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.

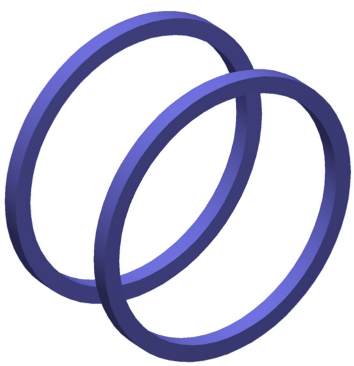


Figure 1: The Helmholtz coil consists of two coaxial circular coils, one radius apart along the axial direction. The coils carry parallel currents of equal magnitude.

Model Definition

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

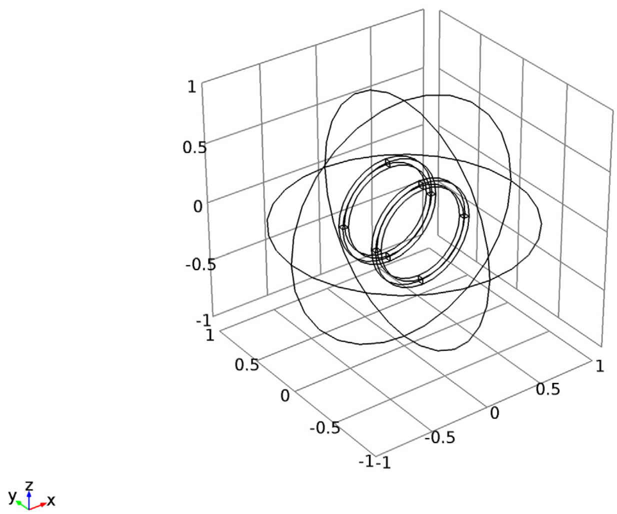


Figure 2: The model geometry.

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. You can see that the flux is relatively uniform between the coils, except for the region close to the edges of the coil.

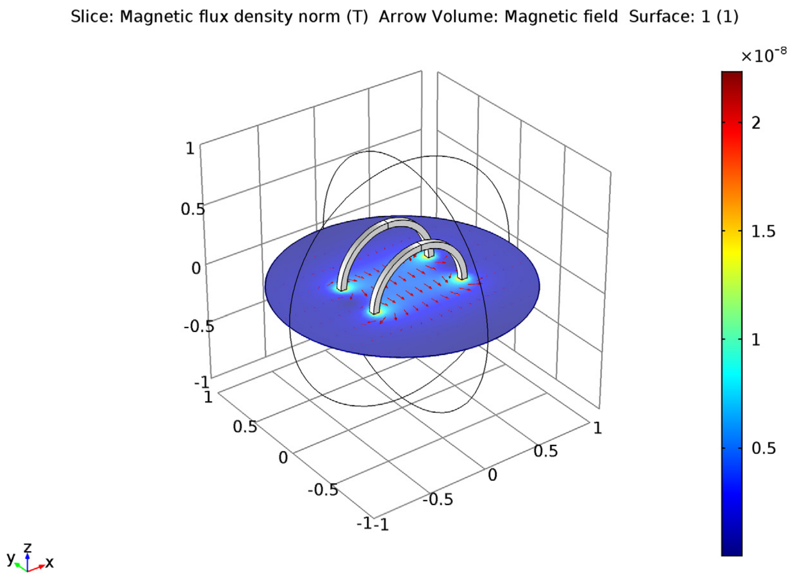


Figure 3: The slice plot shows the magnetic flux density. The arrows indicate the magnetic field (H) strength and direction.

This uniformity is the main property and often the sought feature of a Helmholtz coil.

Application Library path: `ACDC_Module/Inductive_Devices_and_Coils/helmholtz_coil`

Modeling Instructions

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

NEW

1 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>Magnetic Fields (mf)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select study** tree, select **Preset Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters

1 On the **Home** toolbar, click **Parameters**.

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)

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

Square 1 (sq1)

1 On the **Geometry** toolbar, click **Primitives** and choose **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`.

Square 2 (sq2)

1 On the **Geometry** toolbar, click **Primitives** and choose **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`.

Revolve 1 (rev1)

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

Sphere 1 (sph1)

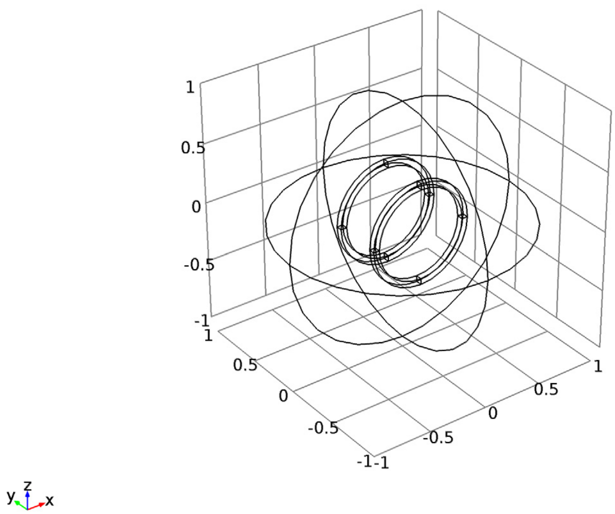
1 On the **Geometry** toolbar, click **Sphere**.

2 In the **Model Builder** window, right-click **Sphere 1 (sph1)** and choose **Build All Objects**.

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

Your geometry is now complete. To see its interior, choose wireframe rendering.

4 Click the **Wireframe Rendering** button on the **Graphics** toolbar.



ADD MATERIAL

1 On 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.

By default, the first material you add applies on all domains so you need not alter any settings.

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

MAGNETIC FIELDS (MF)

Multi-Turn Coil 1

1 On the **Physics** toolbar, click **Domains** and choose **Multi-Turn Coil**.

2 Select Domain 2 only.

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

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

5 Find the **Coil parameters** subsection. In the N text field, type `10`.

6 In the I_{coil} text field, type `10`.

In order to specify the direction of the wires in the circular coil, you need to 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.

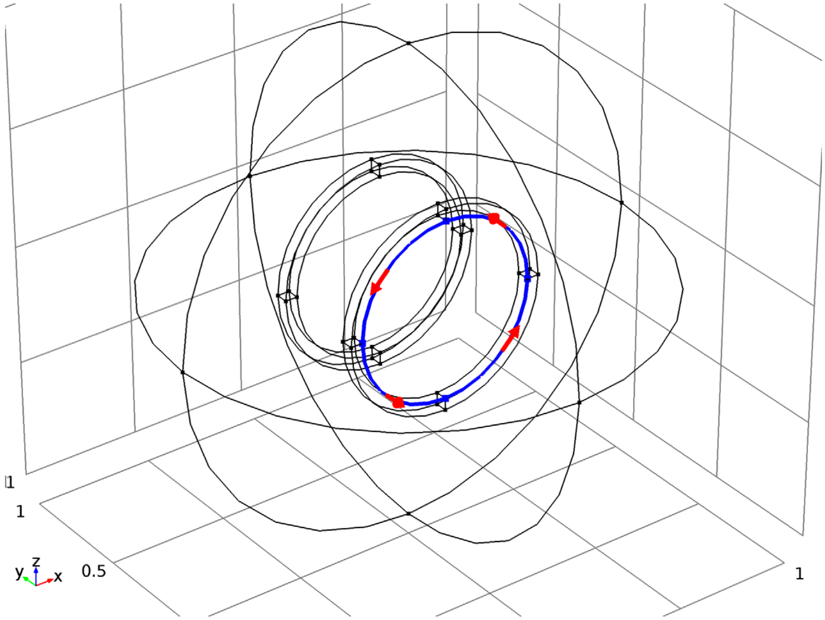
Coil Geometry 1

1 In the **Model Builder** window, expand the **Multi-Turn 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.

Multi-Turn Coil 2

1 On the **Physics** toolbar, click **Domains** and choose **Multi-Turn Coil**.

2 Select Domain 3 only.

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

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

5 Find the **Coil parameters** subsection. In the N text field, type `10`.

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

Coil Geometry 1

1 In the **Model Builder** window, expand the **Multi-Turn 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.

MESH 1

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

2 In the **Settings** window for Mesh, locate the **Mesh Settings** 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, under **Component 1 (comp1)>Mesh 1** 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 the **Build All** button.

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

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

DEFINITIONS

Explicit 1

1 On 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.

Selection

On the **Results** toolbar, click **Selection**.

Data Sets

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

2 From the **Geometric entity level** list, choose **Boundary**.

3 From the **Selection** list, choose **Coils**.

3D Plot Group 1

1 On the **Results** toolbar, click **3D Plot Group**.

2 In the **Model Builder** window, right-click **3D Plot Group 1** and choose **Slice**.

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

4 From the **Plane** list, choose **xy-planes**.

5 In the **Planes** text field, type 1.

6 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**.

7 On the **3D Plot Group 1** toolbar, click **Plot**.

8 Right-click **3D Plot Group 1** and choose **Arrow Volume**.

9 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**.

10 Locate the **Arrow Positioning** section. Find the **x grid points** subsection. In the **Points** text field, type 24.

11 Find the **y grid points** subsection. In the **Points** text field, type 10.

12 Find the **z grid points** subsection. In the **Points** text field, type 1.

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

14 In the associated text field, type 25.

15 On the **3D Plot Group 1** toolbar, click **Plot**.

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

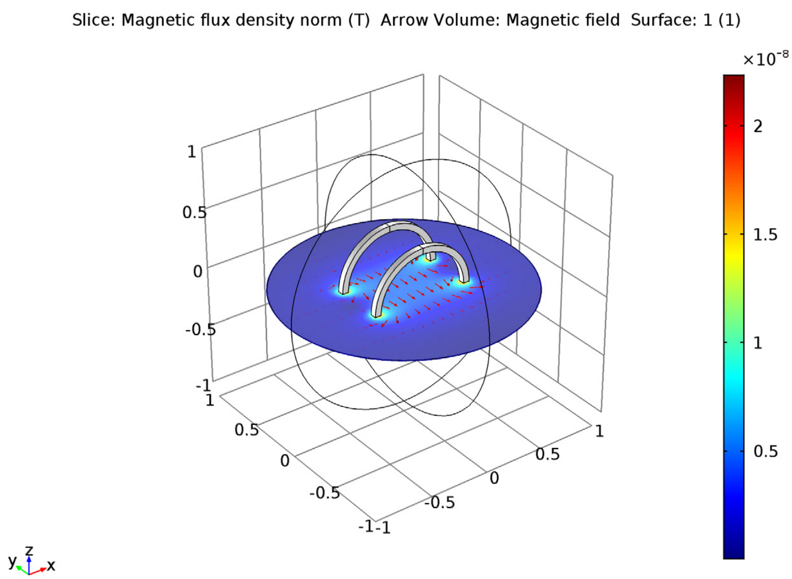
16 Right-click **3D Plot Group 1** and choose **Surface**.

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

18 In the **Expression** text field, type 1.

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

20 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 On the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Model Builder** window, right-click **3D Plot Group 2** and choose **Streamline**.

3 Select Boundary 5 only.

4 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.mtcd1.eCoilx,...,mf.mtcd1.eCoilz - Coil direction**.

5 Right-click **3D Plot Group 2** and choose **Streamline**.

6 Select Boundary 12 only.

7 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.mtcd2.eCoilx,...,mf.mtcd2.eCoilz - Coil direction**.

8 Locate the **Coloring and Style** section. From the **Color** list, choose **Blue**.

9 On the **3D Plot Group 2** toolbar, click **Plot**.