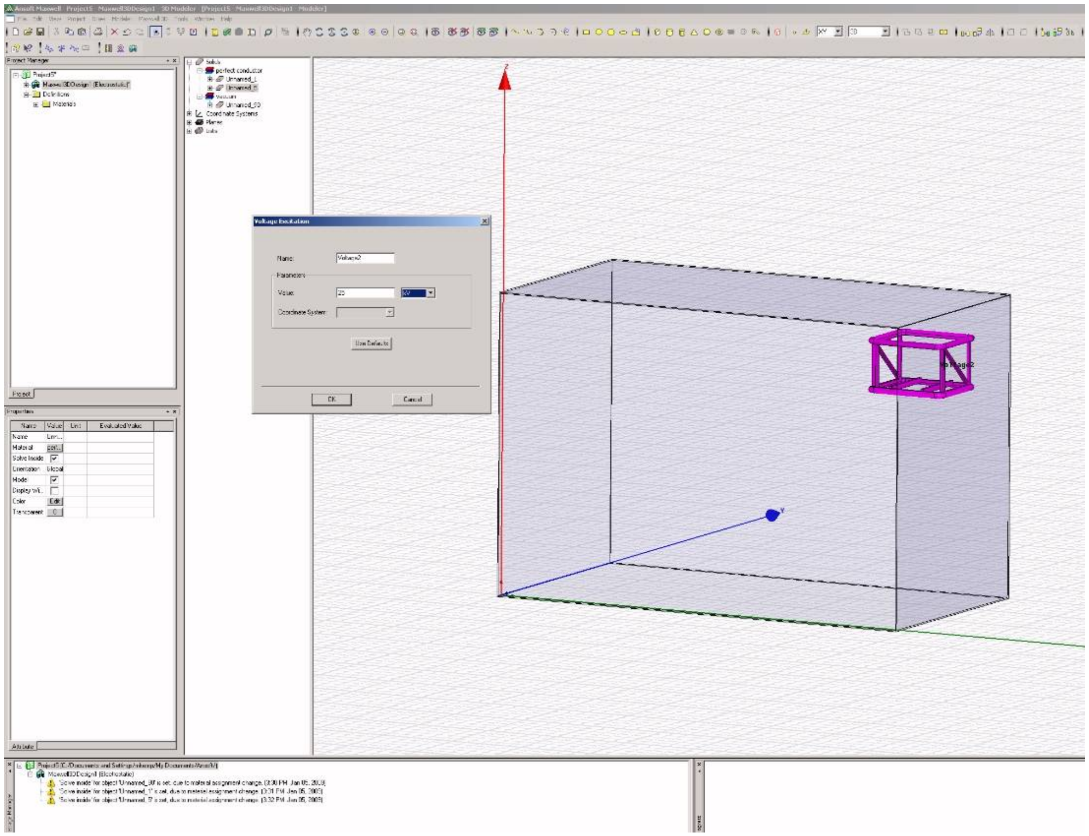
- Create Geometry
  - Through external CAD program
  - Through included CAD program
  - By manually entering text coordinates
- Define Boundaries and Sources
  - Ex. Force on a surface, voltage on a conductor, or charge in a volume.
- Define Solution Type
- Create Mesh
- Simulate
- Post-Process

# Typical Workflow



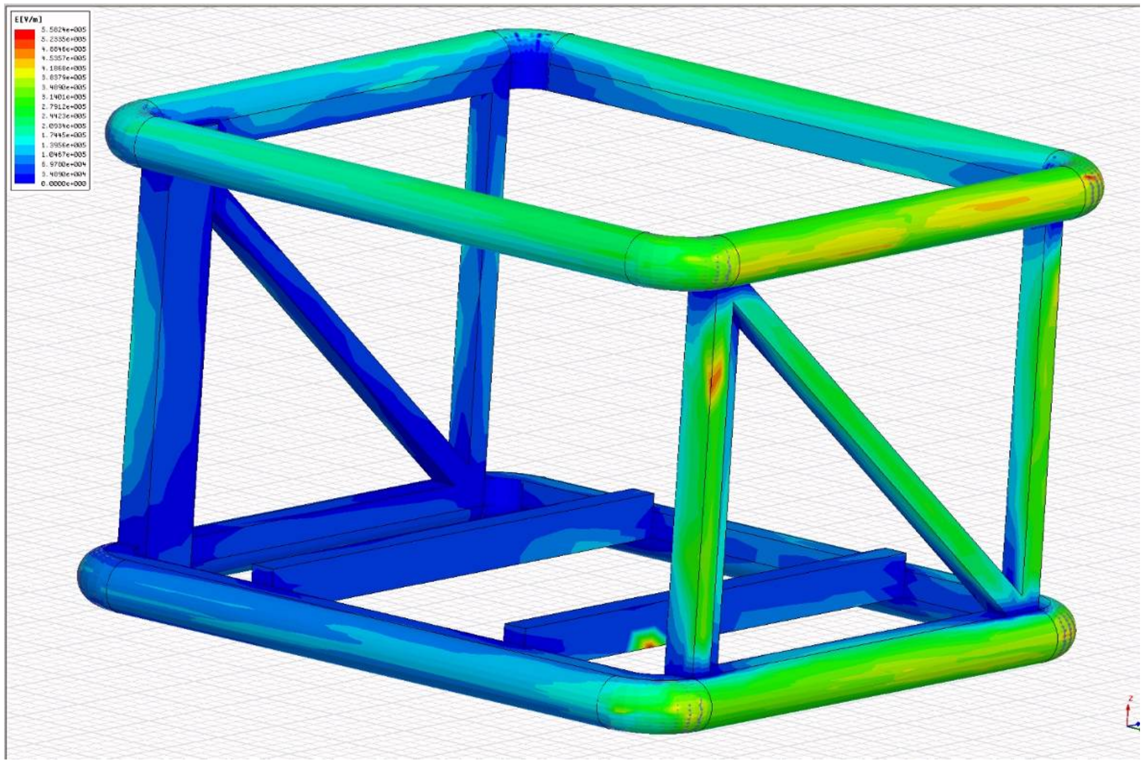
- A complex geometry is created in a CAD program
- Can be 2D or 3D depending on the software and the nature of the problem

# Typical Workflow



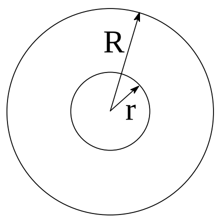
- The specific area of interest is imported to the simulation software.
- Excitations and boundary conditions are set.
- Simulation settings are entered.

# 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

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

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

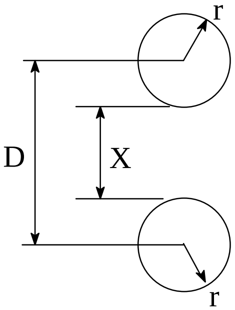
Concentric Cylinders (symbols as for concentric spheres)

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

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

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

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




Equal Spheres

Maximum Stress ($E_M$)

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

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

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

Equal parallel Cylinders (symbols as for equal spheres)

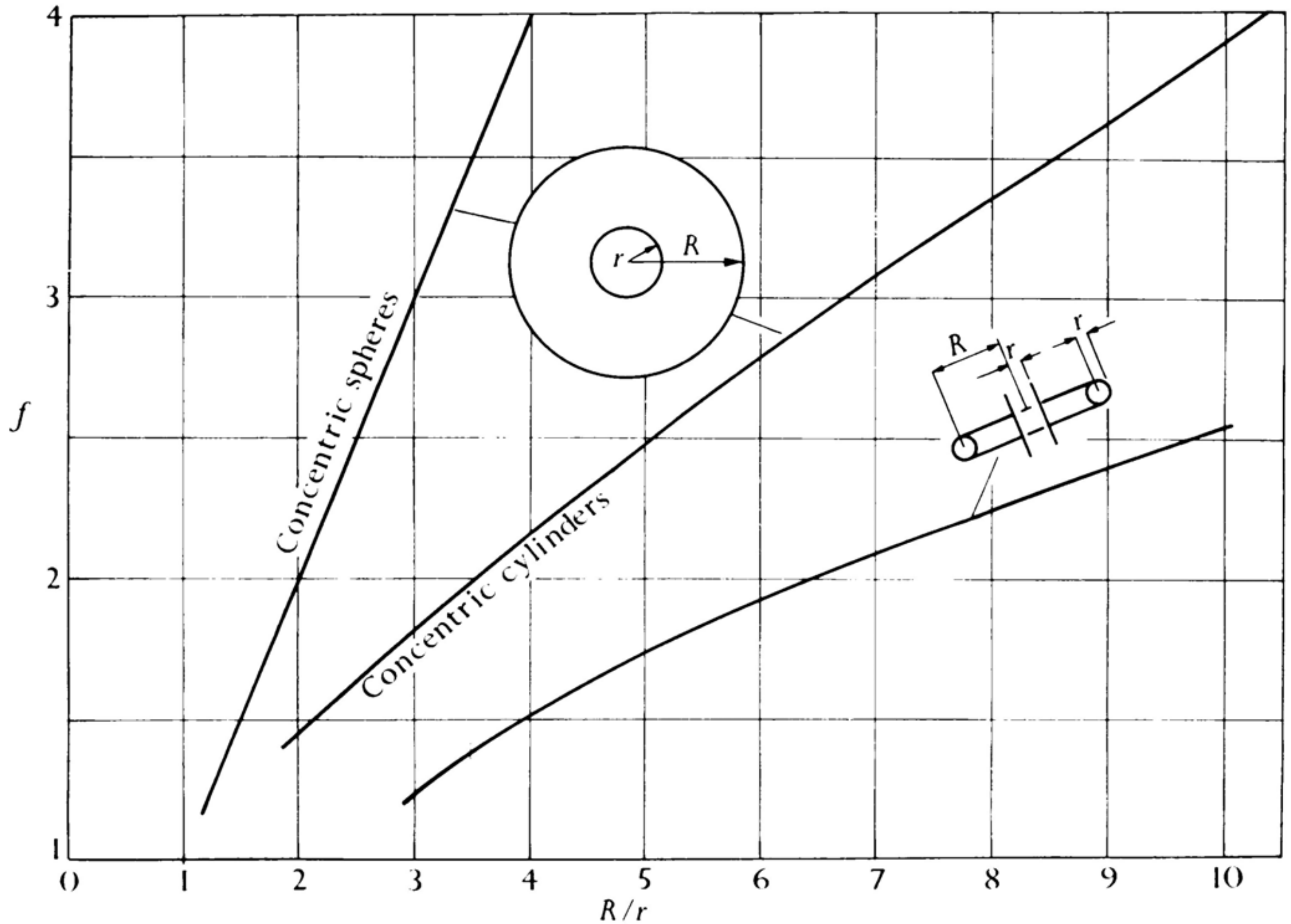
$$E_M = \frac{V\sqrt{(D^2-4r^2)}}{2r(D-2r)\ln\left[\frac{D}{2r}+\sqrt{\left\{\left(\frac{D}{2r}\right)^2-1\right\}}\right]}$$

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

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

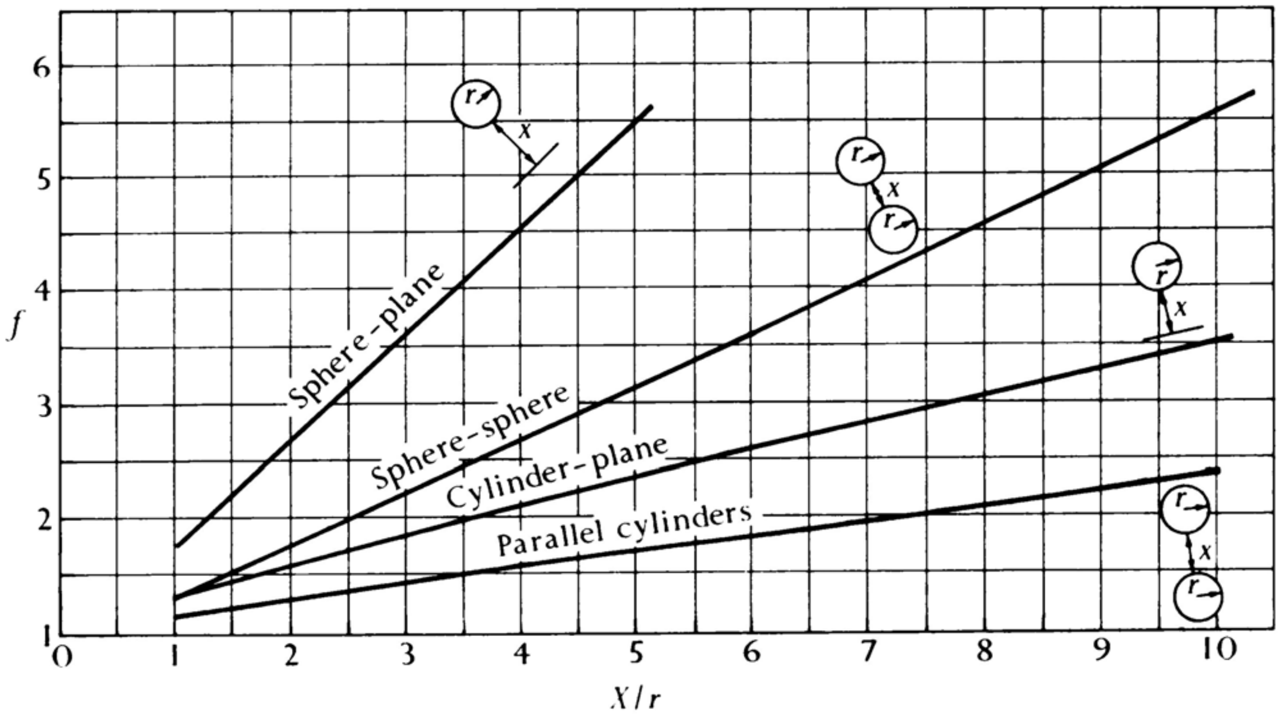
$$f \cong \frac{X}{2r\ln\frac{X}{r}} \quad \text{if } \frac{X}{r} >> 4$$

# Estimating Electric Fields



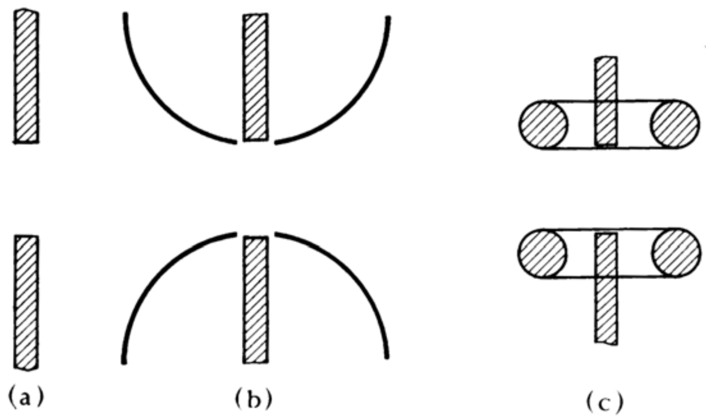

Dependence of the ratio $f = \frac{\text{maximum stress}}{\text{mean stress}}$ on electrode geometry for concentric cylinders and spheres (calculated from stress table) and for cylinder surrounded by a torus.

# Estimating Electric Fields



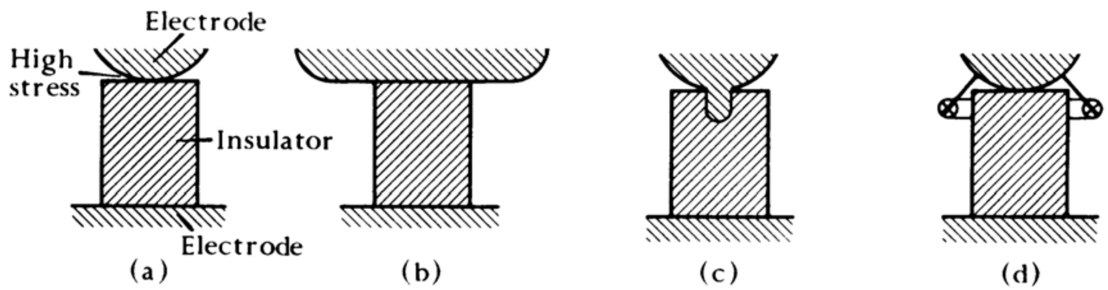

Dependence of the ratio $f = \frac{\text{maximum stress}}{\text{mean stress}}$ on electrode geometry for separate spheres and separate cylinders (calculated from stress table) and sphere-plane and cylinder-plane assemblies

# Control of High Stress Points




Use of stress shields.

(triple point)




Control of stress at an electrode edge.