Created in COMSOL Multiphysics 6.2

FEM Resistor in Circuit

Introduction

This introductory model illustrates two different ways to couple an electrical circuit model to a finite element simulation. The finite element part represents a cylindrical resistor in the circuit, and will be coupled to the circuit by either using two External I-Terminal features or by using an External I vs. U feature. Differences between the two approaches will then be highlighted.

Model Definition

The electrical circuit is the same in both cases and consists of three resistors (one of them being the FEM model) and a voltage source connected in series. The difference lies in how this circuit is connected to the finite element model. In the first case, two Terminal features are added to the two ends of the cylinder in the Electric Currents physics interface - each of them connected to an External I-Terminal feature in the Electrical Circuit physics interface. An External I-Terminal feature is only applied to a single node in the circuit, which is why two of them are needed.

In the second case, a single External I vs. U feature is used in the Electrical Circuit physics interface. This feature is connected to a Terminal feature in the Electric Currents model. The External I vs. U feature has two nodes, as it represents a differential external voltage measurement. This means that instead of having a terminal at each end of the cylinder, one end needs to be at a local ground. This is done by adding a Ground feature in the Electric Currents interface.

Results and Discussion

The electric potential in the cylindrical resistor in the first and second cases is shown in Figure 1 and Figure 2, respectively. Note that even though the absolute values of the potential differ between the two cases, the voltage drop over the resistor is still the same. In the case with two terminal features, there is one consistent electric potential definition in the model and just one single ground reference. This means that the values plotted in Figure 1 agree with the node voltages in the circuit. However, when having a local ground in the finite element model, there will be two shifted electric potentials - one in the Electric Currents interface and one in Electrical Circuit interface. As a result, the absolute values plotted in Figure 2 do not agree with the corresponding node voltages in the circuit. As long as this is properly accounted for, it does not make a difference, as voltage drops and currents will be the same in both cases. The node voltages along with the computed resistance of the cylinder are evaluated in the model.

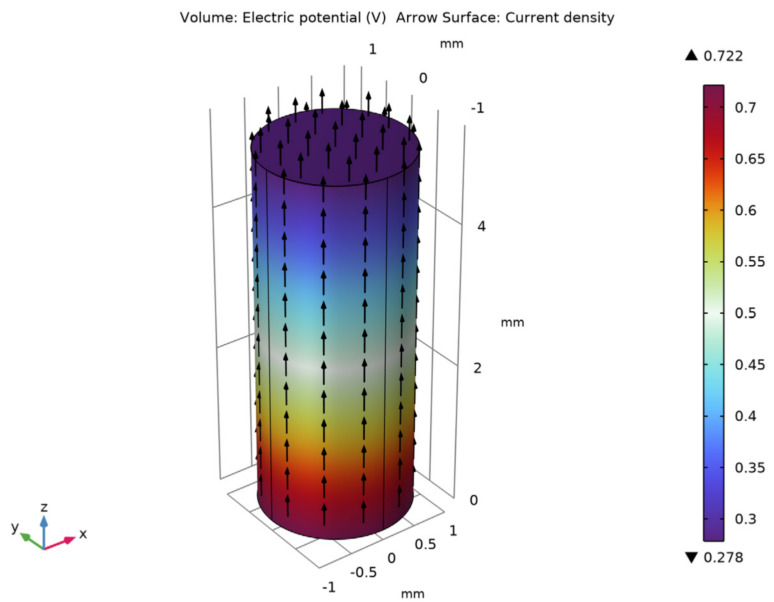

Figure 1: The top and bottom electric potential values in the FEM model are coupled separately to the node voltages in the circuit. No local ground is used or required in the FEM model and the electric potential is consistently defined in both the FEM and the circuit part of the model.

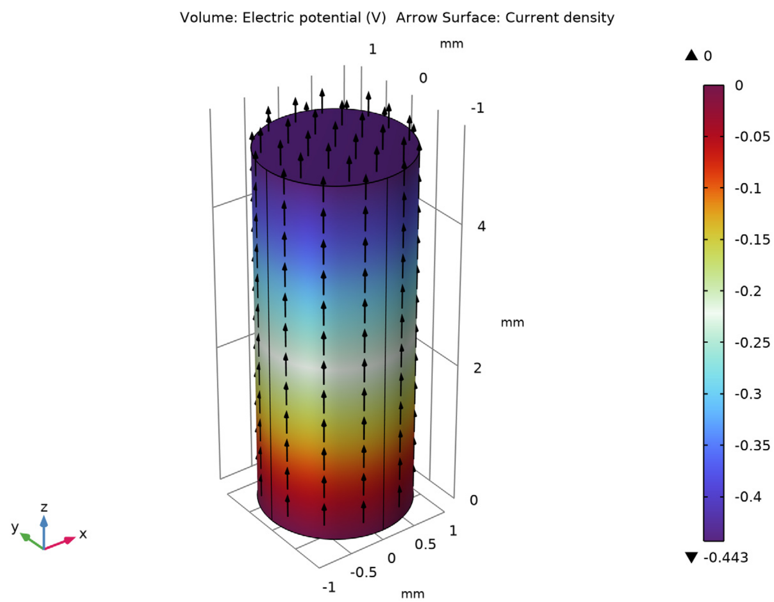

Figure 2: The potential difference between bottom and top in the FEM model is coupled as a difference between two node voltages in the circuit. A local ground is used in the FEM model. The electric potential is not consistently defined in the FEM and circuit parts of the model whereas potential differences within each part of the model as well as electric field and currents are identical to when using a consistent electric potential definition.

To conclude both presented approaches will, for a single circuit device (resistor etc.) in the FEM model, give correct results when it comes to currents and node voltages in the circuit as well as for current density and electric field in the FEM model. For FEM models representing, in the same geometry, more than one circuit device, the first modeling method is the preferred choice. This is because any coupling between the devices within the FEM model requires the electric potential definition being consistent throughout the entire coupled model.

Application Library path: `ACDC_Module/Electromagnetics_and_Circuits/circuit_fem_resistor`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **AC/DC>Electric Fields and Currents>Electric Currents (ec)**.

3 Click **Add**.

4 In the **Select Physics** tree, select **AC/DC>Electrical Circuit (cir)**.

5 Click **Add**.

6 Click **Study**.

7 In the **Select Study** tree, select **General Studies>Stationary**.

8 Click **Done**.

First, define some parameters that will be used when building the model.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
sigma	1e3[S/m]	1000 S/m	
R1	1[Ω]	1 Ω	
R2	1[Ω]	1 Ω	
L	5[mm]	0.005 m	
r	1[mm]	0.001 m	

GEOMETRY 1

Set the length unit of the model to millimeters, and create the cylinder that represents a resistor in the circuit.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **mm**.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `r`.

4 In the **Height** text field, type `L`.

Now, add a material with a conductivity that is representative of a resistor.

MATERIALS

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, locate the **Material Contents** section.

3 In the table, enter the following settings:

Property	**Variable**	**Value**	**Unit**	**Property group**
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	`sigma`	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1	1	Basic

Add two Terminal features, one for each end of the resistor. In order to connect these to the Electrical Circuit interface, set the Terminal type in each feature to Circuit.

ELECTRIC CURRENTS (EC)

Terminal 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Electric Currents (ec)** and choose the boundary condition **Terminal**.

2 Select Boundary 4 only.

3 In the **Settings** window for **Terminal**, locate the **Terminal** section.

4 From the **Terminal type** list, choose **Circuit**.

Terminal 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Terminal**.

2 Select Boundary 3 only.

3 In the **Settings** window for **Terminal**, locate the **Terminal** section.

4 From the **Terminal type** list, choose **Circuit**.

Finally, add the remaining components to the circuit in the Electrical Circuit physics interface. Add two resistors, a voltage source, and two External I-Terminal features that connect to the two Terminal features.

ELECTRICAL CIRCUIT (CIR)

In the **Model Builder** window, under **Component 1 (comp1)** click **Electrical Circuit (cir)**.

Resistor 1 (R1)

1 In the **Electrical Circuit** toolbar, click **Resistor**.

2 In the **Settings** window for **Resistor**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
n	0

4 Locate the **Device Parameters** section. In the R text field, type `R1`.

External I-Terminal 1 (termI1)

1 In the **Electrical Circuit** toolbar, click **External I-Terminal**.

2 In the **Settings** window for **External I-Terminal**, locate the **External Terminal** section.

3 From the V list, choose **Terminal voltage (ec/term1)**.

4 Locate the **Node Connections** section. In the **Node name** text field, type `1`.

External I-Terminal 2 (termI2)

1 In the **Electrical Circuit** toolbar, click **External I-Terminal**.

2 In the **Settings** window for **External I-Terminal**, locate the **External Terminal** section.

3 From the V list, choose **Terminal voltage (ec/term2)**.

Resistor 2 (R2)

1 In the **Electrical Circuit** toolbar, click **Resistor**.

2 In the **Settings** window for **Resistor**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	3
n	2

4 Locate the **Device Parameters** section. In the R text field, type `R2`.

Voltage Source 1 (V1)

1 In the **Electrical Circuit** toolbar, click **Voltage Source**.

2 In the **Settings** window for **Voltage Source**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	3
n	0

Add a second 3D component to the model, with the same geometry and materials as the previous component. Also add the same physics interfaces. The only differences will be that one of the Terminal features will be replaced by a Ground feature, and that the two External I-Terminal features will be replaced by an External I vs. U feature.

ADD COMPONENT

Right-click **Voltage Source 1 (V1)** and choose **Add Component>3D**.

GEOMETRY 2

1 In the **Settings** window for **Geometry**, locate the **Units** section.

2 From the **Length unit** list, choose **mm**.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `r`.

4 In the **Height** text field, type `L`.

ADD PHYSICS

1 In the **Home** toolbar, click **Add Physics** to open the **Add Physics** window.

2 Go to the **Add Physics** window.

3 In the tree, select **AC/DC>Electric Fields and Currents>Electric Currents (ec)**.

4 Click **Add to Component 2** in the window toolbar.

5 In the tree, select **AC/DC>Electrical Circuit (cir)**.

6 Click **Add to Component 2** in the window toolbar.

7 In the **Home** toolbar, click **Add Physics** to close the **Add Physics** window.

MATERIALS

Material 2 (mat2)

1 In the **Model Builder** window, under **Component 2 (comp2)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, locate the **Material Contents** section.

3 In the table, enter the following settings:

Property	**Variable**	**Value**	**Unit**	**Property group**
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	`sigma`	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1	1	Basic

ELECTRIC CURRENTS 2 (EC2)

In the **Model Builder** window, under **Component 2 (comp2)** click **Electric Currents 2 (ec2)**.

Terminal 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Terminal**.

2 Select Boundary 4 only.

3 In the **Settings** window for **Terminal**, locate the **Terminal** section.

4 From the **Terminal type** list, choose **Circuit**.

Ground 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Ground**.

2 Select Boundary 3 only.

ELECTRICAL CIRCUIT 2 (CIR2)

In the **Model Builder** window, under **Component 2 (comp2)** click **Electrical Circuit 2 (cir2)**.

Resistor 1 (R1)

1 In the **Electrical Circuit** toolbar, click **Resistor**.

2 In the **Settings** window for **Resistor**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	1
n	0

4 Locate the **Device Parameters** section. In the R text field, type `R1`.

External I vs. U 1 (IvsU1)

1 In the **Electrical Circuit** toolbar, click **External I vs. U**.

2 In the **Settings** window for **External I vs. U**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	1
n	2

4 Locate the **External Device** section. From the V list, choose **Terminal voltage (ec2/term1)**.

Resistor 2 (R2)

1 In the **Electrical Circuit** toolbar, click **Resistor**.

2 In the **Settings** window for **Resistor**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	3
n	2

4 Locate the **Device Parameters** section. In the R text field, type `R2`.

Voltage Source 1 (V1)

1 In the **Electrical Circuit** toolbar, click **Voltage Source**.

2 In the **Settings** window for **Voltage Source**, locate the **Node Connections** section.

3 In the table, enter the following settings:

Label	Node names
p	3
n	0

STUDY 1

In the **Home** toolbar, click **Compute**.

RESULTS

Arrow Surface 1

1 Right-click **Electric Potential (ec)** and choose **Arrow Surface**.

2 In the **Settings** window for **Arrow Surface**, locate the **Coloring and Style** section.

3 From the **Color** list, choose **Black**.

Electric Potential (ec)

1 In the **Model Builder** window, click **Electric Potential (ec)**.

2 In the **Electric Potential (ec)** toolbar, click **Plot**.

Arrow Surface 1

1 In the **Model Builder** window, right-click **Electric Potential (ec2)** and choose **Arrow Surface**.

2 In the **Settings** window for **Arrow Surface**, locate the **Coloring and Style** section.

3 From the **Color** list, choose **Black**.

Electric Potential (ec2)

1 In the **Model Builder** window, click **Electric Potential (ec2)**.

2 In the **Electric Potential (ec2)** toolbar, click **Plot**.

Add two Global Evaluation nodes that can be used to check some of the circuit variables. In the first one, compare the voltages at the different nodes for the two components. In the second one, compare the computed resistance of the FEM model with the analytical expression for the resistance of a cylinder.

Global Evaluation 1

1 In the **Results** toolbar, click **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.

3 In the table, enter the following settings:

Expression	Unit	Description
cir.v_0	V	Voltage at node 0
cir.v_1	V	Voltage at node 1
cir.v_2	V	Voltage at node 2
cir.v_3	V	Voltage at node 3
comp2.cir2.v_0	V	Voltage at node 0
comp2.cir2.v_1	V	Voltage at node 1
comp2.cir2.v_2	V	Voltage at node 2
comp2.cir2.v_3	V	Voltage at node 3

4 Click **Evaluate**.

Global Evaluation 2

1 In the **Results** toolbar, click **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.

3 In the table, enter the following settings:

Expression	Unit	Description
((cir.v_2-cir.v_1)/cir.R1_v)*R1	Ω	
((comp2.cir2.v_2-comp2.cir2.v_1)/ comp2.cir2.R1_v)*R1	Ω	
L/(pi*r^2*sigma)	Ω	

4 Click **Evaluate**.