Hochschule Aachen
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Simulation of electric and magnetic fields using FEMM 4.2 - User handbook and Definition of examples

Bachelor of Science Course
In Electrical Engineering

Bachelor of Science Thesis

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I certify that this work has been carried out and written up entirely by myself.
No literature references and resources other than cited have been used.

Jülich , Germany , June 2011

Acknowledgments

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Contents

0. Introduction

Finite Element Method Magnetics (FEMM) is a finite element package for solving 2-dimensional planar and axisymmetric problems in electrostatics, current flow, heat flow and in low frequency magnetics. It is a very convenient program.

FEMM is divided into three parts:

• **Interactive shell** (`femm.exe`). This program is a Multiple Document Interface pre-processor and a post-processor for the various types of problems solved by FEMM. It contains a CAD like interface for laying out the geometry of the problem to be solved and for defining material properties and boundary conditions. Autocad DXF files can be imported to facilitate the analysis of existing geometries. Field solutions can be displayed in the form of contour and density plots. The program also allows the user to inspect the field at arbitrary points, as well as evaluate a number of different integrals and plot various quantities of interest along user-defined contours.

•**Triangle.exe**. Triangle breaks down the solution region into a large number of triangles, a vital part of the finite element process. This program was written by Jonathan Shewchuk and is available from his Carnegie-Mellon University web page at http://www.cs.cmu.edu/˜quake/triangle.html or from Netlib.

• **Solvers** (fkern.exe for magnetics; belasolv for electrostatics); hsolv for heat flow problems; and csolv for current flow problems. Each solver takes a set of data files that describe problem and solves the relevant partial differential equations to obtain values for the desired field throughout the solution domain.[1]

What I have done in my thesis is showing you how to analyze model using FEMM 4.2. Here I assembled some lists of procedures that you can follow while solving problems

Electrostatics procedures:

1. Create a new file. Choose a type of the problem
2. Set problem definition.
3. Create a model.
4. Add materials to the model.
5. Define conductor properties.
6. Place block labels and associate them with corresponding Materials.
7. Generate mesh and run FEA.
8. Display results.
9. Plot field values.
10. Compare with theoretical values

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1 《Finite Element Method Magnetics: Version 4.2User’s Manual》 David Meeker May 29, 2009

Current flow procedures:

1. Create a new file. Choose a type of the problem
2. Set problem definition.
3. Create a model.
4. Add materials to the model.
5. Define conductor properties.
6. Place block labels and associate them with corresponding Materials.
7. Generate mesh and run FEA.
8. Display results.
9. Plot field values.
10. Compare with theoretical values

Magnetics procedures:

1. Create new file.
2. Set Problem Definition.
3. Draw boundary.
4. Create a new coil
5. Add material properties.
6. Define boundary .
7. Define circuits.
8. Place Block Labels.
9. Associate Properties with Block Labels
10. Associate Properties with boundaries.
11. Generate Mesh and Run FEA.
12. Analysis result.
13. Plot Field Values .
14. Compare with theoretical values

When we have to make a new model, first of all we should decide if we want to make it in planar of axisymmetric. Choose it wisely, because it may save you a lot of time if the model can be made in axisymmetric type.

When we have the plotted field values, we can use them to analyze the property along a contour. A contour is a line or region that we are interested in. Then we can compare it with the theoretical values. If those values match, it means the model we have made is correct. If they didn’t, then we have to look deeper into the model and find out what has gone wrong.

1. Electrostatics

What is Electrostatics?

Electrostatics is the study of time-independent distributions of charges and fields.
It is a branch of science that deals with the phenomena arising from stationary or slow-moving electric charges.Electrostatic phenomena arise from the forces that electric charges exert on each other.[2]
Electrostatics contains some problems like properties analyzing in capacitors and in some containers. No current is involved in Electrostatics.

1.1 Cable 1

Assume we have a perfect concentric copper cable. At inner cable a voltage of 130kV (compare to the ground) is applied. (relative permittivity of copper $\varepsilon_r \approx 1$)

	Layer 1	Layer 2
ε_r	3	2

Table 1-1 Values of the relative permittivity ε_r

We will analyze the curve E=f(r) of this cable and draw a plot of E=f(r).

1.1.1 Create a new file.

"File"→"New"→ "Electrostatics Problem"

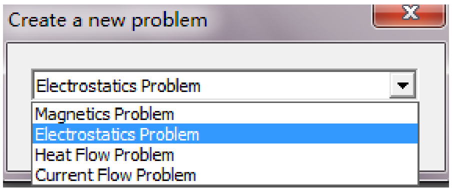


Figure 1-1 Create a new problem dialogue box

1.1.2 Set problem definition.

Press Menu: "Problem".

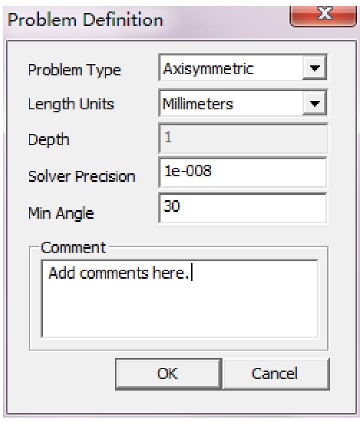
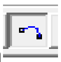
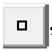
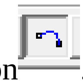


Figure 1-2 Problem definition dialogue box

[2] 《*Electrostatics: Theory and Applications*》 *by Camille L. Bertrand*

Problem Type: Axisymmetric
Length Unit: Centimeters
Frequency, Hz: 60
Depth: 1
Solver Precision: 1e-008
Min Angle: 30

1.1.3 Create a model

Draw three quarters of circle using function “Operate on arc Segments”. First we should mark some nodes using ”Operate on nodes”, then we switch to function. Select 2 nodes one by another to draw an arc segments in between.

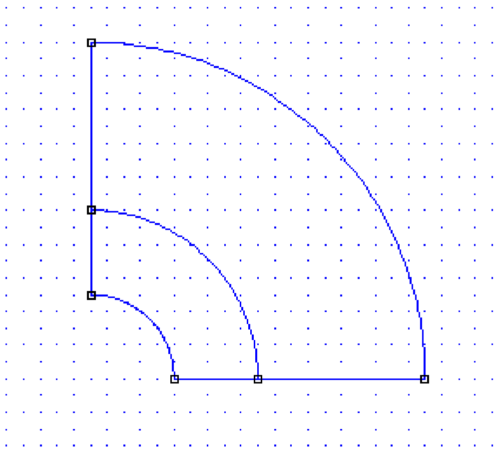
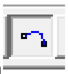
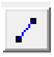


Figure 1-3 New model

Properties of the circles are shown in the picture. We can check this information by right clicking on the arc segment under the function. And we can also do the same thing under  function to check the information of a drawn linear segment.

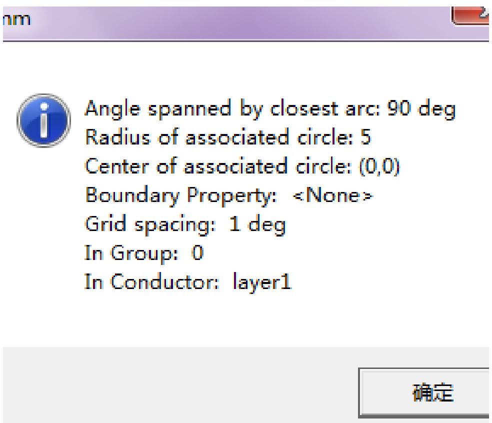


Figure 1-4 Linear property

1.1.4 Add materials to the model

Set up the information of material (schicht1, schicht2, inner, air) and conductor (layer1, layer2, gnd), using the functions under menu “Properties”.

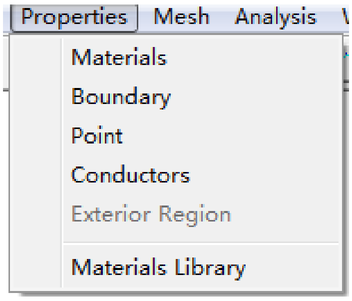


Figure 1-5 Properties menu

The voltage on each layer must be calculated first.

Cylinder- capacitor	$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\frac{ra}{ri}}$	$E(r) = \frac{Q}{2\pi r l \varepsilon_0 \varepsilon_r}$

Table 1-2 Formula

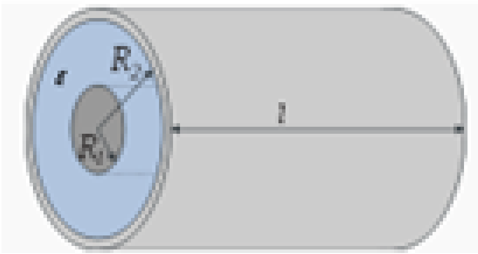


Figure 1-6Cylinder capacitor[3]

$$C' = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\frac{ra}{ri}}$$

→C’1/C’2=3/2

→U1/U2=C’2/C’1=2/3

Uges=U1+U2=130kV

→U1=52kV U2=78kV

Equation 1

If we want to define the voltages, click on “Conductors” and then fill in the names and values. Here we have the values of voltage, so we fill the blank under “Prescribed Voltage”. Otherwise we can fill the “Total Charge, C” if we have the value in unit Column. Voltage on Layer 1 is the total voltage (130kV) from center of cable to the ground.

[3] *http://upload.wikimedia.org/wikipedia/commons/b/b8/Cylindrical_CapacitorII.svg*

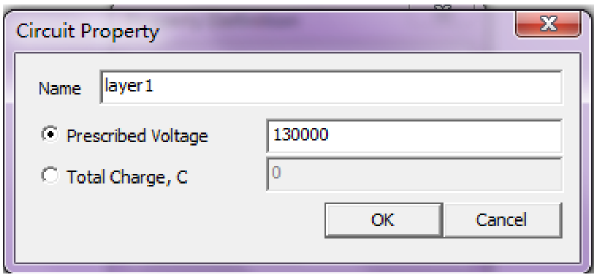


Figure 1-7 Voltage on layer 1

Ground

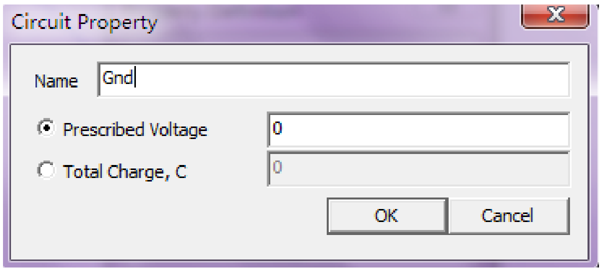


Figure 1-8 Ground

Select an arc segment, press Space button and then in the column "in conductor", we can choose which conductor it should be in. As shown below.

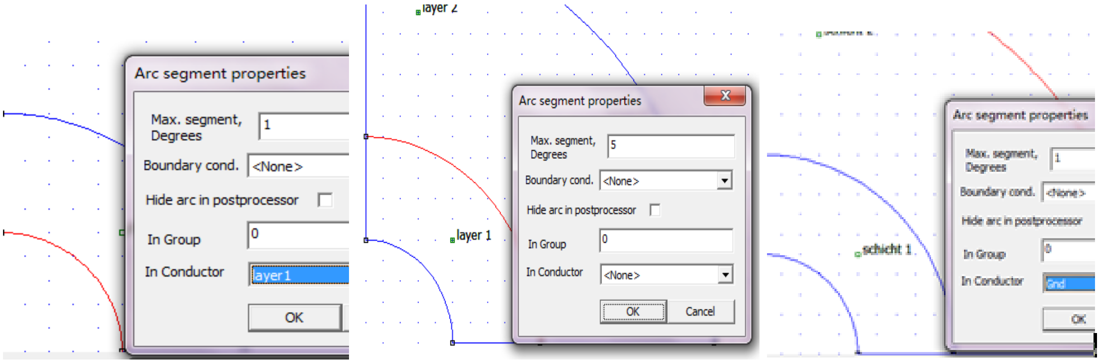


Figure 1-9 Layer 1, 2, 3

1.1.5 Define conductor properties

The properties of material are already given, Ɛr of material in 'schicht1' is 3; Ɛr of material in 'schicht2'is 2. We use "Properties"→"Materials" to define them.

Here we give both Ɛx and Ɛy the same number. In this way, Ɛr will be determined as the value we need.

εr =3 for schicht1

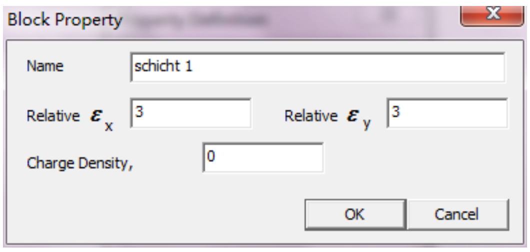


Figure 1-10Property of material 1

εr=2 for schicht2

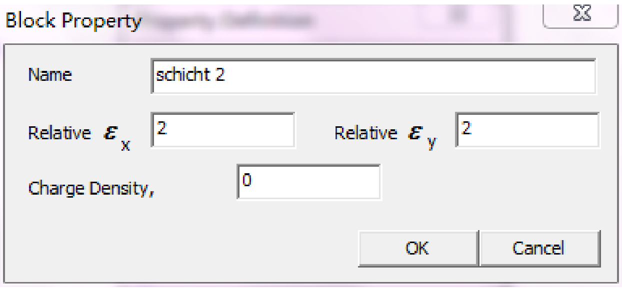


Figure 1-11Property of material 2

1.1.6 Place block labels and associate them with corresponding Materials

Set the inner block as 'schicht1', the outer block as 'schicht2', using function "Operate on block labels". Left click on a closed area to mark the label, then right click on the label and press Space button to call the menu.

Under "Block type", we can mark the block as any materials that we have set before. This means we will build this layer with this material. Uncheck "Let Triangle choose Mesh Size" and make size to 0.1 so that the result is fine enough.

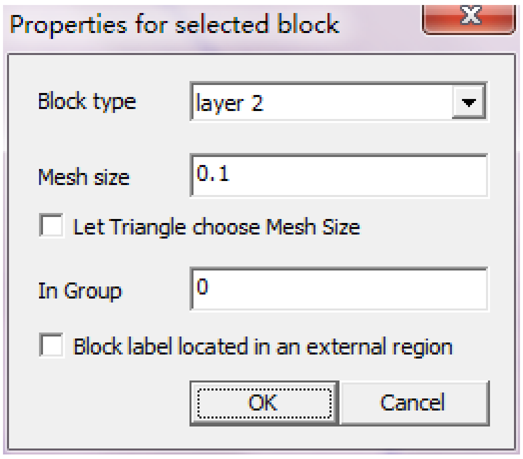


Figure 1-12 Properties for selected block dialogue box

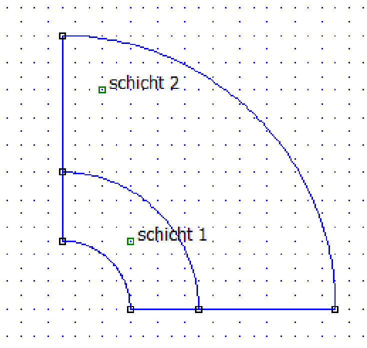


Figure 1-13 Final model

1.1.7 Generate mesh and run FEA

Run the analysis, first press “Run mesh generator”, then you can see the meshes it created. If you forgot to label a block, the area will be gray, so that you should label that area.

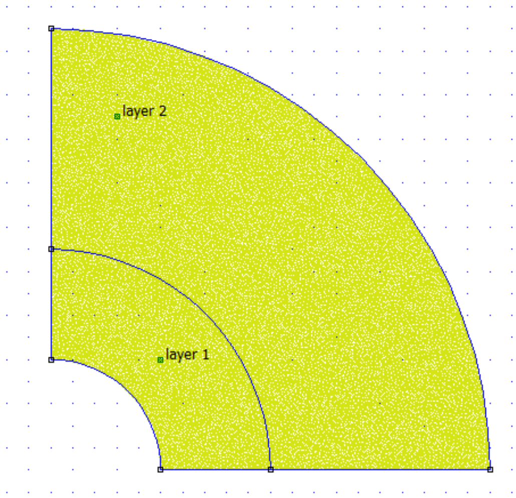


Figure 1-14 Mesh

1.1.8 Display results

Press”Run analysis”, after few seconds when it’s done, click the button”View Result” and the result is shown here.

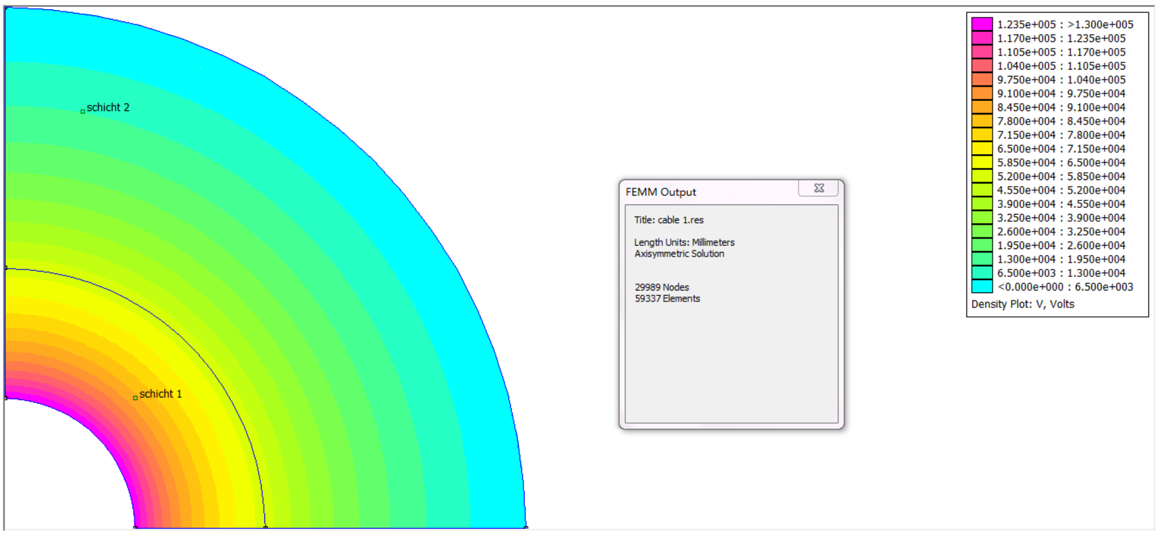
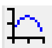


Figure 1-15 Result

The result is the density plot of a concentric cable.

1.1.9 Plot field values

Here we can draw any plots we need to use the function ”X-Y plot of field values”. Under plot type, we can select the ones we need. And we can set the number of points in plot, so it will calculate more points if we need. In this case, we make the number 1000.

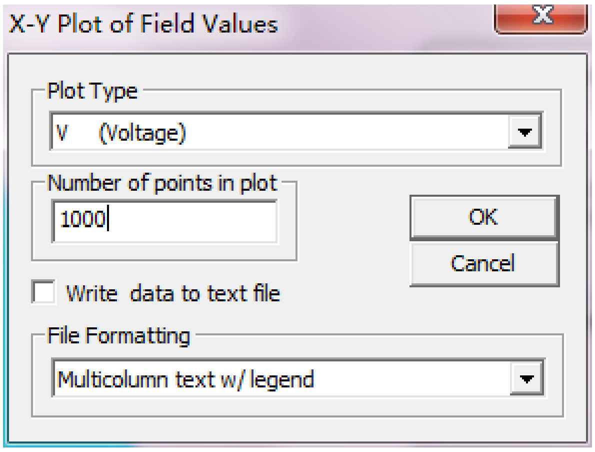
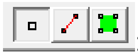
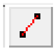


Figure 1-16 X-Y plot of field Values dialogue box

But before that, we need to select a contour to decide which part of the object which we are interested in.

Switch to Contour mode by pressing the Contour Mode toolbar button. Now we can define a contour along which the properties will be plotted. There are three methods to add points or areas to a contour :

1. Left Mouse Button Click adds the nearest input node to the contour;
2. Right Mouse Button Click adds the current mouse pointer position to the contour;
3. <TAB> Key displays a point entry dialog that allows you to enter in the coordinates of a point to be added to the contour.

Here we need the plot along a radius. So we press  and right click on (0,0) and (14.1, 14.1) to draw two points, making up a segment as following. The contour is a vector so we have to decide its direction as well. If we left click on the graph, then the program will automatically choose the nearest node as the point.

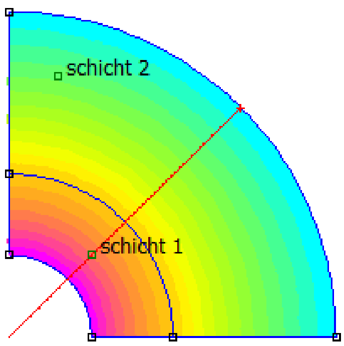


Figure 1-17 Contour

Now we can draw the plot we need to analyze the properties along the contour. We need E,t plot (tangential electrical field intensity) here.

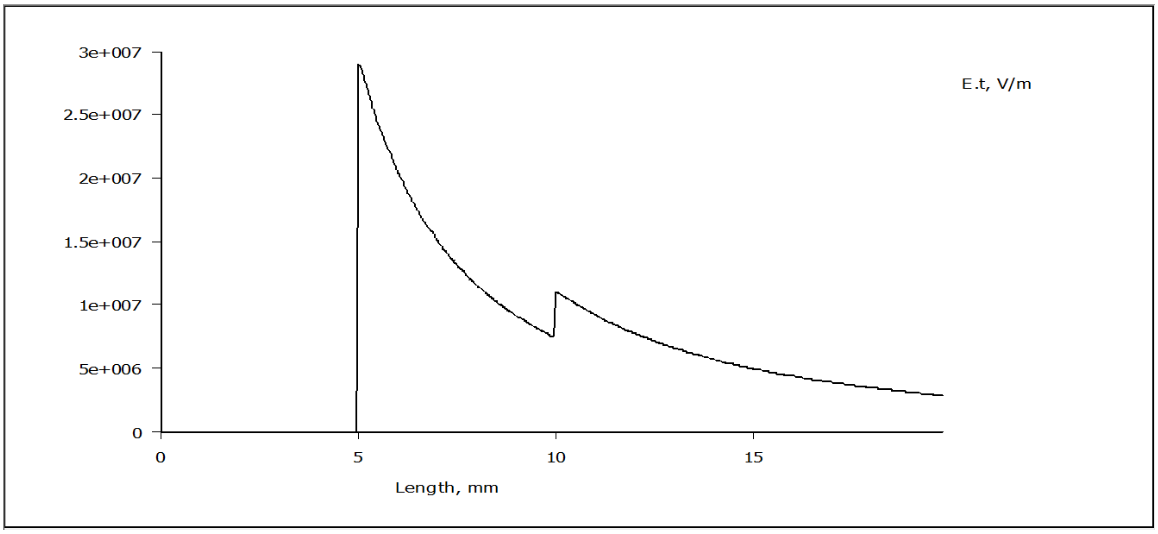


Figure 1-18E,t plot

And this plot can be used to analyze the component.
If we don't change the number of points, the default value will be 150.

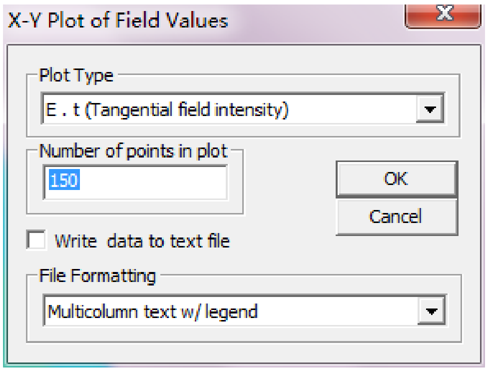


Figure 1-19 Change number of points in plot

This is the plot when the number is 150, which is rougher than the plot above.

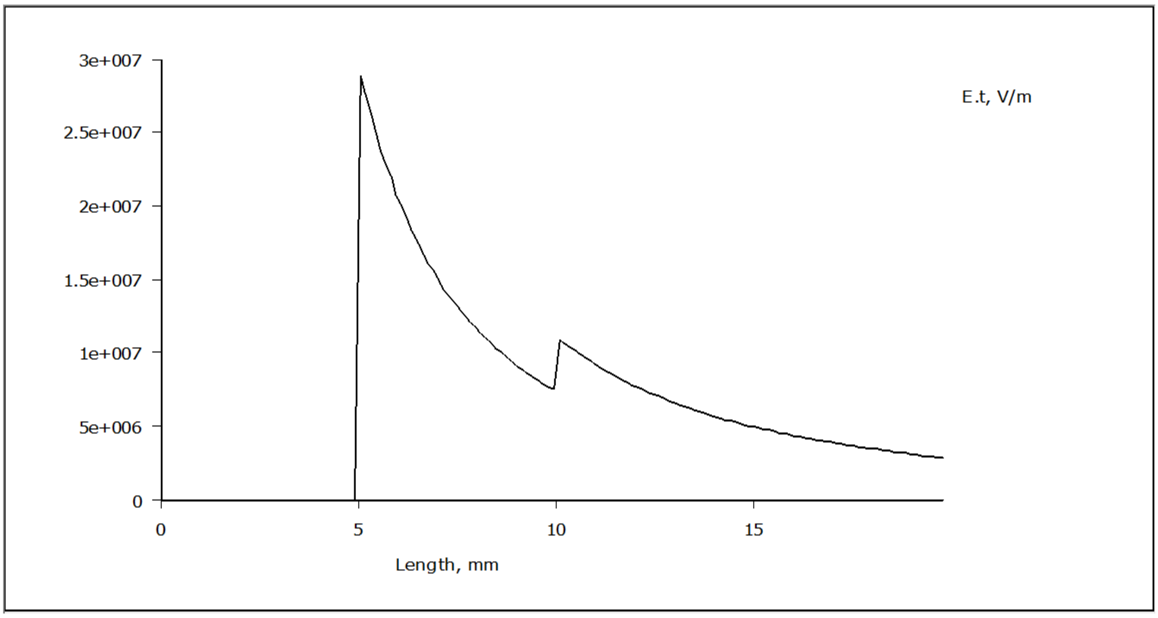


Figure 1-20E,t plot with 600 points in it

1.1.10 Compare with theoretical values

Since we have already calculated the voltage on each layer, we can use the result plot to check our work.
Click on menu "View"→ "Point Props" to view the detail information of points. Click on the point that you are interested in and you will get the detail information of it.

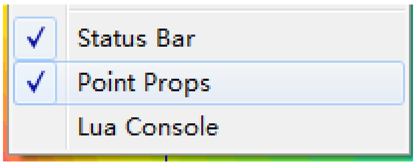


Figure 1-21 Point Props

As is shown here, we picked the point (0, 10), and its info is in figure 1-22

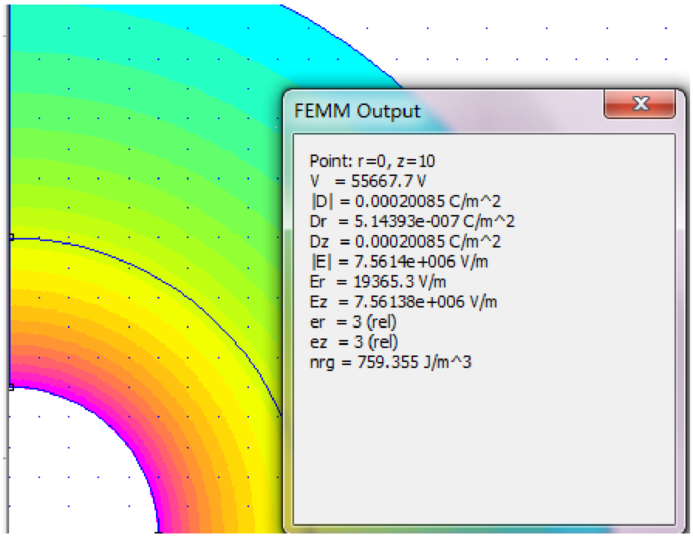


Figure 1-22 Point info

As we calculated before, the voltage on this layer should be 52kV, and here we get 55.6kV, a little bit higher than the theoretical value. But the difference is acceptable, so it is correct.

1.2 Cable 2

Assume we have a non-concentric copper cable. The inner cable is 3mm aside from the center. At the inner cable a voltage of 130kV (compare to the ground) is applied. (relative permittivity of copper $\varepsilon_r \approx 1$)

	Layer 1	Layer 2
ε_r	10	1

Table 1-3 Values of the relative permittivity ε_r

We will analyze the curve of E=f(r) of this cable and draw a plot of it.

1.2.1 Create a new file.

"File"→"New"→ "Electrostatics Problem"

1.2.2 Set problem definition.

Press Menu: “Problem”.

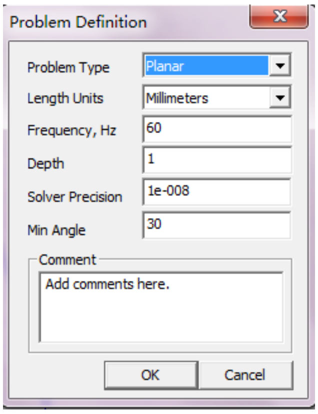
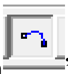
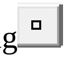
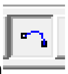


Figure 1-23 Problem definition dialogue box

1.2.3 Create a new model

To draw a set of non-concentric circles, first we need to have three concentric circles using function ”Operate on arc Segments”. First we should mark some nodes using  “Operate on nodes”, then we switch to function . Select 2 nodes one by another to draw an arc segments in between, and then we will have half of the circle. Now we need the other half so we select these 2 nodes again but this time change the selection order. In this way, we will be able to make all three circles.

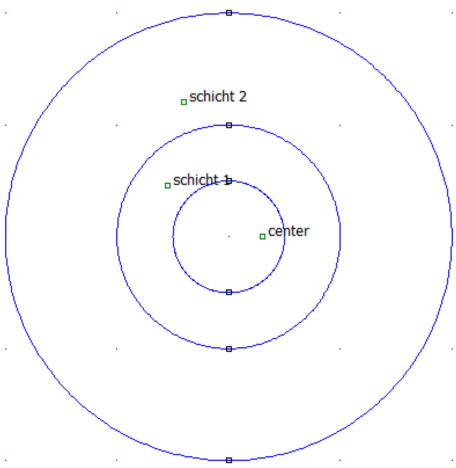
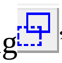
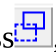


Figure 1-24 New model step 1

Our model is a non-concentric cable, so we shift the inner circle, using ”Move/Remote the selected Object”. First switch to  function and select the inner circle. Press , shift it along X-axis for 3 units.

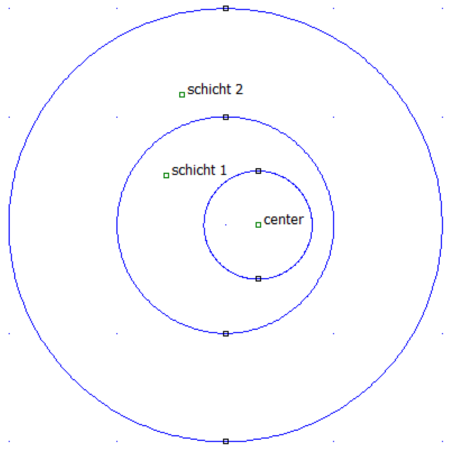


Figure 1-25 New model step 2

1.2.4 Add materials to the model

Set up the information of material (schicht1, schicht2, center, air) and conductor (layer1, layer2, gnd), using the functions under menu "Properties".

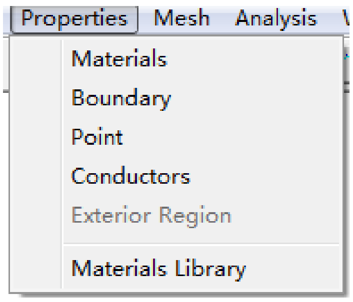


Figure 1-26 Properties menu

But set the middle circle to "In conduct: None", we regard it as a non-material layer.

Cylinder- capacitor	$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\frac{ra}{ri}}$	$E(r) = \frac{Q}{2\pi r l \varepsilon_0\varepsilon_r}$

Table 1-4 Formula

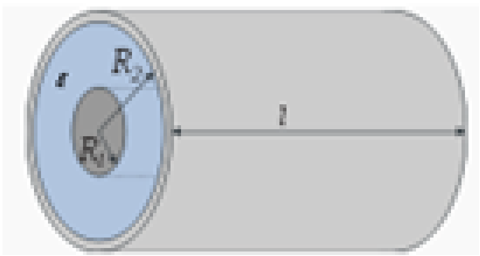


Figure 1-27 Cylinder capacitor[4]

1.2.5 Define conductor and material properties

The voltage on each layer can be calculated first. If the cable is symmetric:

[4] *http://upload.wikimedia.org/wikipedia/commons/b/b8/Cylindrical_CapacitorII.svg*

$$C' = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\frac{ra}{ri}}$$

→C'1/C'2=10/1

→U1/U2=C'2/C'1=1/10

Uges=U1+U2=130kV

→U1=11.82kV U2=118.18kV

Equation 2

But here we have a non-symmetric cable, so the values we calculated can only be used as references

.

If we want to define the voltages, click on "Conductors" and then fill in the names and values. Here we have the values of voltage, so we fill the blank under "Prescribed Voltage". Otherwise we can fill the "Total Charge, C" if we have the value in unit Colum.
Voltage on Layer 1 is the total voltage (130kV) from center of cable to the ground.

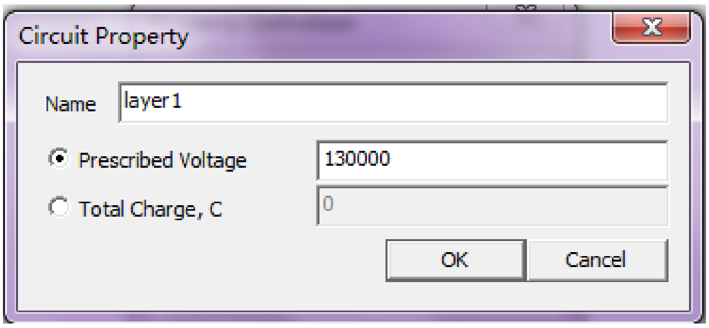


Figure 1-28 Voltage on layer 1

Ground

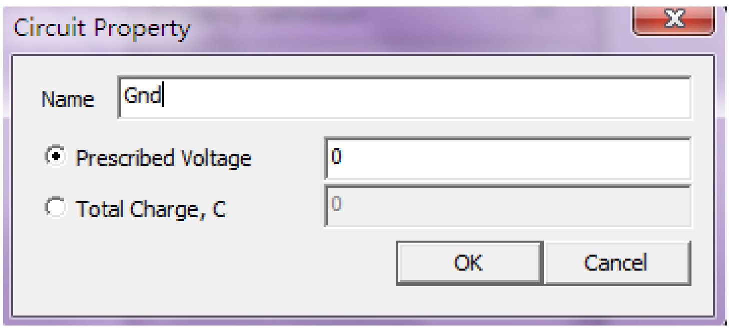


Figure 1-29 Ground

Select an arc segment, hit space bar and then in the column "in conductor", we can choose which conductor it should be in. As shown below.
But set the middle circle to "In conduct: None", we regard it as a non-material layer.

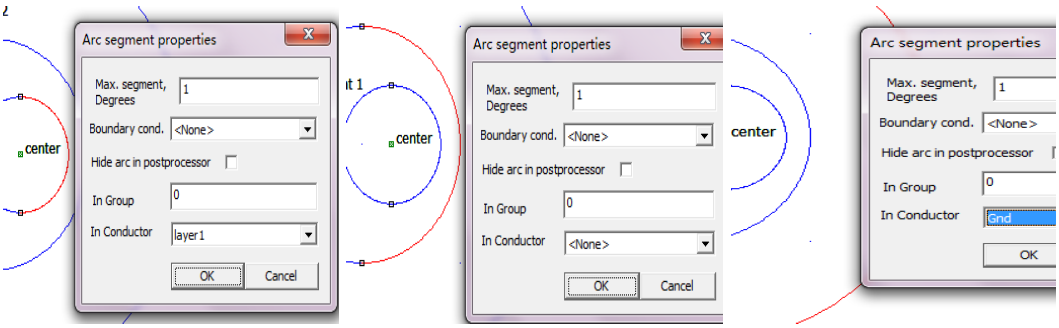


Figure 1-30 Layer 1 None Gnd

The properties of material are already given, Ɛr of material in ‘schicht1’ is 10; Ɛr of material in ‘schicht2’is 1. We use “Properties”→“Materials” to define them.

Here we give both Ɛx and Ɛy the same number. In this way, Ɛr will be determined as the value we need.

Ɛr = 10 for schicht1

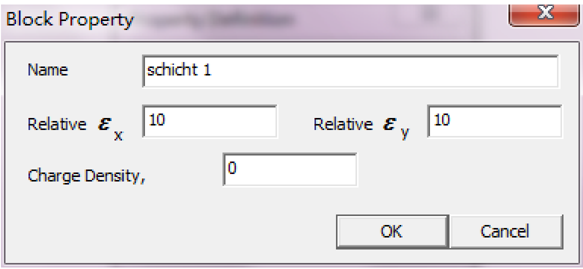


Figure 1-31Property of material 1

Ɛr= 1 for schicht2

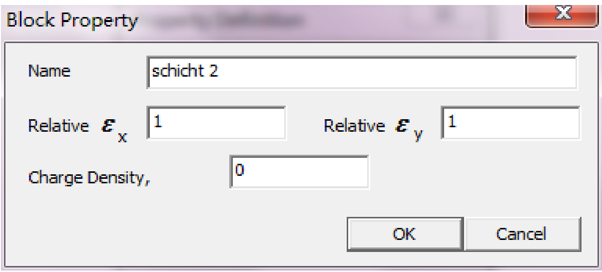


Figure 1-32Property of material 2

And also set the properties of “center” which is made by copper, whose relative permittivity is 1. We must set all the properties of all blocks so that the program can begin analysing.

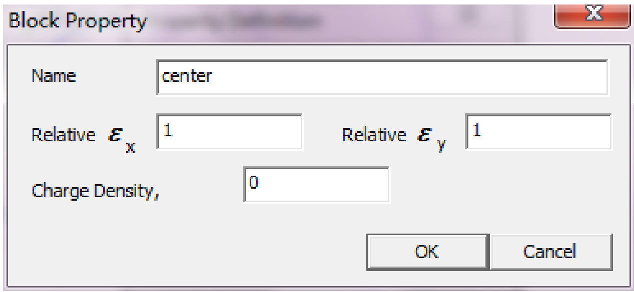


Figure 1-33Property of material 3

1.2.6 Define conductor and material properties

Set the center block as “center”, inner block as ‘schicht1’, the outer block as ‘schicht2’, using function “Operate on block labels”. Left click on a closed area to mark the label, then right click on the label and press Space button to call the menu.

Under “Block type”, we can mark the block as any materials that we have set before. This means we will build a layer with this material.

And here we also uncheck the option and set the mesh size to 0.1.

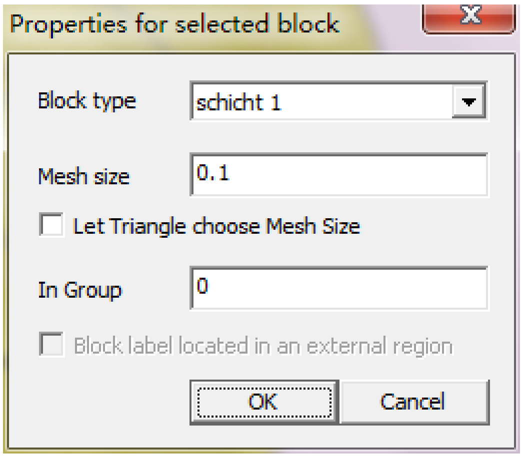


Figure 1-34 Properties for selected block dialogue box

1.2.7 Generate mesh and run FEA

Run the analysis, first press “Run mesh generator”, then you can see the meshes it created. If you forgot to label a block, the area will be gray, so that you should label that area.

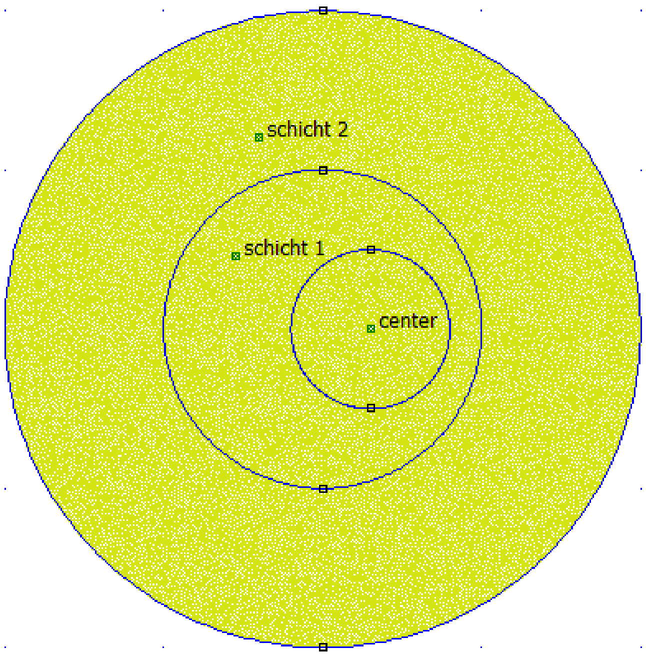


Figure 1-35 Mesh

1.2.8 Display results

The density plot of a cable, which is not perfectly concentric, is shown here.

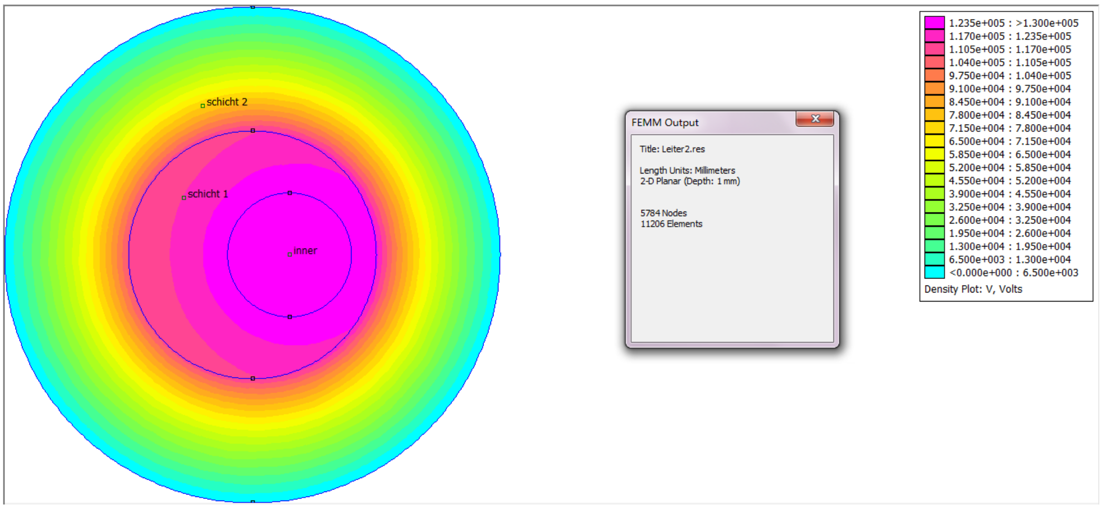


Figure 1-36 Result

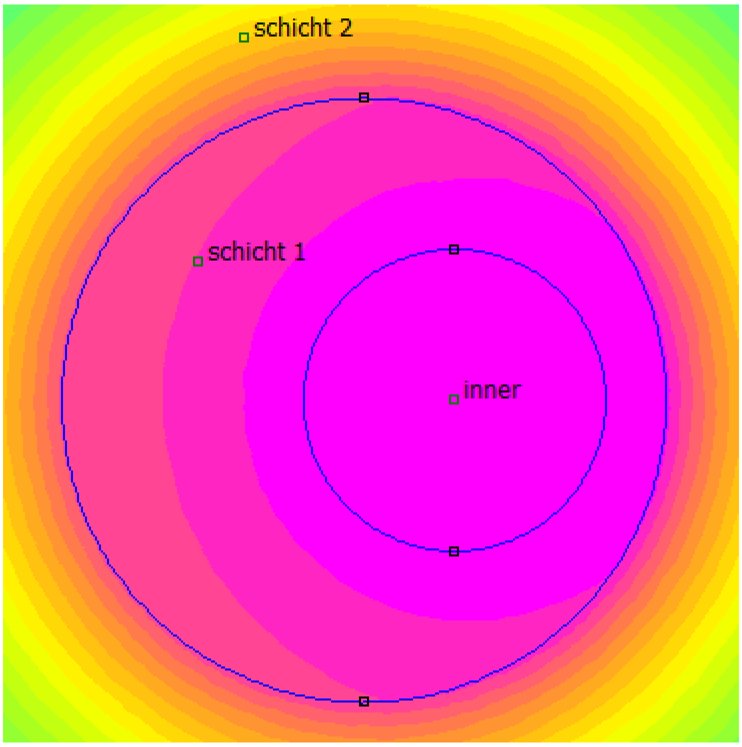


Figure 1-37 Result (zoom)

From this picture we can clearly see the obvious differences between this cable and a concentric cable like ‘Cable 1’.

1.2.9 Plot field values

The contour is a **vector**, so we have to decide its direction as well. Choose the contour starts from (3, 0), ends in (20,0), as following.

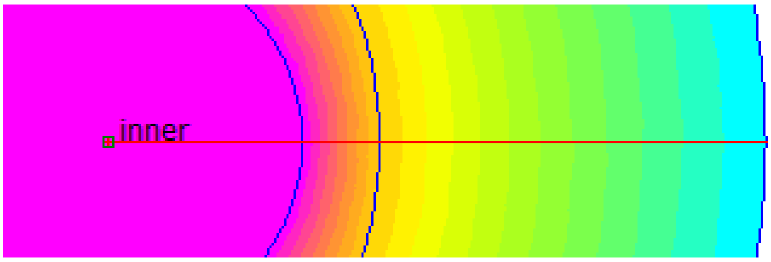


Figure 1-38 Contour

Then select E, t plot with number of points 1000 in it.

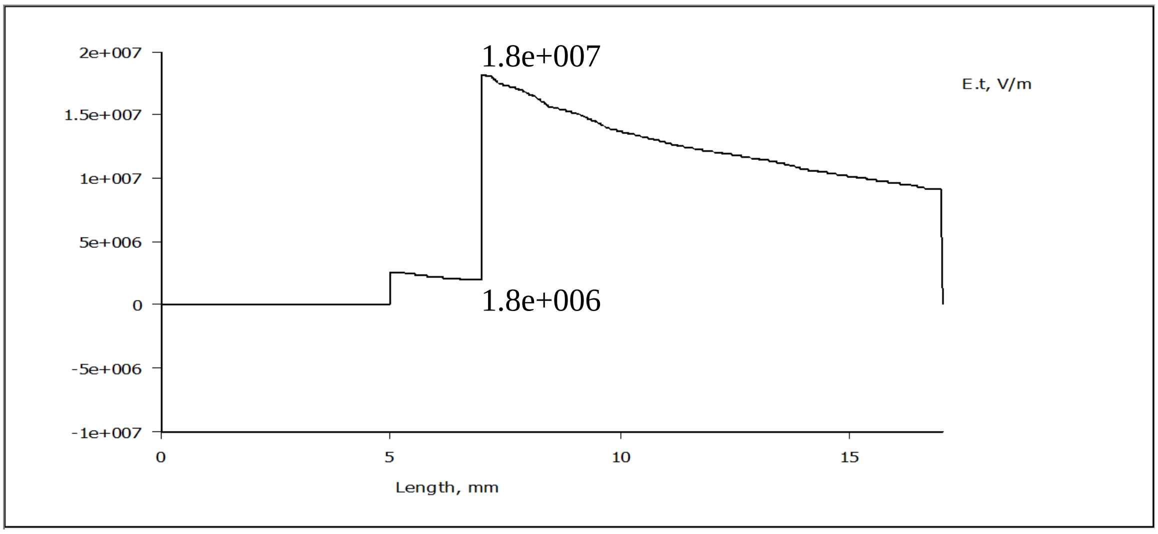


Figure 1-39 E,t plot

1.2.10 Compare with the theoretical values

The theoretical values we calculated before were for a concentric cable.Here we have a non-concentric cable. Although our cable is not symmetric, but the voltage differences are caused by the distance difference between center and layers. So if we add the voltages on two points along a diameter together, the result should be equal to the sum of the voltages on the same two points when they are in a concentric cable.

So we have to check two points, which are (10, 0) and (-10, 0).

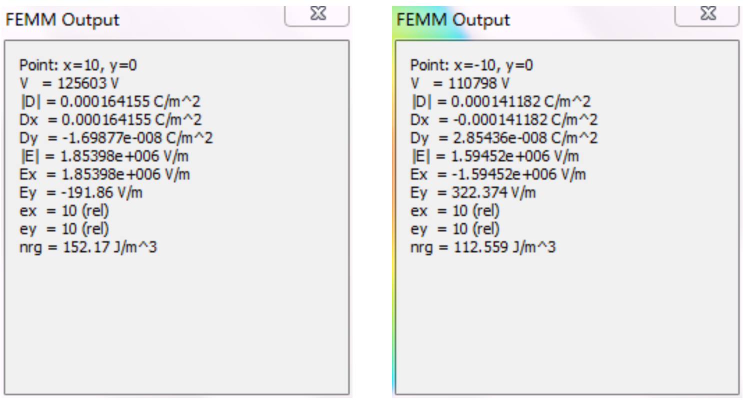


Figure 1-40 Voltages on two points U’1 and U’2

U’1+ U’2= 125603V+ 110798V= 236.401kV

2* U1= 236.36 kV

So the theoretical value equals the practical value. This means our model is correct.

1.3 Capacitor- Plate

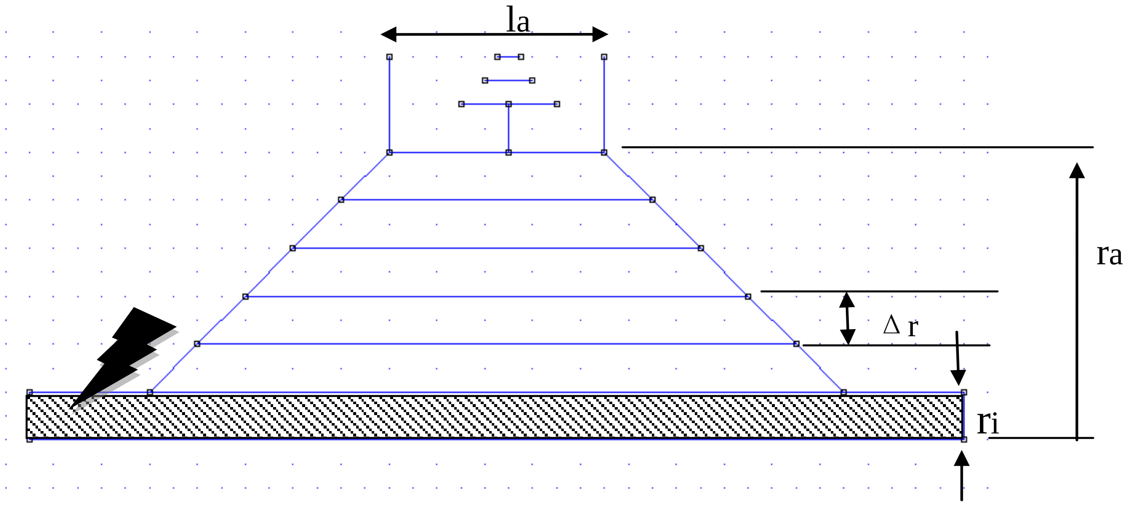


Figure 1-41 Ue8-1

Inner cable 2*ri=10 mm   Flange (Flansch) diameter 2*ra=100 mm

Flange length la=100 mm Ed=20 MV/m

The total voltage applied is 115 kV (compare to the ground).

If Δr= const. The lengths of metal pads are l1… l4. If the model is treated as a homogenous field (Plate capacitor) with an isodynamic voltage divide.
We will draw the field profile E=(r).

1.3.1 Create a new file.

"File"→"New"→ "Electrostatics Problem"

1.3.2 Set problem definition

Menu "Problem"

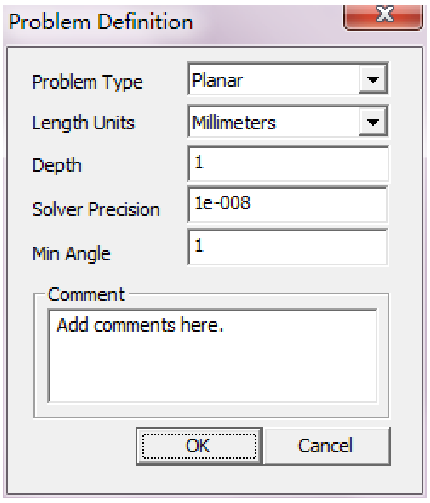


Figure 1-42 Problem definition dialogue box

1.3.3 Create a new model

We treat the model as a homogenous field so it should be a Plate capacitor.

1.3.4 Define conductor and material properties

First of all, we must calculate the values of Rx and Lx.

	I	1	2	3	4	5
Rx	5	14	23	32	41	50
Lx	/	519	250	166	125	100

Table 1-5 Calculated values of Rx and Lx

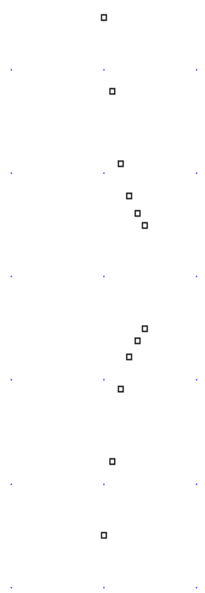


Figure 1-43 Nodes

To draw such a model, we have several methods. Here I will show you two of them.

- Mark one node randomly. Select the node and press TAB, then type in the coordinate of node.

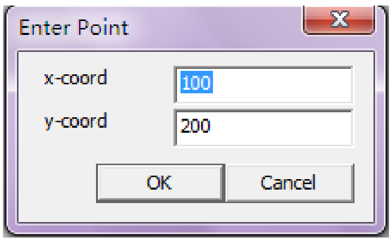
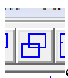


Figure 1-44 Enter point dialogue box

Then we can see a new point is copied to the new coordinate.

- Find (0, 0), use function  "copy"

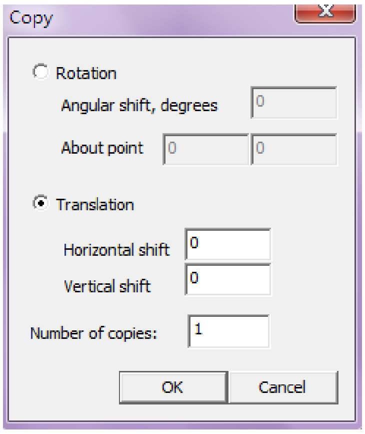


Figure 1-45 Copy dialogue box

Select translation → horizontal shift, and give a value that we need. Repeat this procedure several times until we get all points we need. As shown.

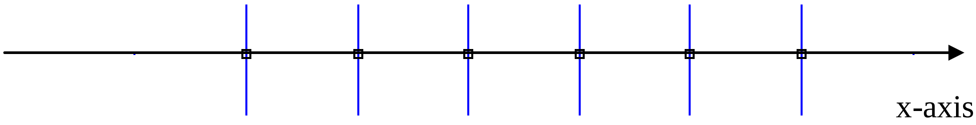
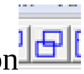
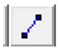


Figure 1-46 x-axis

Then use copy function  to copy every nodes above and under x-axis. In this way, we can set coordinates of the points precisely.

This is the model we need to solve this problem. Use  function to draw all the segments between nodes.

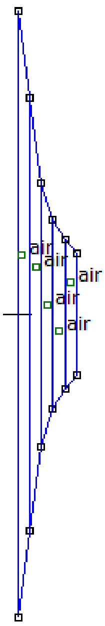


Figure 1-47 Final model

1.3.5 Set up the properties of materials and conductors

The material is irrelevant for the voltage distribution, if it is the same in the entire lead through, so we just add ‘air=1’.

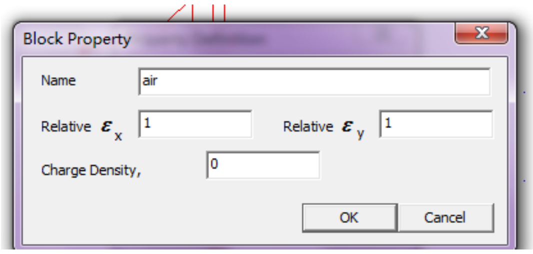


Figure 1-48 Property of material

We set l5=la=100mm as Gnd and l1 as 115kV and then calculate the voltages on each layer one after another.

Click on “Conductors” and then fill in the names and values so we can set the information of Voltages.

Set the total voltage to 115000V. Attach every layer with its conductor. The layers in between are set to “conductor: None”, and the two outer layers are set as following:

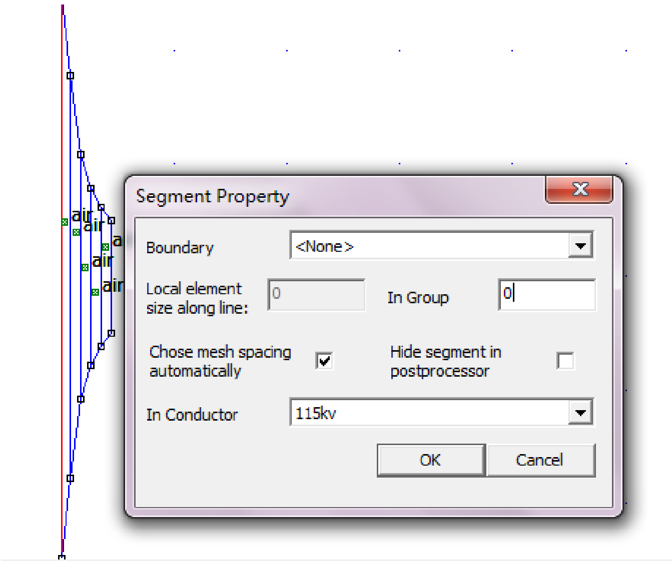


Figure 1-49 Conductor 1

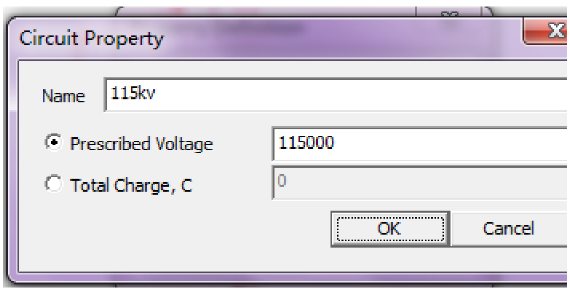


Figure 1-50 Total voltage

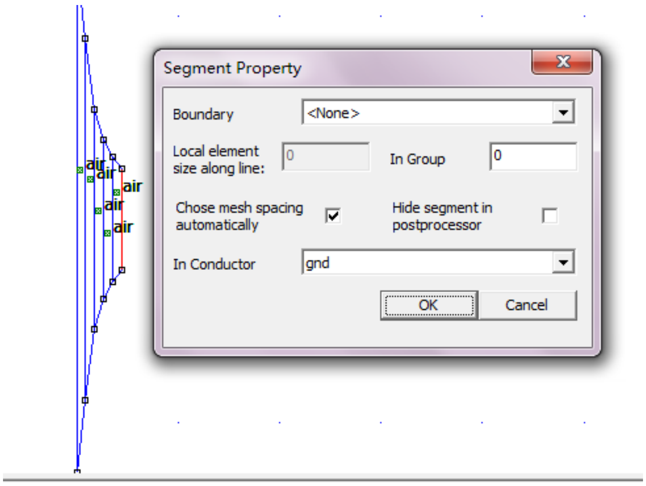


Figure 1-51 Conductor 2

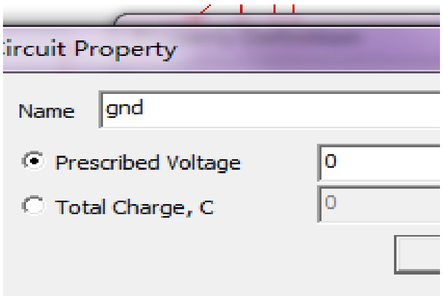
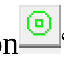


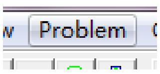
Figure 1-52 Ground

1.3.6 Place block labels and associate them with corresponding materials

Set up block properties, using function“Operate on block labels”. Left click on a closed area to mark the label, then right click on the label and press Space button to call the menu.

We set every block between 2 boards to ‘air’. (air: εx = εy= 1)

1.3.7 Notice

If the program can’t calculate the mesh, which means the angle is too small to calculate, click on 

to adjust the minimal angle to 1°.

1.3.8 Generate mesh and run analysis

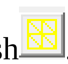
Now save the file and click on the toolbar button with yellow mesh. And the result is shown here.

Figure 1-53 Result

1.3.9 Plot field values

Then choose a horizontal contour to draw the electrical field plot for this module. Select plot type “E, t”.

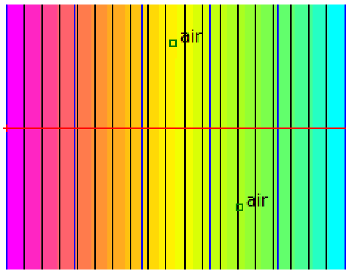


Figure 1-54 Result (zoom)

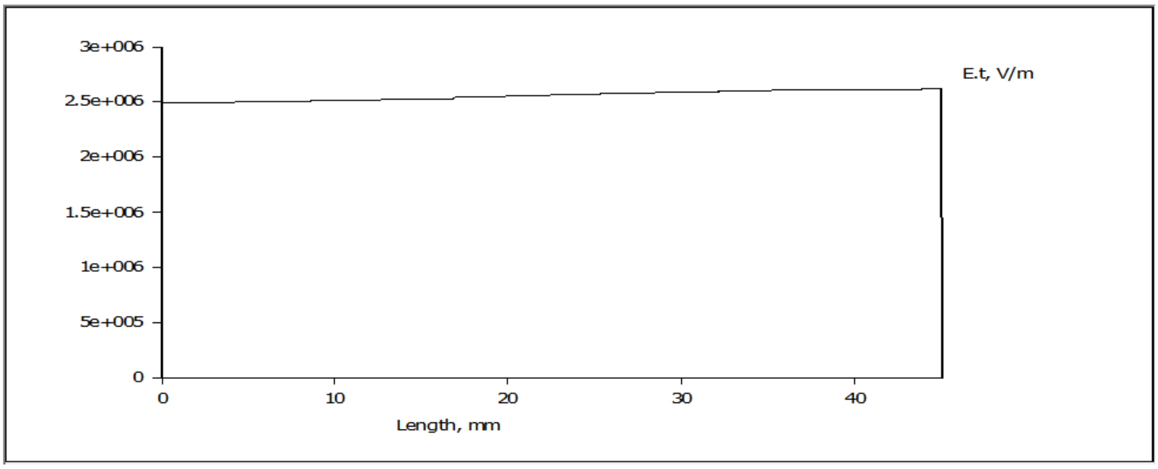


Figure 1-55E,t plot

From the plot we can see the model is perfect homogenous. And it matches the facts.

1.3.10 Compare with theoretical values

Because the $\triangle U$=constant=23kV so voltage on each layer can be easily calculated.

U1=92kV U2=69kV U3=46kV U4=23kV

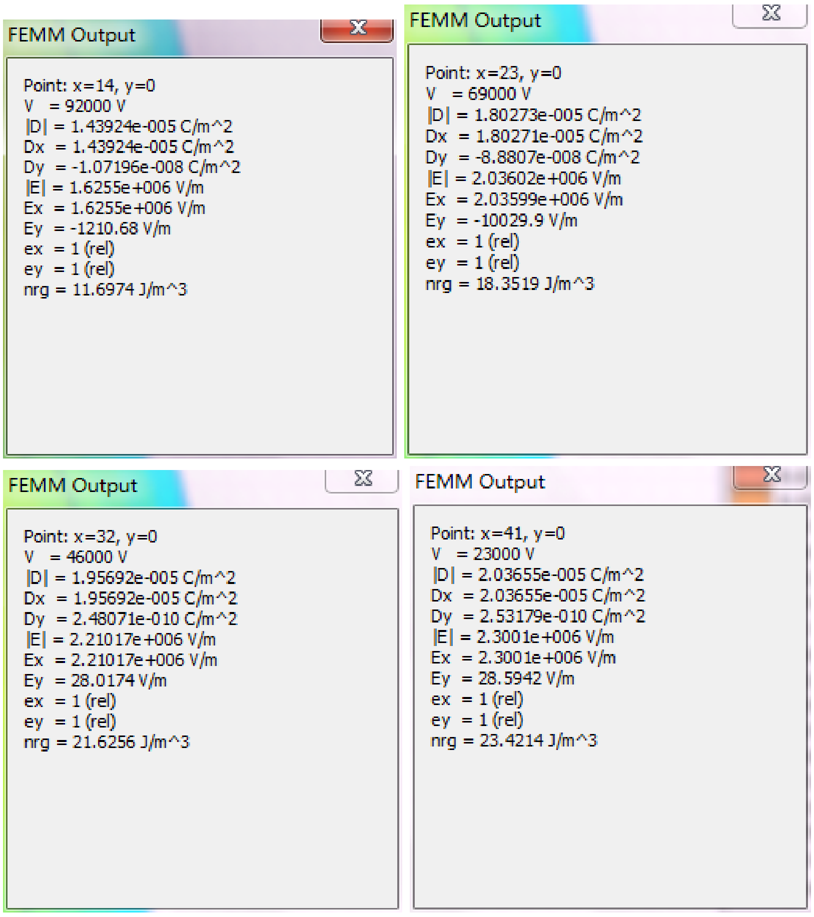


Figure 1-56 Info on each layer

Practical values and theoretical values match. This means our model is correct.

1.4 Capacitor- Cylinder

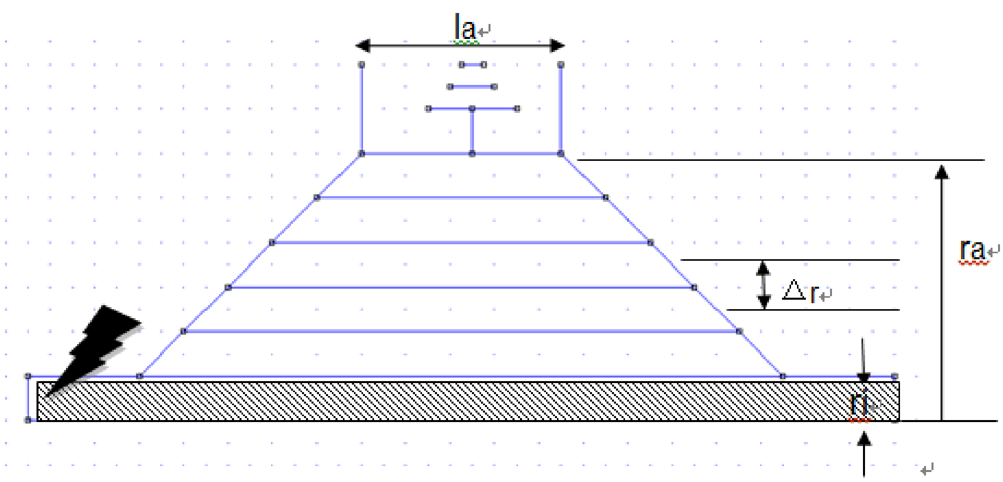


Figure 1-57 Ue8-2

Inner cable 2*r_i=10 mm   Flange(Flansch) diameter 2*r_a=100 mm

Flange length la=100 mm E_d=20 MV/m

The total voltage applied is 115kV(compare to the ground).

If △r = const. The lengths of metal pads are $l_1 \ldots l_4$. If the model is treated as a cylinder field with an isodynamic voltage divide.
Here we will draw the field profile E=(r).

1.4.1 Create a new file.

“File”→“New”→ “Electrostatics Problem”

1.4.2 Set problem definition

We can use the default definitions here.

1.4.3 Create a new model

When this model is treated as a cylinder field, we draw the cross section of the cable. First step, draw 6 concentric circles.

Calculate r_x and l_x first, and then mark all the points in coordinate.

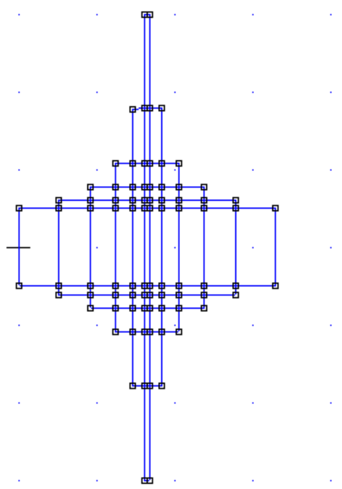


Figure 1-58 Capacitor

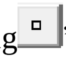
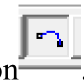
$$C_x = \frac{2\pi * lx}{\ln \frac{rx}{r_{x-1}}} \neq konst$$

$$\rightarrow \frac{l_x}{\ln \frac{l_x}{l_{x-1}}} = konst$$

Equation 3

	I	1	2	3	4	5
Rx	5	14	23	32	41	50
Lx	/	519	250	166	125	100

Table 1-6 Calculated values for Rx and Lx

Mark some nodes using "Operate on nodes", then switch to function . Select 2 nodes one by another to draw an arc segments in between. Then select again in the other way around. So we will get a complete circle. Finish the rest circles.

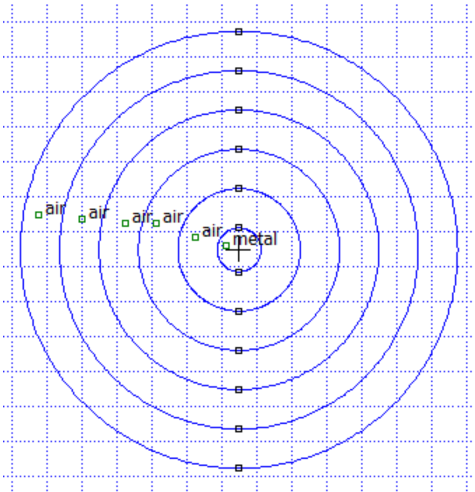


Figure 1-59Model Cross section

1.4.4 Define conductor and material properties

Cylinder- capacitor	$C = \dfrac{2\pi\varepsilon_0\varepsilon_r}{\ln\dfrac{ra}{ri}}$	$E(r) = \dfrac{Q}{2\pi r l \varepsilon_0 \varepsilon_r}$

Table 1-7 Formula

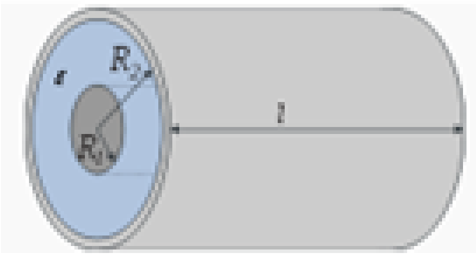


Figure 1-60Cylinder capacitor[5]

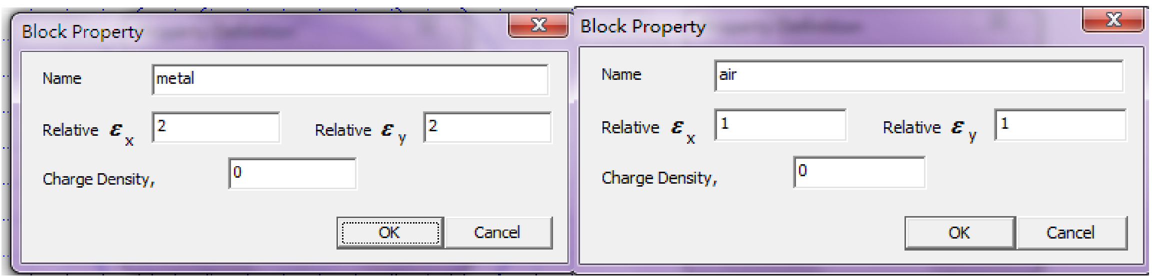


Figure 1-61 Material properties

[5]http://upload.wikimedia.org/wikipedia/commons/b/b8/Cylindrical_CapacitorII.svg

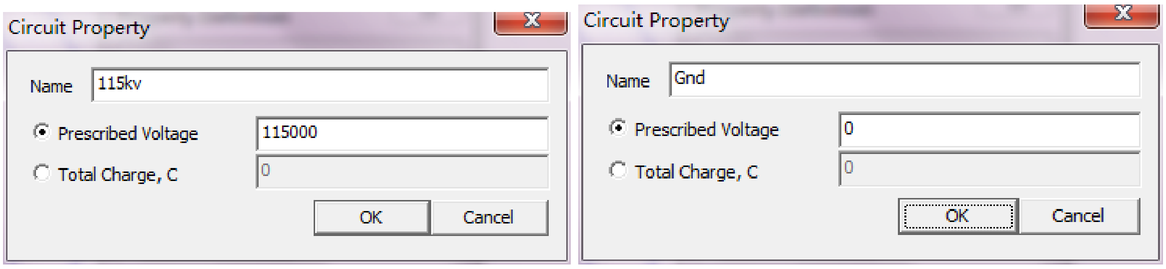


Figure 1-62 Conductor properties

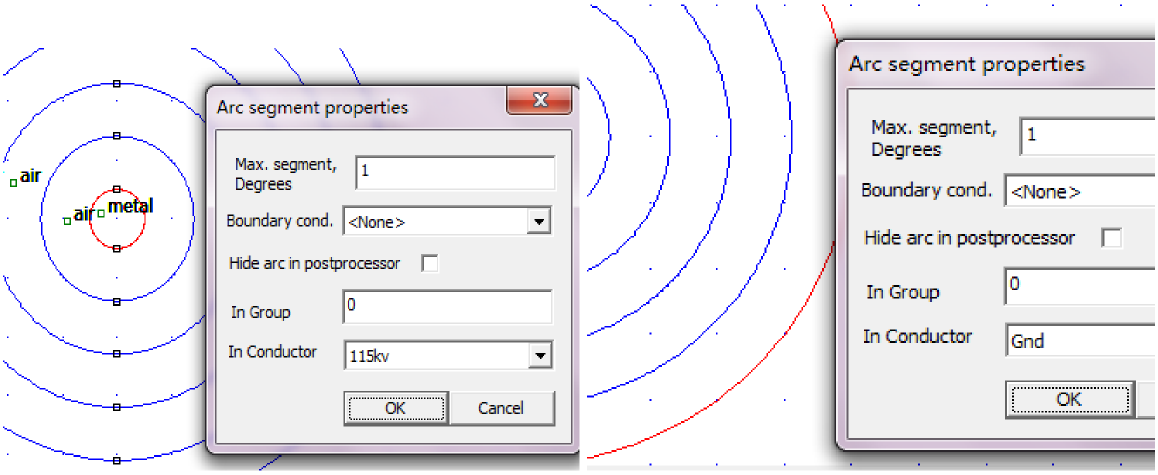


Figure 1-63 Conductor attachments

Set the center layer to conductor “115kv” and the outer layer to “Gnd”. Rest of the layers are set “in conductor:None”.

1.4.5 Place block labels and associate with corresponding materials

Use function Operate on block labels”. Left click on a closed area to mark the label, then right click on the label and press Space button to call the menu. We set the center block to “metal” because it’s a metal rod, and the rest blocks will be set as “air”.

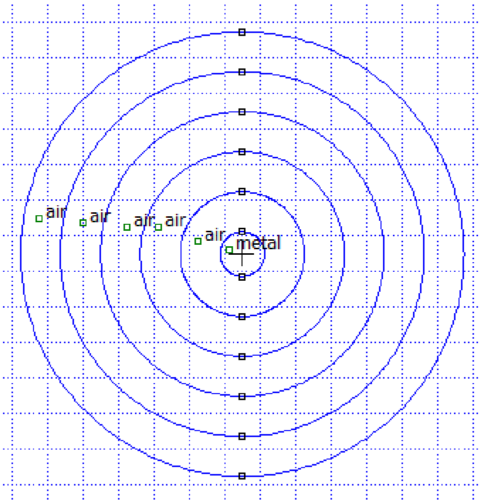


Figure 1-64 Final model

1.4.6 Generate mesh and run analysis.

Mesh size is set to 1 in this case, and we can get 14000 meshes.

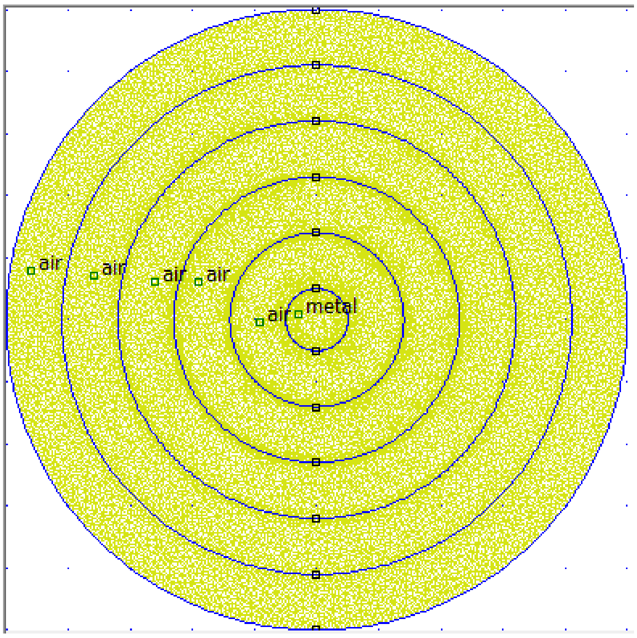


Figure 1-65 Mesh

1.4.7 Display results

The density plot will be looking like this.

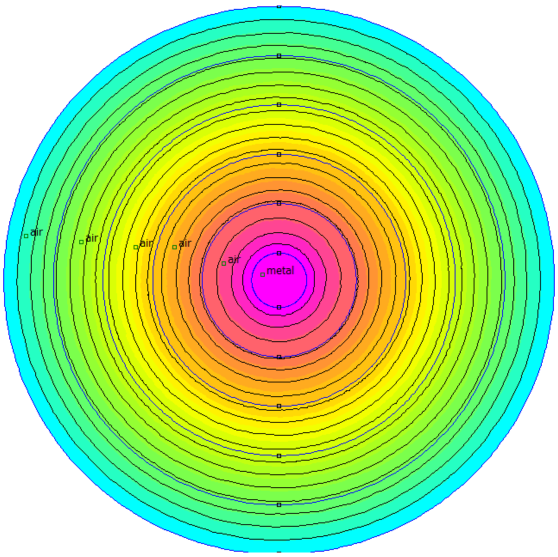
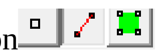


Figure 1-66Result

1.4.8 Plot field values

Select a contour, the contour is a vector so we have to decide its direction as well. Here we draw it from inner to the outer shell. Use the function  so that we can select nodes directly.

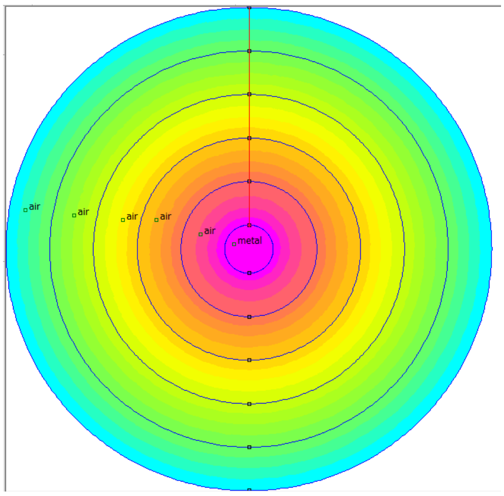
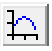


Figure 1-67Contour

Use function  to draw the plot of electric field."E,t" (tangential electrical field intensity) plot is shown below.

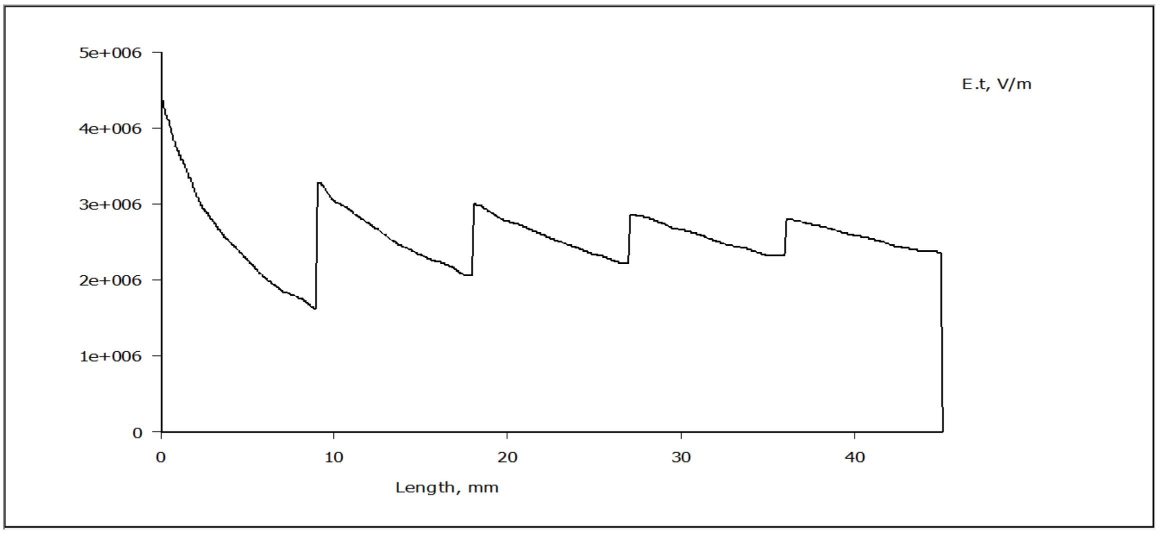
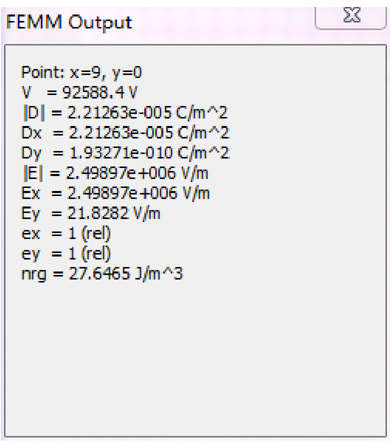


Figure 1-68E,t plot

1.4.9 Compare with theoretical values

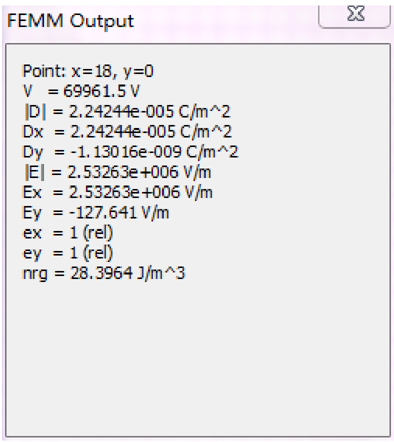
Because the △U=constant=23kV so voltage on each layer can be easily calculated.

U1=92kV U2=69kV U3=46kV U4=23kV



FEMM Output

Point: x=9, y=0
V = 92588.4 V
|D| = 2.21263e-005 C/m^2
Dx = 2.21263e-005 C/m^2
Dy = 1.93271e-010 C/m^2
|E| = 2.49897e+006 V/m
Ex = 2.49897e+006 V/m
Ey = 21.8282 V/m
ex = 1 (rel)
ey = 1 (rel)
nrg = 27.6465 J/m^3



FEMM Output

Point: x=18, y=0
V = 69961.5 V
|D| = 2.24244e-005 C/m^2
Dx = 2.24244e-005 C/m^2
Dy = -1.13016e-009 C/m^2
|E| = 2.53263e+006 V/m
Ex = 2.53263e+006 V/m
Ey = -127.641 V/m
ex = 1 (rel)
ey = 1 (rel)
nrg = 28.3964 J/m^3

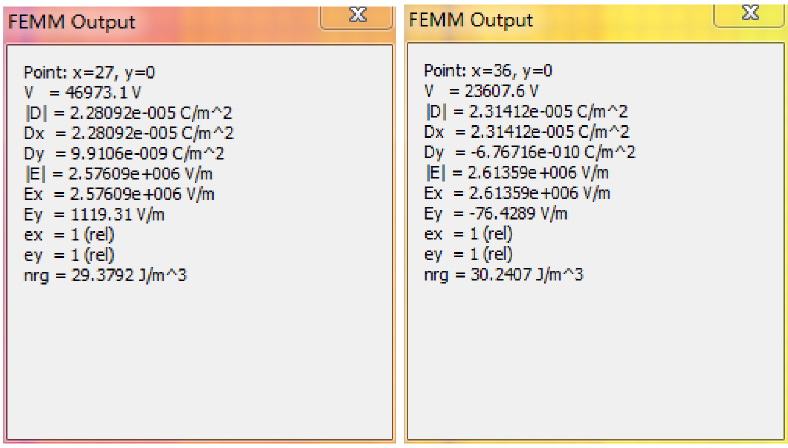


Figure 1-69 Info on each layer

Practical values and theoretical values match. This means our model is correct.

1.5 Hollow sphere 1

Now, if we are given a problem that involves a point charge, how do we solve it? A point charge is a particle which is zero-dimensional, does not take up space. A point particle is an appropriate representation of any object whose size, shape, and structure is irrelevant in a given context.[6]

How do we represent such a particle using this program? Let’s try it by two different methods.

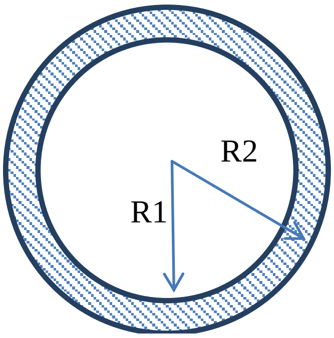


Figure 1-70 Hollow sphere

A positive point charge Q is centered in a metal hollow sphere. Inner radius R1, Outer radius R2. The Sphere is connected with ground, the potential of the sphere is zero.

Here we will draw a plot of the field profile E=(r)

First of all, I should notice you that this method is not correct.

1.5.1 Create a new file.

“File”→“New”→ “Electrostatics Problem”

[6]H.C. Ohanian, J.T. Markert (2007). *Physics for Engineers and Scientists*. **1** (3rd ed.). Norton. ISBN 9780393930030.

1.5.2 Set problem definition.

Press Menu: “Problem”.

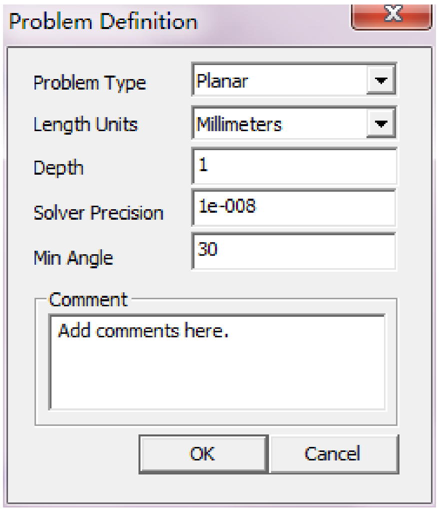


Figure 1-71 Problem Definition

1.5.3 Create a new model

Then, simply draw a circle as shown

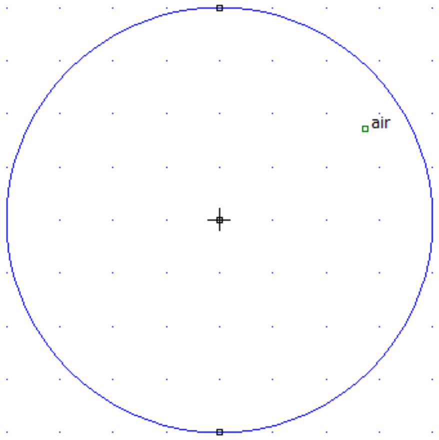


Figure 1-72 New model

Draw a node on the center of circle, and we will use it as the point charge later.

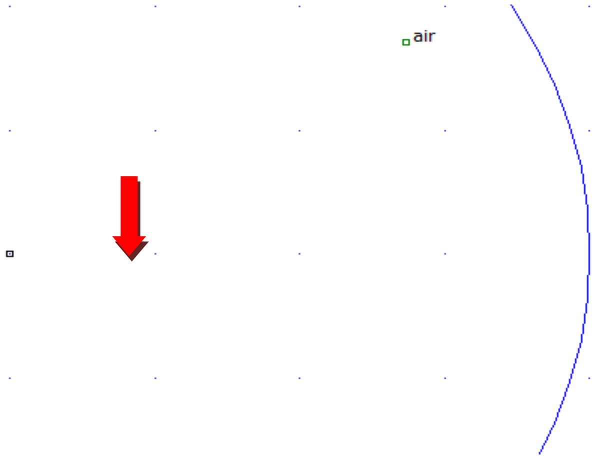


Figure 1-73 Node in center of circle

1.5.4 Define conductor properties

Set properties of material, conductor and point. The nodal properties must be set ahead. Menu "Properties"→ "Point"→ "Add Property"

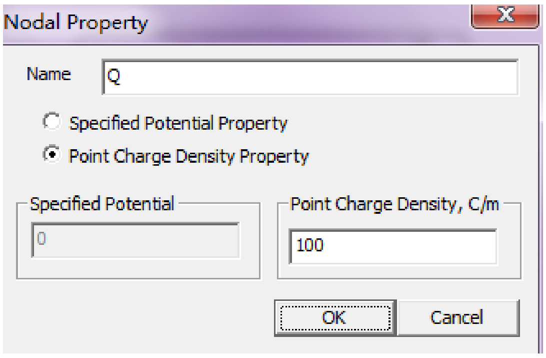


Figure 1-74 Nodal property dialogue box

In nodal property, we set the point charge density as 100C/m . In the Problem definition, we have set the depth to 1 mm. So the point charge has 100C/m* 0.001m= 0.1C.

Sphere capacitor	$C = 4\pi\varepsilon_0\varepsilon_r\left(\frac{1}{R_1} - \frac{1}{R_2}\right)^{-1}$	$E(r) = \frac{Q}{4\pi r^2\varepsilon_0\varepsilon_r}$
Sphere	$C = 4\pi\varepsilon_0\varepsilon_r R_1$	

Table 1-8 Formula

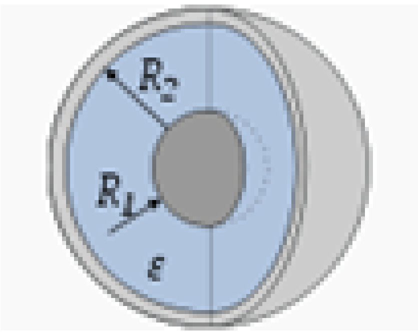


Figure 1-75Sphere Capacitor[7]

1.5.5 Add materials to the model

We set εr 'air' as 1.

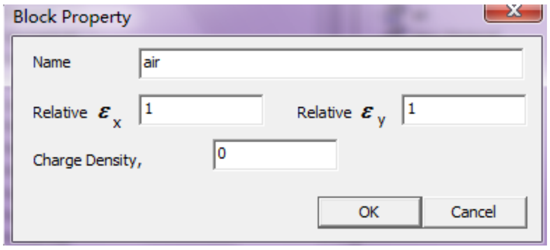


Figure 1-76Material property

---

[7] http://upload.wikimedia.org/wikipedia/commons/3/3f/Spherical_Capacitor.svg

1.5.6 Define conductor properties

The outer shell is connected with ground, so we set it as Gnd. Select the outer shell and press Space bar to set the further properties.

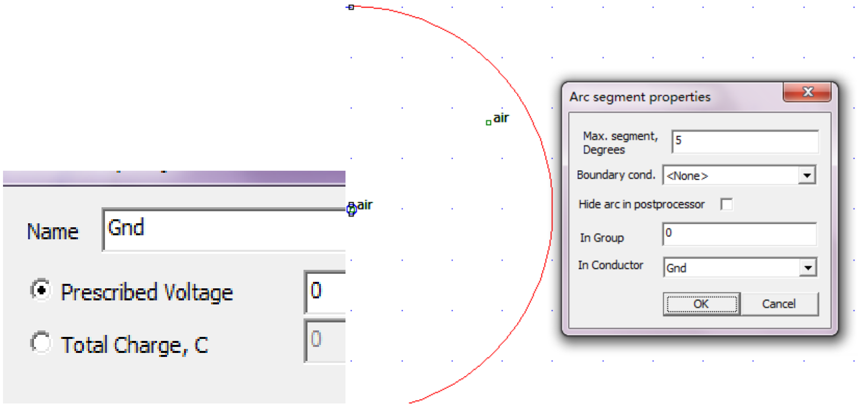
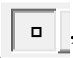


Figure 1-77Attach conductors to their properties

First, select the node in the center of circle by left clicking on it under

function ”Operation on node”. Then press Space bar to pop the dialogue box, where we can define the property of a node. Select “Nodal Property” to Q, which we have defined already.

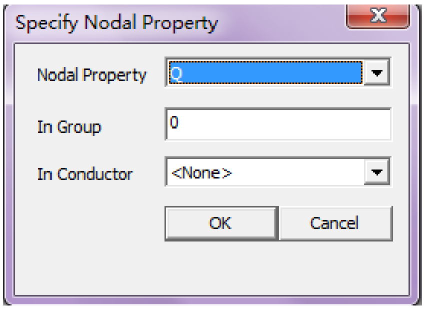


Figure 1-78Attach node to its property

1.5.7 Place block labels and associate them with materials.

Set the only block as “air”.

1.5.8 Generate mesh and run FEA

The mesh size was chosen by triangle.

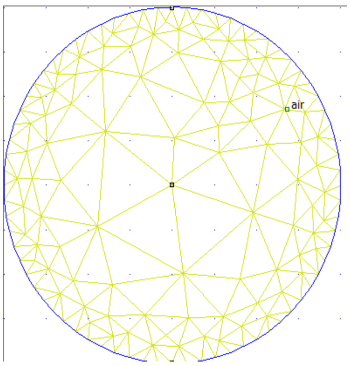


Figure 1-79

1.5.9 Display results

Run analyses and we will get a plot as below. As we can see, the result is not in circles but in some shapes like Hexagons, which is very strange but interesting.

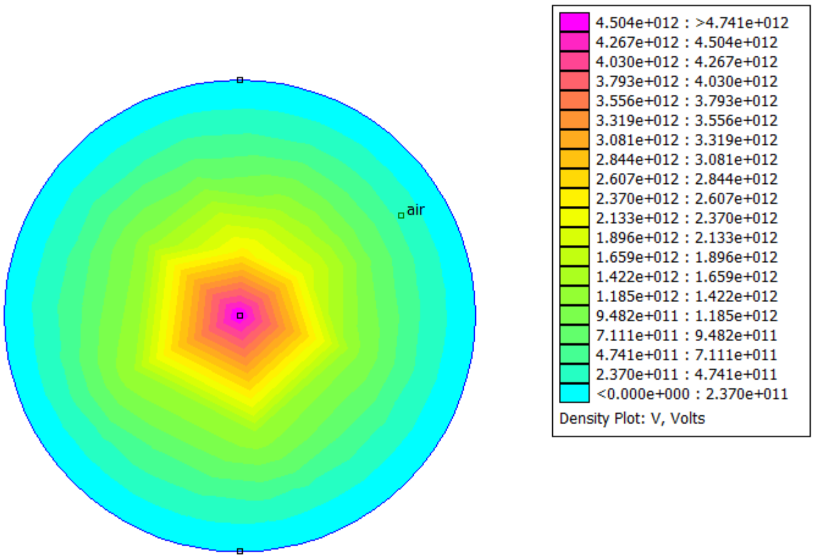


Figure 1-80 Result

1.5.10 Plot field values

Draw E (electrical field intensity) and D (flux density) plot for this module.

Figure 1-81 Contour

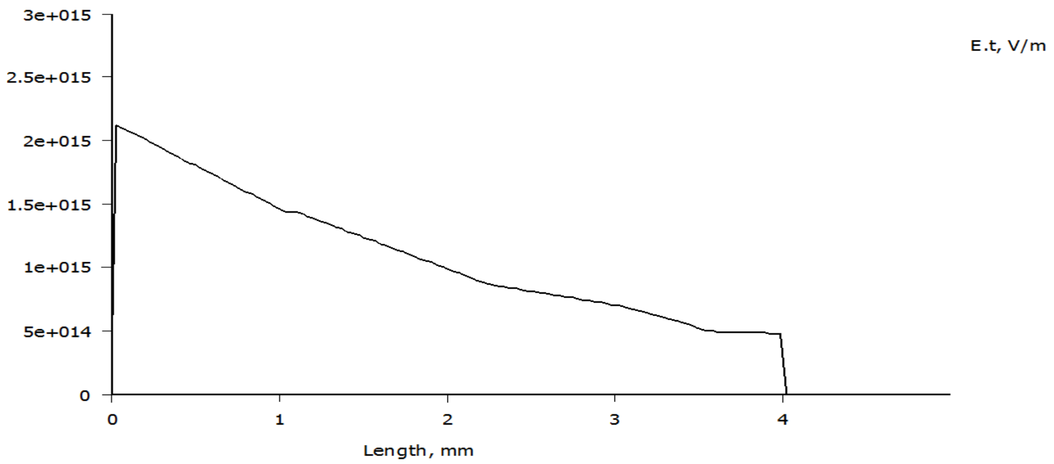


Figure 1-82E,t plot

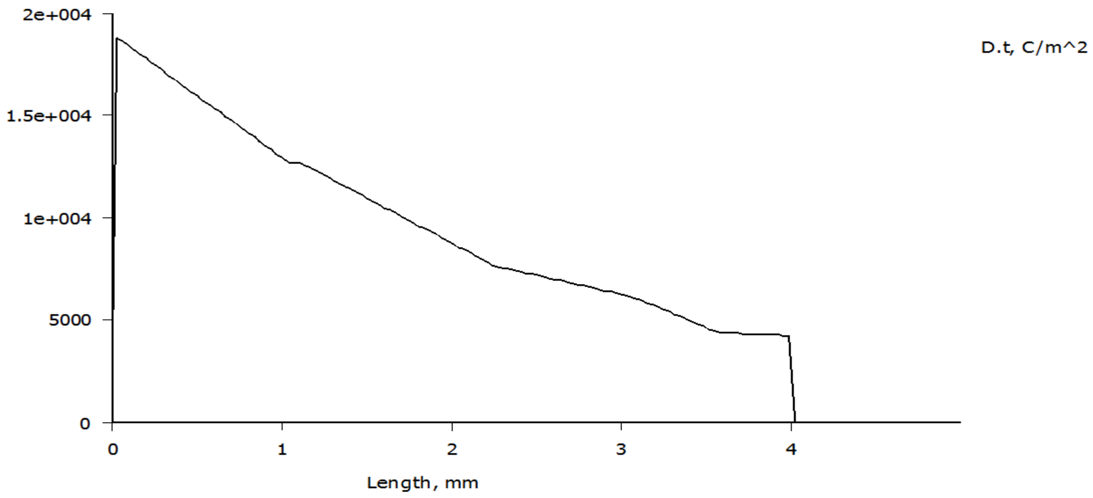


Figure 1-83D,t plot

1.5.11Comparison with the theoretical values

If this method is correct, we should get a plot of function $\mathbf{E(r)} = \dfrac{Q}{4\pi r^2 \varepsilon_0 \varepsilon_r}$, but the curve does not match the facts. This method is not available.

And there is one more interesting thing. The electrical field density is not symmetric according to the plot. So I ran a mesh generate as well.

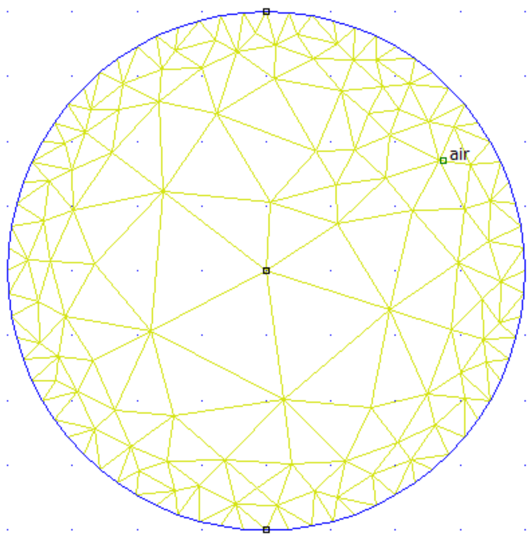


Figure 1-84 Mesh

As we can see, the meshes aren't perfectly symmetric either.

If we uncheck the box "Let the triangle choose mesh size" and set it to a very small value, for example 0.1.

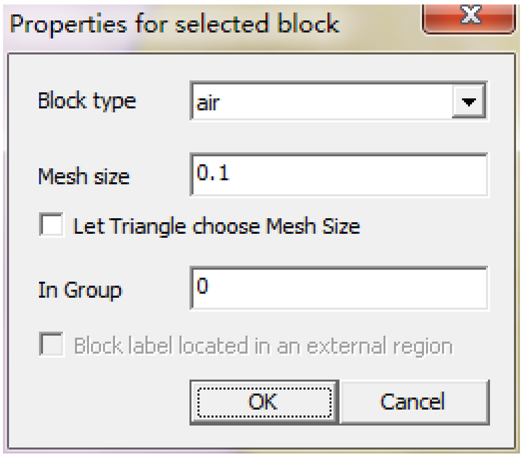


Figure 1-85 Uncheck the box

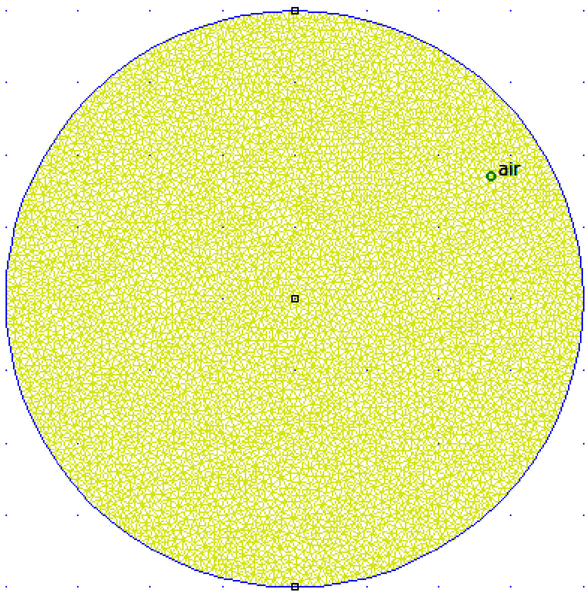


Figure 1-86 New meshes

Run analysis again.

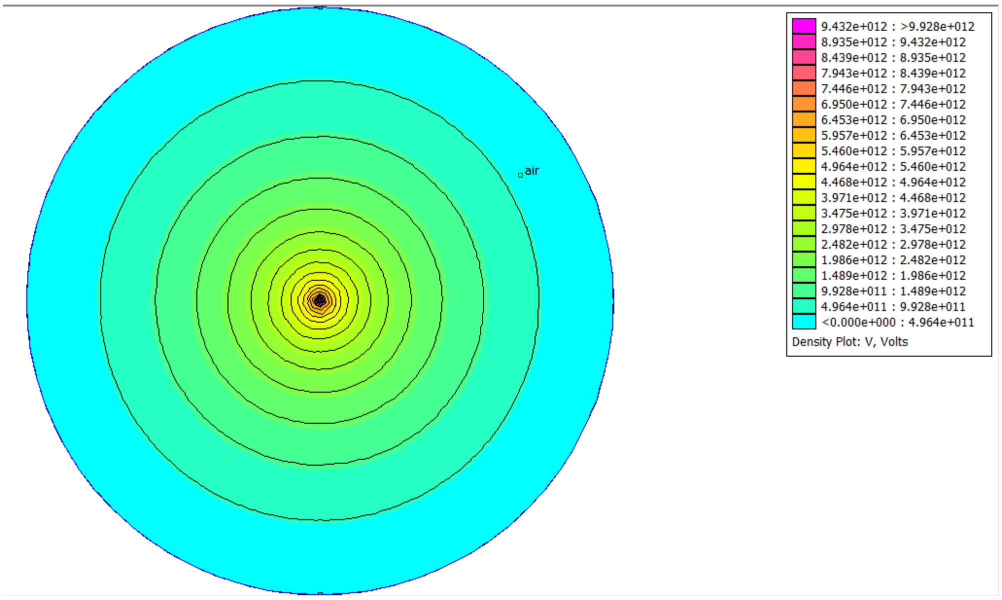


Figure 1-87 New result

And this time it seems to be smoother. But if we zoom in a little, we can still see that the center is not a circle.

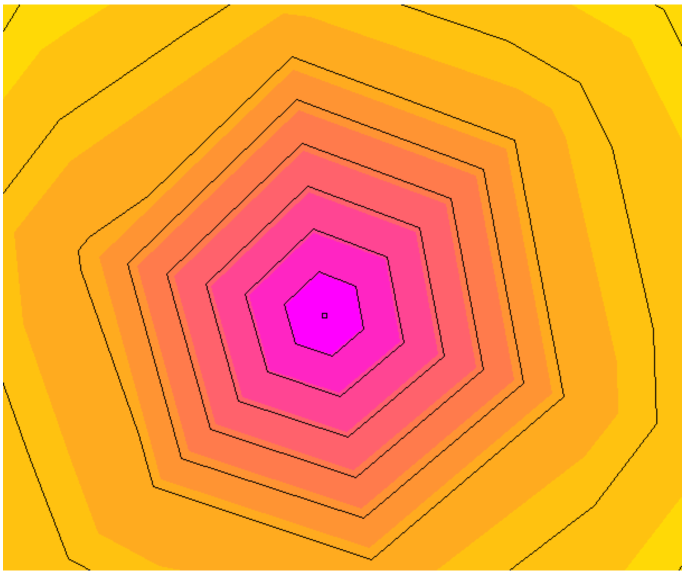


Figure 1-88 New zoom

Thus, I assume the node in this program may have a shape, and probably not a perfect model of point.

1.6 Hollow sphere 2

Here we do the same problem once again, but in a correct way.

1.6.1 Create a new file.

"File"→"New"→ "Electrostatics Problem"

1.6.2 Set problem definition.

Press Menu: "Problem". And we can use the default definitions.

1.6.3 Create a new model

Draw a circle to make the shell of the capacitor.

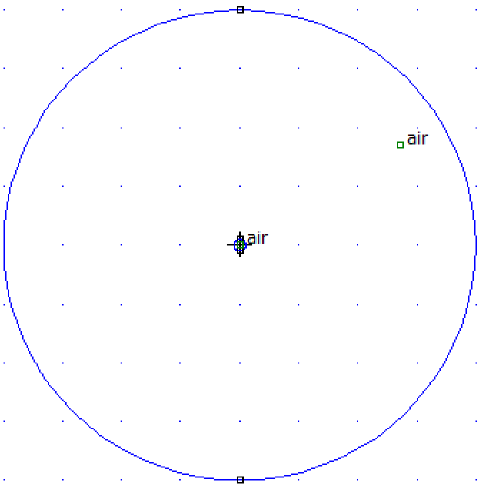


Figure 1-89 New model

Draw a little circle on the center of it, used as the point charge.

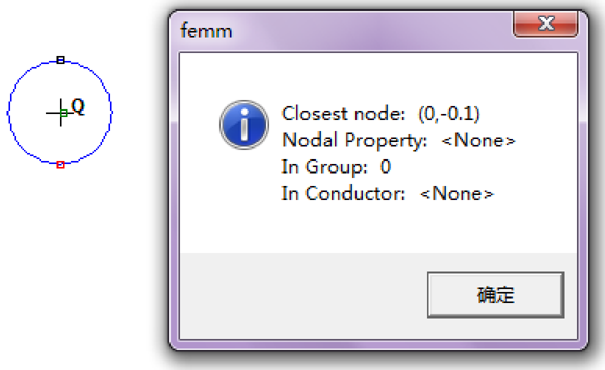


Figure 1-90 Circle in the center

1.6.4 Set the properties of materials, conductors

Sphere capacitor	$C = 4\pi\varepsilon_0\varepsilon_r\left(\frac{1}{R_1} - \frac{1}{R_2}\right)^{-1}$	$E(r) = \frac{Q}{4\pi r^2\varepsilon_0\varepsilon_r}$
Sphere	$C = 4\pi\varepsilon_0\varepsilon_r R_1$	

Table 1-9Formula

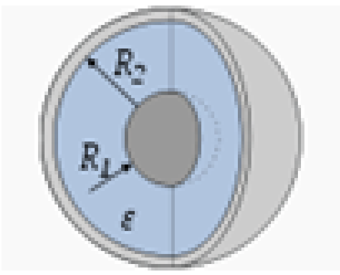


Figure 1-91 Sphere capacitor[8]

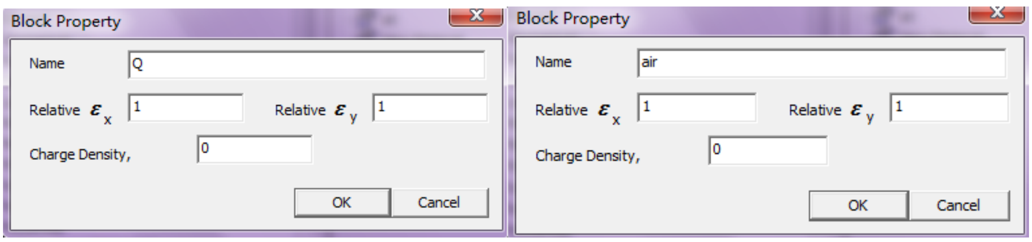


Figure 1-92 Properties of material

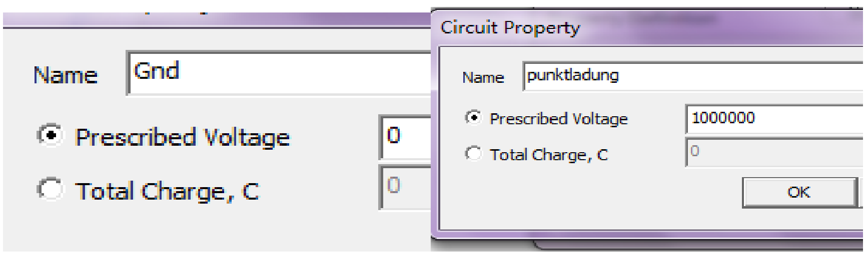


Figure 1-93 Properties of conductor

[8]http://upload.wikimedia.org/wikipedia/commons/3/3f/Spherical_Capacitor.svg

The outer shell is connected with ground, so we set it as Gnd. Select the outer shell and press Space bar to set the further properties.

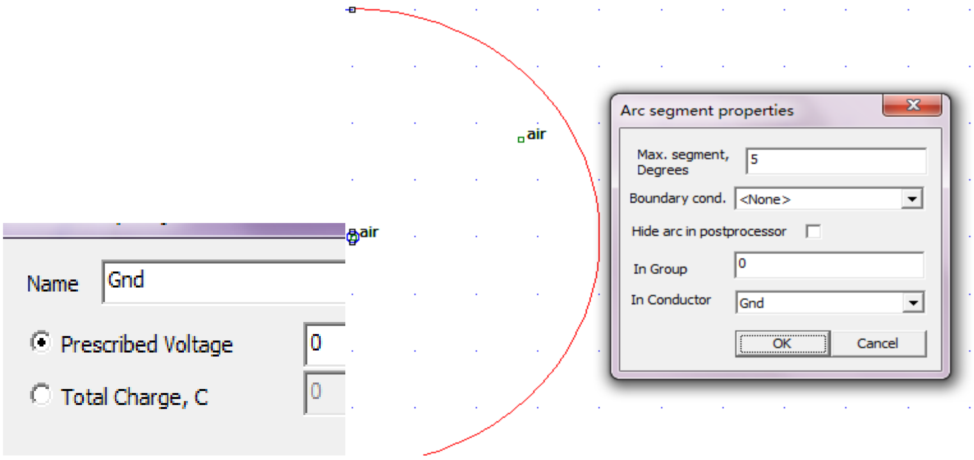


Figure 1-94 Attach conductor to its property (part 1)

Use the little circle as a point charge. Set its conductor as “Punktladung”
Set the conductor property of the little circle as “Punktladung” and the other block will be set as “air”. The radius of this little circle is 0.1mm in this case and don’t forget to select both halves of the circle.

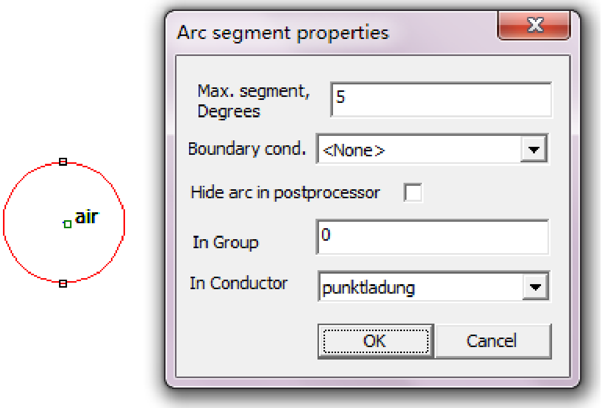


Figure 1-95 Attach conductor to its property (part 2)

1.6.5 Place block labels and associate them with corresponding materials

Set the block as “air”. And in this case, set the mesh size of both blocks to 0.025.

1.6.6 Generate mesh and run analysis

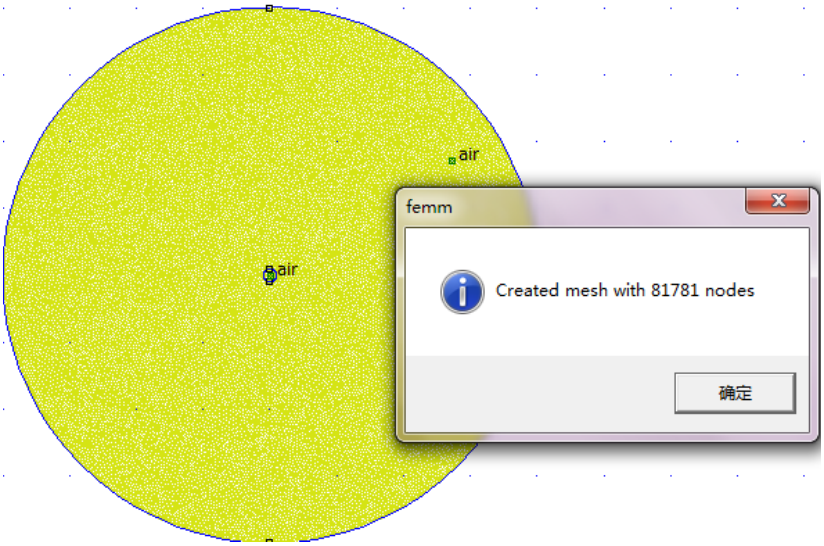


Figure 1-96 Mesh

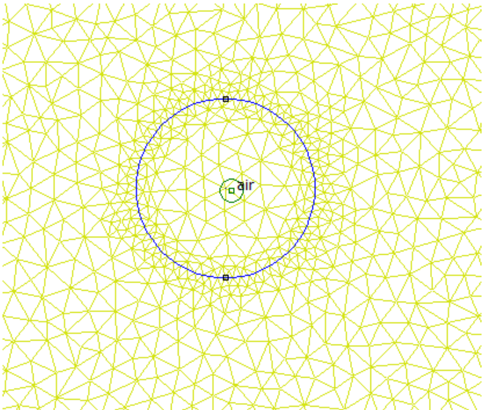


Figure 1-97 Mesh (zoom)

1.6.7 Display results

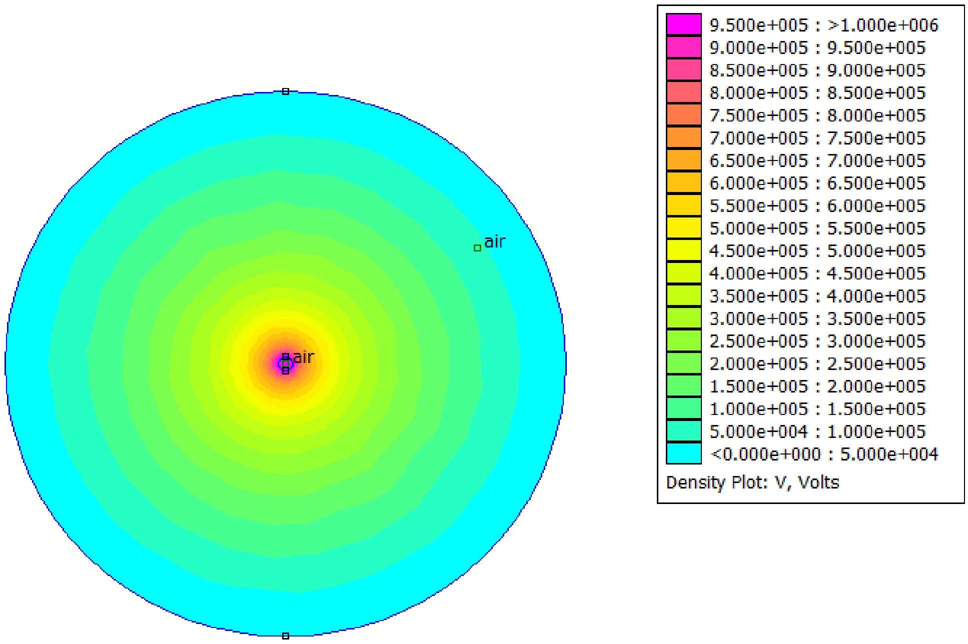


Figure 1-98 Result

1.6.8 Plot field values

Draw E and D plot for this module. First choose the contour . Connect the two nodes (0, 0.1) and (0, 40).

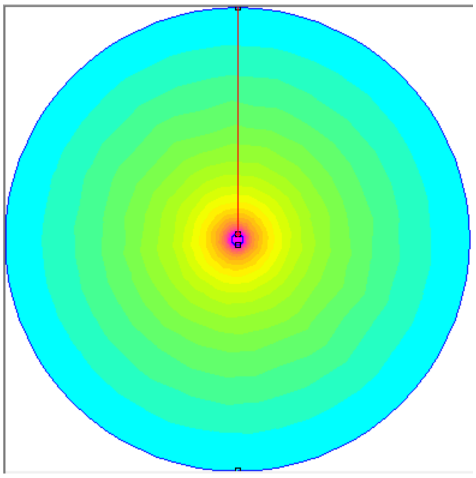


Figure 1-99 Contour

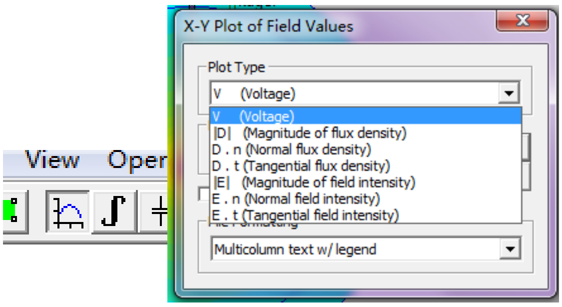


Figure 1-100 X-Y plot of field values dialogue box

We choose E,t here because we need electrical field along the red line. Normal field means the field vertical to the line we chose. So is D,t.

If you find your curve too rough, you can go back to 1.6.6 to change the mesh size and run the analysis again. The smaller the mesh size is, the finer your curve may get.

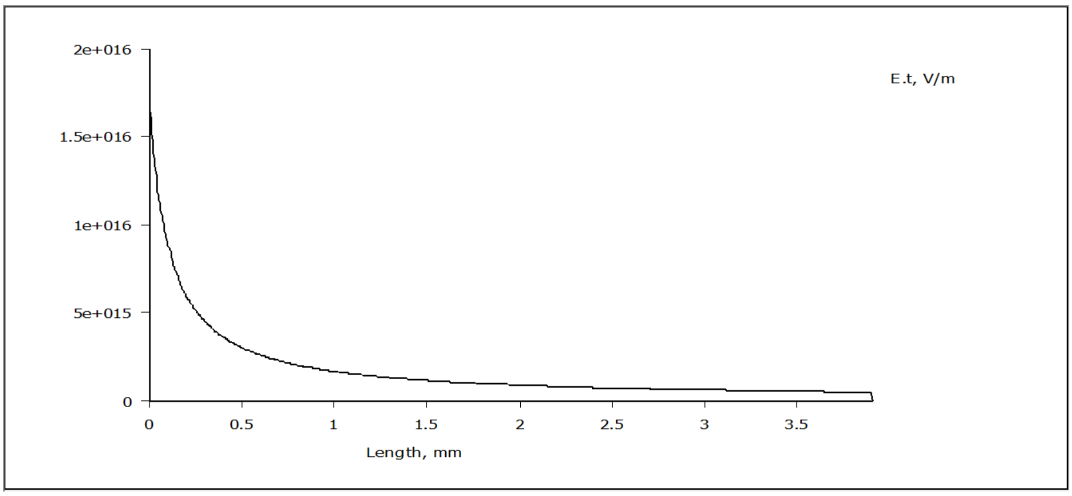


Figure 1-101E,t plot

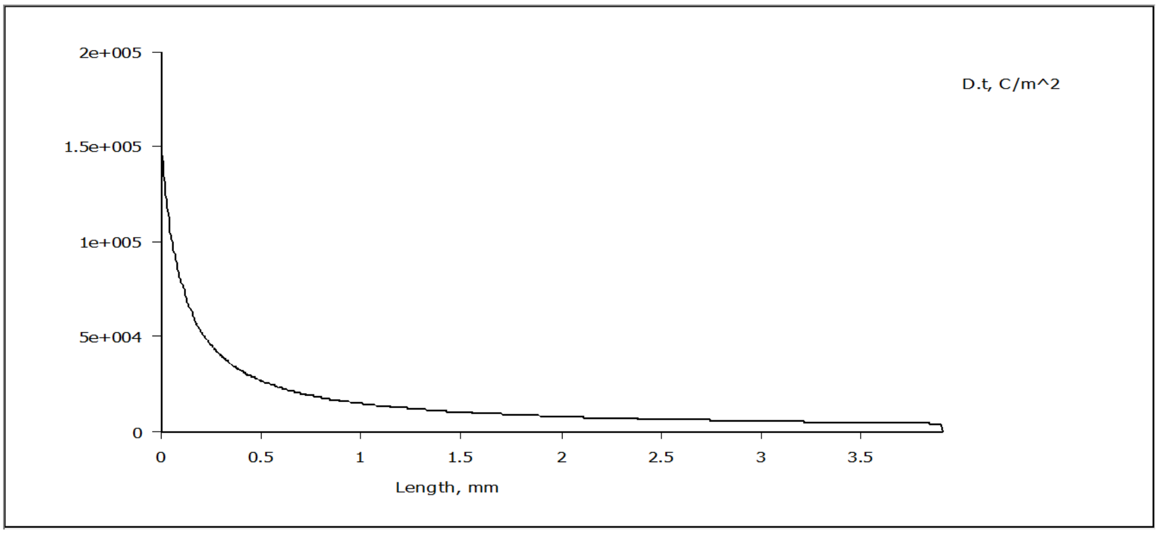


Figure 1-102D,t plot

1.6.9 Comparison with the theoretical values

This plot matches the facts. So this is the right method to solve the problem with point charge.

1.7 Plate capacitor

A capacitor is made of 3 thin metal plates. The area of those plates are A=100cm^2 . The capacitor will be first connected to a voltage supply U=1750 V and then separate from it. Please draw a field profile E=(r)

1.7.1 Create a new file.

“File”→“New”→ “Electrostatics Problem”

1.7.2 Set problem definition.

Press Menu: “Problem”.

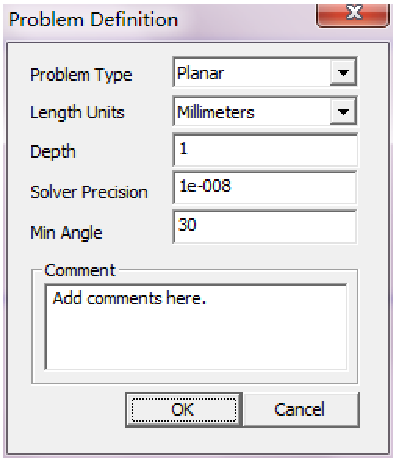


Figure 1-103 Problem Definition

1.7.3 Create a new model

Draw 3 segments which parallel to x-axis. Then connect the nodes so we get a Plate capacitor like this.

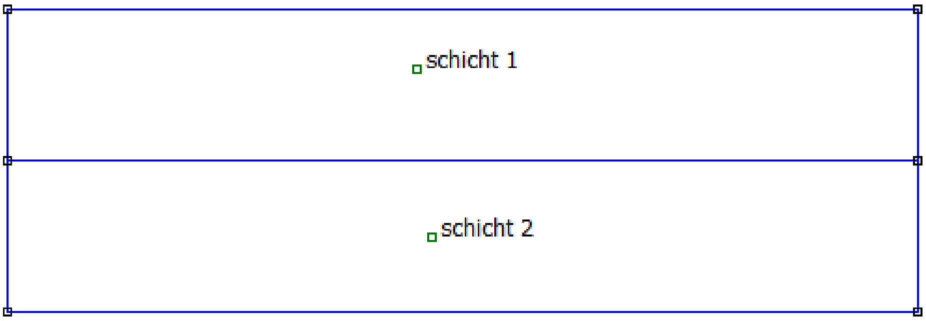


Figure 1-104 New model

1.7.4 Add materials to the model

Set properties of material and conductor

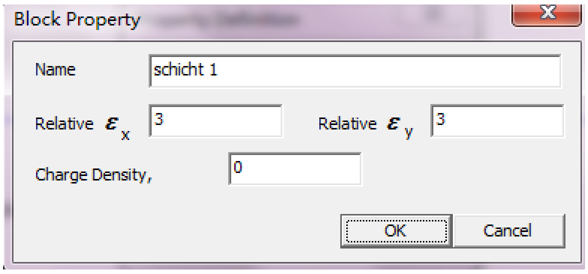


Figure 1-105 Properties of material 2

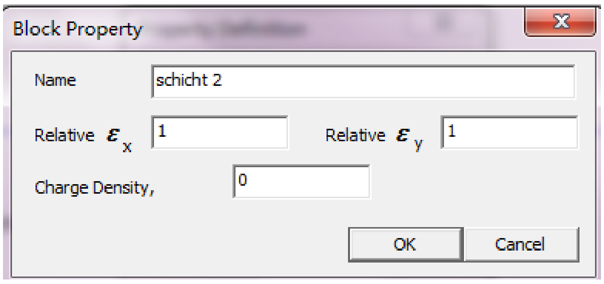


Figure 1-106 Properties of material 2

1.7.5 Define conductor properties

Plate capacitor	$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$	$E = \frac{Q}{\varepsilon_0 \varepsilon_r A}$

Table 1-10 Formula

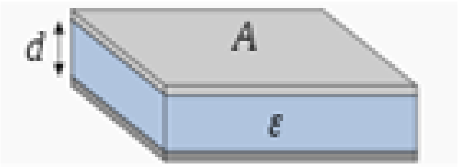


Figure 1-107 Plate capacitor[9]

[9]http://upload.wikimedia.org/wikipedia/commons/2/20/Plate_CapacitorII.svg

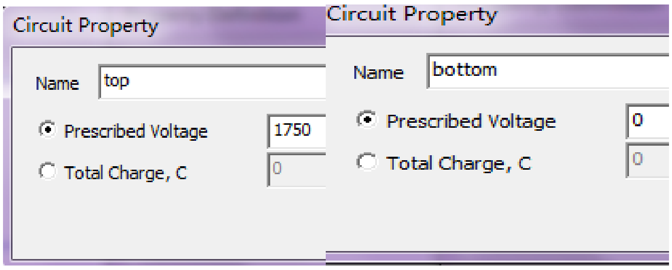
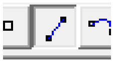


Figure 1-108 Properties of conductor

Set the conductor information of the three segments, from top to bottom, as “top” and “bottom”. Select each segment under function  “Operate on segment”, press Space bar to call the dialog box.

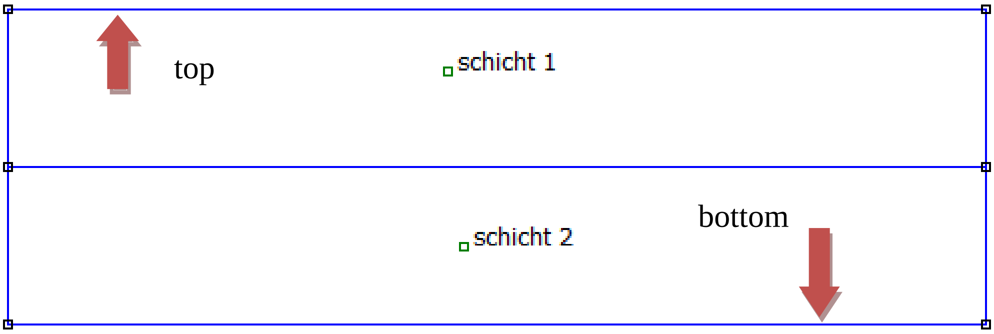


Figure 1-109Attach conductors to their properties

1.7.6 Place block labels and associate them with corresponding materials

Set material of the blocks schicht1 (upper half), schicht2 (lower half). And here we can let the triangle choose the mesh size.

1.7.7 Generate mesh and run analysis

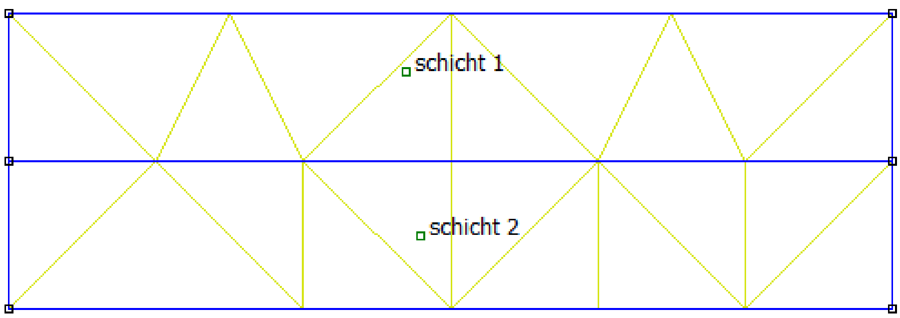


Figure 1-110 Mesh

1.7.8 Display results

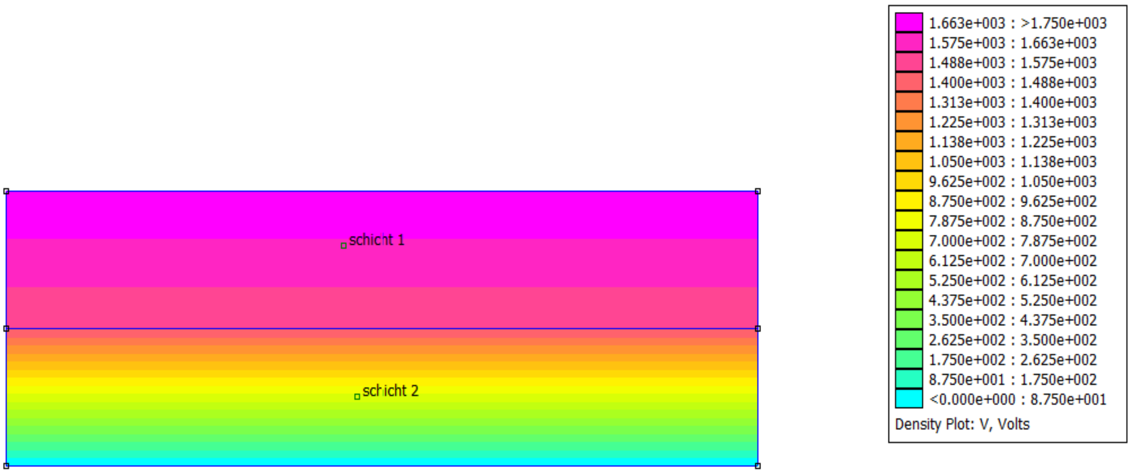


Figure 1-111Result

1.7.9 Plot field values

Draw E and D plot for this module. First draw the contour  from top to bottom as is shown in figure 1-107. Then draw the plot .

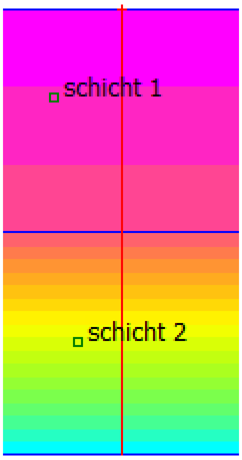


Figure 1-112Contour

Choose E,t (tangential field intensity) plot

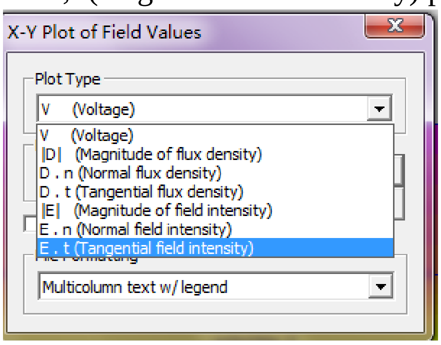


Figure 1-113 X-Y plot of field values dialogue box

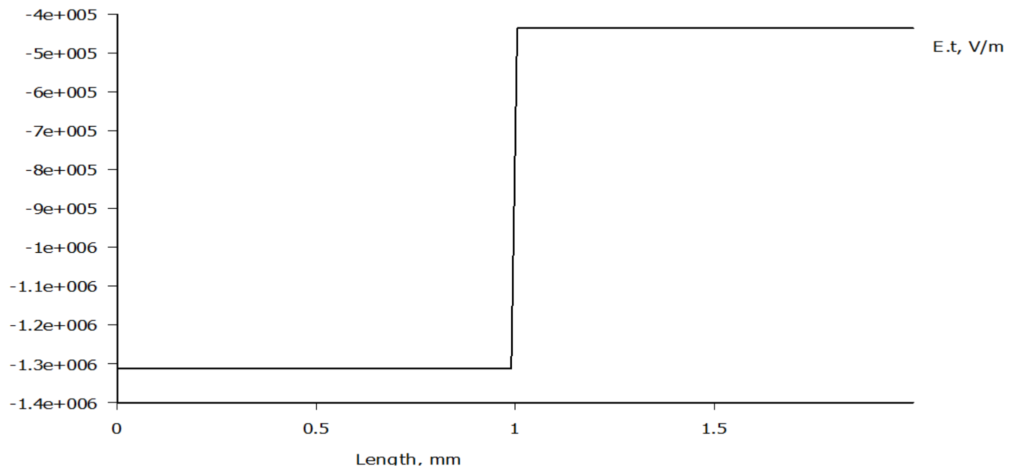


Figure 1-114E,t plot

1.7.10 Compare with theoretical value

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}.$$

$\rightarrow C_1 : C_2 = \varepsilon_1 : \varepsilon_2 = 3:1$

$\rightarrow U_1/U_2 = C_2/C_1 = 1/3$

Equation 4

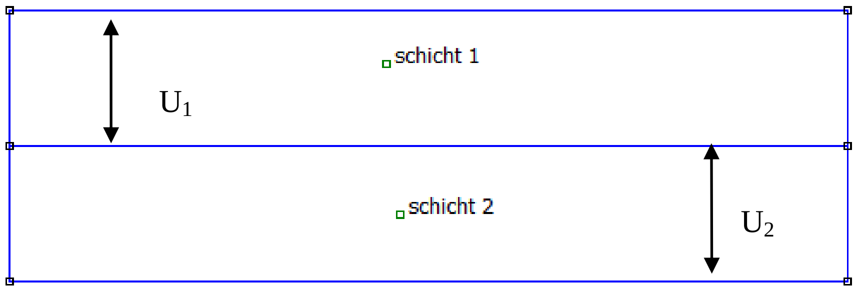


Figure 1-115 Voltages

So the voltage on middle layer should be 1750V* 3/4= 1312.5V. And according to the "Points props", our model is correct.

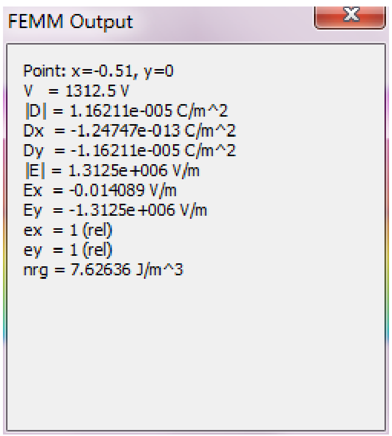


Figure 1-116 Detail info

2. Electrical Field

Before we deal with some current flow problems, we should first understand--

What is an electrical field?

In physics, an electric field surrounds electrically charged particles and time-varying magnetic fields. This electric field exerts a force on other electrically charged objects. *Michael Faraday* introduced the concept of an electric field.
The electric field is a vector field with SI units of newtons per coulomb (N/ C) or, equivalently, volts per meter (V/m). The strength or magnitude of the field at a given point is defined as the force that would be exerted on a positive test charge of 1 coulomb placed at that point; the direction of the field is given by the direction of that force. Electric fields contain electrical energy with energy density proportional to the square of the field amplitude. The electric field is to charge (E=F/q) as gravitational acceleration is to mass ($a=g*m/r^2$) and force density is to volume (f= dF/dV).
An electric field that changes with time, such as due to the motion of charged particles in the field, influences the local magnetic field. That is, the electric and magnetic fields are not completely separate phenomena; what one observer perceives as an electric field, another observer in a different frame of reference perceives as a mixture of electric and magnetic fields. For this reason, one speaks of "electromagnetism" or "electromagnetic fields". In quantum mechanics, disturbances in the electromagnetic fields are called photons, and the energy of photons is quantized.[10]

2.1 Cable 1

Assume we have a perfect concentric cable. At inner cable a voltage of 130kV (compare to the ground) is applied.

	Layer 1	Layer 2
σ_r (S/m)	3	2

Table 2-1 Value of the electrical conductivity

We will draw the field profile E=f(r) of this cable as well as a plot of E=f(r).

2.1.1 Create a new file.

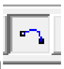
"File"→"New"→ "Current Flow Problem"

2.1.2 Set problem definition.

Press Menu: "Problem". Change problem type to "Axisymmetric" and Unit length to "millimeters".

[10] Electric field in "Electricity and Magnetism", R Nave

2.1.3 Create a new model

Draw three quarters of circle using function  “Operate on arc segment”.

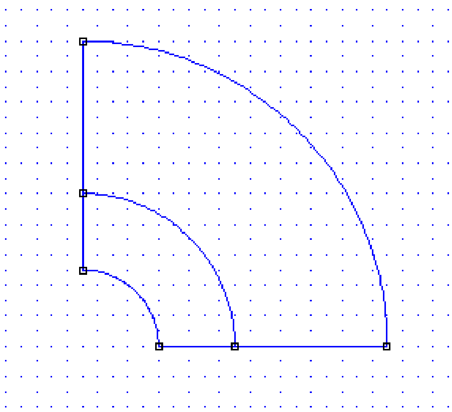


Figure 2-1 New model

2.1.4 Add materials to the model

Set up the properties of material (schichte1, schichte2, inner, air). The values of the material are already given, **δ**r of material in ‘schicht1’ is 3; **δ**r of material in ‘schicht2’is 2.

Here we give both **δx** and **δ**y the same number. In this way, **δ**r is determined.

δr =3 for schicht1

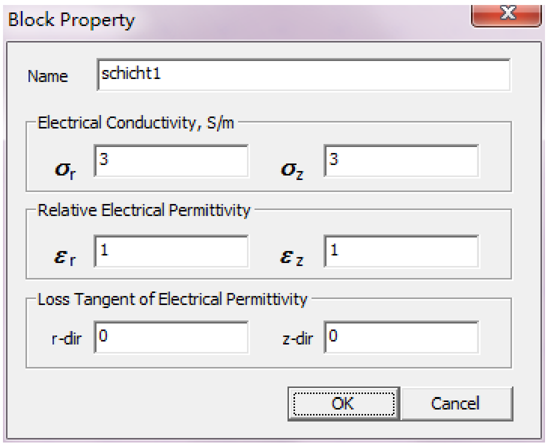


Figure 2-2 Property of material 1

δr=2 for schicht2

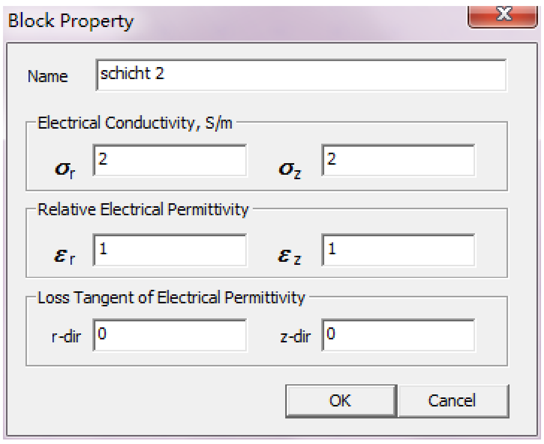


Figure 2-3 Property of material 2

2.1.5 Define conductor properties

Set the properties of conductors (layer1, layer2, gnd).
The voltage on each layer must be calculated first.
Electrical conductivity

$$\sigma = \frac{1}{\rho}.$$

Unit: S/m

Electrical resistivity ρ

$$\rho = \frac{E}{J}$$

ρ is the static resistivity (measured in ohm-meters, Ω • m)
E is the magnitude of the electric field (measured in volts per meter, V/m);
J is the magnitude of the current density (measured in amperes per square meter, A/m^2).

$$\mathbf{E} = \frac{U}{d}$$

$$\mathbf{E} = \mathbf{J} \cdot \boldsymbol{\rho} = \frac{J}{\sigma}$$

$$\rightarrow \mathbf{E} \sim \mathbf{U} \sim \frac{\mathbf{1}}{\sigma}$$

$$\rightarrow \frac{\mathbf{U1}}{\mathbf{U2}} = \frac{\sigma_2}{\sigma_1} = \frac{\mathbf{2}}{\mathbf{3}}$$

Equation 5

Voltage on Layer 1 is the total voltage (130kV) from center of cable to the ground.

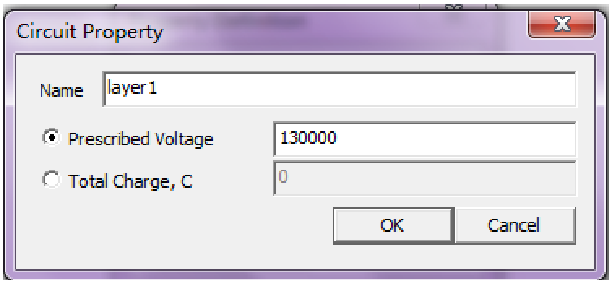


Figure 2-4 Voltage on layer 1

Ground

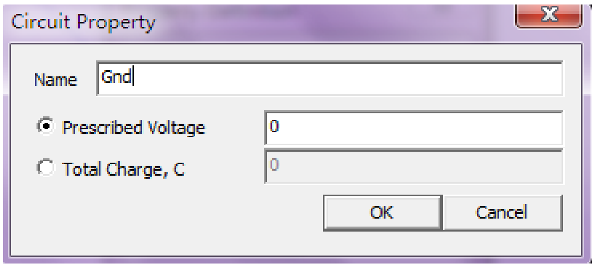


Figure 2-5Voltage on layer 3

2.1.6 Place block labels and associate them with corresponding materials

Set the inner block as ‘schicht1’, the outer block as ‘schicht2’. Then change the mesh size to 0.1.

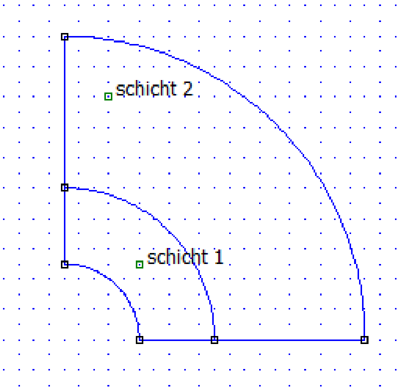


Figure 2-6 Final model

2.1.7 Generate mesh and run FEA

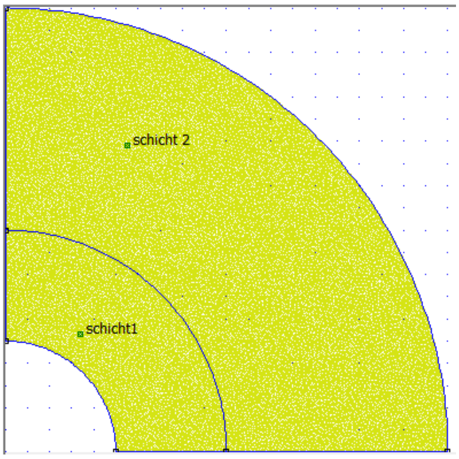


Figure 2-7 Mesh

2.1.8 Display results

Run the analysis, and the result is shown here

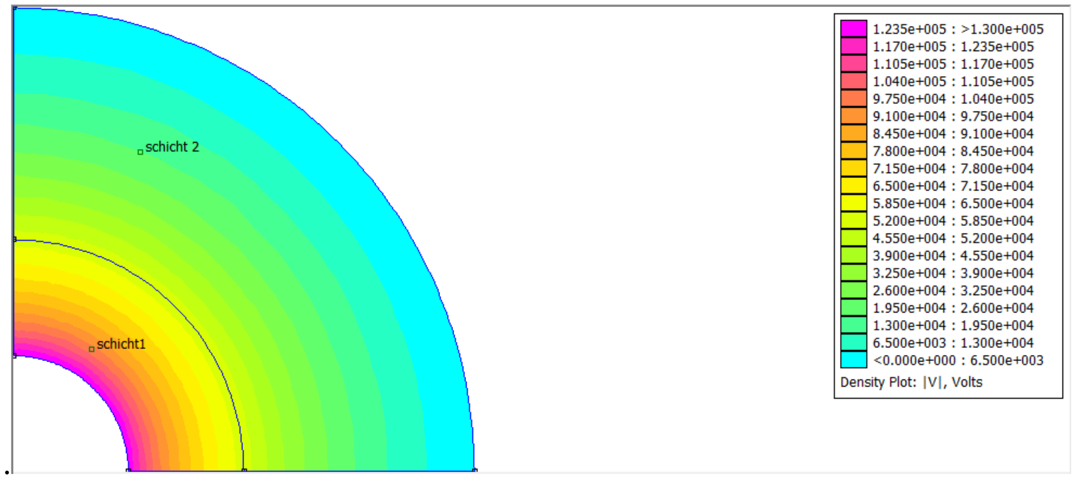


Figure 2-8 Result

Draw the contour from (0, 0) to (14.1, 14.1). The result is the density plot in a concentric cable.

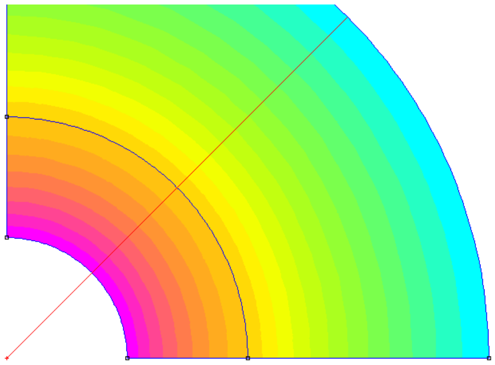


Figure 2-9 Contour

2.1.9 Plot field values

We can choose the |E| plot here, so the {Re} and {Im} part won't be shown separately.

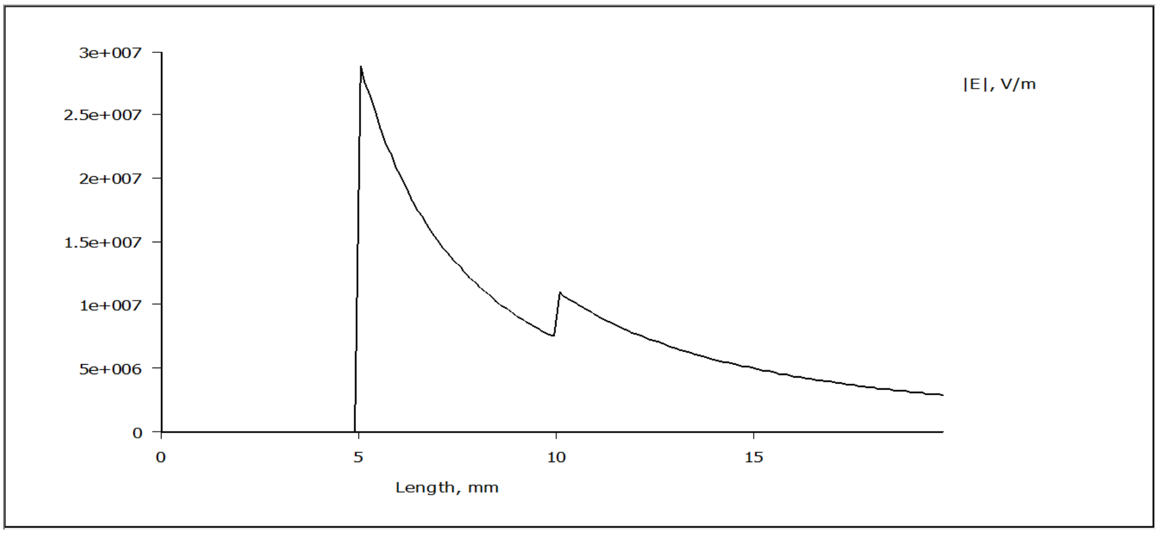


Figure 2-10|E| plot

This is what it looks like when we choose E,t plot again.

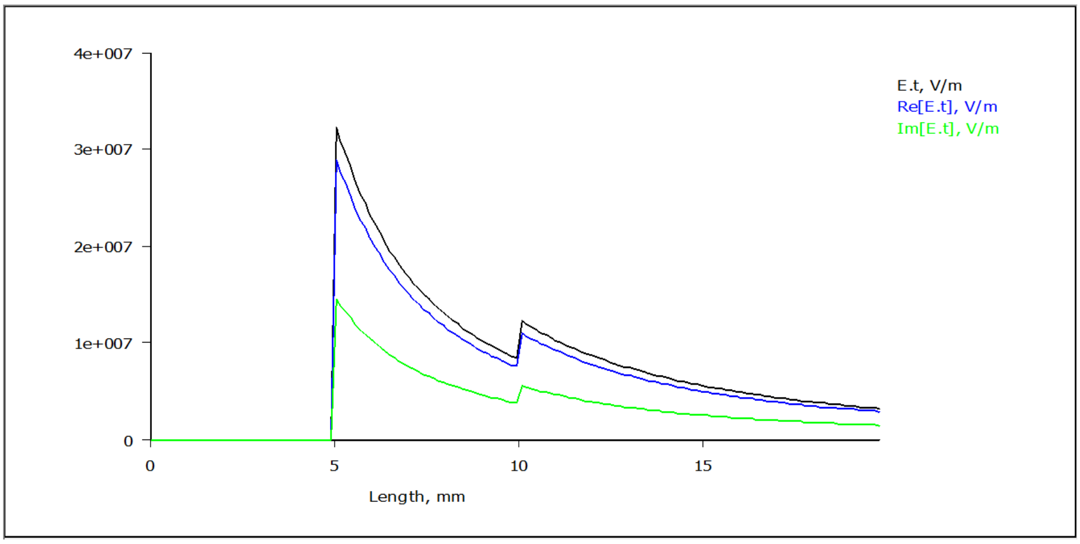


Figure 2-11E,t plot

2.2 Cable2

Assume we have a non-concentric cable. The inner cable is 3mm aside from the center. At the inner cable a voltage of 130kV (compare to the ground) is applied. (Type: AC Frequency: 50Hz DC=0V)

	Layer 1	Layer 2
σ r (S/m)	10	1

Table 2-2 Values of the electrical conductivity

Here we will draw the field profile E=f(r) of this cable as well as a plot of E=f(r).

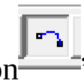
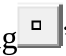
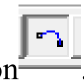
2.2.1 Create a new file.

“File”→“New”→ “Current Flow Problem”

2.2.2 Set problem definition.

Press Menu: “Problem”. Change problem type to “Planar” and units to “centimeters”.

2.2.3 Create a new model

Draw three concentric circles with given radii. To draw a set of non-concentric circles, first we need to have three concentric circles using function ”Operate on arc Segments”. First we should mark some nodes using ”Operate on nodes”, then we switch to function . Select 2 nodes one by another to draw an arc segments in between, and then we will have half of the circle. Now we need the other half so we select these 2 nodes again but this time change the selection order. In this way, we will be able to make all three circles.

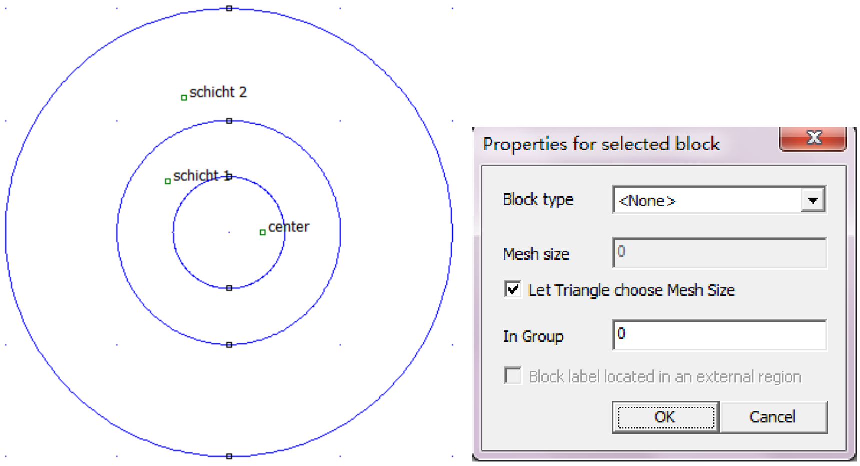


Figure 2-12New model step 1

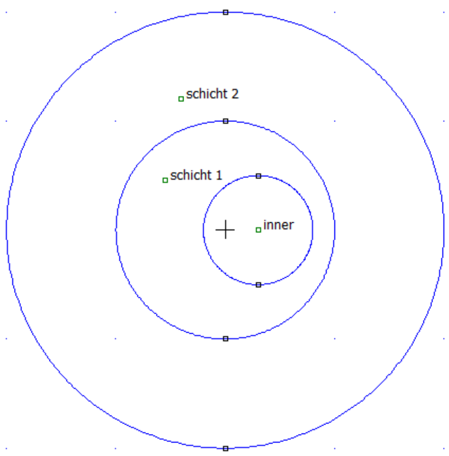


Figure 2-13 New model step 2

2.2.4 Define conductor properties

First we need to calculate the voltages on each shell.

$$\mathbf{E} = \frac{U}{d}$$

$$\mathbf{E} = \mathbf{J} \cdot \boldsymbol{\rho} = \frac{J}{\sigma}$$

$$\rightarrow \mathbf{E} \sim \mathbf{U} \sim \frac{\mathbf{1}}{\sigma}$$

$$\rightarrow \frac{\mathbf{U1}}{\mathbf{U2}} = \frac{\sigma_2}{\sigma_1} = \frac{\mathbf{1}}{\mathbf{10}}$$

Equation 6

Voltage on Layer 1 is the total voltage (130kV) from center of cable to the ground. Voltage on Layer 2 is U2.The rest layer is Ground

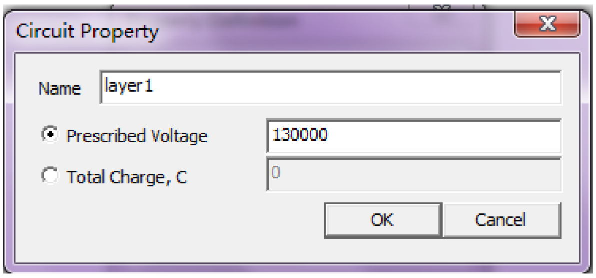


Figure 2-14 Voltage on layer 1

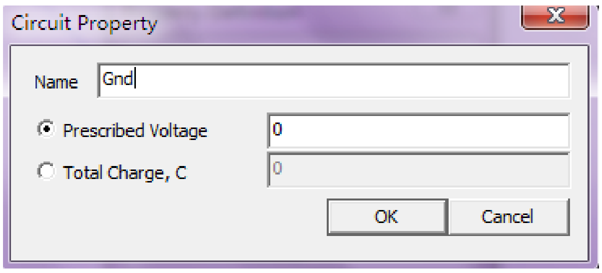


Figure 2-15 Gnd

Select an arc segment, press Space button and then in the column "in conductor", we associate them with matching conductors.
Set up the properties of conductor and material. But set the middle circle to "In conduct: None", we regard it as a non-material layer. The other settings remain the same. As shown below.

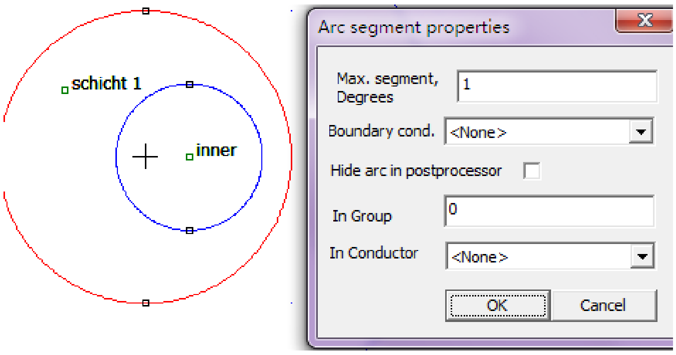


Figure 2-16 Attach conductor to its property

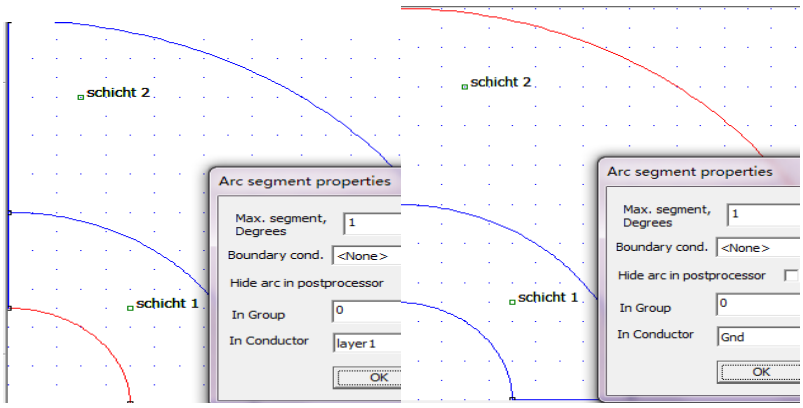


Figure 2-17 Layer 1 Gnd

2.2.5 Add materials to the model

The properties of material are already given, σ r of material in 'schicht1' is 10; σ r of material in 'schicht2'is 1. We use "Properties"→"Materials" to define them.
Here we give both σ x and σ y the same number. In this way, σ r will be determined as the value we need.
σ r =10 for schicht1. The relative electrical permittivity can't be 0, so we make it 1 here, but it doesn't influence the result.

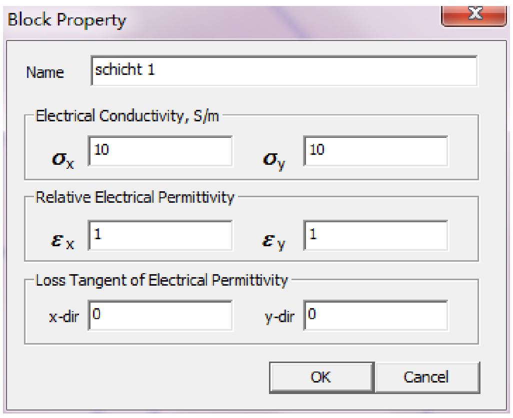


Figure 2-18 Property of material 1

σ r=1 for schicht2

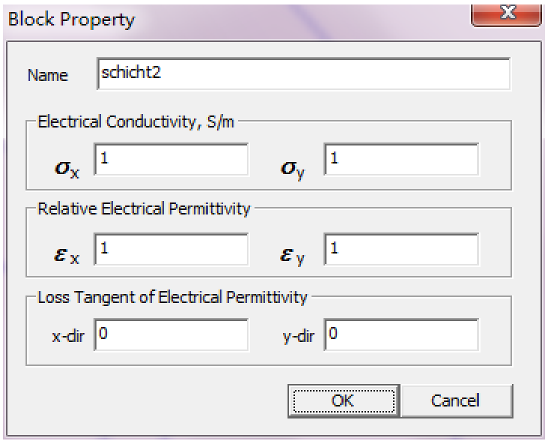


Figure 2-19Property of material 2

2.2.6 Place block labels and associate them with corresponding materials

Set the inner block as 'schicht1', the outer block as 'schicht2', using function"Operate on block labels". Left click on a closed area to mark the label, then right click on the label and press Space button to call the menu. Then we can associate them with corresponding materials.

Set the mesh size to 0.1 in this case as well.

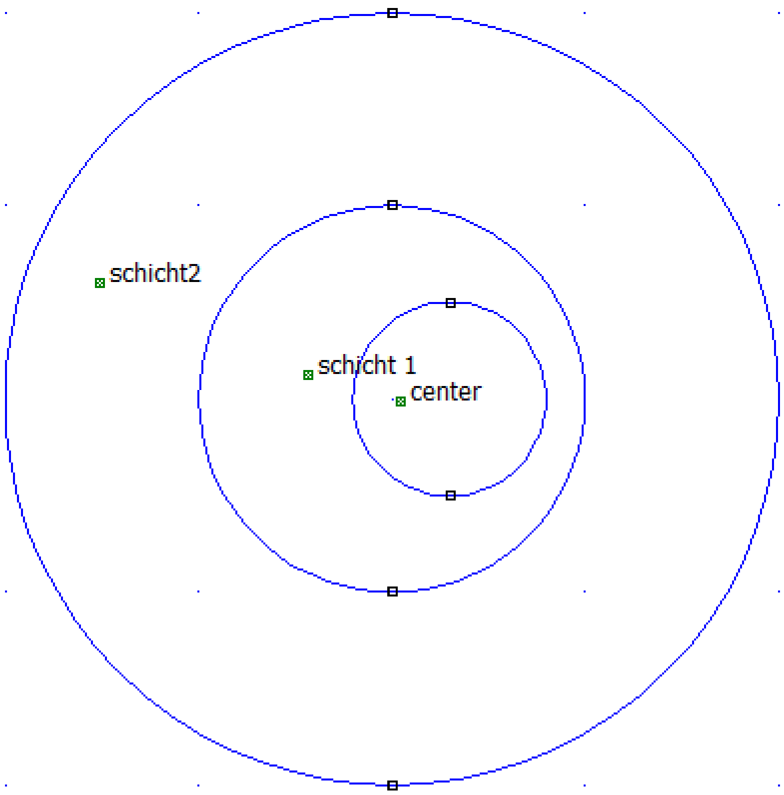


Figure 2-20 Final model

2.2.7 Generate mesh and run analysis.

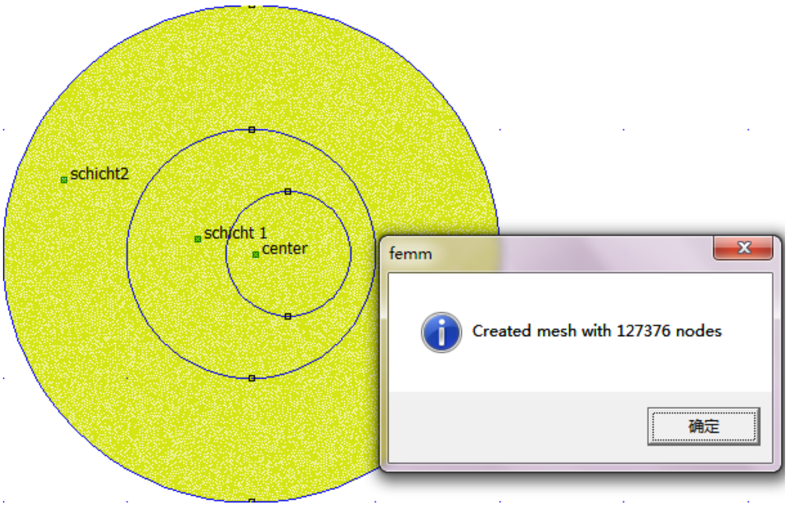


Figure 2-21 Mesh

2.2.8 Display results

This is a density plot of a cable, which is not perfectly concentric, is shown here.

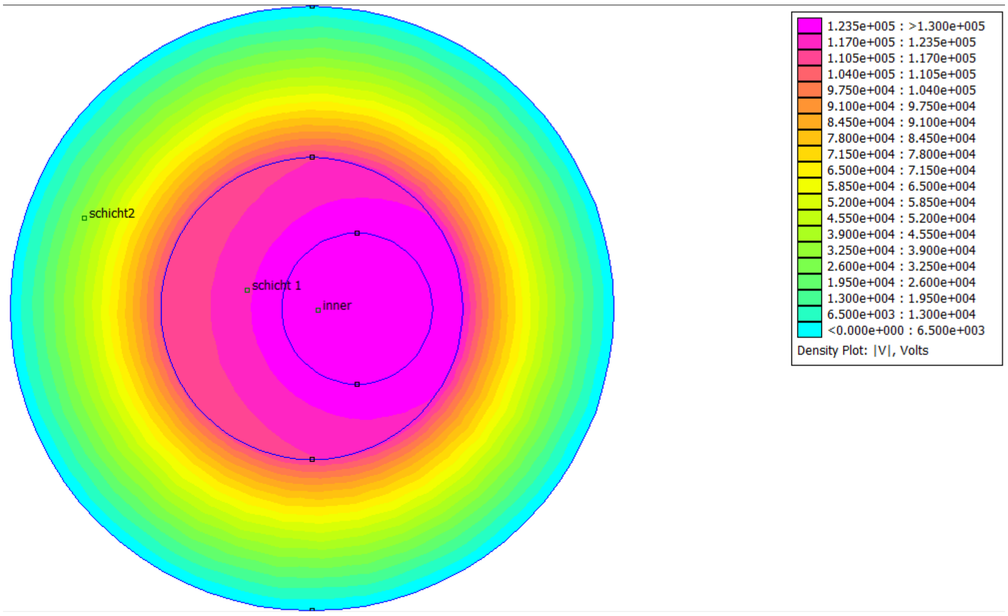


Figure 2-22 Result

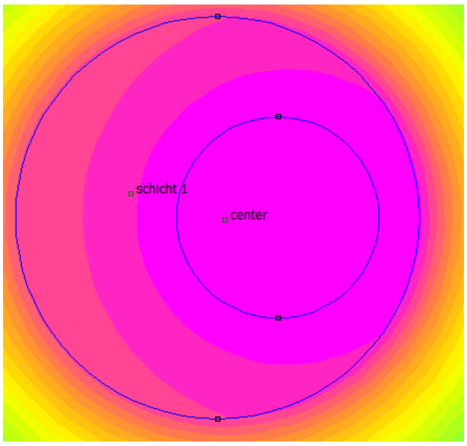


Figure 2-23 Result (zoom)

2.2.9 Plot field values

Choose contour from (3,0) to (20, 0)

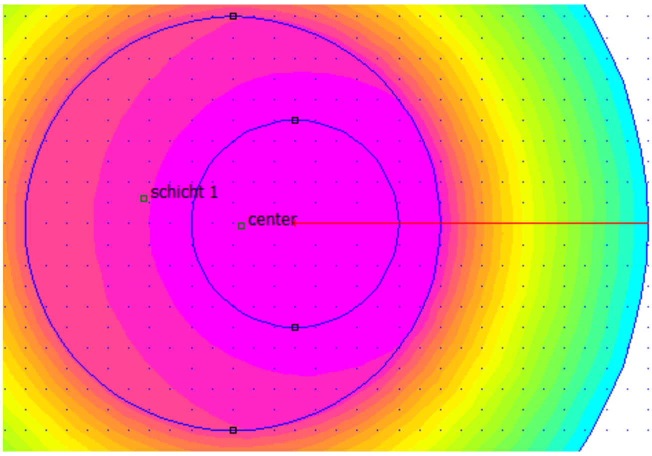


Figure 2-24 Contour

Draw contour from center of the inner circle to the outer shell. Then if we draw E,t plot here, we will get a plot with Real and Imaginary part of current.

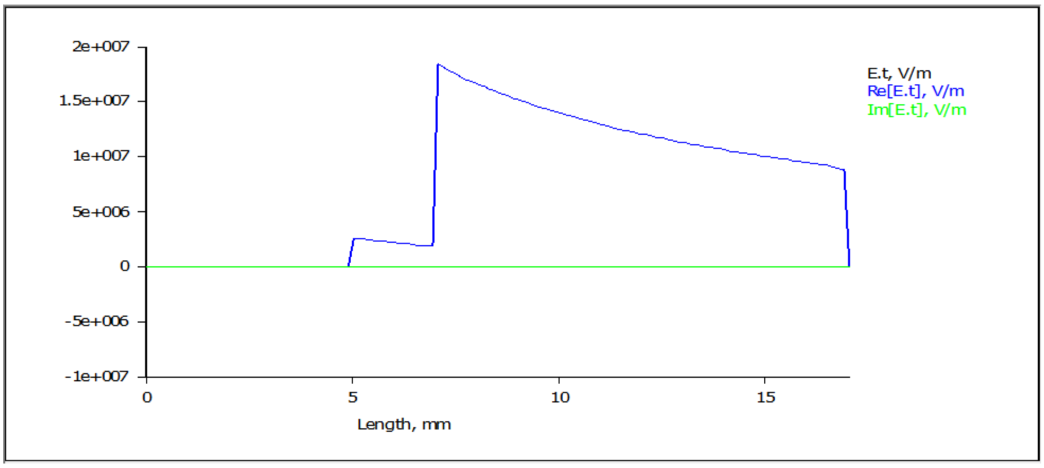


Figure 2-25E,t plot

But if we want the curve of the total current, we choose |E| (Magnitude of electrical field intensity).

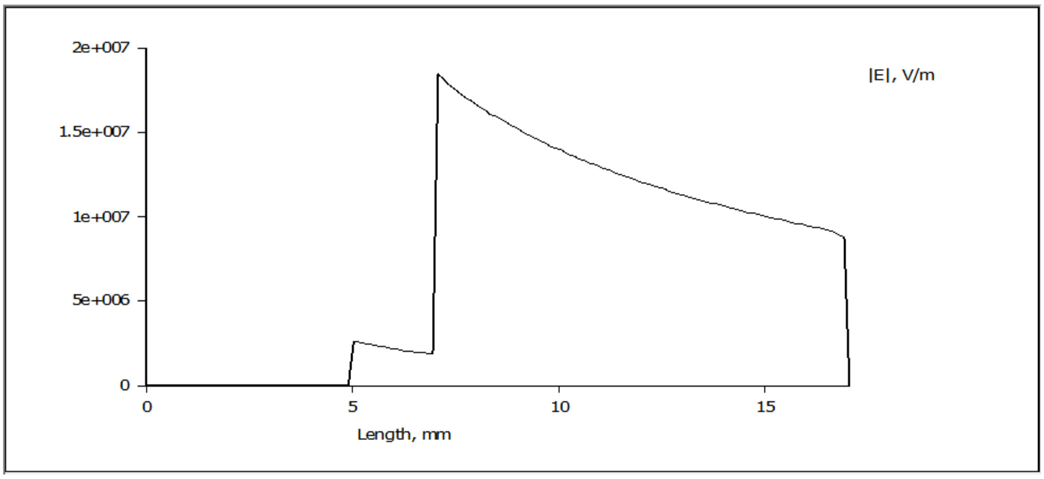


Figure 2-26 |E| plot

3. Magnetics

What is magnetics?

A magnetic field is a field of force produced by moving electric charges, by electric fields that vary in time, and by the 'intrinsic' magnetic field of elementary particles associated with the spin of the particle. There are two separate but closely related fields to which the name 'magnetic field' can refer: a magnetic B field and a magnetic H field. The magnetic field at any given point is specified by both a direction and a magnitude (or strength); as such it is a vector field. The magnetic field is most commonly defined in terms of the Lorentz force it exerts on moving electric charges.[11]

3.1 No air gap

Assume we have a square coil built up by 50 turns of copper wire (16 AWG). The length of its side is 6cm. And through the wire flows a 60A current.

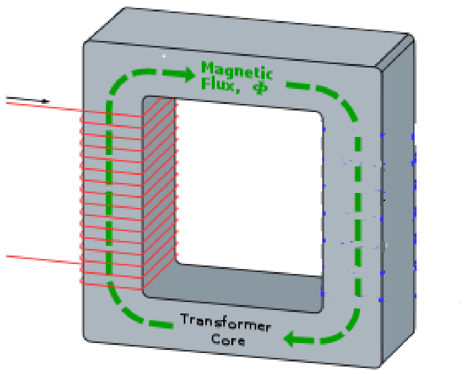


Figure 3-1 Coil wrapped up with copper wire

We will draw the field profile of its magnetic flux density and also the B- and H-field plots.

3.1.1 Create a new file

“File”→“New”→ “Current Flow Problem”

3.1.2 Set Problem Definition

Problem Type: Planar
Length Units: Centimeters
Frequency: 0
Depth: 1
Solver Precision
Min Angle: 30
AC Solver: Succ. Approx

[11]<<Electromagnetics>>, by Rothwell and Cloud

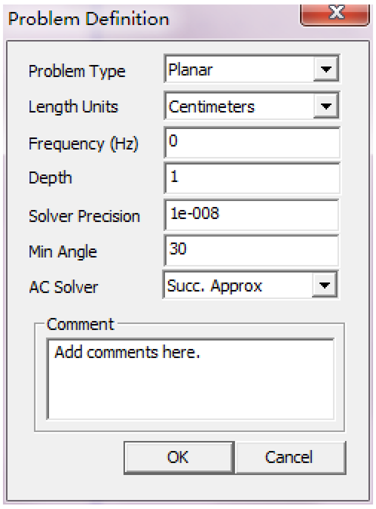


Figure 3-2 Problem definition

3.1.3 Draw boundary

Draw a boundary to be the solution region that we are interested in. The shape and area of this region can be selected as you want. Here, we draw it as a square, so that we can have an axisymmetric solution. Point nodes at (-5, -5), (-5, 11), (11, -5), (11, 11), then connect them to make a square boundary.

3.1.4 Create a new coil

Draw 2 squares in the center of boundary to make the core. Point nodes at (0, 0), (0, 6), (6, 0), (6, 6). Connect the nodes to make the first square. Point nodes at (1, 1), (1, 5), (5, 1), (5, 5), connect them to make the second.

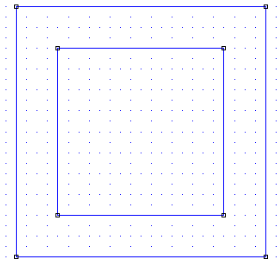
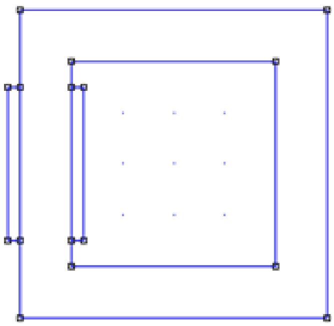


Figure 3-3 Core

Point nodes at (-0.25, 4.5), (-0.25, 1.5), (0, 4.5), (0, 1.5), (1, 4.5), (1, 1.5), (1.25, 4.5), (1.25, 1.5). Then connect them as shown to make the coil.



.

Figure 3-4 Coil

3.1.5 Add material properties

"Properties"→"Materials Library"

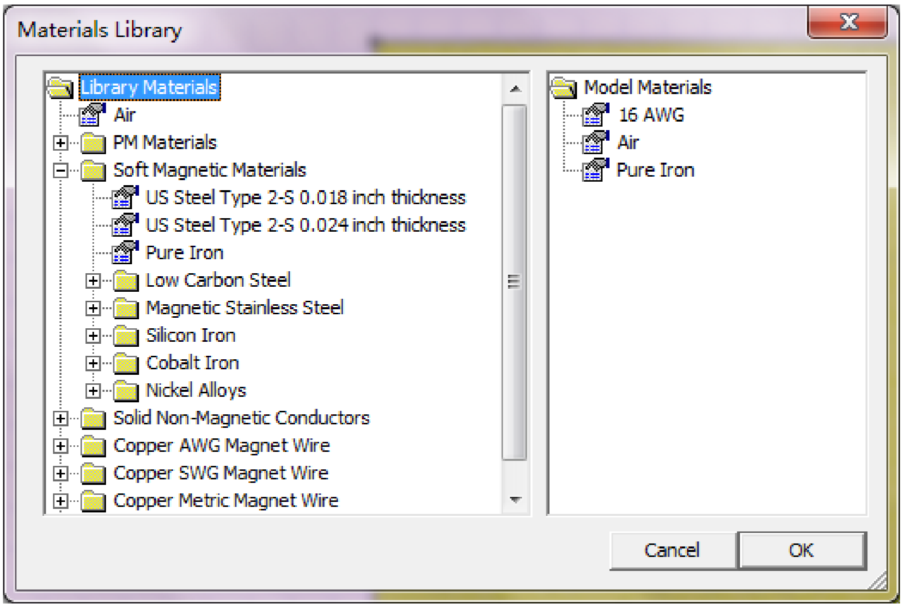


Figure 3-5 Material Library

Find the material we need in this library and drag it to the "Model Materials" box. Here we need copper 16 AWG, which is under "Copper AWG Magnet Wire", Pure Iron under "Soft magnetic material". And also we need material Air.

3.1.6 Define boundary

Select "Properties"→"Boundary" from the main menu , then click on the "Add Property" button. Rename the boundary to "A=0"and Select type to "Prescribed A", which means here we selected Dirichlet to be the boundary condition. Fill all the values with 0. Then click on "OK".

(There are 5 boundary conditions for magnetic problems:

Dirichlet. In this type of boundary condition, the value of potential *A* or *V* is explicitly defined on the boundary.

Neumann. This boundary condition specifies the normal derivative of potential along the boundary.

Robin. The Robin boundary condition is sort of a mix between Dirichlet and Neumann, prescribing a relationship between the value of *A* and its normal derivative at the boundary.

Periodic.*A* periodic boundary conditions joins two boundaries together. In this type of boundary condition, the boundary values on corresponding points of the two boundaries are set equal to one another.

Antiperiodic. The antiperiodic boundary condition also joins together two boundaries. However, the boundary values are made to be of equal magnitude but opposite sign.)

3.1.7 Define circuits.

Select menu "Properties"→"Circuits". Add a circuit named "I" with type "Series". The value of circuit can be defined as we need. Here we set it to 60A just to make an example.

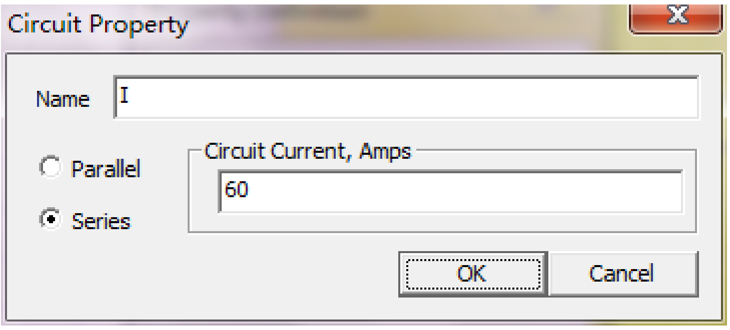


Figure 3-6 Circuit Property

3.1.8 Place Block Labels

Put one label on each block as shown below.

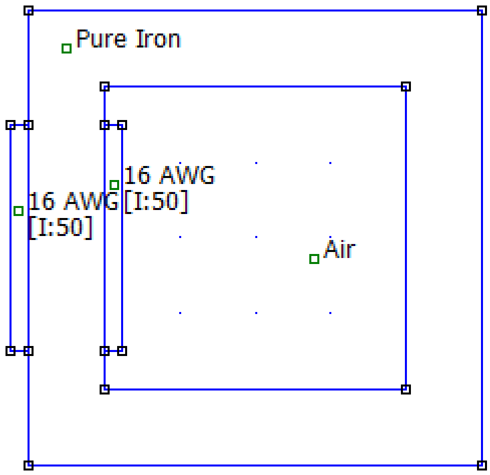


Figure 3-7 Labels

3.1.9 Associate Properties with Block Labels

Right click on the inner label under function "Operate on the block label". Set it to "air". Then select the label on coil. Call the dialogue box, set block type to "16AWG", in circuit "I", number of turns to "50", denoting that the region is filled with 50 turns wrapped in a counter-clockwise direction. And if we want to denote that the turns are wrapped in a clockwise direction instead, we could change the current to -I. Also, we should uncheck the box "Let triangle choose Mesh Size" and make the mesh size to 0.1, which can let the program draw more meshes.

The last label will be set to "Air" too.

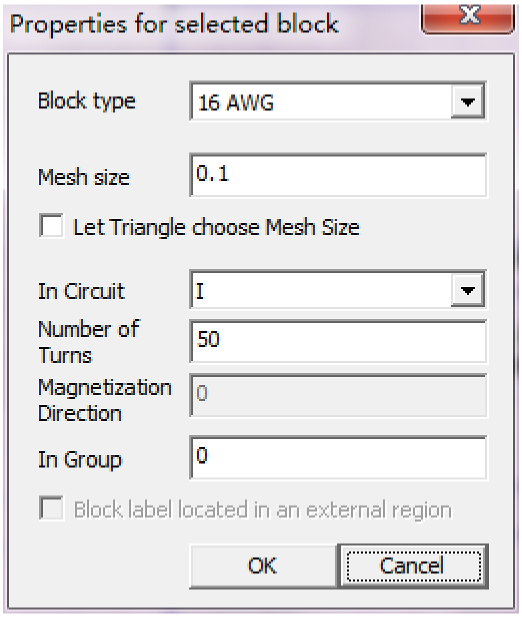


Figure 3-8 Block Type

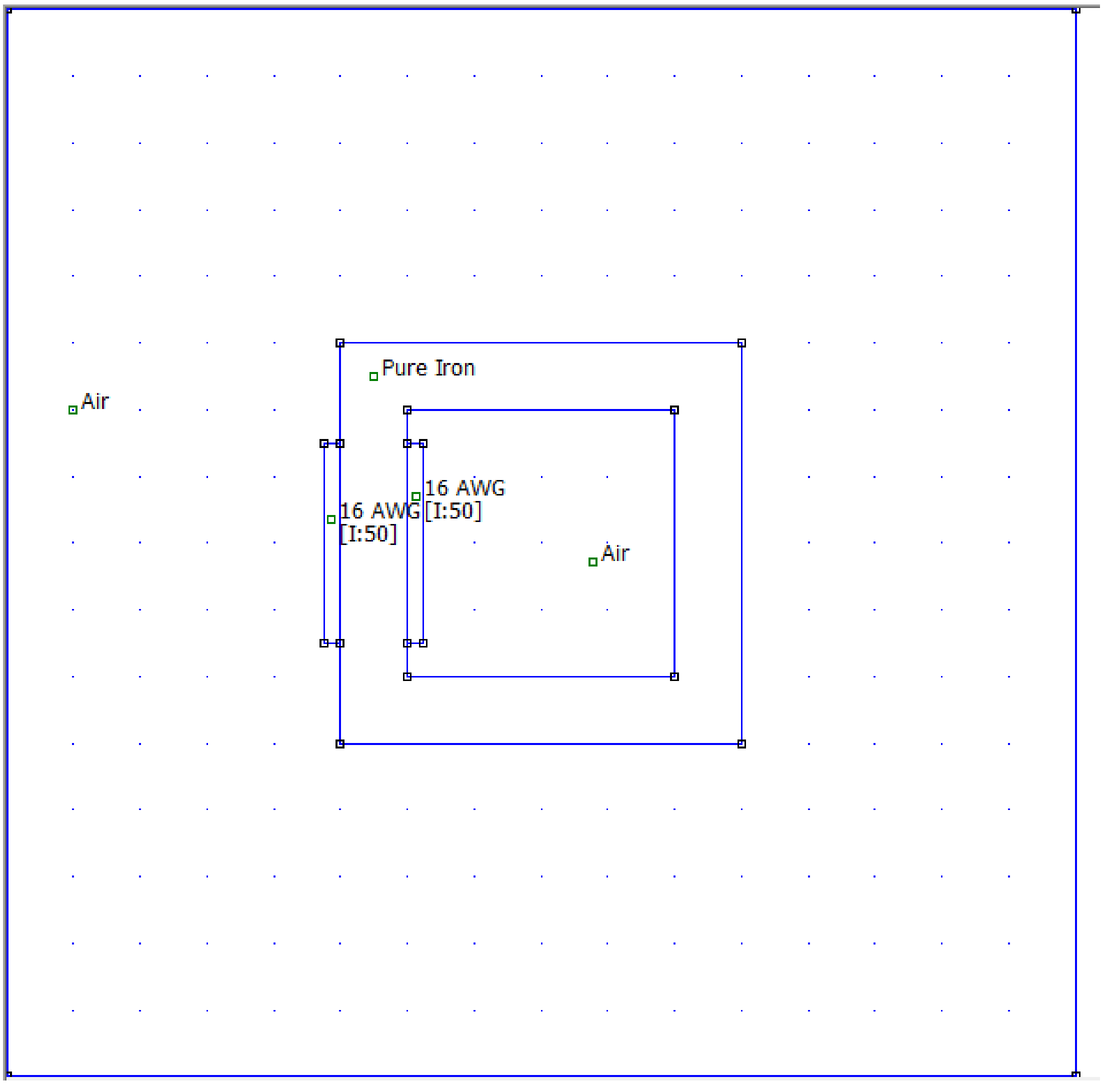


Figure 3-9 Final model

This is the finished model.

3.1.10 Associate Properties with boundaries.

Select all four sides of the outer square. Press Space bar to set them into boundary type “A=0.

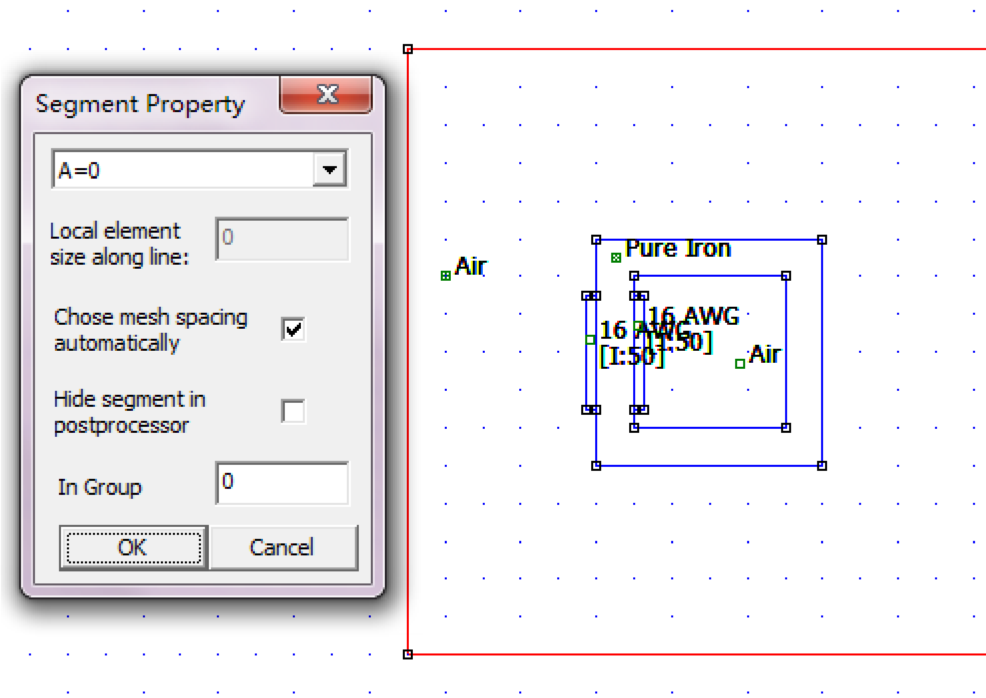
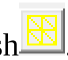


Figure 3-10 Boundary Property

3.1.11 Generate Mesh and Run FEA

Now save the file and click on the toolbar button with yellow mesh. If the mesh spacing seems to fine or too coarse you can select block labels or line segments and adjust the mesh size defined in the properties of each object.

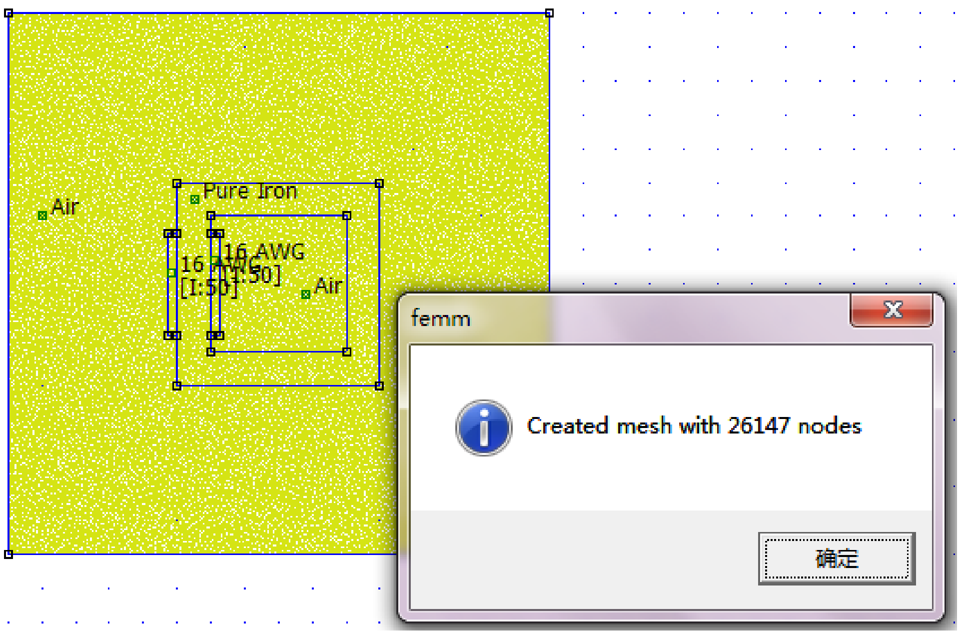


Figure 3-11 Mesh

3.1.12Analysis result

Run analysis first. Click on the glasses icon to view the analysis results.

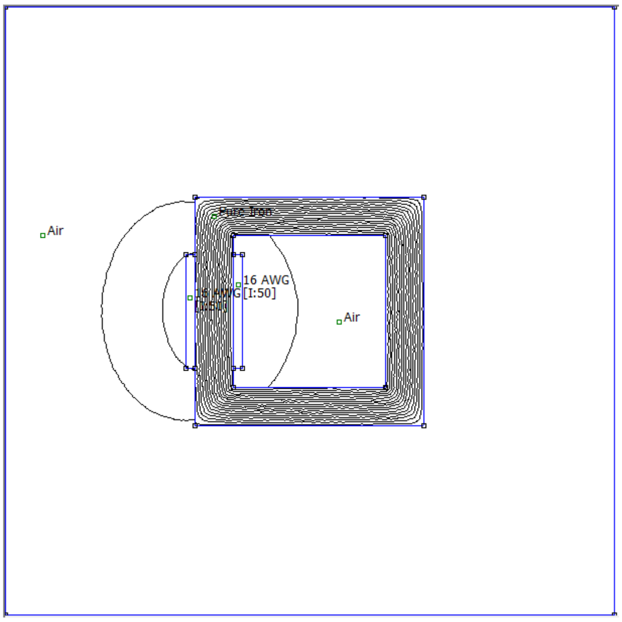


Figure 3-12 Result

And we can also choose to show vectors in our result. Click on button. For example, we want to plot the vector for B field. Scaling factor can affect the scale of arrows.

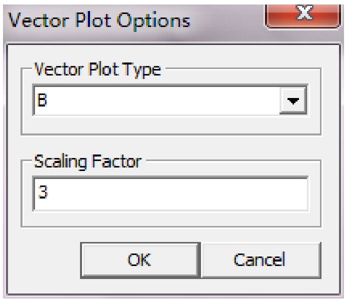


Figure 3-13 Vector Plot Options

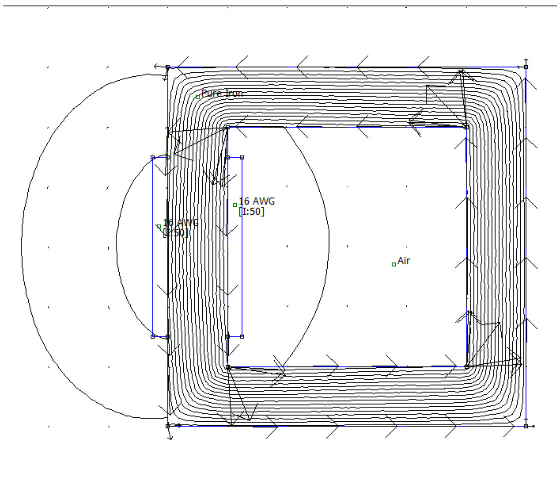


Figure 3-14 Result with vector

Click on button. Then in the dialogue box, check the option "Show density plot"

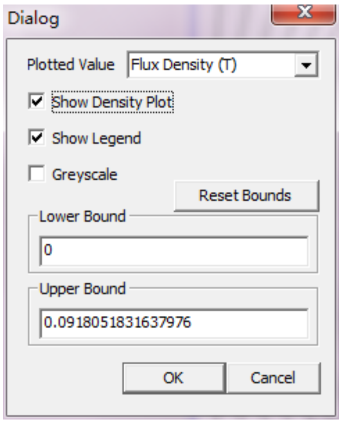


Figure 3-15 Dialog

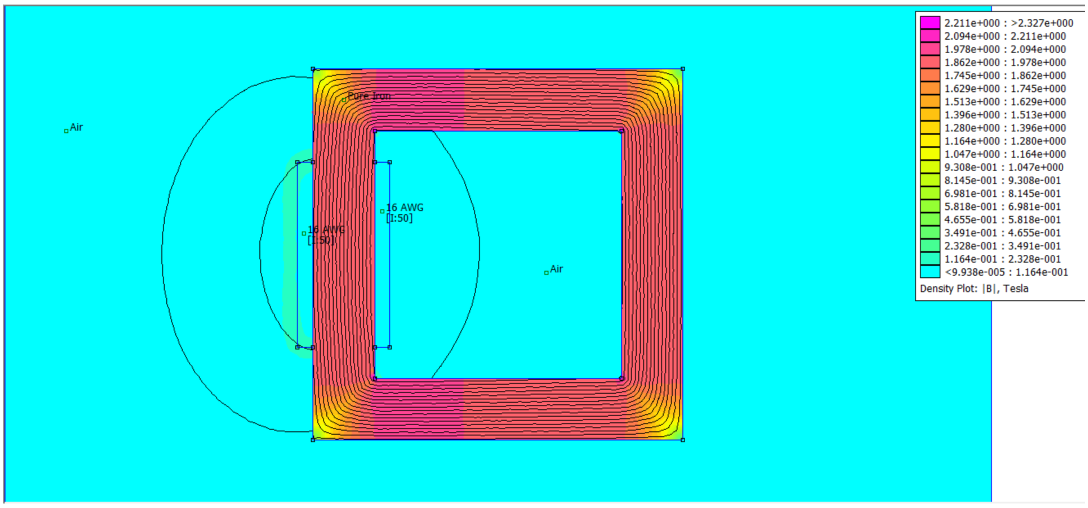


Figure 3-16 Result with density plot

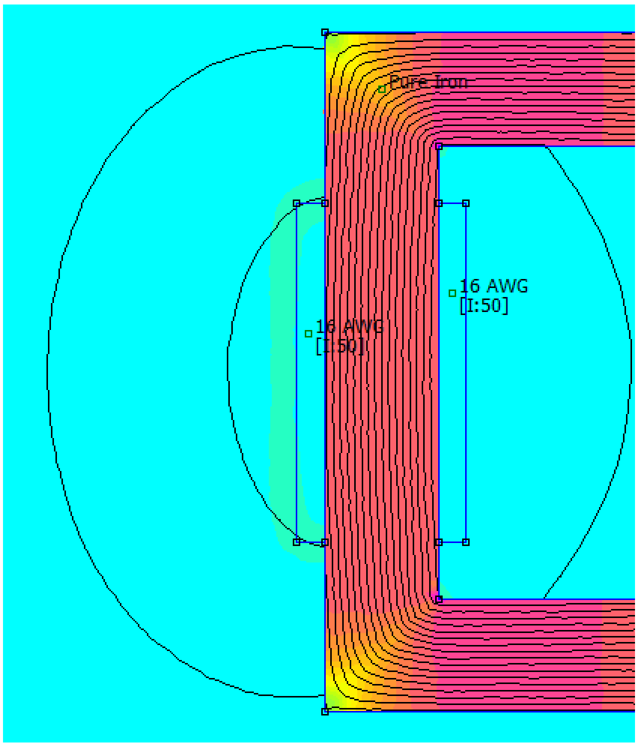


Figure 3-17Result with density plot (zoom)

3.1.13 Plot Field Values

First, draw a contour from center(0, 3) to the outer boundary (-5, 3).

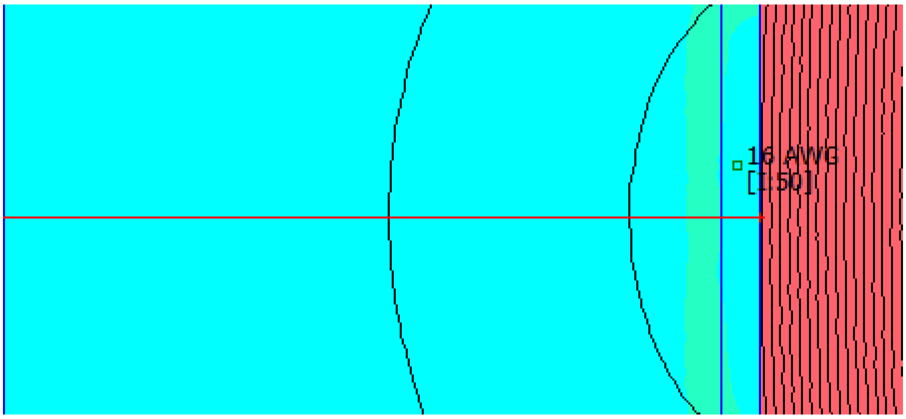
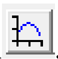


Figure 3-18 Contour

Then click on button , choose to plot type |B|“Magnitude of flux density”.

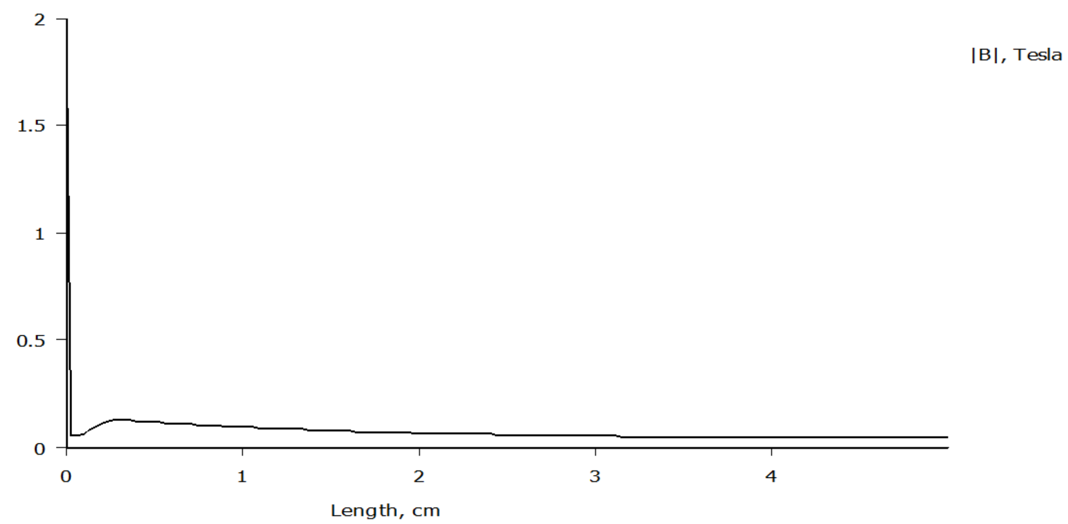


Figure 3-19 |B| plot

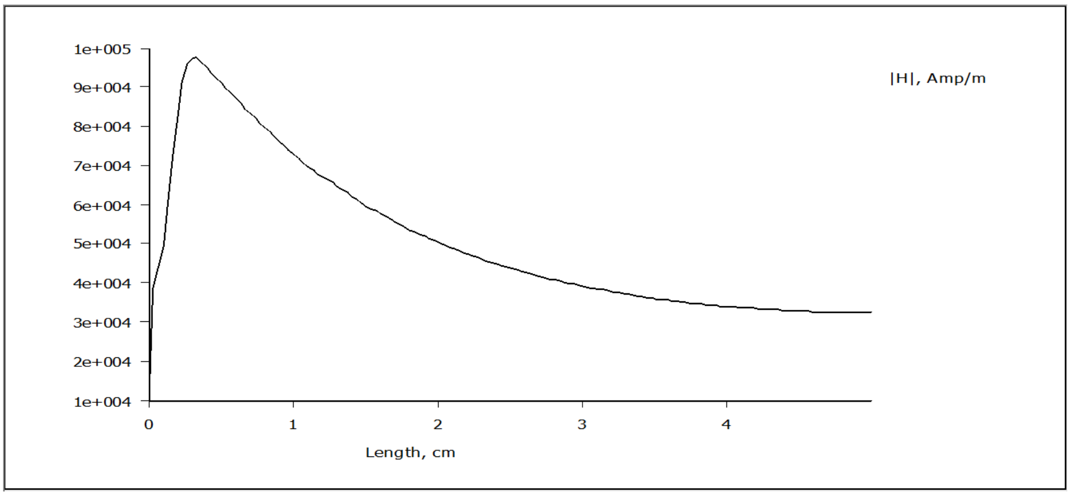
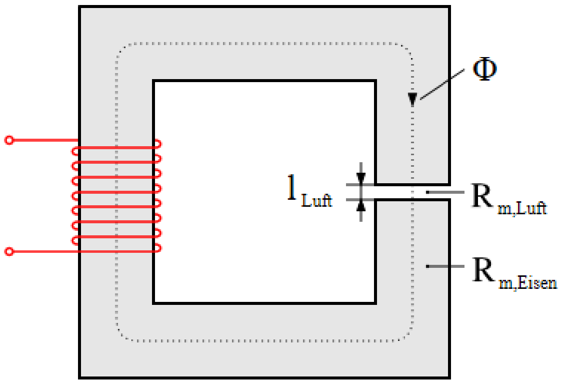


Figure 3-20 |H| plot

3.2 Air gap

Here we have a square coil with air gap which is built up by 50 turns of wire. The wire is copper 16 AWG. The length of its side is 6cm and the length of air gap is 0.75cm. Through the wire flows a current of 60A.



[12]

Figure 3-21 Coil with air gap

Please draw a plot with magnetic flux density.

3.2.1 Create new file

“File”→“New”→ “Current Flow Problem”

3.2.2 Set Problem Definition

Problem Type: Planar
Length Units: Centimeters
Frequency: 0
Depth: 1
Solver Precision
Min Angle: 30
AC Solver: Succ. Approx

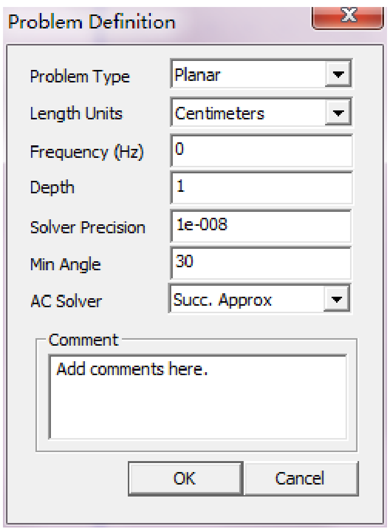


Figure 3-22 Problem definition

[12] http://upload.wikimedia.org/wikipedia/commons/1/13/EisenkernMitLuftspalt.svg

3.2.3 Draw boundary

Draw a boundary to be the solution region that we are interested in. The shape and area of this region can be selected as you want. Here, we draw it as a square, so that we can have a axisymmetric solution. Point nodes at (-15, -10), (-15, 14), (20, 14), (20, -10), then connect them to make a square boundary.

3.2.4 Create a new core and coil

Draw a model with air gap the center of boundary to make the core.
Point nodes at (0, 0), (0, 6), (6, 6), (6, 0), (1, 5), (5, 1), (5, 5), (1, 5), (5, 3.5), (6, 3.5), (5, 2.75), (6, 2.75).
Point nodes at (-0.25, 4.5), (-0.25, 1.5), (0, 4.5), (0, 1.5), (1, 4.5), (1, 1.5), (1.25, 4.5), (1.25, 1.5). Then connect them as shown to make the coil.

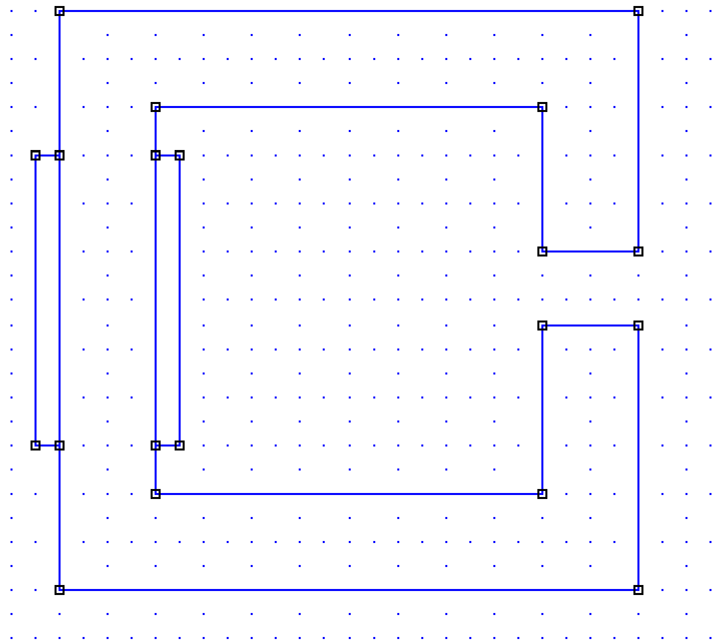


Figure 3-23 Coil

3.2.5 Add material properties

"Properties"→"Materials Library"
Find the material we need in this library and drag it to the "Model Materials" box. Here we need material "Air" and "16 AWG".

3.2.6 Define boundary

Select "Properties"→"Boundary" from the main menu , then click on the "Add Property" button. Rename the boundary to "A=0"and Select type to "Prescribed A", which means here we selected Dirichlet to be the boundary condition. Fill all the values with 0. Then click on "OK".

3.2.7 Define circuits.

Select menu "Properties"→"Circuits". Add a circuit named "I" with type "Series". The value of circuit can be defined as we need. Here we set it to 60A just to make an example.

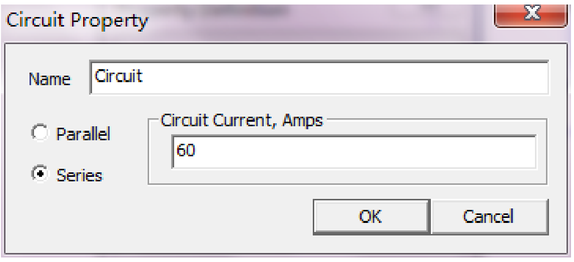


Figure 3-24 Circuit

3.2.8 Place Block Labels

Put one label on each block as shown below.

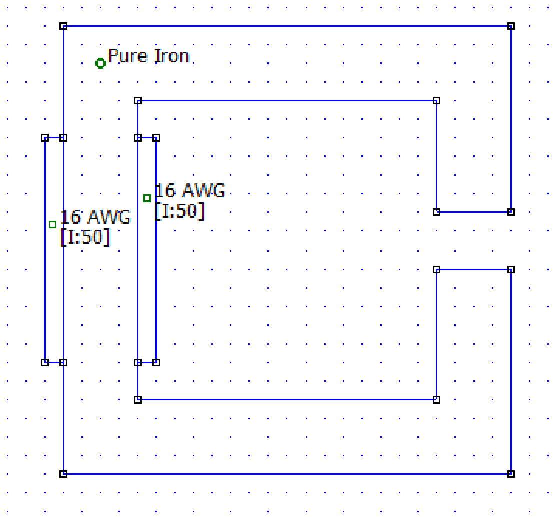


Figure 3-25 Labels

3.2.9 Associate Properties with Block Labels

Right click on the inner label under function “Operate on the block label”. Set it to “air”. Then select the label on coil. Call the dialogue box, set block type to “Coil”, in circuit “I”, number of turns to “50”, denoting that the region if filled with 50 turns wrapped in a counter-clockwise direction. Also, we should uncheck the box “Let triangle choose Mesh Size” and make the mesh size to 0.2, which can let the program draw more meshes.

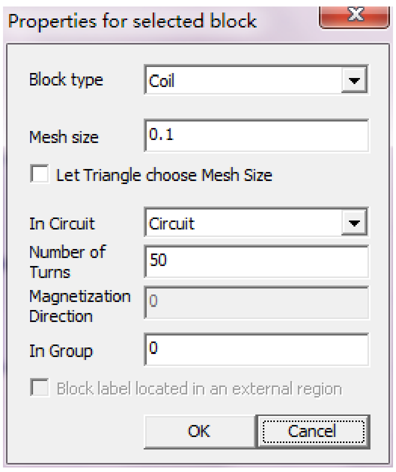


Figure 3-26 Block type

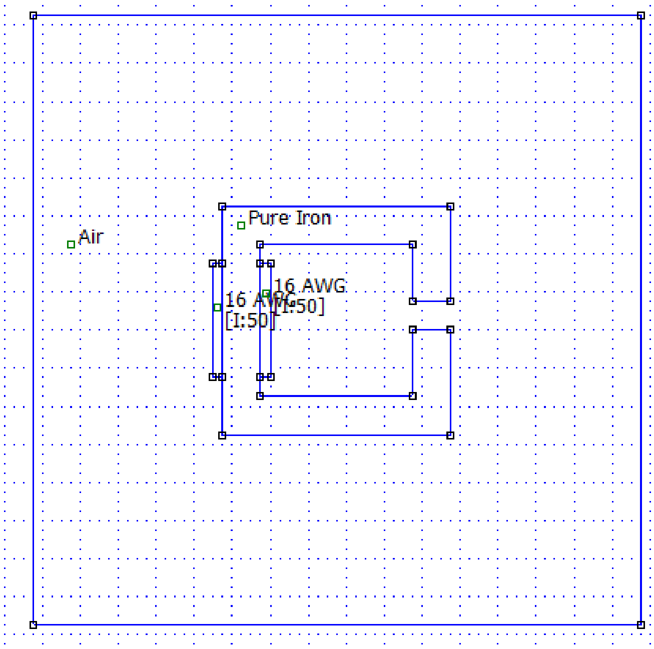


Figure 3-27 Final model

This is the finished model.

3.2.10 Associate Properties with boundaries.

Select all four sides of the outer square. Press Space bar to set them into boundary type "A=0.

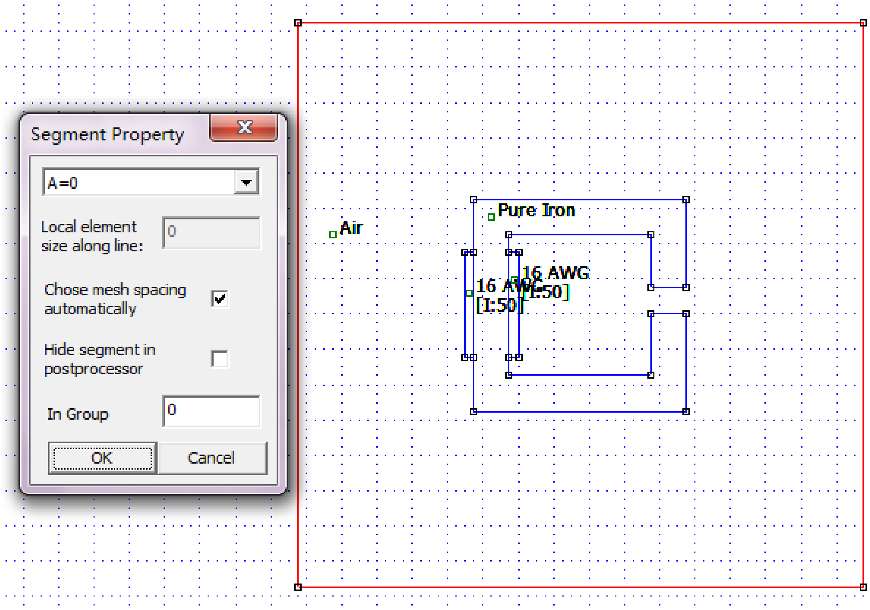
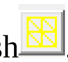


Figure 3-28 Boundary property

3.2.11 Generate Mesh and Run FEA

Now save the file and click on the toolbar button with yellow mesh . If the mesh spacing seems to fine or too coarse you can select block labels or line segments and adjust the mesh size defined in the properties of each object.

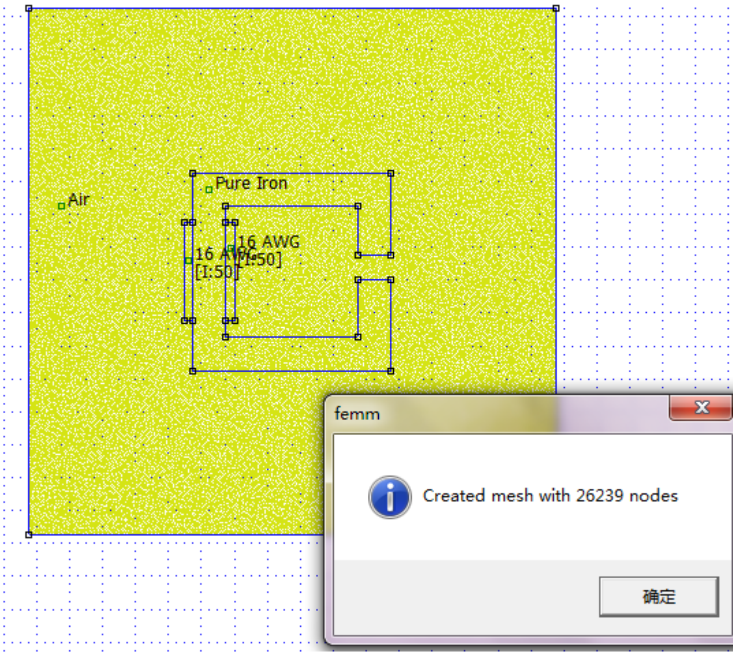


Figure 3-29 Mesh

3.2.12Analysis result

Run analysis first.Click on the glasses  icon to view the analysis results.

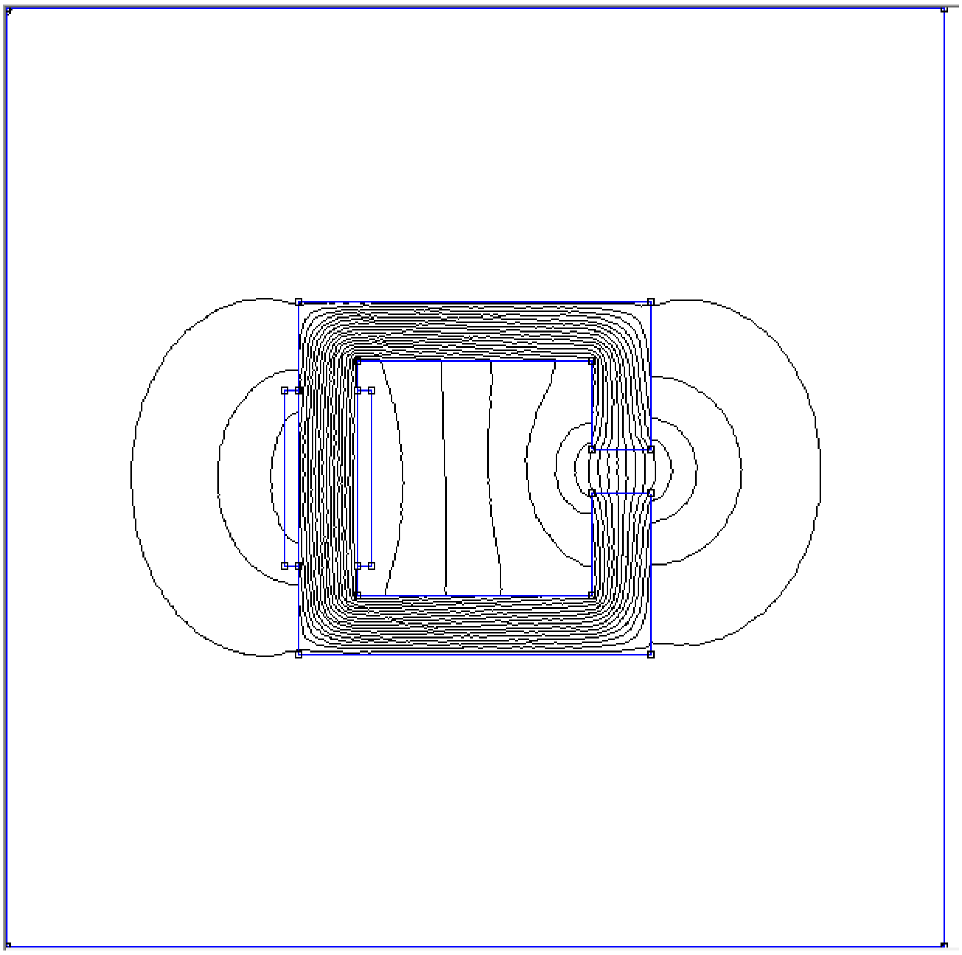


Figure 3-30 Result

And we can also choose to show vectors in our result. Click on button . For example, we want to plot the vector for B field. Scaling factor can affect the scale of arrows.

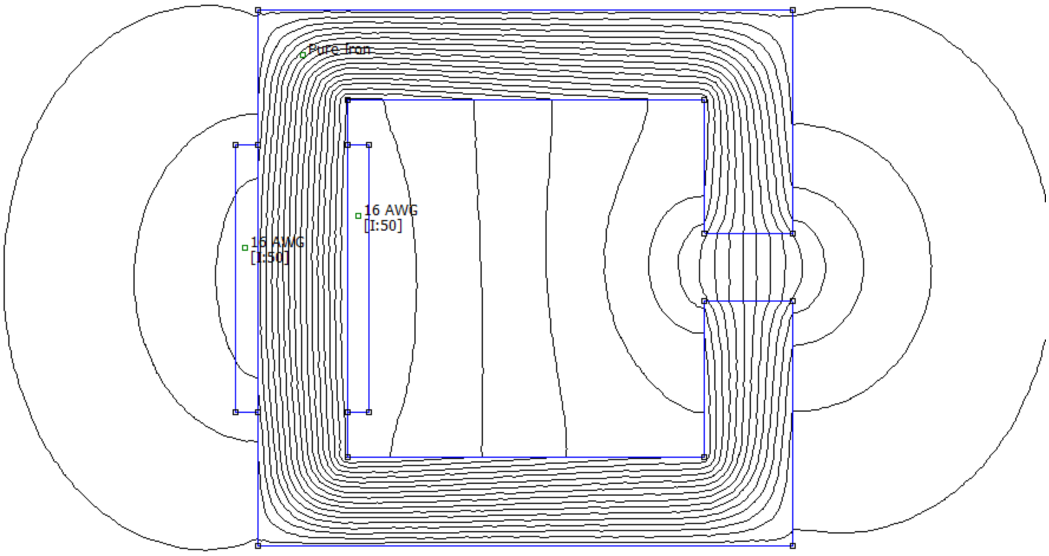


Figure 3-31 Result with vectors

Click on button . Then in the dialogue box, check the option “Show density plot”

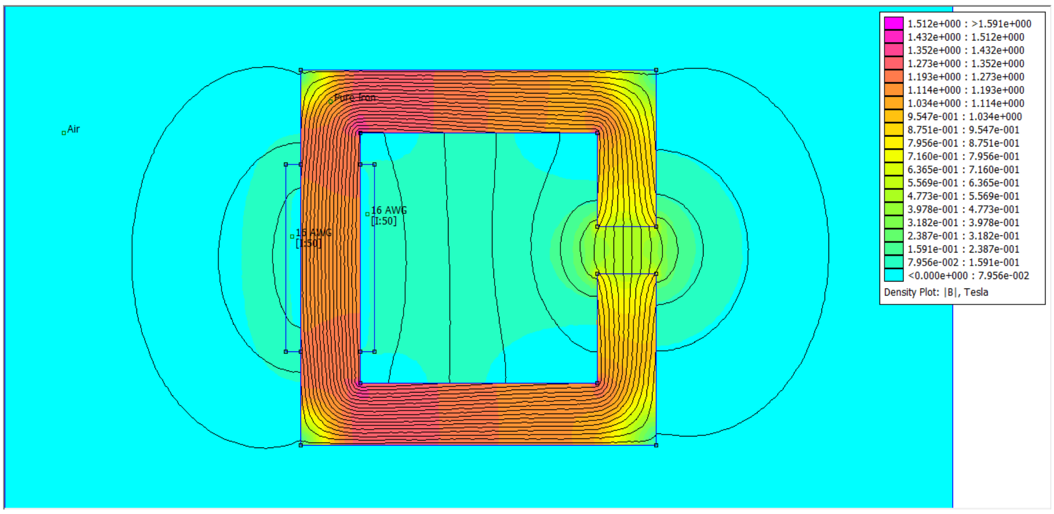


Figure 3-32 Result with density plot

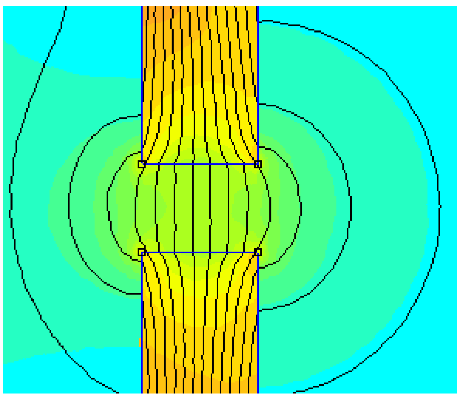
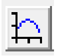


Figure 3-33 Result (zoom)

3.2.13 Plot Field Values

Draw contour from (3, 3.1) to (9, 3.1), so it will be across the air gap right in the middle.

Then click on  and select |B| plot.

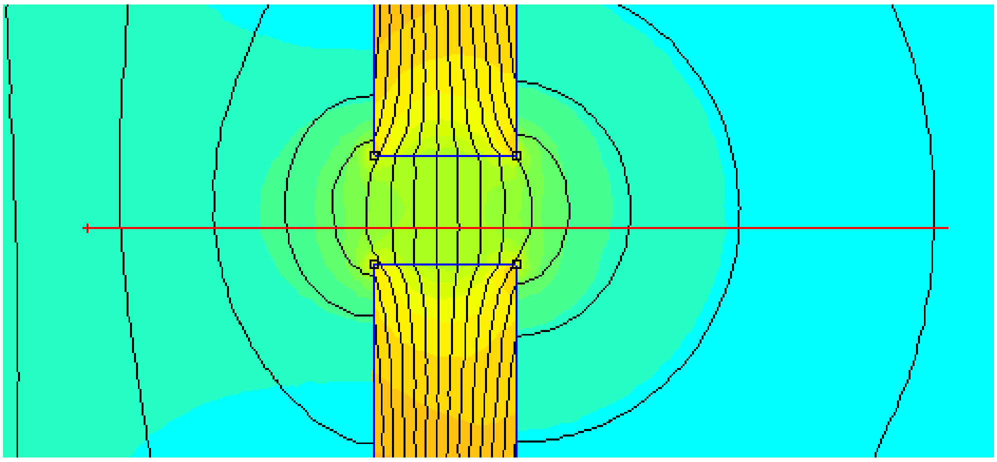


Figure 3-34 Contour

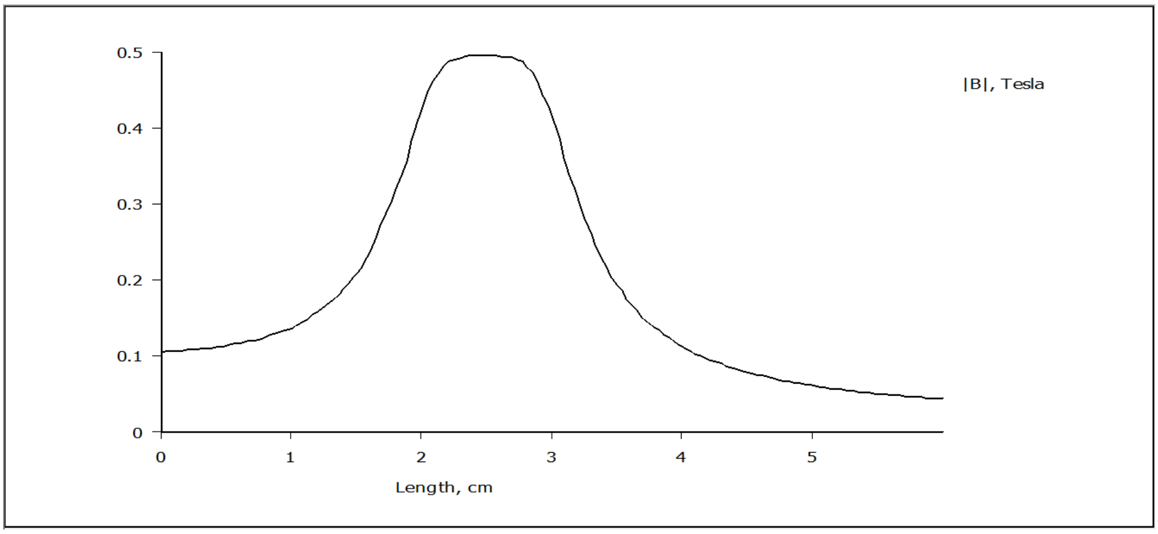


Figure 3-35 |B| plot

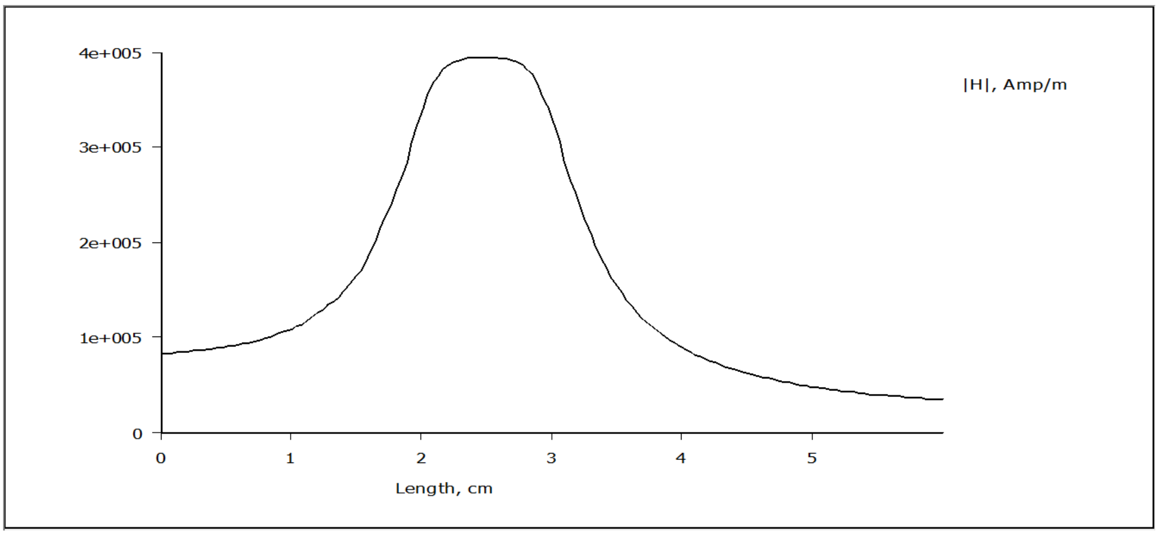


Figure 3-36 |H| plot

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- http://img.tfd.com/mgh/cep/thumb/Magnetic-circuit-with-an-air-gap.jpg

List of figures

List of tables

List of Equations

List of Files

Cable1.FEE
Cable 2.FEE
hollow sphere 1.FEE
hollow sphere 2.FEE
Plate capacitor.FEE
Capacitors- Plate.FEE
Capacitors- Cylinder.FEE
Current1.FEC
Current2.FEC
No air gap.FEM
Air gap.FEM