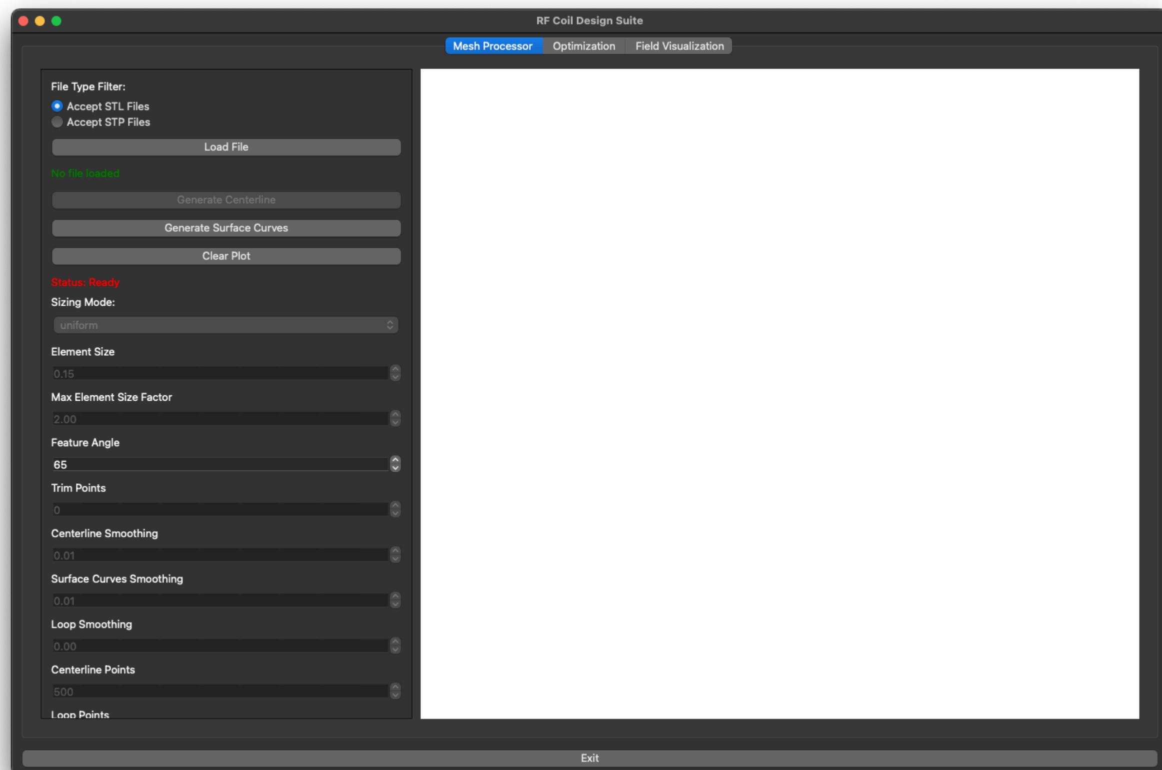
RF Coil Field Visualizer Tutorial and Examples (2025/09/12)

Before you begin: Application Overview

The RF Coil Field Visualizer is a PyQt5 application designed for the analysis and design of RF coils. It allows you to calculate and visualize the magnetic (B-field) and electric (E-field) fields generated by coil structures.

On startup, you should see a GUI window with three main tabs.



The application has two distinct workflows:

Pathway 1: From Physical Geometry to Simulation (Analysis)

- STL/STEP File → Mesh Processor Tab → Field Visualization Tab
- Use this path to import and analyze the field from an existing coil design

Pathway 2: From Parameters to Optimized Simulation (Synthesis)

- Base Parameters → Optimization Tab → Field Visualization Tab
- Use this path to generate and evaluate a population of virtual coil designs

The Field Visualization Tab serves as the common endpoint for both workflows.

Prerequisites

Before starting, ensure you have:

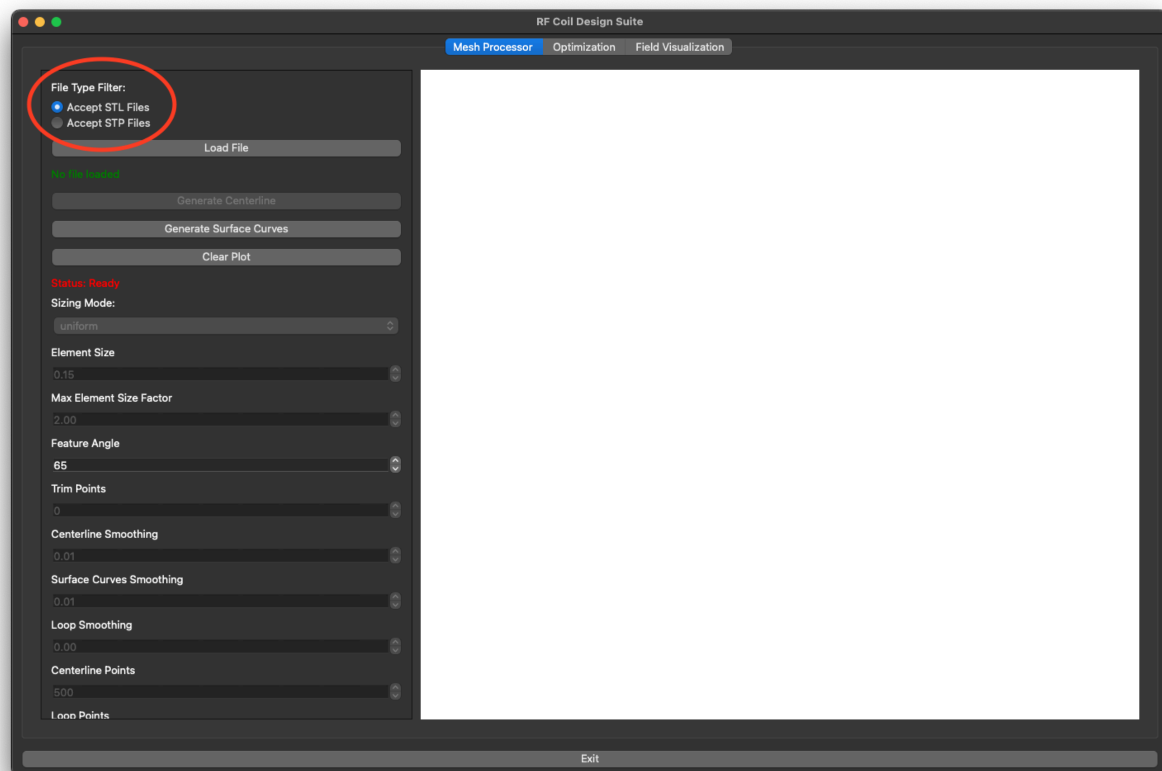
- Python 3.7+
- Required packages: PyQt5, numpy, matplotlib, pyvista, pyvistaqt
- An STL or STEP file of a coil geometry (for Pathway 1)

Understanding the Mesh Processor Tab Controls

The Mesh Processor tab controls how mesh files are loaded and processed. Understanding why some controls are greyed out will help you navigate the interface:

File Type Filter:

- **Accept STL Files/Accept STP Files**: Choose your file type before loading. This selection determines which processing parameters become available.



Processing Workflow:

- **Load File**: Always enabled. Opens file browser to select your geometry file.
- **Generate Centerline**: Disabled until a file is successfully loaded.
- **Generate Surface Curves**: Disabled until centerline is generated.
- **Export to Visualizer**: Disabled until surface curves are generated.

Advanced Parameters (STEP files only): When "Accept STP Files" is selected, additional parameters become enabled:

- Sizing Mode, Element Size, Max Element Size Factor
- Feature Angle, Trim Points, Smoothing options
- Points configuration for centerline and loop generation

These parameters are greyed out for STL files since STL files are treated as fixed surface meshes.

Tutorial 1: Analyzing a Physical Coil (Pathway 1)

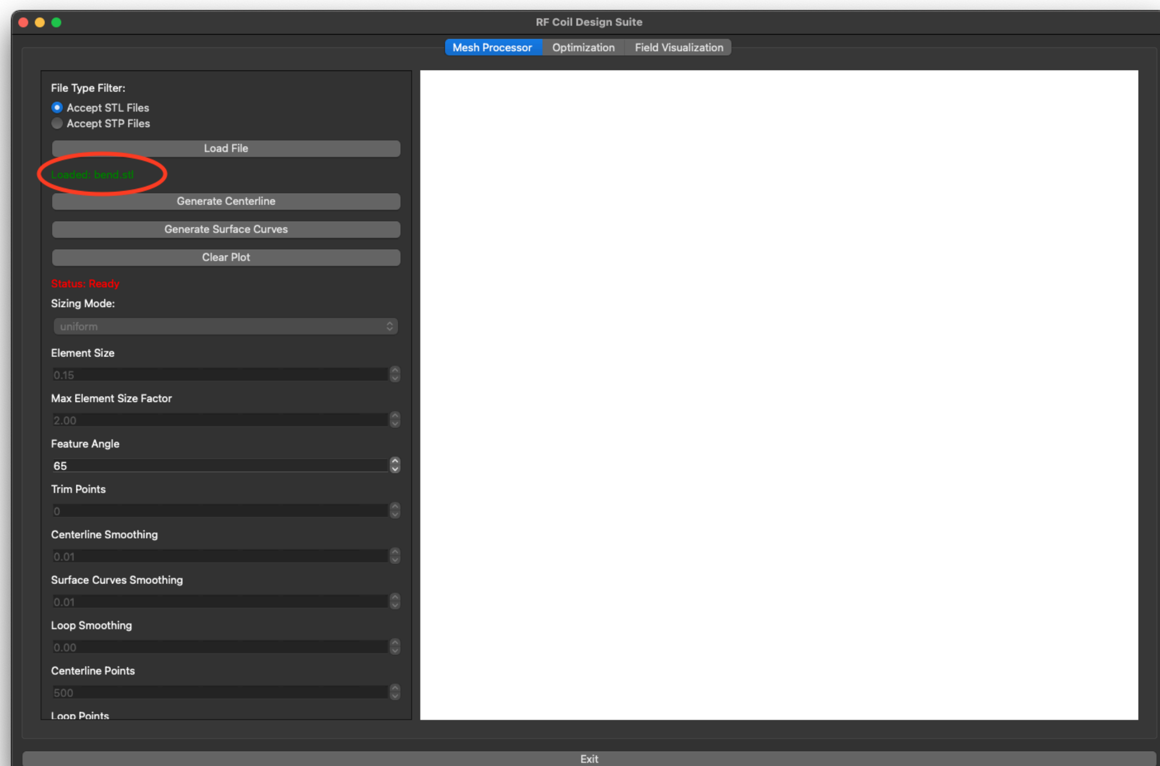
This tutorial guides you through importing an existing coil geometry and analyzing its magnetic field.

Step 1.1: Loading Your Coil File

Navigate to the Mesh Processor tab. Select the appropriate file type:

- **Accept STL Files**: For stereolithography files (.stl)
- **Accept STP Files**: For STEP CAD files (.stp, .step)

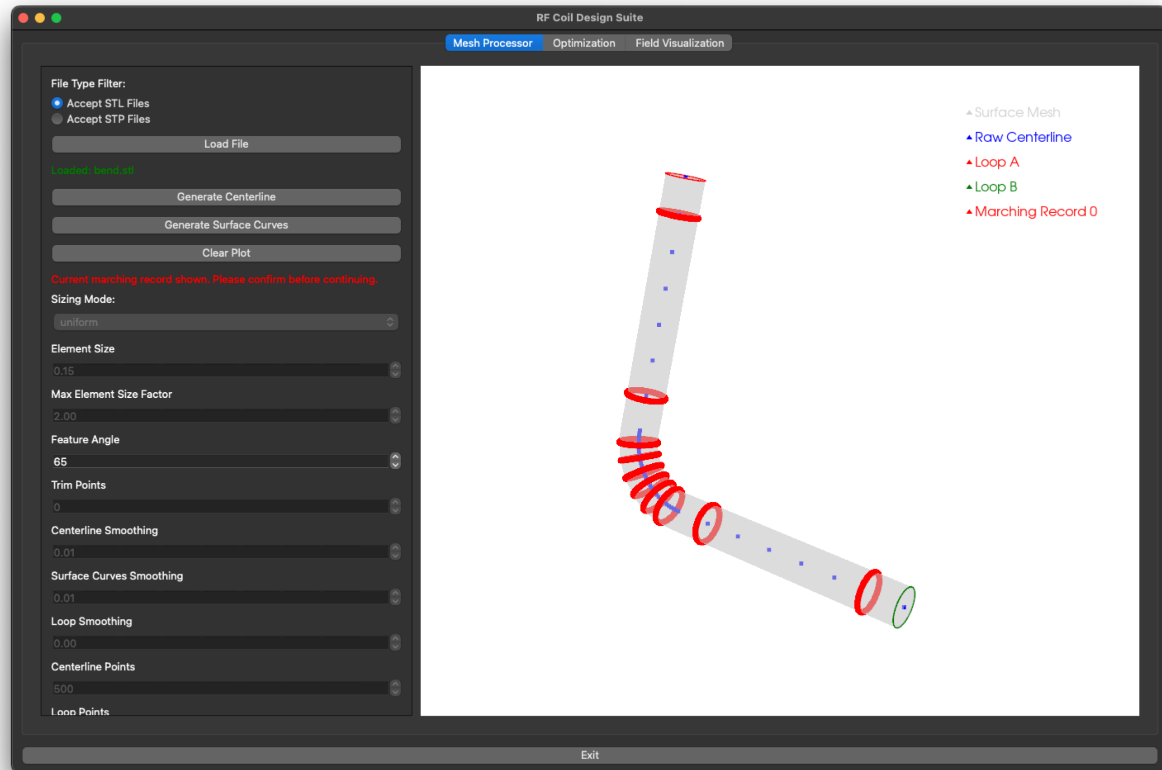
Click "Load File" and select your coil geometry file. The filename will appear below the button, and "Generate Centerline" will become active.



Step 1.2: Extracting the Centerline

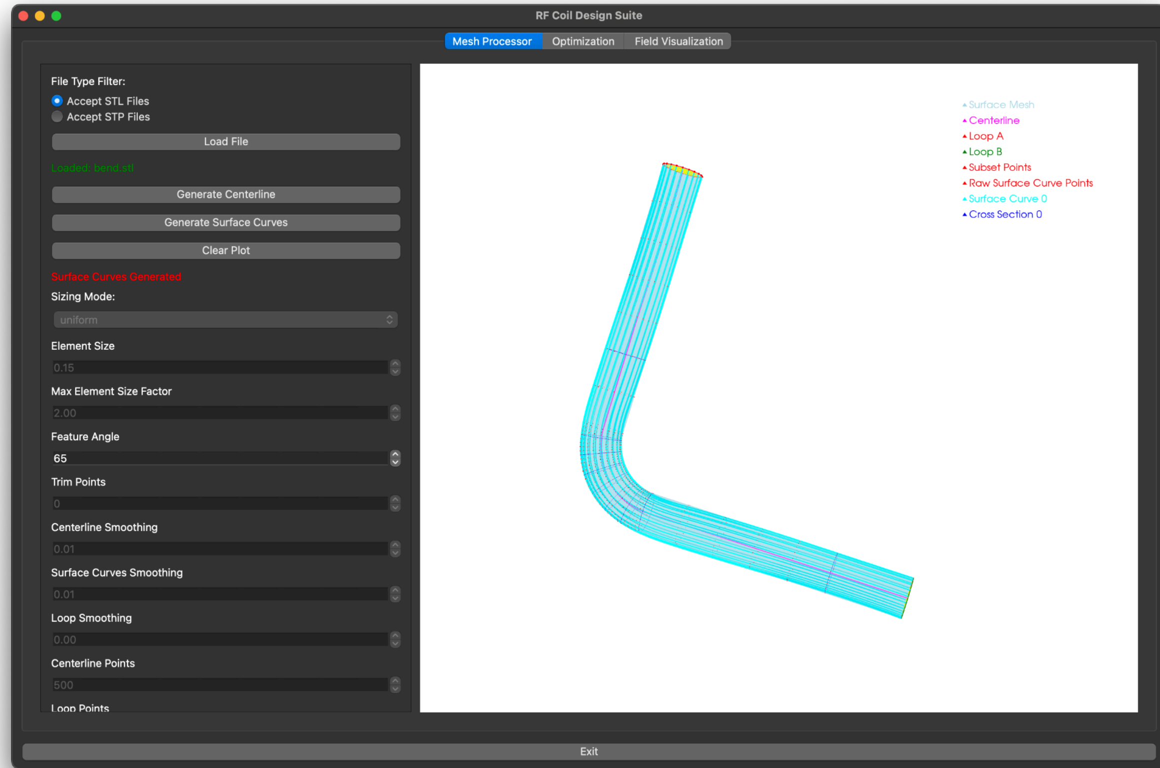
Click "Generate Centerline". The application processes your mesh to find the coil's central path. The 3D view will update to show:

- Original surface mesh (lightblue)
- Computed end loops (red and green)
- Extracted centerline (magenta)
- Cross-sections along the centerline (blue)



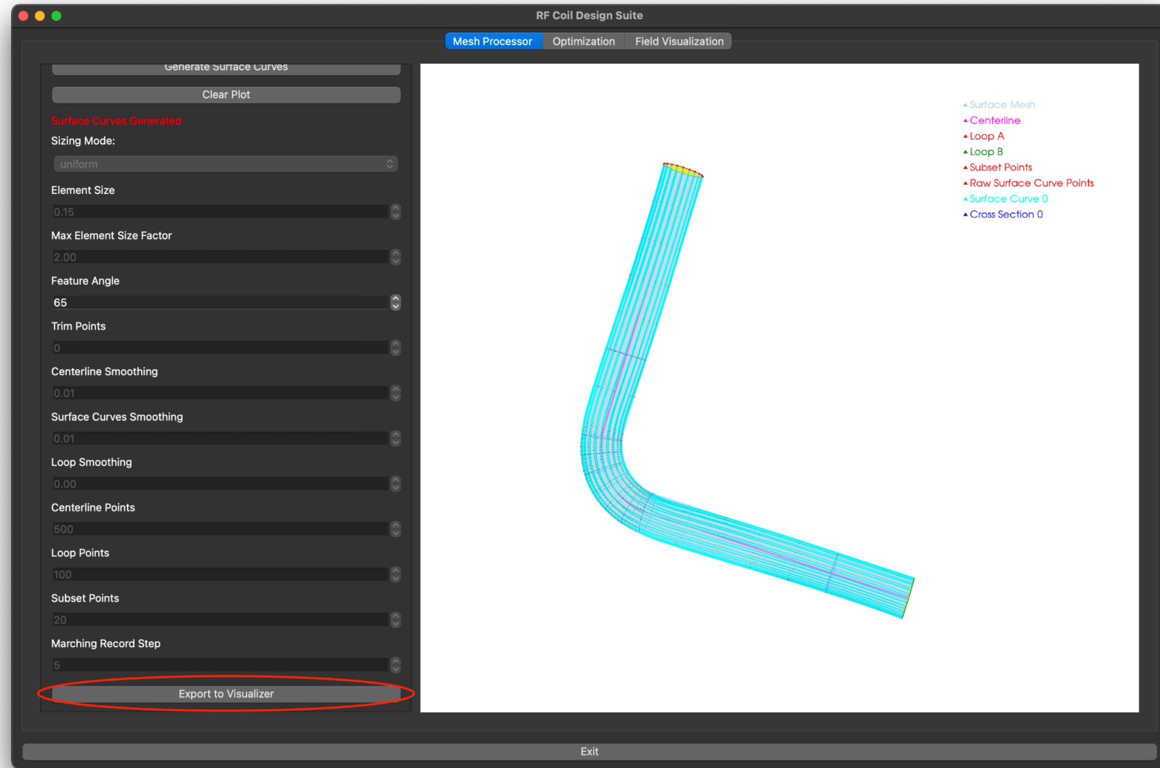
Step 1.3: Generating Surface Curves

Click "Generate Surface Curves". This creates curves that represent the actual wire paths on your coil surface. The view updates to show new cyan surface curves overlaid on the previous elements.



Step 1.4: Exporting to Field Visualization

Scroll down and click "Export to Visualizer". A confirmation message appears, and the application switches to the Field Visualization tab where your coil geometry is now available for field calculations.



Tutorial 2: Computing and Visualizing Fields

Now that your coil geometry is loaded, you can compute its electromagnetic fields.

Step 2.1: Setting the Computation Region

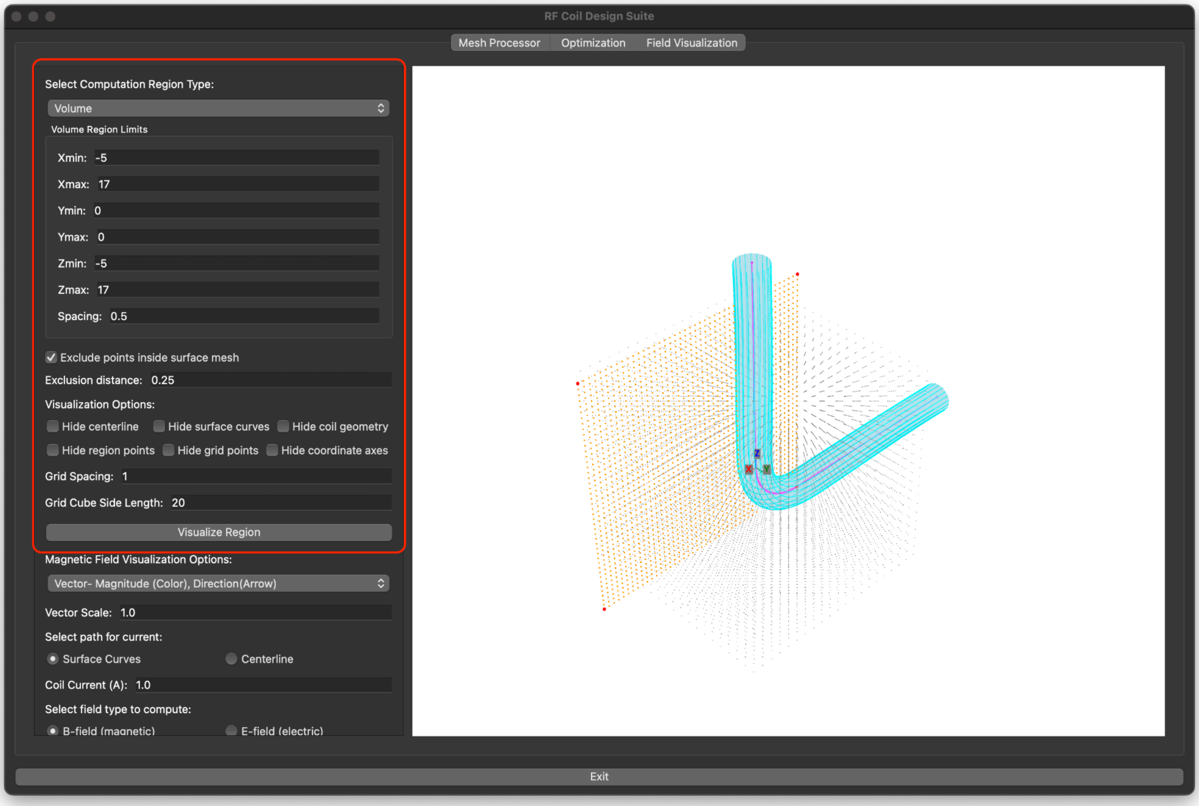
Choose your region type from the dropdown:

- **Volume**: 3D box of points (most detailed, slowest)
- **Plane**: 2D grid of points (good for cross-sections)
- **Line**: 1D line of points (fastest, for quick analysis)

Configure the region parameters. For a Volume, set X/Y/Z min/max coordinates and spacing between points.

Important: Check "Exclude points inside surface mesh" to avoid calculating fields inside the wire itself.

Before computing, click the **"Visualize Region" button**. This will populate the 3D view with points or a grid showing you exactly where the field will be calculated. This allows you to verify that your region correctly encompasses your coil and that the spacing is appropriate.



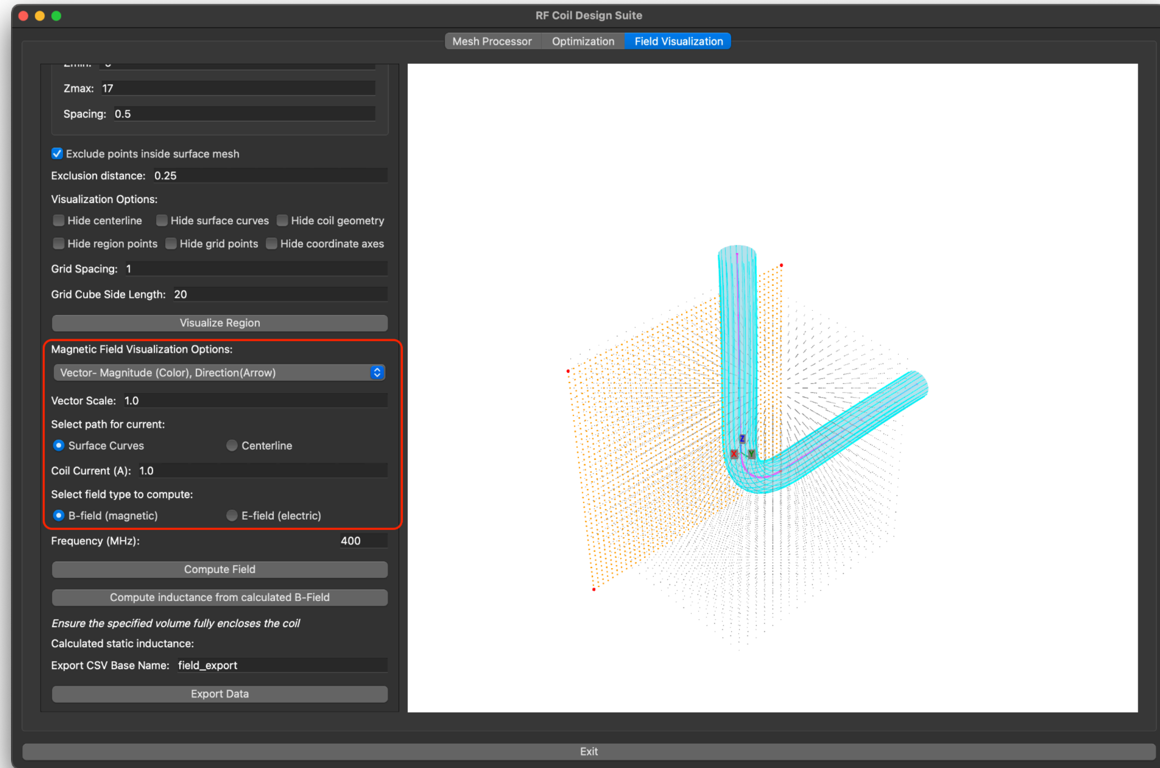
Step 2.2: Configuring Field Calculation

Select path for current: Choose "Surface Curves" (recommended for imported coils) or "Centerline" for faster calculation.

Coil Current (A): Set to 1.0 for normalized results.

Field type:

- **B-field (magnetic)**: Static magnetic field
- **E-field (electric)**: Requires setting "Frequency (MHz)"

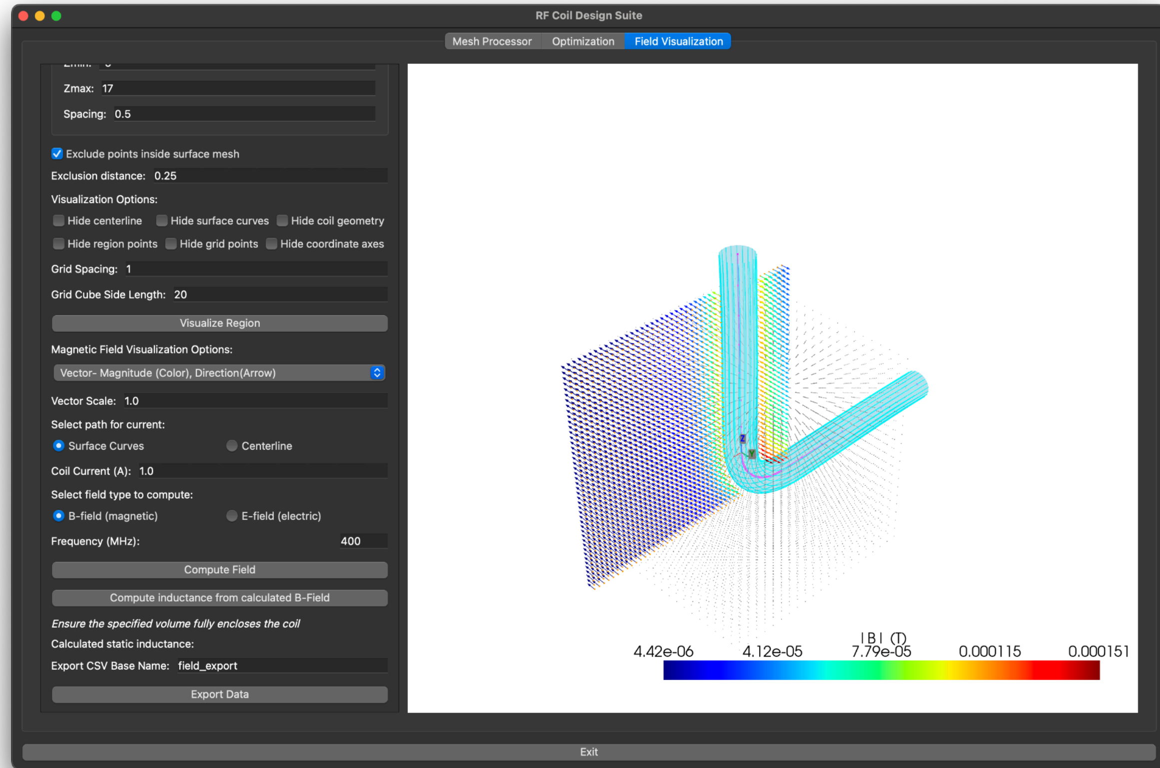


Step 2.3: Computing and Visualizing

Click "Compute Field". Monitor the status log for progress. Once complete, select a visualization style:

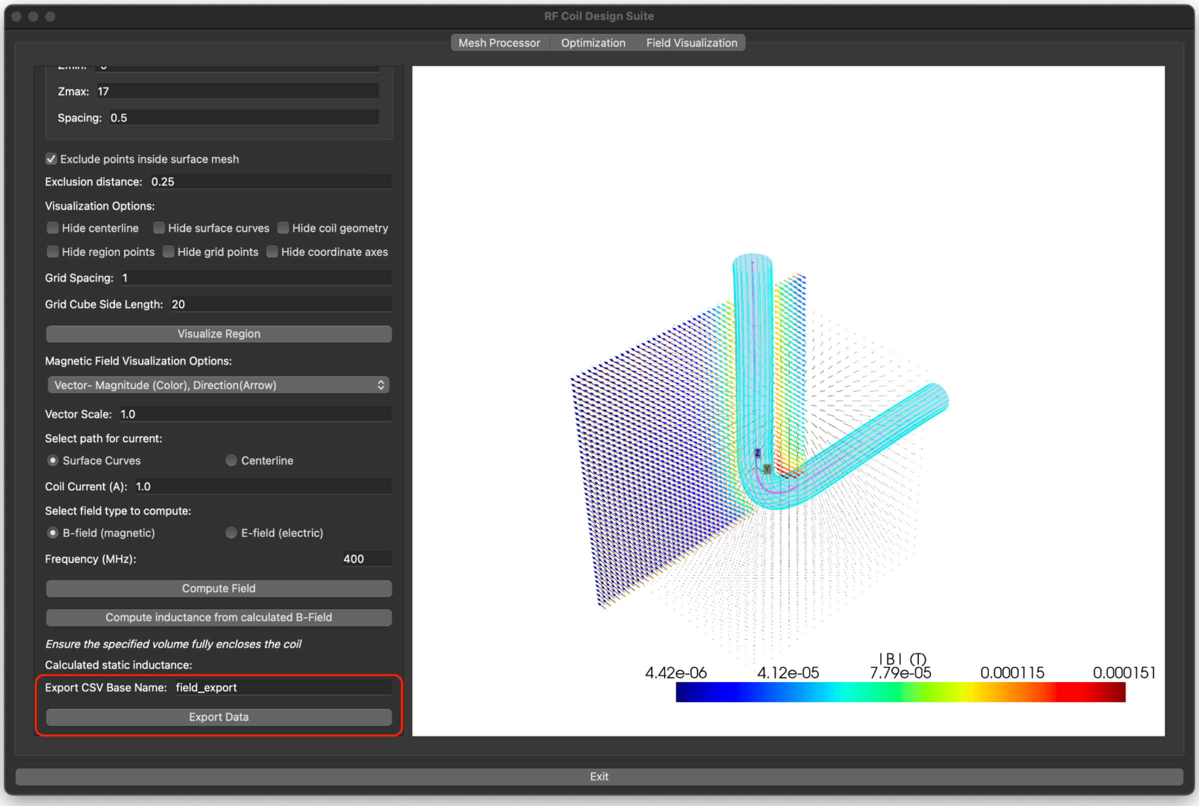
- **"Vector- Magnitude (Color), Direction(Arrow)"**: Shows field direction with color-coded strength
- **"Magnitude"**: Colors points by field strength only

Adjust "Vector Scale" to optimize arrow visibility.



Step 2.4: Exporting Results (Optional)

Enter a base filename and click "Export Data" to save field data as CSV files containing coordinates and field components for further analysis.



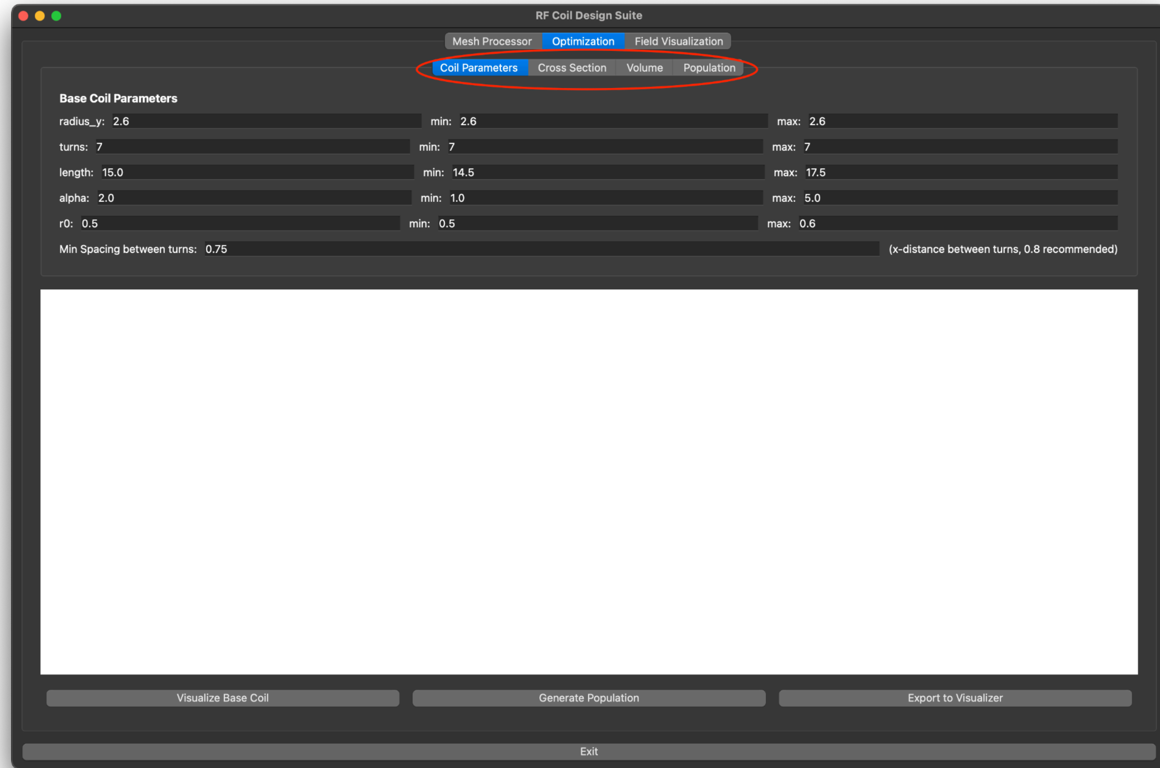
Tutorial 3: Generating Optimized Coil Designs (Pathway 2)

This tutorial covers creating and optimizing virtual coil designs from mathematical parameters.

Step 3.1: Setting Design Parameters

Navigate to the Optimization tab. Configure four main sections:

1. **Coil Parameters**: Set base values and min/max bounds for:
   - radius_y, turns, length, alpha, r0
2. **Cross Section**: Define wire radius and bounds
3. **Volume**: Set the cylindrical evaluation volume where each coil's performance will be assessed
4. **Population**: Specify number of coils to generate

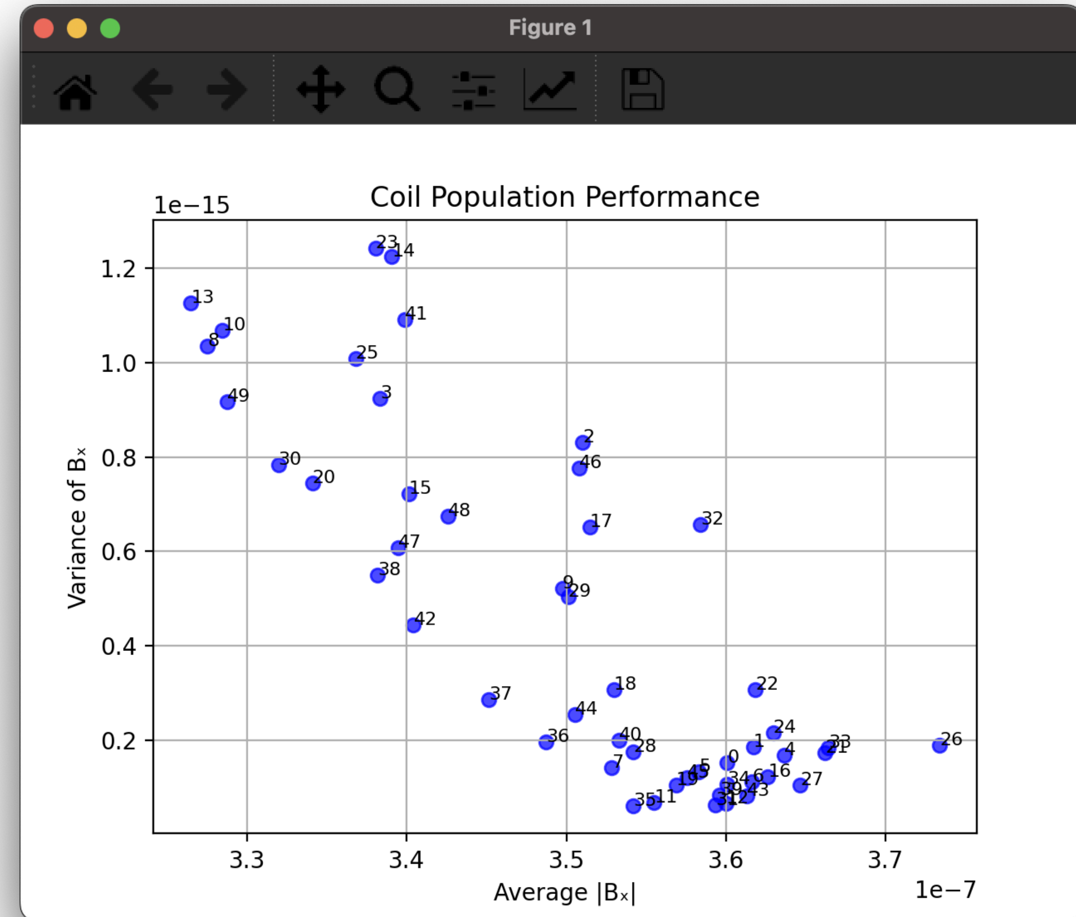


Step 3.2: Generating Population

In the Population tab, enter the number of coils (e.g., 50) and click "Generate Population".

The application creates random coils within your bounds and evaluates each one's B-field performance. A scatter plot opens showing:

- X-axis: Average $|B_x|$ (field strength)
- Y-axis: Variance of B_x (field homogeneity)
- Each point represents a coil labeled with its ID

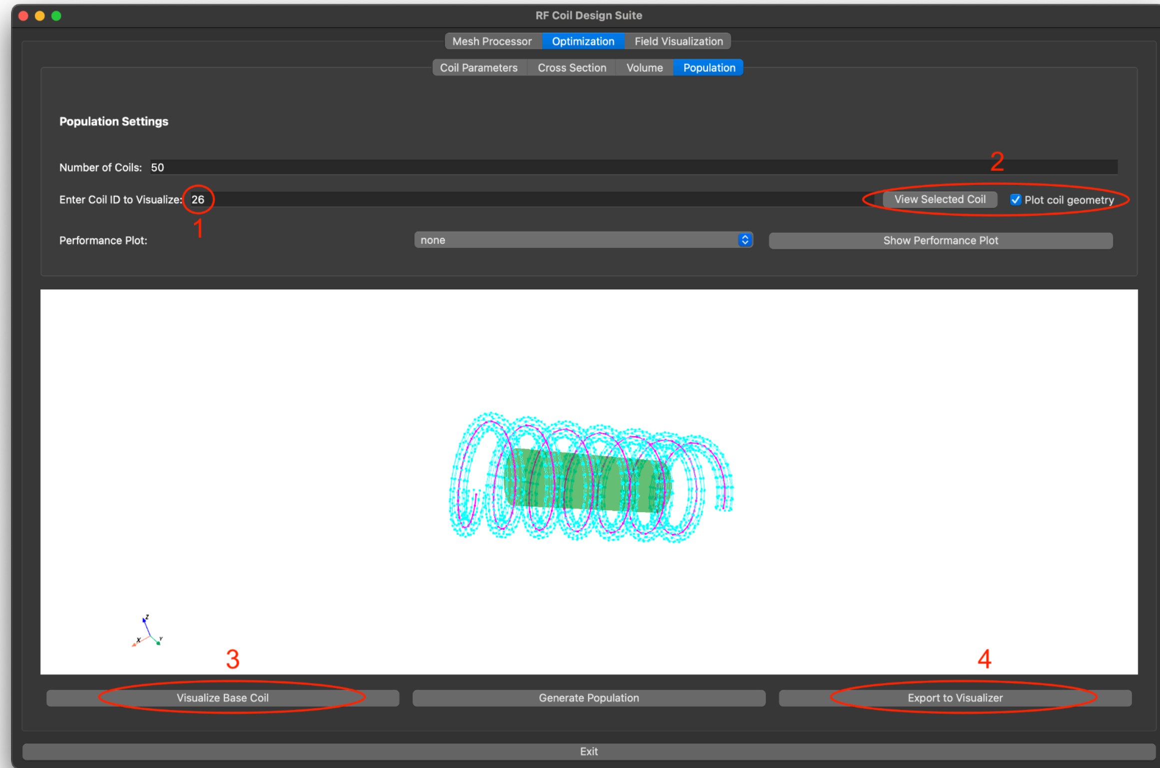


Step 3.3: Selecting Your Optimal Design

Analyze the scatter plot to identify coils meeting your criteria (e.g., high field strength, low variance). Note the ID of your preferred coil.

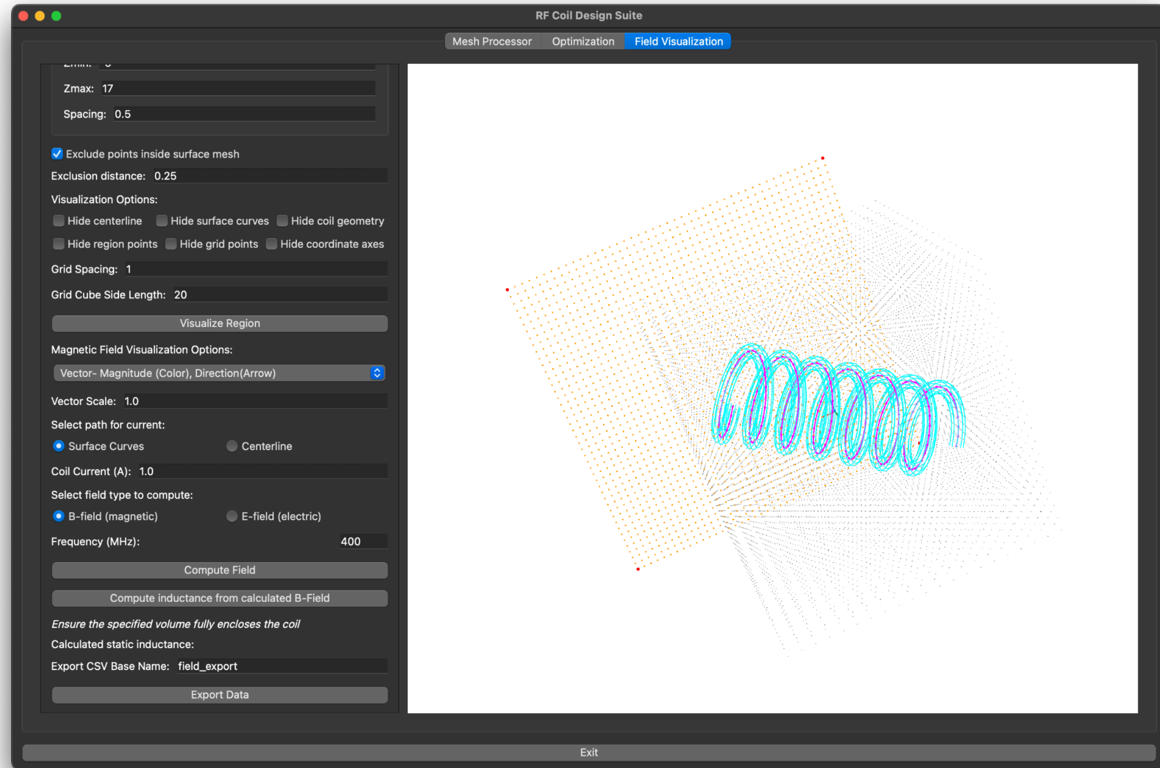
Back in the Optimization tab:

1. Enter the Coil ID in the "Enter Coil ID to Visualize" field
2. Check "Plot coil geometry"
3. Click "View Selected Coil" or “Visualize Base Coil” to see the geometry
4. Click "Export to Visualizer" to send it to the Field Visualization tab



Step 3.4: Analyzing Your Optimized Coil

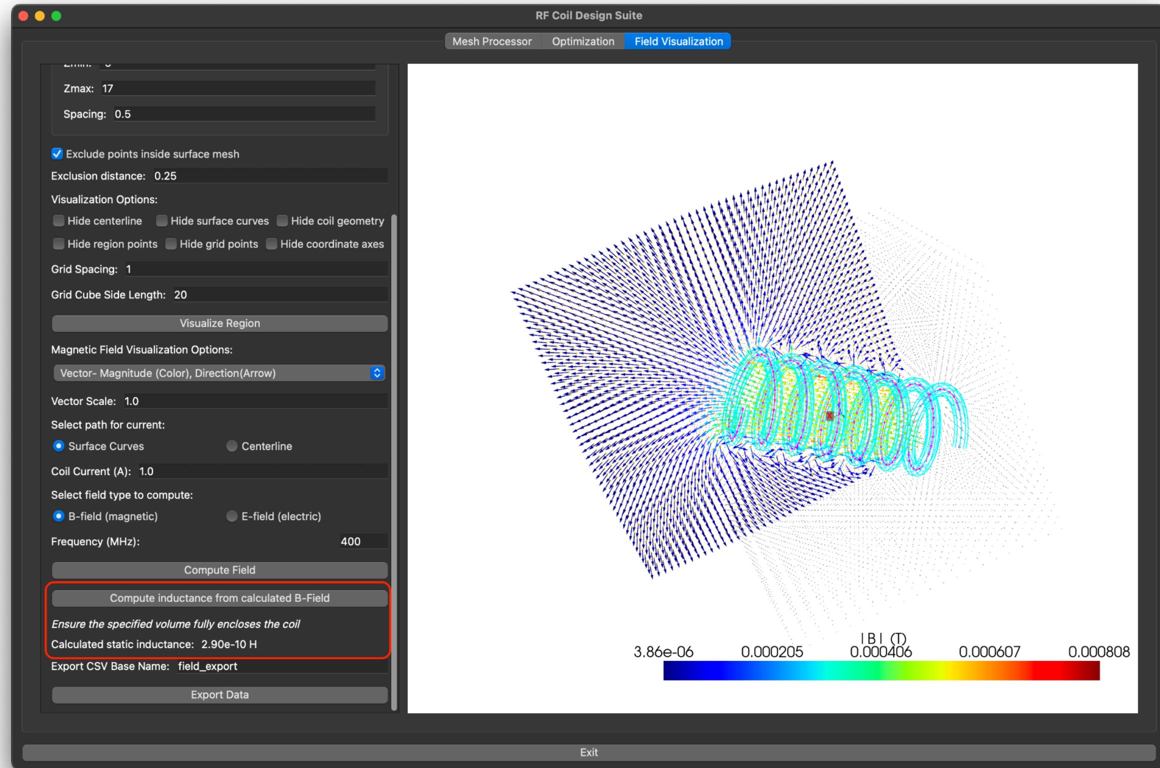
Switch to the Field Visualization tab. Your selected coil is now available for detailed field analysis using the same steps from Tutorial 2.



Advanced Features

Computing Inductance

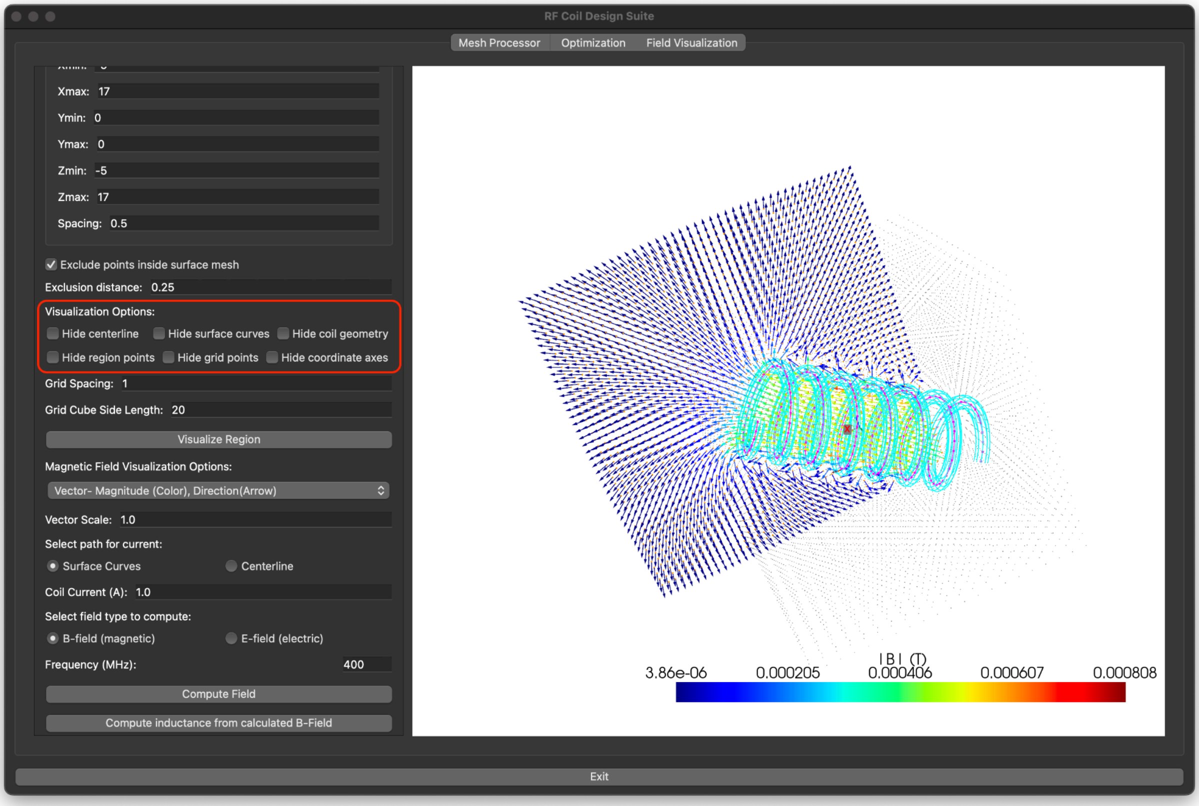
After computing a B-field for a Volume region, click "Compute inductance from calculated B-Field". The calculated inductance value (in Henries) will be displayed.



Visualization Options

Use checkboxes to toggle visibility:

- Hide centerline/surface curves/coil geometry
- Hide region points/grid points/coordinate axes

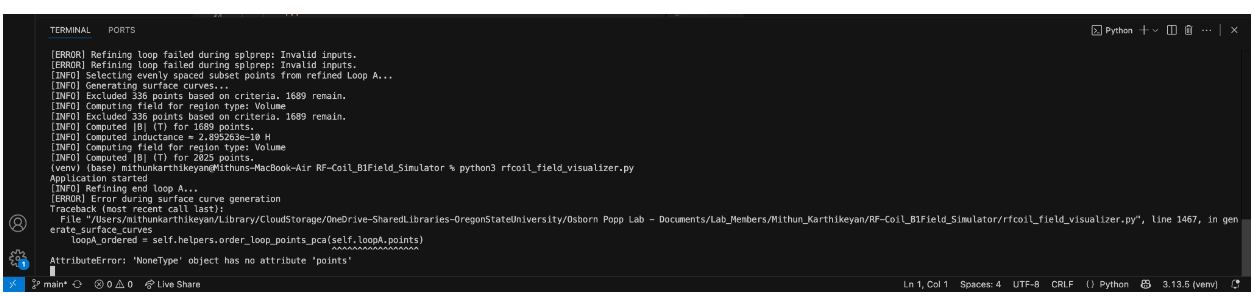


Troubleshooting and Application Management

Monitoring for Errors

While the application provides status messages in the GUI, more detailed error and information messages are printed to the terminal or console from which you launched the program.

- If an operation fails or behaves unexpectedly (e.g., a field fails to compute, a mesh fails to load), check the terminal window for any error messages or warnings logged by the application. These logs often contain specific details that can help diagnose the issue.



Exiting the Application

To close the application cleanly, use the "Exit" button located at the bottom of the main window. This ensures all resources are properly released.