Created in COMSOL Multiphysics 5.5

Magnetic Field of a Helmholtz Coil

Introduction

A Helmholtz coil is a parallel pair of identical circular coils spaced one radius apart and wound so that the current flows through both coils in the same direction. This winding results in a uniform magnetic field between the coils with the primary component parallel to the axis of the two coils. The uniform field is the result of the sum of the two field components parallel to the axis of the coils and the difference between the components perpendicular to the same axis.

The purpose of the device is to allow scientists and engineers to perform experiments and tests that require a known ambient magnetic field. Helmholtz field generation can be static, time-varying DC, or AC, depending on application.

Applications include canceling the Earth's magnetic field for certain experiments; generating magnetic fields for determining magnetic shielding effectiveness or susceptibility of electronic equipment to magnetic fields; calibration of magnetometers and navigational equipment; and biomagnetic studies.

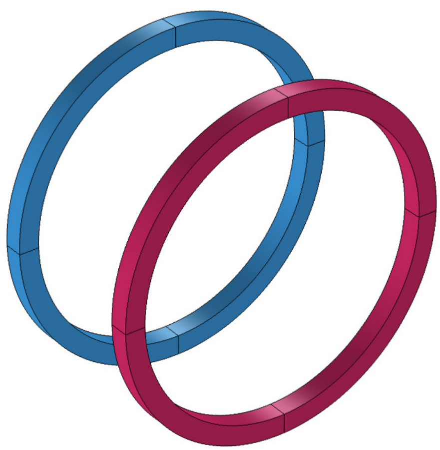


Figure 1: The Helmholtz coil consists of two coaxial circular coils, one radius apart along the axial direction. The coils carry parallel currents of equal magnitude.

Model Definition

The application is built using the 3D Magnetic Fields interface. The model geometry is shown in Figure 2.

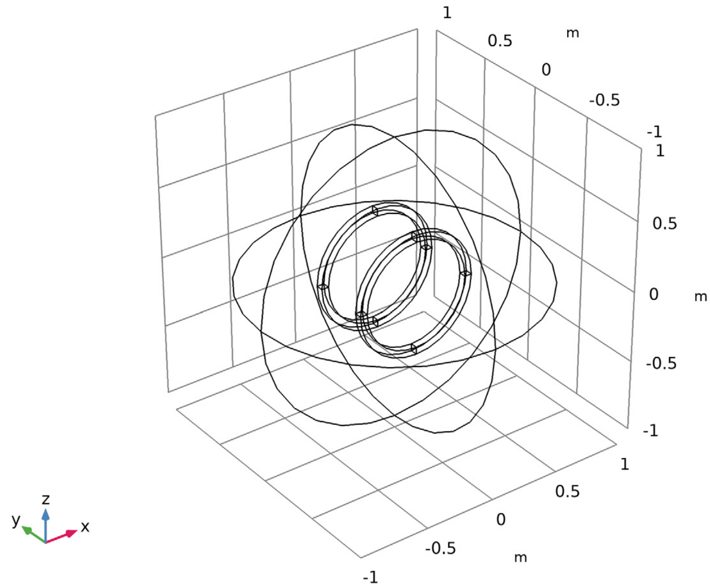


Figure 2: The model geometry.

DOMAIN EQUATIONS

Assuming static currents and fields, the magnetic vector potential **A** must satisfy the following equation:

$$\nabla \times (\mu^{-1} \nabla \times \mathbf{A}) = \mathbf{J}_e$$

where μ is the permeability, and $\mathbf{J}_e$ denotes the externally applied current density.

The relations between the magnetic field **H**, the magnetic flux density **B** and the potential are given by

$$\mathbf{B} = \nabla \times \mathbf{A}$$

$$\mathbf{H} = \mu^{-1} \mathbf{B}$$

This model uses the permeability of vacuum, that is, $\mu = 4\pi \times 10^{-7}$ H/m. The external current density is computed using a homogenized model for the coils, each one made by

10 wire turns and excited by a current of 0.25 mA. The currents are specified to be parallel for the two coils.

Results and Discussion

Figure 3 shows the magnetic flux density between the coils. The flux is relatively uniform in the region between the coils. This uniformity is the main property and often the sought feature of a Helmholtz coil.

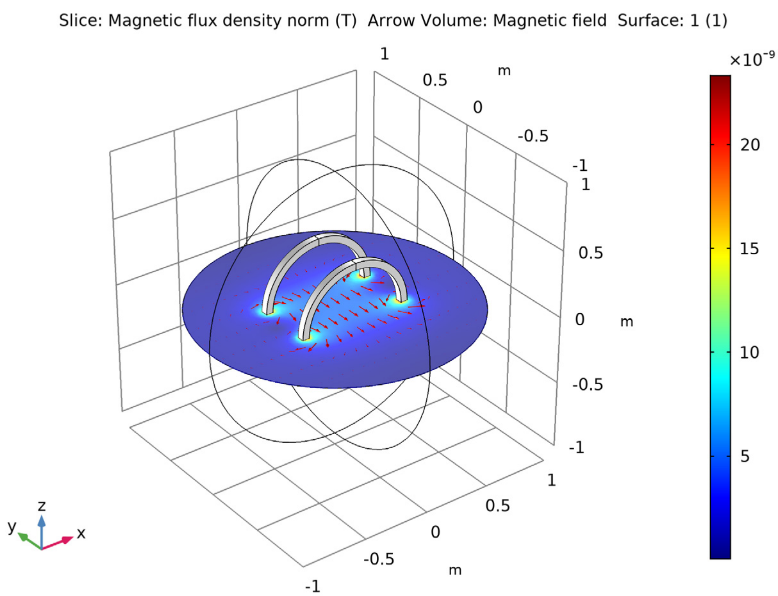


Figure 3: The slice plot shows the magnetic flux density. The arrows indicate the magnetic field (H) strength and direction.

Application Library path: `ACDC_Module/Inductive_Devices_and_Coils/helmholtz_coil`

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>Electromagnetic Fields>Magnetic Fields (mf)**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **General Studies>Stationary**.
6 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
`I0`	`0.25[mA]`	2.5E-4 A	`Coil current`

GEOMETRY 1

Work Plane 1 (wp1)

In the **Geometry** toolbar, click **Work Plane**.

Work Plane 1 (wp1)>Plane Geometry

Right-click **Work Plane 1 (wp1)** and choose **Show Work Plane**.

Work Plane 1 (wp1)>Square 1 (sq1)

1 In the **Work Plane** toolbar, click **Square**.
2 In the **Settings** window for **Square**, locate the **Size** section.
3 In the **Side length** text field, type `0.05`.
4 Locate the **Position** section. From the **Base** list, choose **Center**.
5 In the **xw** text field, type `-0.4`.
6 In the **yw** text field, type `0.2`.

Work Plane 1 (wp1)>Square 2 (sq2)

1. In the **Work Plane** toolbar, click **Square**.
2. In the **Settings** window for **Square**, locate the **Size** section.
3. In the **Side length** text field, type `0.05`.
4. Locate the **Position** section. From the **Base** list, choose **Center**.
5. In the **xw** text field, type `-0.4`.
6. In the **yw** text field, type `-0.2`.

Work Plane 1 (wp1)

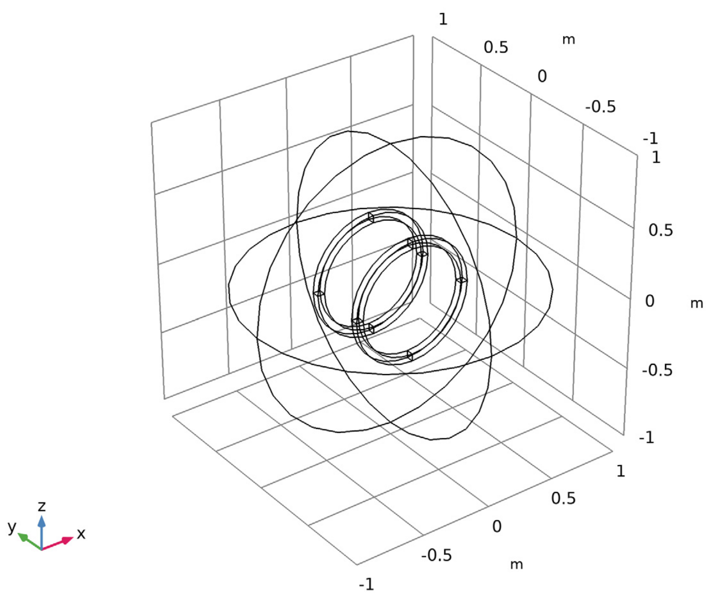
In the **Model Builder** window, click **Work Plane 1 (wp1)**.

Revolve 1 (rev1)

In the **Geometry** toolbar, click **Revolve**.

Sphere 1 (sph1)

1. In the **Geometry** toolbar, click **Sphere**.
2. Right-click **Sphere 1 (sph1)** and choose **Build All Objects**.
3. Click the **Zoom Extents** button in the **Graphics** toolbar.
4. The geometry is now complete. To see its interior, click the **Wireframe Rendering** button in the **Graphics** toolbar.



MATERIALS

Define the materials for the model.

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

By default, the first material added is applied on all domains.

Add another material for the coil domains. Since the coil will use a homogenized model for the metallic wires, only the relative permittivity and permeability are required from the material.

MATERIALS

Material 2 (mat2)

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 `Coil Insulator` in the **Label** text field.

3 Select Domains 2 and 3 only.

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

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

MAGNETIC FIELDS (MF)

Coil 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Magnetic Fields (mf)** and choose the domain setting **Coil**.

2 Select Domain 2 only.

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

4 From the **Conductor model** list, choose **Homogenized multi-turn**.

5 From the **Coil type** list, choose **Circular**.

6 In the I_{coil} text field, type `I0`.

In order to specify the direction of the wires in the circular coil, use the **Coil Geometry** subfeature to select a group of edges forming a circle. The path of the wires will be automatically computed from the geometry of the selected edges. For the best results, the radius of the circular edges selected should be close to the average radius of the coil.

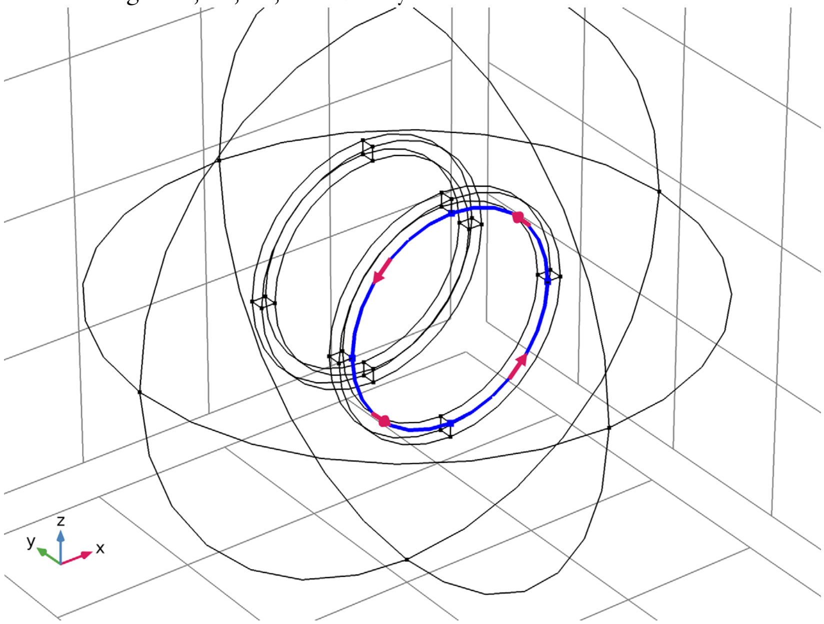
Coil Geometry 1

1 In the **Model Builder** window, expand the **Coil 1** node, then click **Coil Geometry 1**.

2 In the **Settings** window for **Coil Geometry**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edges 20, 21, 36, and 39 only.



Now set up the second coil in the same way.

Coil 2

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

2 Select Domain 3 only.

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

4 From the **Conductor model** list, choose **Homogenized multi-turn**.

5 From the **Coil type** list, choose **Circular**.

6 In the I_{coil} text field, type `I0`.

Coil Geometry 1

1 In the **Model Builder** window, expand the **Coil 2** node, then click **Coil Geometry 1**.

2 In the **Settings** window for **Coil Geometry**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edges 25, 26, 56, and 59 only.

Create a finer mesh in the coils.

MESH 1

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

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Coarse**.

Free Tetrahedral 1

Right-click **Component 1 (comp1)>Mesh 1** and choose **Free Tetrahedral**.

Size 1

1 In the **Model Builder** window, right-click **Free Tetrahedral 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 Select Domains 2 and 3 only.

5 Locate the **Element Size** section. Click the **Custom** button.

6 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

7 In the associated text field, type `0.05`.

8 Click **Build All**.

STUDY 1

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

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

3 Clear the **Generate default plots** check box.

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

Add a selection to the computed data set to exclude the outer boundaries.

Explicit 1

1 In the **Definitions** toolbar, click **Explicit**.

2 Select Domains 2 and 3 only.

3 In the **Settings** window for **Explicit**, locate the **Output Entities** section.

4 From the **Output entities** list, choose **Adjacent boundaries**.

5 Right-click **Explicit 1** and choose **Rename**.

6 In the **Rename Explicit** dialog box, type `Coils` in the **New label** text field.

7 Click **OK**.

Now add the plots.

RESULTS

In the **Model Builder** window, expand the **Results** node.

Study 1/Solution 1 (sol1)

In the **Model Builder** window, expand the **Results>Datasets** node, then click **Study 1/ Solution 1 (sol1)**.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.
2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
3 From the **Geometric entity level** list, choose **Boundary**.
4 From the **Selection** list, choose **Coils**.

3D Plot Group 1

1 In the **Results** toolbar, click **3D Plot Group**.
2 In the **Settings** window for **3D Plot Group**, type `Magnetic Flux Density` in the **Label** text field.

Slice 1

1 Right-click **Magnetic Flux Density** and choose **Slice**.
2 In the **Settings** window for **Slice**, locate the **Plane Data** section.
3 From the **Plane** list, choose **XY-planes**.
4 In the **Planes** text field, type `1`.
5 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1>Magnetic Fields>Magnetic>mf.normB - Magnetic flux density norm - T**.
6 In the **Magnetic Flux Density** toolbar, click **Plot**.

Arrow Volume 1

1 In the **Model Builder** window, right-click **Magnetic Flux Density** and choose **Arrow Volume**.
2 In the **Settings** window for **Arrow Volume**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1>Magnetic Fields>Magnetic>mf.Hx,mf.Hy,mf.Hz - Magnetic field**.
3 Locate the **Arrow Positioning** section. Find the **X grid points** subsection. In the **Points** text field, type `24`.
4 Find the **Y grid points** subsection. In the **Points** text field, type `10`.
5 Find the **Z grid points** subsection. In the **Points** text field, type `1`.

6 Locate the **Coloring and Style** section. Select the **Scale factor** check box.

7 In the associated text field, type `25`.

8 In the **Magnetic Flux Density** toolbar, click **Plot**.

To make the coil look like a solid object, can add a surface plot on its boundaries.

Surface 1

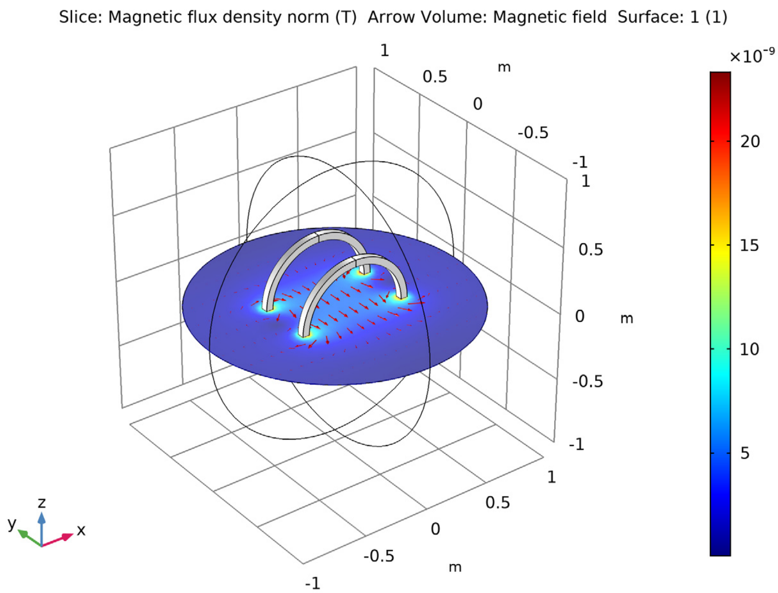
1 Right-click **Magnetic Flux Density** and choose **Surface**.

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

3 In the **Expression** text field, type `1`.

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

5 From the **Color** list, choose **White**.



To verify that the current path is computed correctly, plot the **Coil direction** variable for each coil.

3D Plot Group 2

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Coil Direction` in the **Label** text field.

Streamline 1

1 Right-click **Coil Direction** and choose **Streamline**.

2 Select Boundary 5 only.

3 In the **Settings** window for **Streamline**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1>Magnetic Fields> Coil parameters>mf.coil1.eCoilx,...,mf.coil1.eCoilz - Coil direction**.

Streamline 2

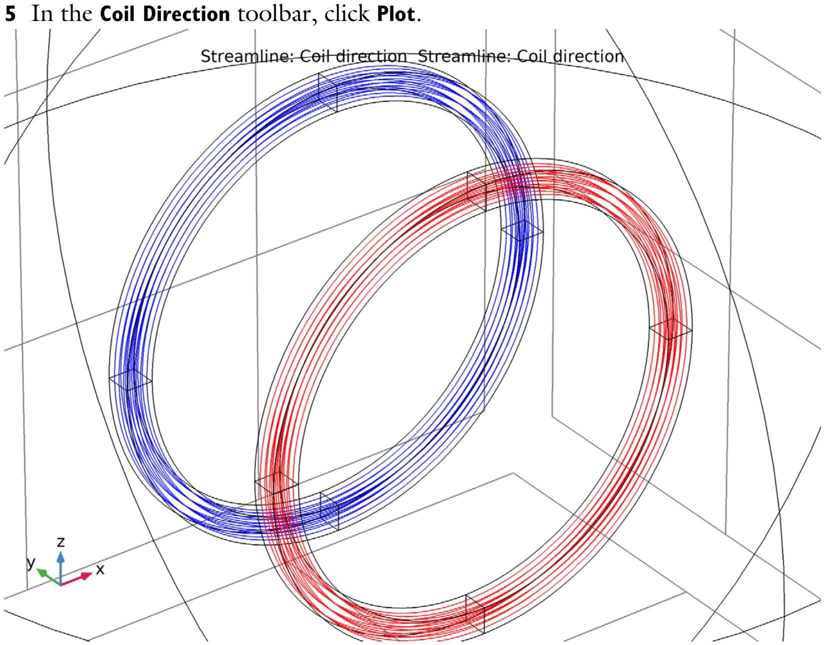
1 In the **Model Builder** window, right-click **Coil Direction** and choose **Streamline**.

2 Select Boundary 12 only.

3 In the **Settings** window for **Streamline**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1>Magnetic Fields> Coil parameters>mf.coil2.eCoilx,...,mf.coil2.eCoilz - Coil direction**.

4 Locate the **Coloring and Style** section. Find the **Point style** subsection. From the **Color** list, choose **Blue**.

5 In the **Coil Direction** toolbar, click **Plot**.



The streamlines show the computed path of the coil currents.