

EMR Assignment

by Joshua Asare

Submission date: 10-May-2023 05:45AM (UTC+0100)

Submission ID: 205505449

File name: 32752_Joshua_Asare_EMR_Assignment_497416_431133200.pdf (1.65M)

Word count: 2330

Character count: 14858

BEng Embedded
Electronic Systems
Electromagnetic
Radiation ACDA5009
Joshua Ofosu Asare
2111739

Contents



Introduction	4
Task 1: Rectangular Electrostatic problem	5
Problem scope	5
Design.....	5
Differences between problems	6
Problem analysis	6
Task 2: S-shape bending electrostatic problem.....	8
Problem scope	8
Design.....	8
Differences between problems	9
Problem analysis	10
Task 3: Transformer simulation	12
Problem scope	12
Design.....	12
Problem analysis	14
Conclusions and recommendations.....	14
Bibliography	15

Figure 1: A screenshot of the design of the air rectangle of dimensions 10x8cm with upper and lower boundaries $V=0$, left and right $V=9$	5
Figure 2: A screenshot of the design of the silicon rectangle of dimensions 10x8cm with upper and lower boundaries $V=0$, left and right $V=9$	5
Figure 3: A screenshot of the analysis of the air problem	6
Figure 4: A screenshot of the analysis of the silicon problem	6
Figure 5: Magnitude of electric flux density from centre left to right across a air rectangle.....	7
Figure 6: Magnitude of electric flux density from centre left to right across a silicon rectangle.....	7
Figure 7: Copper s-shape bending electrostatic problem.....	8
Figure 8: Aluminium s-shape bending electrostatic problem.....	9
Figure 9: Analysis of a copper s-shape bending electrostatic problem	10
Figure 10: Analysis of an aluminium s-shape bending electrostatic problem	10
Figure 11: The magnitude of current density within a copper polygon	11
Figure 12: The magnitude of current density within an aluminium polygon	11
Figure 13: A screenshot of the design of the transformer	12
Figure 14: Transformer current density	14

Introduction

This assignment examines 3 problems using the FEMM4.2 (Finite Element Method Magnetics) software. "FEMM is a Windows program for solving 2D and axisymmetric problems of AC and DC magnetism, electrostatics, heat flow, and current flow" [1]. FEMM will be used to solve two DC problems and an AC problem. The two DC problems will each compare and contrast two different materials in their respective shape boundaries. The first of the two DC problems will analyse a rectangle made of silicon, then of air. The second problem will analyse a polygon with voltage boundaries at either end, with insulation surrounding the path the current takes from one end to another.

Task 1: Rectangular Electrostatic problem

Problem scope

A rectangular model with dimensions 10 x 8 cm which has $V = 0$ for the upper and lower boundaries and $V = 9$ for the left and right boundaries demonstrated below in Figure 1.

Design

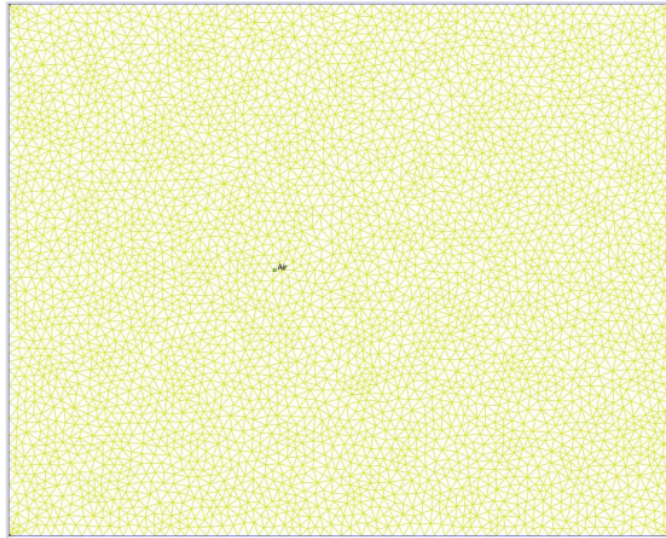


Figure 1: A screenshot of the design of the air rectangle of dimensions 10x8cm with upper and lower boundaries $V=0$, left and right $V=9$

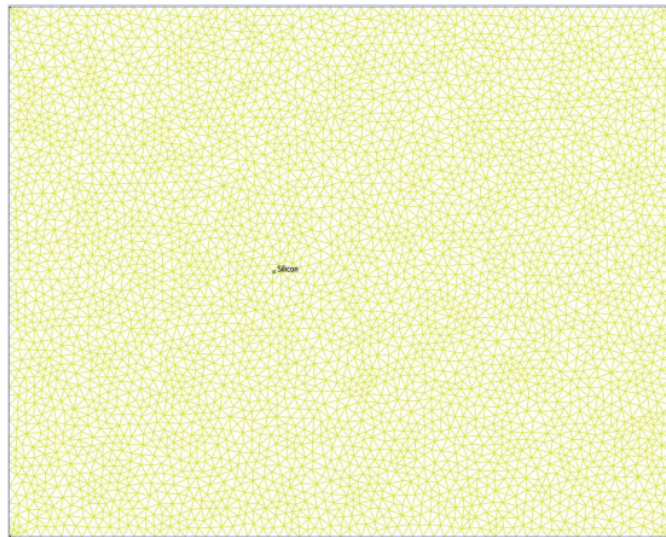


Figure 2: A screenshot of the design of the silicon rectangle of dimensions 10x8cm with upper and lower boundaries $V=0$, left and right $V=9$

Differences between problems

Both problem designs have identical boundaries, the only difference between the two is the relative permittivity of 1 for air, and 12 for silicon.

Air and Silicon have different relative permittivity's. In FEMM 4.2, air is considered to have a relative permittivity of $\epsilon_r = \epsilon_0 = 1$, the same as a vacuum, ϵ_0 . For the purposes of this task, the difference between the considered permittivity and air's actual permittivity, are negligible. Whereas silicon has a relative permittivity of 12 [2]. Since the effective field between charged plates separated by a dielectric is equal to:

$$E = \frac{\sigma}{\epsilon_0} [2]$$



As relative permittivity increases, the effective field between charged plates separated by a dielectric decreases. This is due to the polarisation of the particles in the medium, the dielectric, producing an electric field in the opposing direction to the that of the two charged plates.

Problem analysis

Below are two figures, Figure 3 and Figure 4, which show the analysis of the two problems.

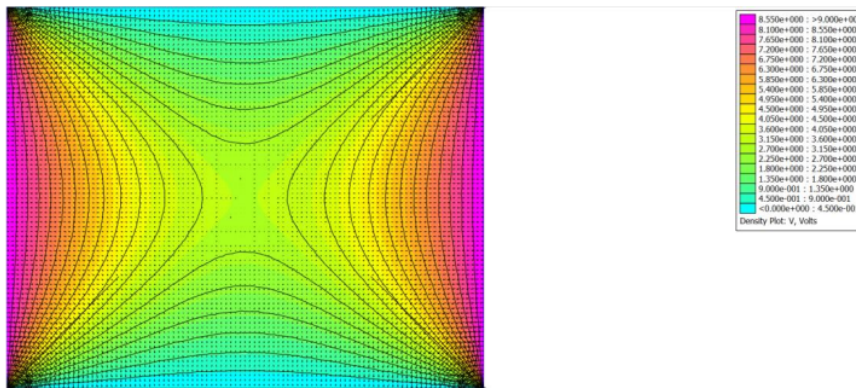


Figure 3: A screenshot of the analysis of the air problem

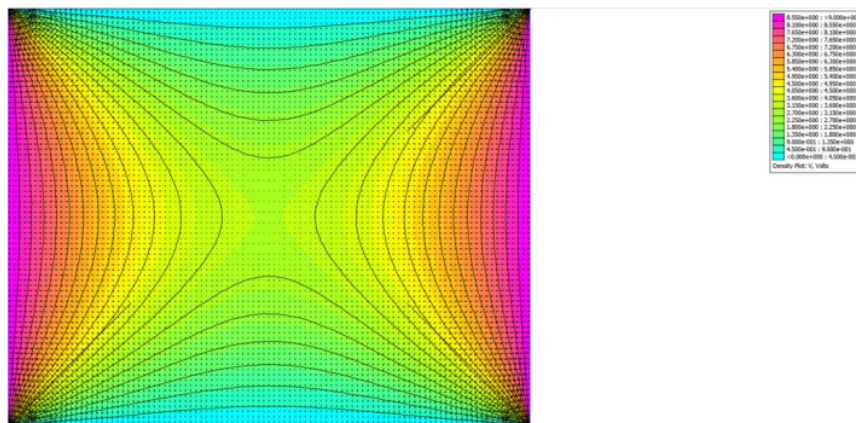


Figure 4: A screenshot of the analysis of the silicon problem

Both of the problems look the same once analysed. This is because the analysis is displaying the electric field strengths in each material, which is proportional the voltages at each boundary.

Differences start to emerge when we examine the electric flux density.

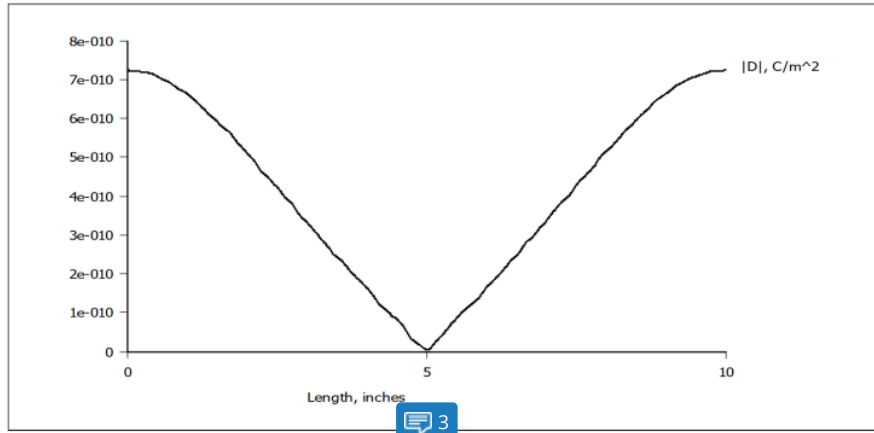


Figure 5: Magnitude of electric flux density from centre left to right across a air rectangle

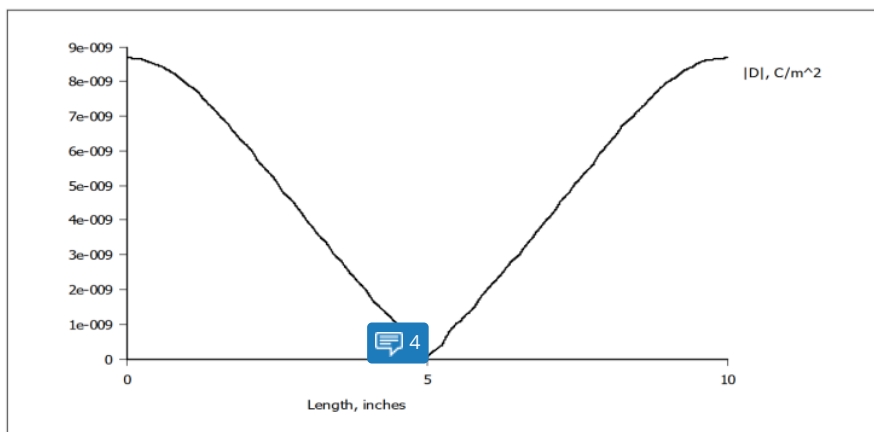


Figure 6: Magnitude of electric flux density from centre left to right across a silicon rectangle

The flux density is higher in the silicon rectangle than in the air rectangle by an order of magnitude.

This is because the magnitude of electric flux density, the integration of field lines normal to a surface, is:

$$D = \epsilon E$$

The density of electric flux is directly proportional to the relative permittivity of the medium the electric field lines are passing through. In the case of this problem, the maximum magnitude of electric flux density in the air and silicon rectangles respectively are:

$$\text{Air: } 7.23639e - 010 \text{ C/m}^2$$

$$\text{Silicon: } 8.68366e - 009 \text{ C/m}^2$$

According to the equation:

$$D = \epsilon E$$

If we want to find the ratio of *Silicon: Air* electric flux density for the same electric field E , we find that

$$\frac{D_{si}}{D_{air}} = \frac{\epsilon_{si}}{\epsilon_{air}}$$

Which is equal to:

$$\frac{D_{si}}{D_{air}} = \frac{12}{1}$$

If we use the results from the FEMM analysis, we find:

$$\frac{8.68366e - 009 \frac{C}{m^2}}{7.23639e - 010 \frac{C}{m^2}} = 11.9999889$$
$$\approx 12$$

Task 2: S-shape bending electrostatic problem

Problem scope

A polygon model which has $V = 0$ for the lower left boundary and $V = 9$ for the upper right boundary illustrated below in Figure 7 and Figure 8. All other boundaries are made of insulation and have an insulation property with a surface current density of 0. This prevents the electric field lines from penetrating outside of the bounds of this polygon.

Design

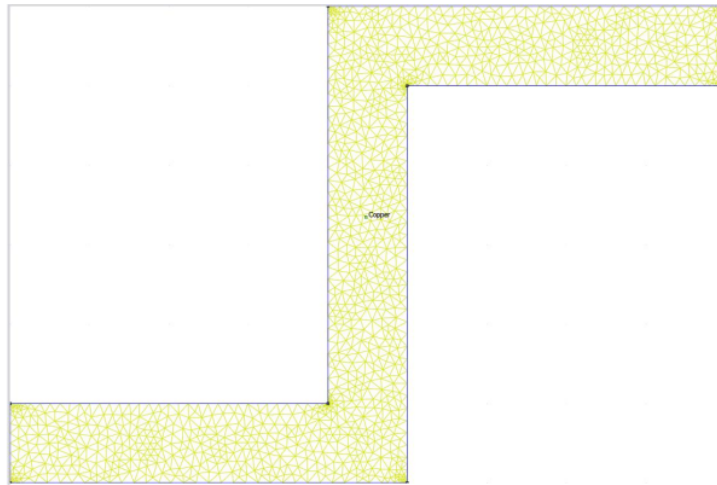


Figure 7: Copper s-shape bending electrostatic problem

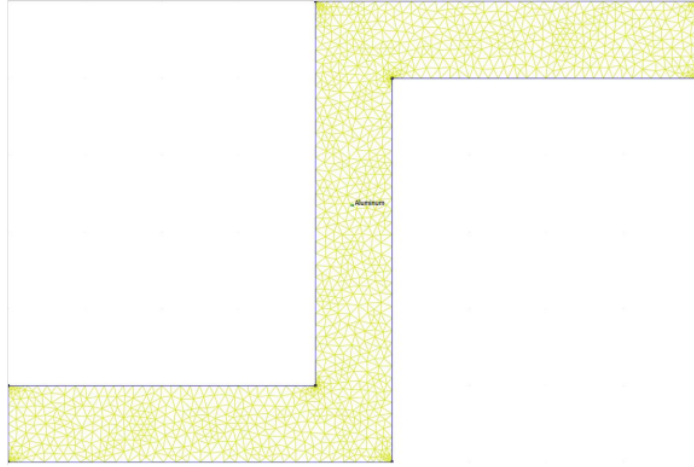


Figure 8: Aluminium s-shape bending electrostatic problem

Differences between problems

Both problems have identical shapes and boundaries. The differences in the two problems lie only in the materials used. In this problem, copper has an electrical conductivity σ , of 58000000 S/m [2] and aluminium an electrical conductivity σ , of 37700000 S/m [2]. It is important to note that electrical conductivity is derived from the resistivity of a material:

$$\rho = \frac{RA}{L} [3]$$

This equation tells us that the resistivity between two points of a material can be calculated by measuring the cross-sectional surface area, length and electrical resistance (Ω). This resistivity can then be used to calculate the electrical conductivity with the following:

$$\sigma = 1/\rho [3]$$

The electrical conductivity of a material is important as it can then be used to calculate the current density with the following equation:

$$J = \sigma E [4]$$

This is the value that should change during analysis of the problem we are investigating. The current density is directly proportional to the magnitude of electrical conductivity of a material. Before conducting analysis, it is expected that the magnitude of current density throughout the copper shape will be higher than aluminium due to its higher electrical conductivity.

The expected difference in current density throughout all points, where the magnitude of the electrical field intensity is identical, between the two problems can be found by:

$$\frac{J_{Cu}}{J_{Al}} = \frac{\sigma_{Cu}}{\sigma_{Al}}$$

$$\frac{J_{Cu}}{J_{Al}} = \frac{58000000}{37700000} \approx 1.538$$

It is expected that the current density throughout all points in the copper material is 1.538 times greater than in aluminium

Problem analysis

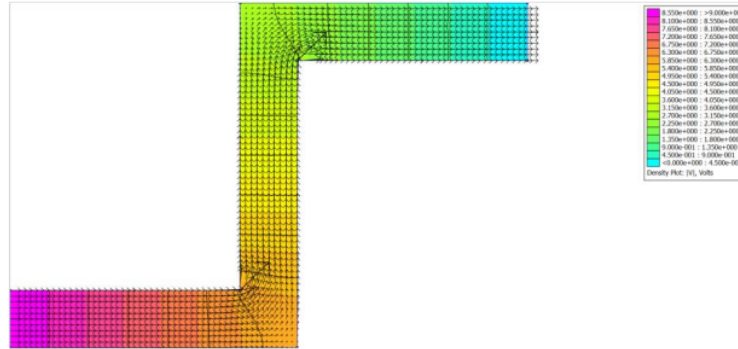


Figure 9: Analysis of a copper s-shape bending electrostatic problem

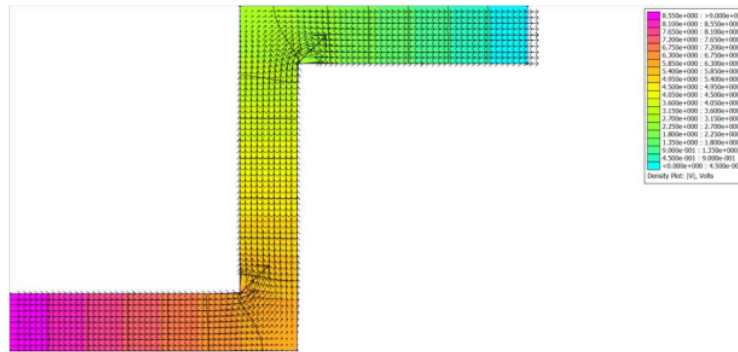


Figure 10: Analysis of an aluminium s-shape bending electrostatic problem

Analysing both copper and aluminium problems, return identical results when examining the magnitudes of the electrical fields within the materials. This is because the voltages at either end of the conductor are identical. We can observe that the magnitude of electrical field intensity is very low in the outer corners in the s-shaped polygon. We know from the equation for electrical field density:

$$J = \sigma E \text{ [4]}$$

That these areas are where we expect the current density to be lowest and it is directly proportional to the magnitude of the electrical field intensity.

Examining the magnitude of the current density by plotting lines through the middle of three s-shape polygon from the 0V boundary in the bottom left to the 9V boundary in the top right, we observe a noticeable drop in current density of approximately 43% as the plot observes a region that has a lower magnitude of electrical field intensity.

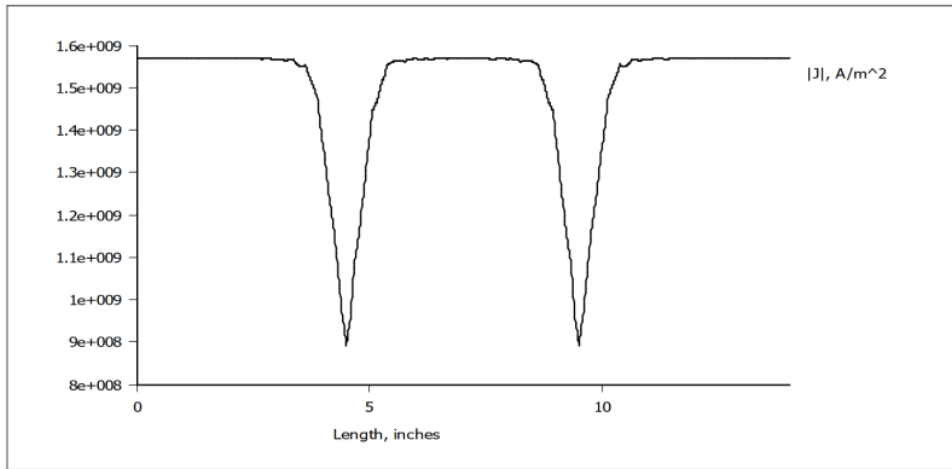


Figure 11: The magnitude of current density within a copper polygon

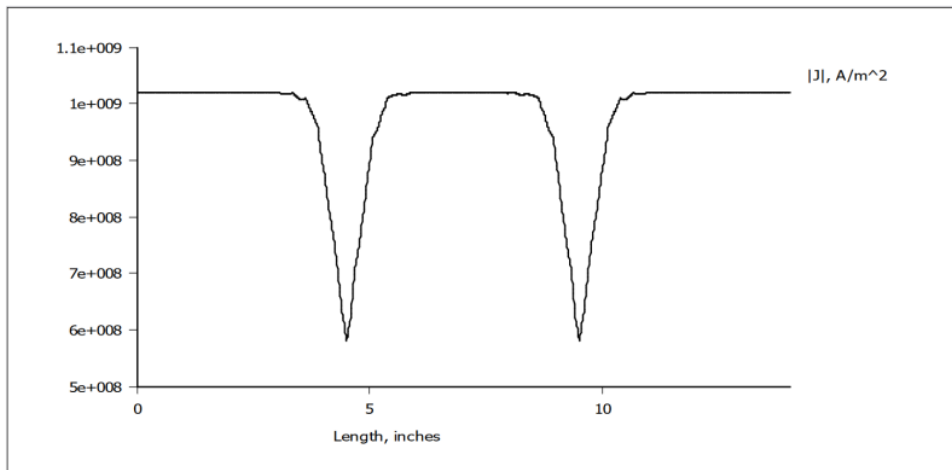


Figure 12: The magnitude of current density within an aluminium polygon

Both problem analyses show the same behaviour as the plot observes a region that has a lower magnitude of electrical field intensity, a reduction in current flow of 43%, but with different current densities.

Calculating the difference in current density between the aluminium s-shaped polygon and the copper s-shaped polygon from analysis results, taking the greatest magnitudes from each, we find:

$$\frac{1.56822e + 009 \text{ A/m}^2}{1.01934e + 009 \text{ A/m}^2} \approx 1.538$$

Task 3: Transformer simulation

Problem scope

A transformer with a pure iron core, surrounded and filled with air. All four coils are identical and are comprised of 10 AWG copper with a total of 5 turns in each coil. The current passing through each of the coils is 150A and the problem has a frequency of 50Hz.

Design

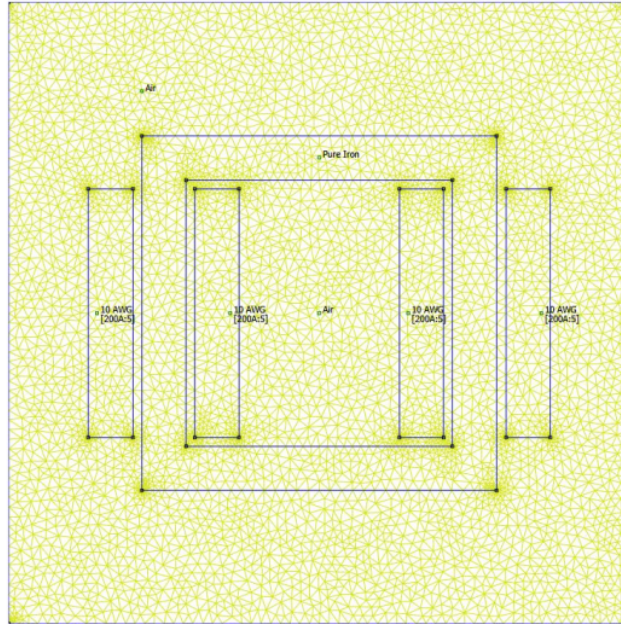


Figure 13: A screenshot of the design of the transformer

The coils in this problem are the source of an alternating current oscillating at 50Hz. The air is a medium which the magnetic fields induced by the change in electric field intensity travels through to reach the pure iron core. This pure iron core is responsible for multiplying the magnetic field of a solenoid [5]. This happens because different domains, local clusters of magnetically-aligned iron molecules, align their poles with the magnetic field that is applied throughout the material.

According to Faraday's law, "Any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be "induced" in the coil." [6]. A magnetic field can be generated from the opposite direction, by applying a voltage to a coil, inducing a magnetic field. Examining Faradays law [6]:

$$Emf = -N \frac{\Delta\Phi}{\Delta t}$$

We see that the Emf (voltage) induced is equal to the negative rate of change of magnetic flux Φ , multiplied by the number of turns in the coil. The magnetic flux in a given area is equivalent to [7]:

$$\Phi = BA$$

Where the magnetic flux Φ , is the average magnetic field B , which is then multiplied by the area perpendicular to the magnetic field A .

Following on from the definition of *Emf* provided by Faradays law, *Emf* is the change in magnetic flux multiplied by a constant related to the number of turns in a coil. Faradays law highlights why it is essential that an alternating current source must be used, instead of a direct current source, as it oscillates over time, providing the change in magnetic flux over time that is required for an induced voltage. There are several options to induce a greater voltage:

- 1) Increasing the number of turns in the coil N , as it is directly proportional the induced voltage;
- 2) Increasing the change magnetic flux Φ , as it is directly proportional the induced voltage;
- 3) Or decreasing the time in which the magnetic flux changes by increasing frequency.

Looking at the ideal transformer equation:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

As the primary and secondary coil both contain the same number of turns, 5, we get

$$\frac{5}{5} = 1 = \frac{V_S}{V_P}$$

Therefore, the primary and secondary coils will have the same voltage running through them.

$$V_S = V_P$$

The expected output from the problem analysis is a constant current density flowing throughout the primary and secondary coils.

Problem analysis

Transformers typically transform one AC voltage up or down to a new level by varying the number of coils in the windings of the copper. However, the transformer used in the problem does not do this but is instead an isolation transformer. Isolation transformers are used to isolate the power source and its destination in cases where there is more than a single ground reference.

Analysing the problem, we can start by examining the current density in the different materials. The copper coils are modelled to have a constant current density throughout them which is the desired output of an isolation transformer.

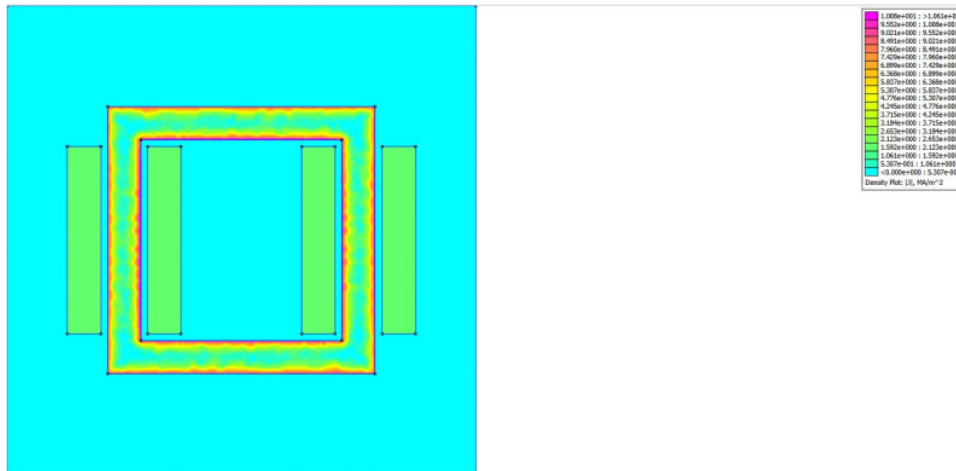


Figure 14: Transformer current density

Conclusions and recommendations

Task 1 could investigate further materials such as superconductors to compare and contrast their relative permittivity's and how electric fields propagate through the materials.

Task 2, the s-shape bending electrostatic problem could be made of curved corners instead of sharp corners to investigate how the transition from sharp to smooth corners effects the distribution of current density throughout the material. The problem could also be analysed at a higher fidelity using the same shape, then exported into a text format to be analysed with a mathematical framework such a MATLAB, Octave or Python packages to find the equipotential path of current density throughout the material.

Bibliography

-  6. Meeker, "femm@groups.io | Home," [Online]. Available: <https://groups.io/g/femm/>. [Accessed 02 05 2023].
- [2] D. Meeker, FEMM 4.2, 2019.
- [3] R. Nave, "Resistivity and Conductivity," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html>. [Accessed 02 05 2023].
- [4] R. Nave, "Microscopic View of Ohm's Law," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/ohmmic.html>. [Accessed 02 05 2023].
- [5] R. Nave, "Transformer," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/transf.html>. [Accessed 02 05 2023].
- [6] R. Nave, "Faraday's Law," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/farlaw.html#c1>. [Accessed 02 05 2023].
- [7] R. Nave, "Magnetic Flux," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/fluxmg.html#c1>. [Accessed 02 05 2023].
- [8] R. Nave, "Polarization of Dielectric," Hyperphysics, [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/dielec.html>. [Accessed 02 05 2023].

EMR Assignment

GRADEMARK REPORT

FINAL GRADE

82/100

GENERAL COMMENTS

Instructor

Engagement with Literature Skills: *Marks: 7/10*

Engagement with an extensive range of relevant and credible literature.
Consistently accurate application of referencing.
more reference from reputable academic publishers
and articles from peer reviewed journals would be better.

Knowledge and Understanding Skills: *Marks: 17/20*

Excellent, detailed knowledge and highly critical understanding of
the well-established concepts and principles of the subject and the main
methods of enquiry.

Cognitive and Intellectual Skills: *Marks: 17/20*

critical evaluation and analysis of concepts and principles
leading to logical, evidence-based, reasoned arguments and judgements.

Practical Application Skills: *Marks : 26/30*

An advanced application of a range of established methods, tools and/or techniques. The context of the application is well
considered, and insightful

Transferable Skills for Life and Professional Practice: *Marks : 15/20*

Can communicate professionally confidently and consistently in a
suitable medium for the audience. Work is coherent, very fluent and is
presented proficiently.

Overall total: 82/100

PAGE 1

PAGE 2



Comment 1

It is better to include chapter/ title / subtitle number in the table of content

PAGE 3

PAGE 4

PAGE 5

PAGE 6



Comment 2

It is better to number the equations

PAGE 7



Comment 3

Size chosen is in inches or centimeter



Comment 4

Size chosen is in inches or centimetre

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14



Comment 5

Over all a good work

PAGE 15



Comment 6

It would have been better if referred from more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.