Created in COMSOL Multiphysics 6.1

Hall Effect Sensor

Introduction

The Hall effect sensor is commonly used for position and proximity sensing. A current is applied across a conducting piece of metal, and in the presence of a magnetic field perpendicular to the current direction, the charge carriers experience a Lorentz force. Owing to current conservation, this force is counterbalanced by charge accumulation building up an electric field. In the stationary case, a voltage drop proportional to the magnetic field applied to the conductor can therefore be measured.

Model Definition

The model is set up in 3D by one-way coupling the **Electric Currents** interface to the **Magnetic Fields, No Currents** interface where the constitutive relation for the conduction current in the former takes into account the magnetic flux density as given by the latter. It is also assumed that the current in the sensor is small enough that the resulting current-induced magnetic field can be neglected. With this current-free assumption, the magnetic field can be described via the gradient of a scalar magnetic potential, and a two-way coupled non-linear problem is avoided.

HALL EFFECT VIA ANISOTROPIC CONDUCTIVITY

The conduction current constitutive relation is:

$$\mathbf{J}_c = \sigma(\mathbf{E} + \mathrm{R_h}\mathbf{J}_c \times \mathbf{B})$$

where $\mathbf{J}_\mathrm{c}$, $\mathbf{E}$, and $\mathbf{B}$, in turn, represent the conduction current, the electric field, and the magnetic field. Furthermore, σ and $\mathrm{R_h}$ denote the isotropic electrical conductivity and the Hall coefficient, respectively. Representing the cross product with a matrix multiplication

$$\mathbf{M}\mathbf{J}_c = \mathbf{J}_c \times \mathbf{B}$$

the current density can be related to the electric field via an anisotropic conductivity tensor $\hat{\sigma}$, which is defined by

$$\mathbf{J}_c = (\mathbf{I} - \sigma\mathrm{R_h}\mathbf{M})^{-1}\sigma\mathbf{E} = \hat{\sigma}\mathbf{E}$$

where $\mathbf{I}$ is the identity matrix. The Hall effect option for the conduction model implements this anisotropic conductivity tensor and requires the isotropic conductivity, the Hall coefficient, and the magnetic flux density as model inputs.

Results

Figure 1 displays the electric potential in the sensor conductor and the magnetic flux density generated by the permanent magnet, with the magnitude and direction of the magnetic field indicated by arrows.

Figure 2 shows the electric potential drop perpendicular to the sensor current direction, as a function of the magnet position.

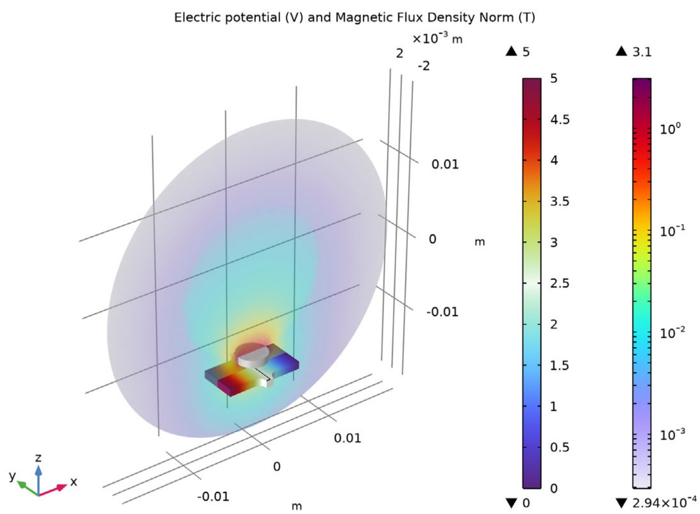


Figure 1: Electric potential plotted in the sensor, and magnetic flux density generated by the permanent magnet. The arrows indicate the magnitude and direction of the magnetic field.

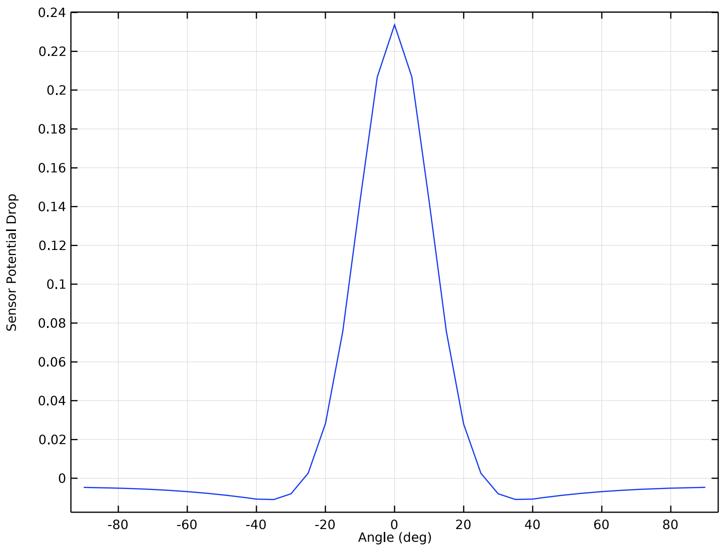


Figure 2: Electric potential drop between the two floating surfaces, plotted as a function of the wheel angle.

Application Library path: `ACDC_Module/Devices,_Capacitive/hall_effect_sensor`

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>Magnetic Fields, No Currents>Magnetic Fields, No Currents (mfnc)**.

5 Click **Add**.

6 Click **Study**.

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

8 Click **Done**.

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
s0	1.04e3[S/m]	1040 S/m	
Rh	1.25e-3[m^3/C]	0.00125 $m^3/(s\cdot A)$	
Angle	0[rad]	0 rad	

GEOMETRY 1

Work Plane 1 (wp1)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Geometry 1** node.

2 Right-click **Geometry 1** and choose **Work Plane**.

3 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

4 In the **z-coordinate** text field, type `-12.5[mm]`.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Rectangle 1 (r1)

1 In the **Work Plane** toolbar, click **Rectangle**.

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

3 In the **Width** text field, type `1[cm]`.

4 In the **Height** text field, type `5[mm]`.

5 Locate the **Position** section. From the **Base** list, choose **Center**.

Work Plane 1 (wp1)>Rectangle 2 (r2)

1 In the **Work Plane** toolbar, click **Rectangle**.

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

3 In the **Width** text field, type `1[mm]`.

4 In the **Height** text field, type `7[mm]`.

5 Locate the **Position** section. From the **Base** list, choose **Center**.

Work Plane 1 (wp1)>Union 1 (uni1)

1 In the **Work Plane** toolbar, click **Booleans and Partitions** and choose **Union**.

2 Click in the **Graphics** window and then press Ctrl+A to select both objects.

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

4 Clear the **Keep interior boundaries** check box.

Work Plane 1 (wp1)>Fillet 1 (fil1)

1 In the **Work Plane** toolbar, click **Fillet**.

2 On the object **uni1**, select Points 4, 5, 8, and 9 only.

3 In the **Settings** window for **Fillet**, locate the **Radius** section.

4 In the **Radius** text field, type `1[mm]`.

Work Plane 1 (wp1)>Plane Geometry

In the **Work Plane** toolbar, click **Build All**.

Extrude 1 (ext1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 In the table, enter the following settings:

Distances (m)
1[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 `2[mm]`.

4 In the **Height** text field, type `1[mm]`.

5 Locate the **Position** section. In the **z** text field, type `-10.5[mm]`.

Cylinder 2 (cyl2)

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 `10[mm]`.

4 In the **Height** text field, type `6[mm]`.

5 Locate the **Position** section. In the **y** text field, type `-3[mm]`.

6 Locate the **Axis** section. From the **Axis type** list, choose **y-axis**.

Union 1 (uni1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 Click the **Zoom Extents** button in the **Graphics** toolbar.

3 Click the **Wireframe Rendering** button in the **Graphics** toolbar.

4 Select the objects **cyl1** and **cyl2** only.

5 In the **Settings** window for **Union**, click **Build Selected**.

Delete Entities 1 (del1)

1 Right-click **Geometry 1** and choose **Delete Entities**.

2 On the object **uni1**, select Boundary 10 only.

Sphere 1 (sph1)

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

2 In the **Settings** window for **Sphere**, locate the **Size** section.

3 In the **Radius** text field, type `25[mm]`.

4 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (m)
`Layer 1`	`5[mm]`

5 In the **Geometry** toolbar, click **Build All**.

DEFINITIONS

Set up an infinite element domain surrounding the sensor setup, to remove the influence of the magnetic insulation boundary condition.

Infinite Element Domain 1 (ie1)

1 In the **Definitions** toolbar, click **Infinite Element Domain**.

2 Select Domains 1–4 and 9–12 only.

3 In the **Settings** window for **Infinite Element Domain**, locate the **Geometry** section.

4 From the **Type** list, choose **Spherical**.

DEFINITIONS

The rotation of the magnet is done in two steps: first a General Extrusion maps the vector field to its rotated coordinates, and then a local vector rotation is performed by defining new magnetic field variables.

General Extrusion 1 (genext1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **General Extrusion**.
2 In the **Settings** window for **General Extrusion**, locate the **Source Selection** section.
3 From the **Selection** list, choose **All domains**.
4 In the **Operator name** text field, type `rotY`.
5 Locate the **Destination Map** section. In the **x-expression** text field, type `x*cos(Angle)-z*sin(Angle)`.
6 In the **z-expression** text field, type `x*sin(Angle)+z*cos(Angle)`.

Variables 1

1 In the **Model Builder** window, right-click **Definitions** and choose **Variables**.
2 In the **Settings** window for **Variables**, locate the **Variables** section.
3 In the table, enter the following settings:

Name	Expression	Unit	Description
rBx	cos(Angle)*rotY(mfnc.Bx)+sin(Angle)*rotY(mfnc.Bz)	T	Rotated Magnetic flux density, x-component
rBy	rotY(mfnc.By)	T	Rotated Magnetic flux density, y-component
rBz	-sin(Angle)*rotY(mfnc.Bx)+cos(Angle)*rotY(mfnc.Bz)	T	Rotated Magnetic flux density, z-component

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.
2 Go to the **Add Material** window.
3 In the tree, select **Built-in>Air**.
4 Click **Add to Component** in the window toolbar.
5 In the tree, select **Built-in>Iron**.
6 Click **Add to Component** in the window toolbar.

7 In the tree, select **AC/DC>Hard Magnetic Materials> Sintered NdFeB Grades (Chinese Standard)>N54 (Sintered NdFeB)**.

8 Click **Add to Component** in the window toolbar.

9 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Conductor

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

2 In the **Settings** window for **Material**, type `Conductor` in the **Label** text field.

3 Select Domain 7 only.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	s0	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	12	1	Basic
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic

Iron (mat2)

1 In the **Model Builder** window, click **Iron (mat2)**.

2 Select Domain 6 only.

N54 (Sintered NdFeB) (mat3)

1 In the **Model Builder** window, click **N54 (Sintered NdFeB) (mat3)**.

2 Select Domain 8 only.

ELECTRIC CURRENTS (EC)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electric Currents (ec)**.

2 In the **Settings** window for **Electric Currents**, locate the **Domain Selection** section.

3 Click **Clear Selection**.

4 Select Domain 7 only.

Ground 1

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

2 Select Boundary 59 only.

Terminal 1

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

2 Select Boundary 17 only.

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

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

5 In the V_0 text field, type 5.

Floating Potential 1

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

2 Select Boundary 30 only.

Floating Potential 2

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

2 Select Boundary 31 only.

MAGNETIC FIELDS, NO CURRENTS (MFNC)

In the **Model Builder** window, under **Component 1 (comp1)** click **Magnetic Fields, No Currents (mfnc)**.

Magnet 1

1 In the **Physics** toolbar, click **Domains** and choose **Magnet**.

2 Select Domain 8 only.

North 1

1 In the **Model Builder** window, click **North 1**.

2 Select Boundary 27 only.

South 1

1 In the **Model Builder** window, click **South 1**.

2 Select Boundary 24 only.

MESH 1

Free Tetrahedral 1

1 In the **Mesh** toolbar, click **Free Tetrahedral**.
2 In the **Settings** window for **Free Tetrahedral**, locate the **Domain Selection** section.
3 From the **Geometric entity level** list, choose **Domain**.
4 Select Domains 5–8 only.

Swept 1

1 In the **Mesh** toolbar, click **Swept**.
2 In the **Settings** window for **Swept**, click to expand the **Source Faces** section.
3 Select Boundaries 9–12, 37, 38, 47, and 50 only.
4 Click to expand the **Destination Faces** section. Select Boundaries 5–8, 35, 36, 46, and 51 only.

Distribution 1

Right-click **Swept 1** and choose **Distribution**.

Size

1 In the **Settings** window for **Size**, locate the **Element Size** section.
2 From the **Predefined** list, choose **Finer**.
3 In the **Model Builder** window, right-click **Mesh 1** and choose **Build All**.

MAGNETIC FIELDS, NO CURRENTS (MFNC)

Zero Magnetic Scalar Potential 1

1 In the **Physics** toolbar, click **Points** and choose **Zero Magnetic Scalar Potential**.
2 Select Point 3 only.

STUDY 1

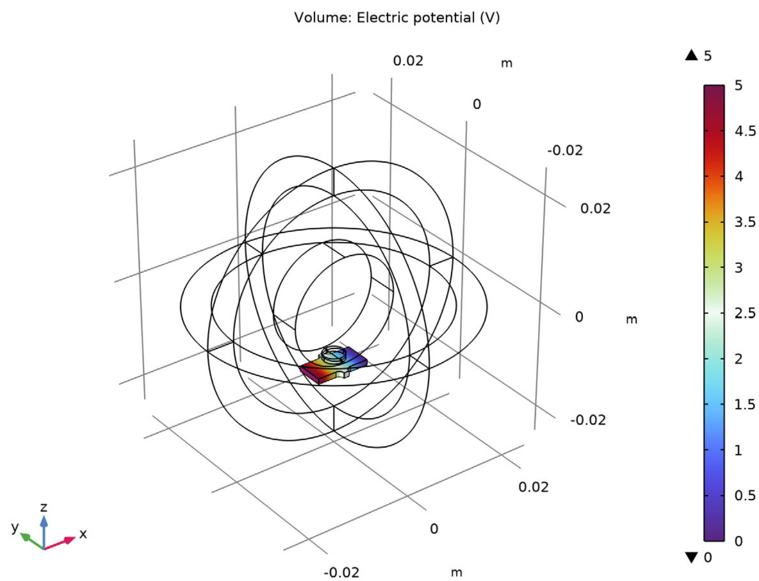
Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.
2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node.
3 In the **Model Builder** window, expand the **Study 1>Solver Configurations> Solution 1 (sol1)>Stationary Solver 1** node.
4 Right-click **Study 1>Solver Configurations>Solution 1 (sol1)>Stationary Solver 1>Direct** and choose **Enable**.

5 In the **Study** toolbar, click **Compute**.

RESULTS

Electric Potential (ec)



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
`ec.fp1.V0 - ec.fp2.V0`		

4 Click next to **Evaluate**, then choose **New Table**.

ELECTRIC CURRENTS (EC)

Current Conservation 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Electric Currents (ec)** click **Current Conservation 1**.

2 In the **Settings** window for **Current Conservation**, locate the **Constitutive Relation Jc-E** section.

3 From the **Conduction model** list, choose **Hall effect**.

4 In the R_H text field, type `Rh`.

5 Specify the $\mathbf{B}$ vector as

rBx	x
rBy	y
rBz	z

STUDY 1

Step 1: Stationary

1 In the **Model Builder** window, under **Study 1** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, click to expand the **Study Extensions** section.

3 Select the **Auxiliary sweep** check box.

4 Click + **Add**.

5 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Angle	range(-90,5,90)	deg

RESULTS

Magnet

1 In the **Model Builder** window, expand the **Results>Electric Potential (ec)** node.

2 Right-click **Electric Potential (ec)** and choose **Volume**.

3 In the **Settings** window for **Volume**, type `Magnet` in the **Label** text field.

4 Locate the **Expression** section. In the **Expression** text field, type `1`.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

6 From the **Color** list, choose **Gray**.

Transparency 1

1 Right-click **Magnet** and choose **Transparency**.

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

3 In the **Transparency** text field, type `0.1`.

Selection 1

1 In the **Model Builder** window, right-click **Magnet** and choose **Selection**.

2 Select Domain 8 only.

Deformation 1

1 Right-click **Magnet** and choose **Deformation**.

2 In the **Settings** window for **Deformation**, locate the **Expression** section.

3 In the **x-component** text field, type `-rotY(x)-x`.

4 In the **y-component** text field, type `0`.

5 In the **z-component** text field, type `rotY(z)-z`.

6 Locate the **Scale** section.

7 Select the **Scale factor** check box. In the associated text field, type `1`.

Electric Potential and Magnetic Flux Density Norm

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

2 In the **Settings** window for **3D Plot Group**, type `Electric Potential and Magnetic Flux Density Norm` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Electric potential (V) and Magnetic Flux Density Norm (T)`.

5 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.

Slice 1

Right-click **Electric Potential and Magnetic Flux Density Norm** and choose **Slice**.

Selection 1

1 In the **Model Builder** window, right-click **Slice 1** and choose **Selection**.

2 Select Domains 5–8 only.

Slice 1

1 In the **Model Builder** window, click **Slice 1**.

2 In the **Settings** window for **Slice**, locate the **Plane Data** section.

3 From the **Plane** list, choose **zx-planes**.

4 In the **Planes** text field, type `1`.

5 Locate the **Expression** section. In the **Expression** text field, type `sqrt(rBx^2 + rBy^2 + rBz^2)`.

6 Select the **Description** check box. In the associated text field, type `Magnetic Flux Density Norm`.

7 In the **Electric Potential and Magnetic Flux Density Norm** toolbar, click **Plot**.

8 Click to expand the **Range** section. Select the **Manual color range** check box.

9 Locate the **Coloring and Style** section. From the **Scale** list, choose **Logarithmic**.

10 Click **Change Color Table**.

11 In the **Color Table** dialog box, select **Rainbow>Prism** in the tree.

12 Click **OK**.

Transparency 1

Right-click **Slice 1** and choose **Transparency**.

Electric Potential and Magnetic Flux Density Norm

Add a contour line for the electric potential to visualize the influence of the magnet.

Contour 1

1 In the **Model Builder** window, right-click **Electric Potential and Magnetic Flux Density Norm** and choose **Contour**.

2 In the **Settings** window for **Contour**, locate the **Levels** section.

3 From the **Entry method** list, choose **Levels**.

4 In the **Levels** text field, type `2.5`.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

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

7 Clear the **Color legend** check box.

8 Click to expand the **Title** section. From the **Title type** list, choose **None**.

Selection 1

1 Right-click **Contour 1** and choose **Selection**.

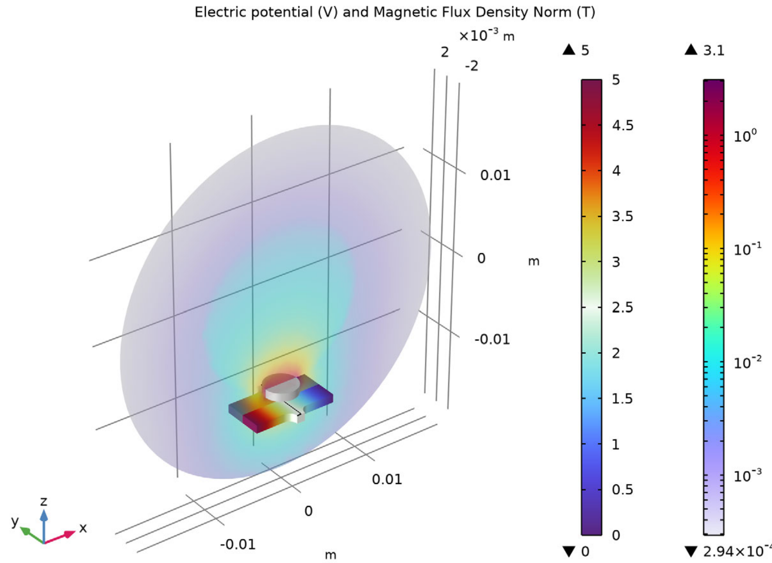
2 Select Boundary 20 only.

Electric Potential and Magnetic Flux Density Norm

1 In the **Model Builder** window, under **Results** click **Electric Potential and Magnetic Flux Density Norm**.

2 In the **Electric Potential and Magnetic Flux Density Norm** toolbar, click **Plot**.

3 Click the Zoom Extents button in the **Graphics** toolbar.



STUDY 1

Step 1: Stationary

1 In the **Model Builder** window, under **Study 1** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, click to expand the **Results While Solving** section.

3 Select the **Plot** check box.

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

RESULTS

Global Evaluation 1

In the **Model Builder** window, under **Results>Derived Values** right-click **Global Evaluation 1** and choose **Evaluate>New Table**.

Sensor Potential Difference

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Sensor Potential Difference` in the **Label** text field.

3 Locate the **Plot Settings** section.

4 Select the **y-axis label** check box. In the associated text field, type `Sensor Potential Drop`.

Table Graph 1

1 Right-click **Sensor Potential Difference** and choose **Table Graph**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Table 2**.

4 In the **Sensor Potential Difference** toolbar, click **Plot**.