Pacemaker Electrode

This model illustrates the use of COMSOL Multiphysics for modeling of ionic current distribution problems in electrolytes, in this case in human tissue. The problem is exemplified on a pacemaker electrode, but it can be applied in electrochemical cells like fuel cells, batteries, corrosion protection, or any other process where ionic conduction takes place in the absence of concentration gradients.

Introduction

The modeled device is a pacemaker electrode that is placed inside the heart and helps the patient's heart to keep a normal rhythm. The device is referred to as an electrode, but it actually consists of two electrodes: a cathode and an anode.

Figure 4-2 shows a schematic drawing of two pair of electrodes placed inside the heart. The electrodes are supplied with current from the pulse generator unit, which is also implanted in the patient.

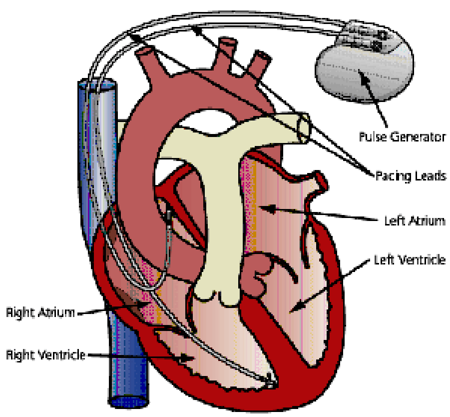


Figure 4-2: Schematic drawing of the heart with two pairs of pacemaker electrodes.

This model deals with the current and potential distribution around one pair of electrodes.

Model Definition

The model domain consists of the blood and tissue surrounding the electrode pair. The actual electrodes and the electrode support are boundaries to the modeled domain. Figure 4-3 shows the electrode in a darker shade, while the surrounding modeling domain is shown in a lighter shade.

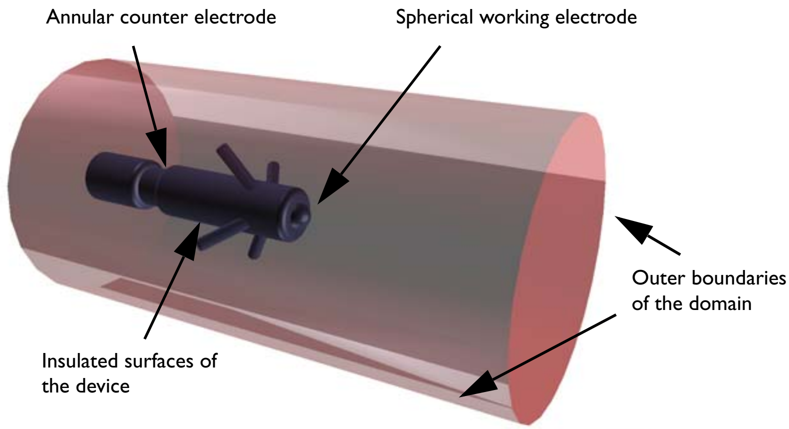


Figure 4-3: Modeling domain and boundaries.

The working electrode consists of a a hemisphere placed on the tip of the supporting cylindrical structure. The counter electrode is placed in the "waist" of this structure. All other surfaces of the supporting structure are insulated. The outer boundaries are placed far enough from the electrode to give a small impact on the current and potential distribution.

In COMSOL Multiphysics, use the 3D Conductive Media DC application mode for the analysis of the electrode. This application mode is useful for modeling conductive materials where a current flows due to an applied electric field.

DOMAIN EQUATIONS

The current in the domain is controlled by the continuity equation, which follows from the Maxwell's equations:

$$-\nabla \cdot (\sigma \nabla V) = 0$$

where σ is the conductivity of the human heart. This equation uses the following relations between the electric potential and the fields.

$$\mathbf{E} = -\nabla V$$
$$\mathbf{J} = \sigma\mathbf{E}$$

BOUNDARY CONDITIONS

Ground potential boundary conditions are applied on the thinner waist of the electrode. The tip of the electrode has a fixed potential of 1 V. All other boundaries are electrically insulated.

$$\mathbf{n} \cdot \mathbf{J} = 0$$

Results and Discussion

This simulation gives you the potential distribution on the surface of the electrode and the streamlines of the current distribution inside the human heart. This plot appears in Figure 4-4.

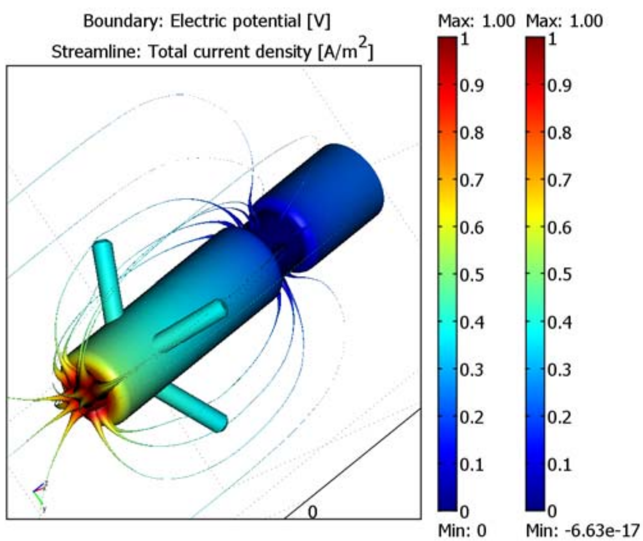


Figure 4-4: The plot shows the electrostatic potential distributed on the surface of the electrode. The total current density is shown as streamlines.

As expected, the current density is highest at the small hemisphere, which is the one that causes the excitation of the heart. The current density is fairly uniform on the working electrode. The counter electrode is larger and there are also larger variations in current density on its surface. Mainly, the current is lower with the distance from the working electrode. The model shows that the anchoring arms of the device have little influence on the current density distribution.

Model Library path: `COMSOL_Multiphysics/Electromagnetics/pacemaker_electrode`

Modeling Using the Graphical User Interface

1. In the **Model Navigator**, select **3D** in the **Space dimension** list.
2. In the **COMSOL Multiphysics>Electromagnetics** folder, select **Conductive Media DC**. Make sure **Lagrange - Quadratic** is selected in the **Element** list.
3. Click **OK**.

GEOMETRY MODELING

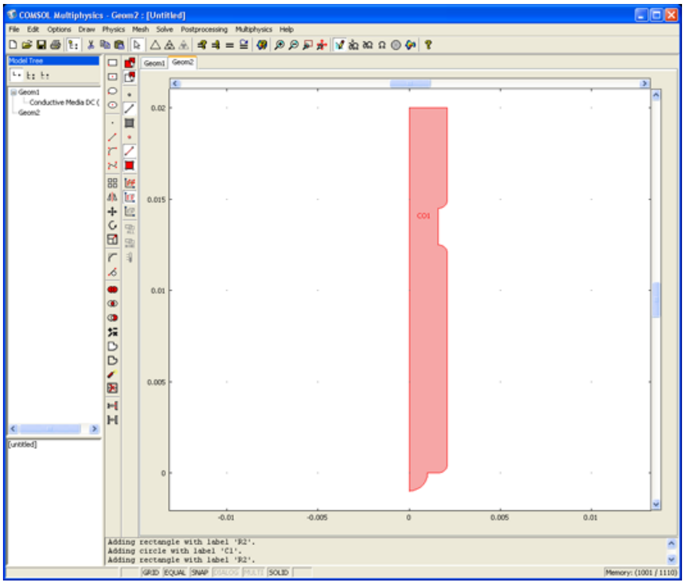
1. Select **Work Plane Settings** from the **Draw** menu.
2. Click the **y-z** radio button and then click **OK**.
3. From the **Draw** menu, select **Specify Objects>Rectangle**. In the **Rectangle** dialog box, enter `2.1e-3` in the **Width** edit field, `5.5e-3` in the **Height** edit field, and enter the corner coordinates (0, 14.5e-3) in the edit fields **x** and **y**. Make sure that **Corner** is selected in the **Base** list. Click **OK**.
4. Select **Fillet/Chamfer** from the **Draw** menu. Expand `R1` and select point number 2. Enter `5e-4` in the **Radius** edit field. Click **OK**.
5. Create a rectangle with width `1.6e-3`, height `2e-3`, and corner position at (0, 12.5e-3).
6. Create a rectangle with width `2.1e-3`, height `12.5e-3`, and corner position at (0, 0).
7. Select **Fillet/Chamfer** from the **Draw** menu. Expand `R2` and select point number 2 and 3. Enter `5e-4` in the **Radius** edit field. Click **OK**.
8. From the **Draw** menu, select **Specify Objects>Circle**. Enter `1e-3` in the **Radius** edit field. Click **OK**.
9. Create a rectangle with width `2e-3`, height `2e-3`, and corner position at (–2e-3, –1e-3).

10 Select **Create Composite Object** from the **Draw** menu. In the dialog box, type the formula `C1-R2` in the **Set formula** edit field. Click **OK**.

11 Select all objects by pressing Ctrl+A. Click on the **Union** toolbar button located to the left side.

12 Click the **Delete Interior Boundaries** toolbar button on the same toolbar.

13 Click the **Zoom Extents** toolbar button. You should have a window similar to the figure below.



14 Select **Revolve** from the **Draw** menu. Click **OK**.

15 Click the **Zoom Extents** toolbar button to see the revolved geometry.

These steps created the electrode, but the electrode also has some hooks that hold it in place.

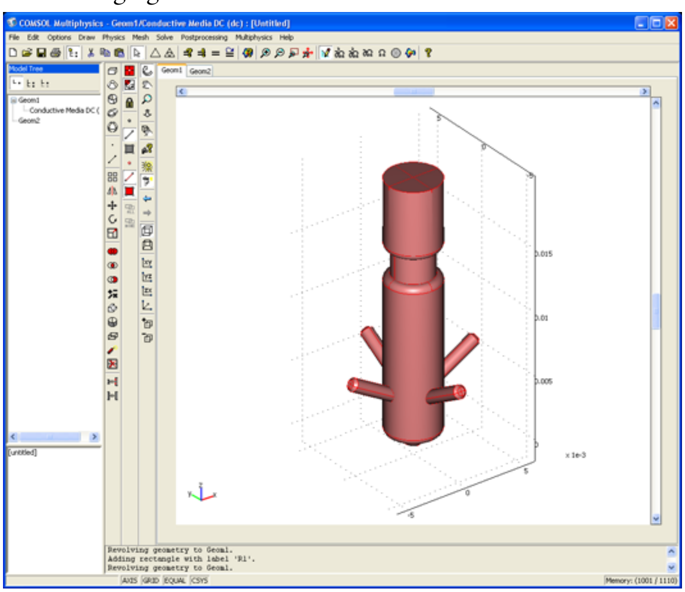
1 Go back to the work plane by clicking on the **Geom2** tab.

2 Create a rectangle with width `5e-4`, height `5.2e-3`, and corner position at (`0`, `3.5e-3`).

3 Select **Fillet/Chamfer** from the **Draw** menu. Expand `R1` and select point number 3. Click the **Chamfer** radio button, and enter `2e-4` in the **Distance** edit field. Click **OK**.

4 Select **Revolve** from the **Draw** menu. Click **OK**.

5. Click the **Rotate** toolbar button and enter `60` in the edit field for the rotation angle. Define the point and axis for the rotation by specifying the coordinate (`0`, `0`, `2.5e-3`) in the **Point on rotation axis** frame, and the direction (`1`, `0`, `0`) in the **Rotation axis direction vector** frame. Click **OK**.
6. Press Ctrl+C to copy the object. Press Ctrl+V to paste it directly. In the **Paste** dialog box, leave all displacement fields set to zero. Click **OK**.
7. Click the **Rotate** toolbar button and set the rotation angle to `90`. Click **OK**.
8. Press Ctrl+V again and click **OK** (zero displacements).
9. Click the **Rotate** toolbar button and set the rotation angle to 180. Click **OK**.
10. Press Ctrl+V and click **OK** (zero displacements).
11. Click on the **Rotate** toolbar button and set the rotation angle to 270. Click **OK**.
12. Press Ctrl+A to select all objects. Click on the **Union** toolbar button and then click on the **Delete Interior Boundaries** toolbar button.
13. Click the **Zoom Extents** and the **Headlight** toolbar buttons to see geometry in the following figure.



Finally, you need to define the volume surrounding the electrode. The simulation only takes place in this volume, where the boundaries of the electrode influence the result.

1 Click on the **Cylinder** toolbar button. In the **Cylinder** dialog box, enter `10e-3` in the **Radius** edit field, `40e-3` in the **Height** edit field, and the coordinate (`0`, `0`, `-20e-3`) in the edit fields of the **Axis base point** frame.

2 Select **Create Composite Object** from the **Draw** menu. In the dialog box, type the formula `CYL1-CO2` in the **Set formula** edit field. Click **OK**.

PHYSICS SETTINGS

Boundary Conditions

The thin waist of the electrode is grounded, and a positive potential is applied to the lower half sphere. All other boundaries are kept electrically insulated.

1 Open the **Boundary Settings** dialog box from the **Physics** menu.

2 Define the boundary condition according to the following table. Click **OK**.

BOUNDARY	ALL OTHER	29, 30, 58, 63	31, 32, 59, 60
Boundary condition	Electric insulation	Ground	Electric potential
V_0			1

Subdomain Settings

Since the electrode is inserted into the human heart, the conductivity for the heart tissue has to be defined.

1 Open the **Subdomain Settings** dialog box from the **Physics** menu.

2 Enter the following values in the corresponding edit fields. Click **OK**.

SUBDOMAIN	1
σ	5000

MESH GENERATION

Use the default mesh settings. Click the **Initialize Mesh** button on the Main toolbar to generate the mesh.

COMPUTING THE SOLUTION

Use the default solver parameters—the stationary solver using the conjugate gradients iterative solver—and algebraic multigrid as the preconditioner.

Click on the **Solve** toolbar button.

POSTPROCESSING AND VISUALIZATION

The potential distribution on the electrode boundary is used together with a streamline plot of the total current density to visualize the result of the simulation.

1 Start by suppressing some boundaries not to be used for visualization. Select **Suppress Boundaries** from the **Options** menu, and select boundaries 1, 2, 3, 4, 45, and 74. Click **OK**.

2 Choose **Plot Parameters** from the **Postprocessing** menu. In the **Plot Parameters** dialog box under the **General** tab, clear the **Slice** check box and select the **Boundary** and **Streamline** check boxes.

3 Click the **Boundary** tab and make sure that **Electric potential** is selected as boundary data.

4 Click the **Streamline** tab and then select **Total current density** from the **Predefined quantities** list. Click the **Line Color** tab, and then click the **Use expression** radio button. Use the default expression—the electric potential.

5 Select **Tube** from the **Line type** list. Click the **Tube Radius** button. In the **Tube Radius Parameters** dialog box, select the **Radius data** check box, and choose **Total current density, norm** from the **Predefined quantities** list. Click **OK** twice. You should now see something similar to the figure below after proper rotation and zoom operations.