SIMULATION PROJECT

Fundamentals of Electromagnetics

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Project Report: Fundamentals of Electromagnetics

1. Introduction This project involves conducting numerical simulations to analyze the behavior of electromagnetic structures with different grid step sizes. Additionally, a modified version of the structure was created and analyzed. This report provides a detailed explanation of the procedures, results, and observations conducted in accordance with the project guidelines.

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2. Problem Definition The project aims to analyze the electromagnetic behavior of a given structure, optimize simulation parameters, and observe the performance effects of modifying the structure. The completed tasks are as follows:

1. Simulating the original structure with grid step sizes of 2 cm, 1 cm, 0.5 cm, and 0.25 cm.
2. Plotting graphs of iteration counts and error tolerances for each grid step size.
3. Modifying the original structure and simulating the modified structure.
4. Comparing the results of the original and modified structures.

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3. Methodology

3.1. Grid Step Size Analysis Simulations were performed with different grid step sizes to examine the effects of step sizes on iteration counts and error tolerances. The grid step sizes used were: 2 cm, 1 cm, 0.5 cm, and 0.25 cm. For each step size, iteration counts and error tolerances were recorded and plotted.

3.2. Structure Modification The original structure was modified in accordance with the project guidelines. The modified structure was analyzed using the same simulation method.

3.3. Tools and Software Used Simulations were conducted using a numerical solver. MATLAB was used for plotting graphs and analyzing results.

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4. Results and Discussion

4.1. Grid Step Size Analysis The output data obtained for each grid step size:

- **Grid Step Size: 2 cm**

```
>> Cgridsize2
Solution converged in 1042 iterations.
Error tolerance achieved: 1.000000e-06
```

- **Grid Step Size: 1 cm**

```
>> Cgridsize1
Solution converged in 1854 iterations.
Error tolerance achieved: 9.999934e-07
```

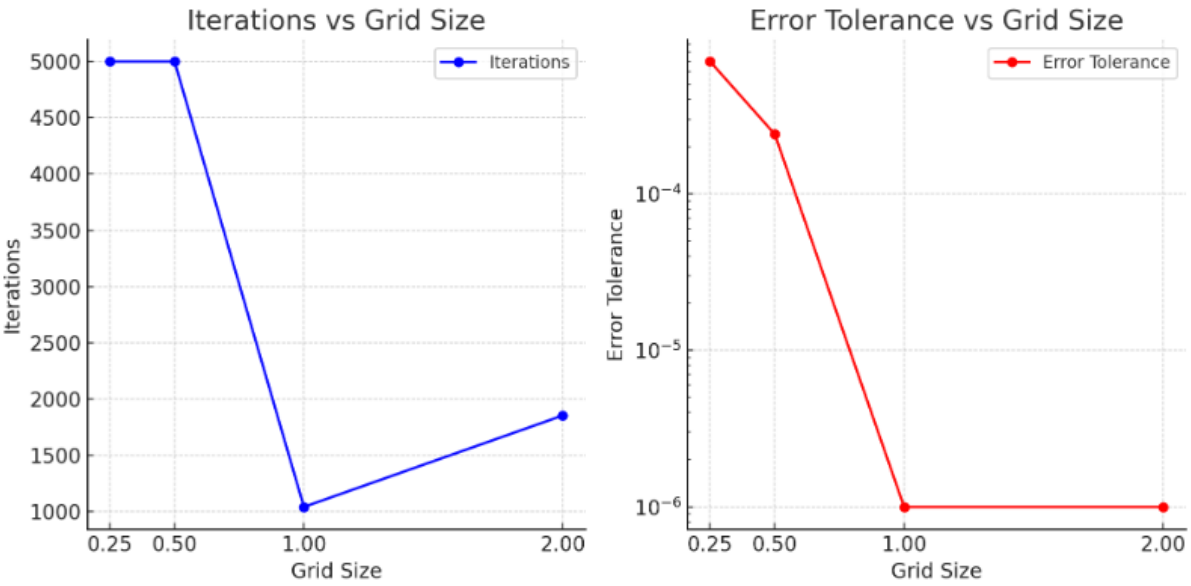
- **Grid Step Size: 0.5 cm**

```
>> Cgridsize05
Solution did not converge within the maximum number of iterations (5000).
Final error: 2.402790e-04
```

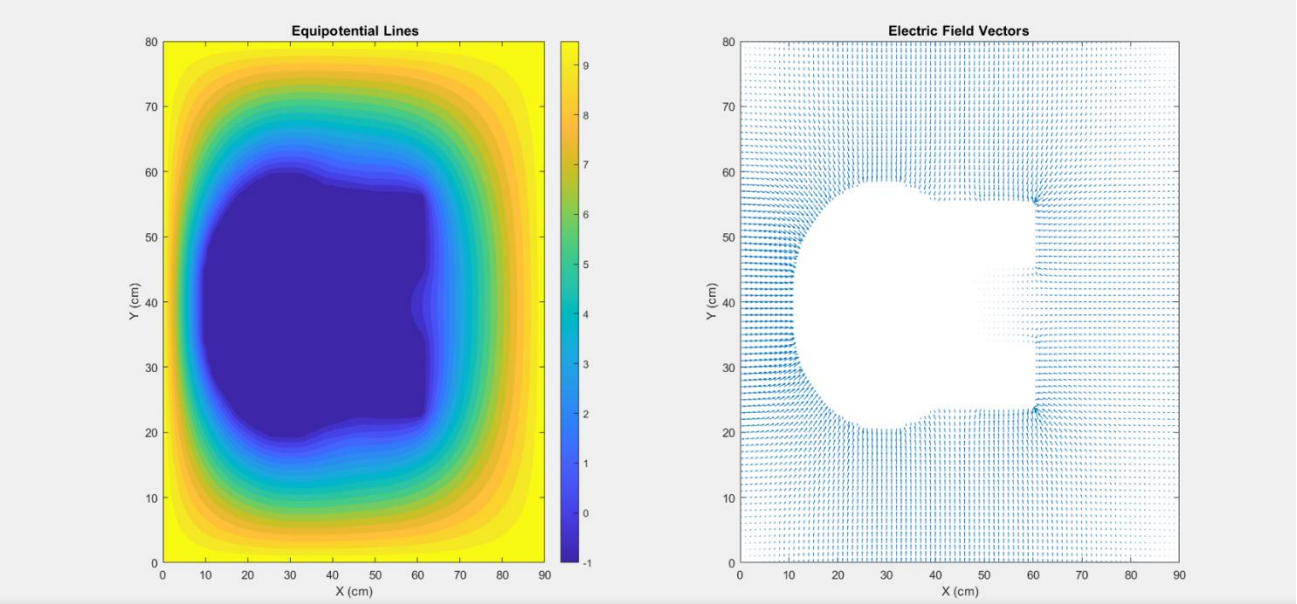
- **Grid Step Size: 0.25 cm**

```
Solution did not converge within the maximum number of iterations (5000).
Final error: 7.000951e-04
```

Graph: The relationship between iteration counts and error tolerances for different grid step sizes is illustrated in the picture below. This graph highlights the balance between grid resolution and computational effort.

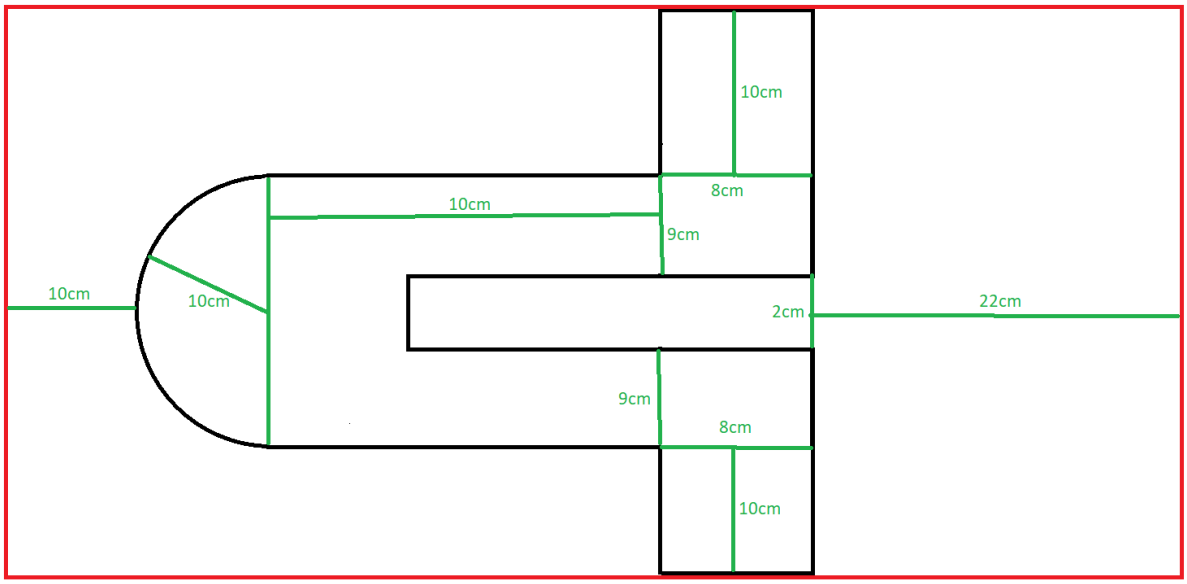


4.2. Original Structure Analysis The graphical output of the original structure is presented in the picture below. This graph illustrates the electromagnetic field distribution and behavior of the structure.

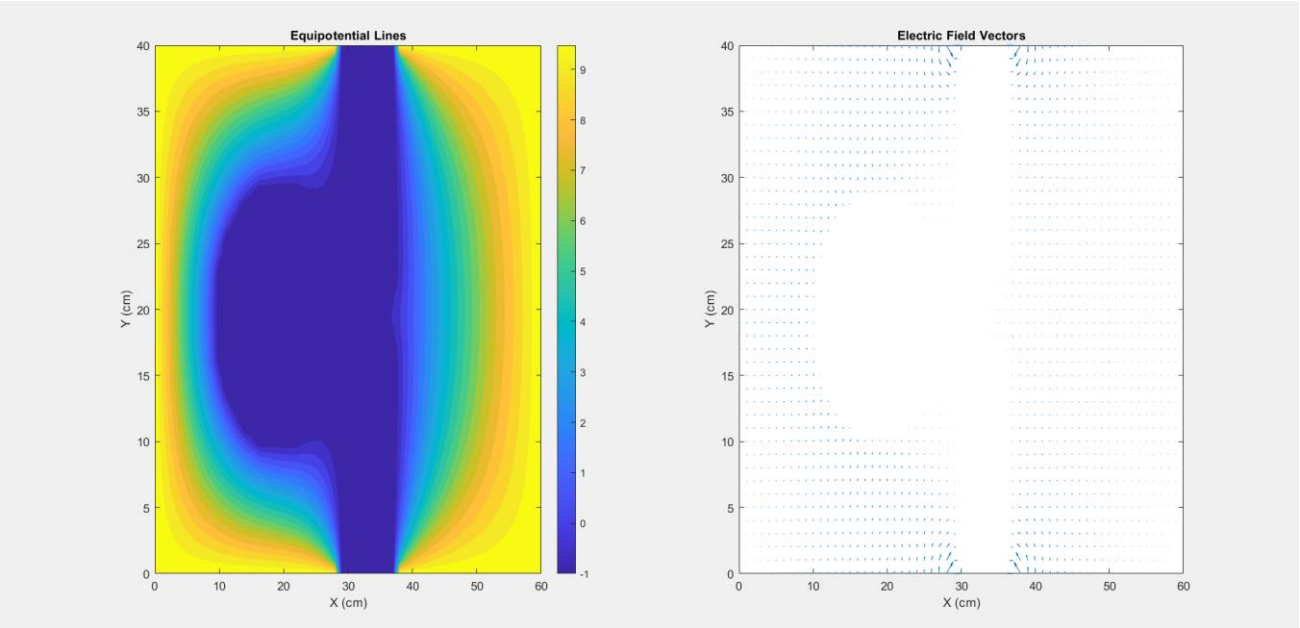


4.3. Modified Structure Analysis

- **Graphical Representation:**
  - The appearance of the modified structure is shown in the picture below



- The graphical output of the modified structure is provided in



- **Numerical Output:**
  - The numerical output of the modified structure is available in the picture below

```
>> modificatedStructure
Solution converged in 954 iterations.
Error tolerance achieved: 9.968852e-07
```

4.4. Comparison The comparison between the original and modified structures reveals the following observations:

Equipotential lines and electric field vectors in the added part of the shape have changed. Iteration and error tolerance values have decreased.

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5. Conclusion This project provided valuable insights into the impact of grid step sizes on simulation performance and accuracy. The modifications made to the original structure had significant effects on its electromagnetic behavior, as evidenced by the graphical and numerical outputs. These results underscore the importance of optimizing structure design and simulation parameters in electromagnetics.

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6. Appendices

6.1. Original Structure Code

```
Nx = 91;
Ny = 81;
V = zeros(Ny, Nx);
V_outer = 10;
V_C = -1;
R = 20;
width_C = 12;
gap_C = 10;
xC = 30;
yC = Ny / 2;
V(1, :) = V_outer;
V(Ny, :) = V_outer;
V(:, 1) = V_outer;
V(:, Nx) = V_outer;
for j = 1:Ny
    for i = 1:Nx
        if (i - xC)^2 + (j - yC)^2 <= R^2 && i < xC + R
            V(j, i) = V_C;
        end
        if (i >= xC + R) && (i <= xC + R + width_C) && ...
           (j >= yC - gap_C/2 - width_C) && (j <= yC - gap_C/2)
            V(j, i) = V_C;
        end
        if (i >= xC + R) && (i <= xC + R + width_C) && ...
           (j >= yC + gap_C/2) && (j <= yC + gap_C/2 + width_C)
            V(j, i) = V_C;
        end
    end
end
max_iter = 5000;
tolerance = 1e-6;
for iter = 1:max_iter
    V_old = V;
    for j = 2:Ny-1
        for i = 2:Nx-1
            if V(j, i) == V_outer || V(j, i) == V_C
                continue;
            end
            V(j, i) = 0.25 * (V(j+1, i) + V(j-1, i) + V(j, i+1) + V(j, i-1));
        end
    end
    error = max(max(abs(V - V_old)));
    if error < tolerance
        fprintf('Solution converged in %d iterations.\n', iter);
        fprintf('Error tolerance achieved: %.6e\n', error);
        break;
    end
end

if iter == max_iter
    fprintf('Solution did not converge within the maximum number of iterations
(%d).\n', max_iter);
    fprintf('Final error: %.6e\n', error);
end
```

```
figure;
subplot(1, 2, 1)
[X, Y] = meshgrid(0:Nx-1, 0:Ny-1);
contourf(X, Y, V, 20, 'LineColor', 'none');
colorbar;
title('Equipotential Lines');
xlabel('X (cm)');
ylabel('Y (cm)');
[Ex, Ey] = gradient(-V);
subplot(1, 2, 2)
quiver(X, Y, Ex, Ey, 'AutoScale', 'on', 'AutoScaleFactor', 1.5);
title('Electric Field Vectors');
xlabel('X (cm)');
ylabel('Y (cm)');
```

6.2. Modified Structure Code

```
Nx = 61;
Ny = 41;
V = zeros(Ny, Nx);
V_outer = 10;
V_C = -1;
R = 10;
width_C = 8;
gap_C = 4;
xC = 20;
yC = Ny / 2;
V(1, :) = V_outer;
V(Ny, :) = V_outer;
V(:, 1) = V_outer;
V(:, Nx) = V_outer;
for j = 1:Ny
    for i = 1:Nx
        if (i - xC)^2 + (j - yC)^2 <= R^2 && i < xC + R
            V(j, i) = V_C;
        end
        if (i >= xC + R) && (i <= xC + R + width_C) && (j >= yC + gap_C / 2)
            V(j, i) = V_C;
        end
        if (i >= xC + R) && (i <= xC + R + width_C) && (j <= yC - gap_C / 2)
            V(j, i) = V_C;
        end
    end
end
max_iter = 5000;
tolerance = 1e-6;
for iter = 1:max_iter
    V_old = V;
    for j = 2:Ny-1
        for i = 2:Nx-1
            if V(j, i) == V_outer || V(j, i) == V_C
                continue;
            end
            V(j, i) = 0.25 * (V(j+1, i) + V(j-1, i) + V(j, i+1) + V(j, i-1));
        end
```

```
    end
    error = max(max(abs(V - V_old)));
    if error < tolerance
        fprintf('Solution converged in %d iterations.\n', iter);
        fprintf('Error tolerance achieved: %.6e\n', error);
        break;
    end
end
if iter == max_iter
    fprintf('Solution did not converge within the maximum number of iterations
(%d).\n', max_iter);
    fprintf('Final error: %.6e\n', error);
end
figure;
subplot(1, 2, 1)
[X, Y] = meshgrid(0:Nx-1, 0:Ny-1);
contourf(X, Y, V, 20, 'LineColor', 'none');
colorbar;
title('Equipotential Lines');
xlabel('X');
ylabel('Y');
xlim([0 Nx-1]);
ylim([0 Ny-1]);
[Ex, Ey] = gradient(-V);
subplot(1, 2, 2)
quiver(X, Y, Ex, Ey);
title('Electric Field Vectors');
xlabel('X');
ylabel('Y');
xlim([0 Nx-1]);
ylim([0 Ny-1]);
```