

2114210 EM Radiation Coursework Jack Lonsdale

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Submission date: 09-May-2023 12:57AM (UTC+0100)

Submission ID: 205257066

File name:

32796_Jack_Lonsdale_2114210_EM_Radiation_Coursework_Jack_Lonsdale_497416_236511871.docx (1.51M)

Word count: 1764

Character count: 9537

Electromagnetic Radiation Assignment

 Embedded Electronic Systems Design and Development Degree
Apprenticeship

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Year 2

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Word Count: 1758

Similarity Grade: 6%

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Introduction

 Element Modelling is a technique to analyse complex problems by breaking them down into thousands of smaller solvable problems. A process called “discretisation” is used to break down large areas/volumes into several smaller elements (connected at nodes) [3]. In the case of this assignment, this is used to break down static electric and electromagnetic fields to analyse them.

Coulomb’s law:

The force between two point-charges can be categorised by Coulomb’s law, shown below:

$$F = \frac{Q_1 \cdot Q_2}{4\pi\epsilon d^2}$$

Above: Eq. 1, Coulomb’s law

The force applied upon one charge from the other is proportional to the product of their respective charges, and inversely proportional to the square of the distance between them.

Electric Field Strength:

To find the electric field strength, we remove the second charge (as the quantity we are measuring changes from force to force per unit charge):

$$\frac{F}{Q_2} = \frac{Q_1}{4\pi\epsilon d^2}$$
$$E = \frac{Q}{4\pi\epsilon d^2}$$

Above: Eq. 2, Electric field strength.

When considering this equation in the context of Finite Element Modelling, it’s necessary to implement with vector algebra so that it can be applied in two or three dimensions:

$$\mathbf{E} = \frac{Q}{4\pi\epsilon d^2} \mathbf{a}$$

Above: Eq.3, Vector equation for Electric Field Strength, where $\mathbf{a}$ is the unit vector from the point charge to the test point, and $\mathbf{E}$ is the electric field strength in vector form [11]

Algorithmic implementation of the Finite Element Method:

The first step in solving a problem using the FEM method is setting suitable parameters for areas, boundary conditions, and materials. Once properly defined, the program can then work to break down the area/volume into small triangles, creating thousands of nodes with respective coordinates in the process.

The program must then iterate through each node and calculate the electric or magnetic field at that location by summing all the external electric or magnetic fields. This process is incredibly computationally complex and is often optimised by searching for symmetry so that multiple areas can be calculated in parallel. [12]

Task 1

Air and Silicone are both highly insulating materials, when a potential difference is applied across them, only a very small current will flow (categorised by Ohm's law, below:)

$$I = \frac{V}{R}$$

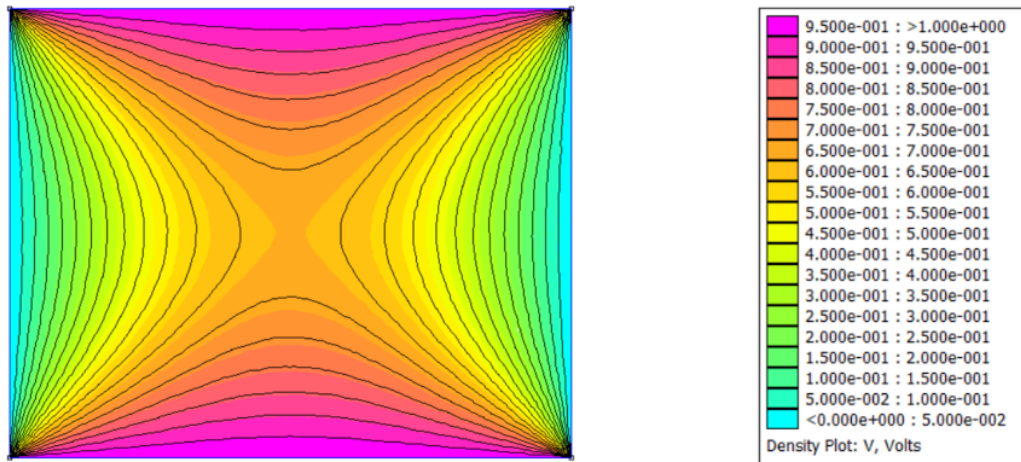
Above: Eq.4, Ohm's law

The assignment called for two of the boundaries to be set as 0V and the other two to be set as the last digit of my student ID. The last digit of my ID is 0, meaning a box with no electric field. Unfortunately, a rectangle of air with no electric field isn't particularly interesting, as displayed in Fig.1 below:



Above: Fig. 1. A very exciting electric field.

It's clear to see that with no potential difference applied anywhere the box, an electric field cannot exist. With little further details to talk about, a similar plot was created with 1V as the horizontal boundaries (the penultimate digit of my student ID number), shown below in Fig.2:



Above, left: Fig. 2 An 8cmx10cm rectangle filled with air and corresponding key. Boundaries of 0V and 1V along the vertical and horizontal borders respectively.

Above, right: Fig. 3 Corresponding colour density key

Each border of the rectangle represents a line charge, given by:

$$E = \int_L^0 \frac{\rho_L}{4\pi\epsilon R^2} \mathbf{a}_R dl$$

Above: Eq.5, The electric field at point P created by the line charge [1].

Where [1]:

- E is the electric field strength at point P
- ρ_L is the line charge density (C/m)
- R is the shortest distance from the line to point P
- $\mathbf{a}_R$ is the direction vector of point P

It naturally follows that the electric field strength at any point in the given area is simply the sum of the individual electric fields (caused by the four line-charges) acting on the point. In the case of this problem, that is the sum of all four line charges.

Equipotential lines:

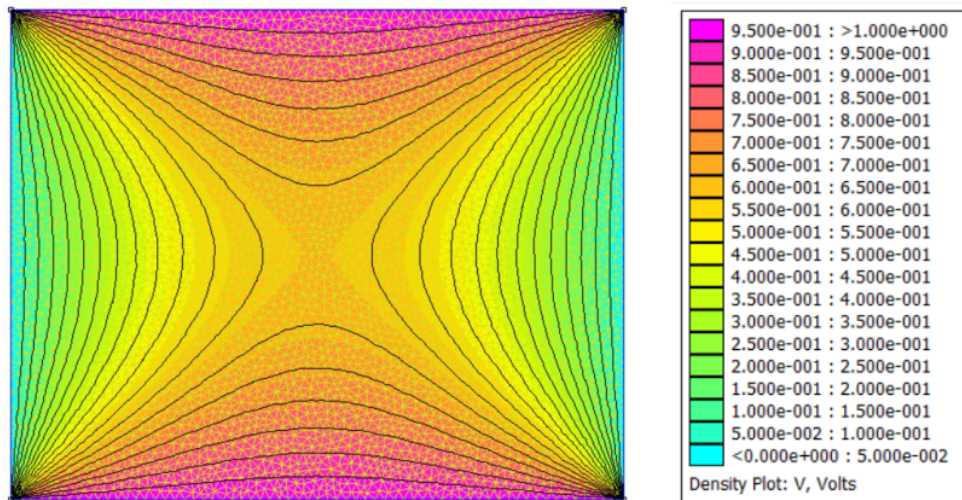
Figure NUM shows several equipotential lines on the plot, these are lines of equal electrical potential energy. This means that a point charge traveling across these lines would neither lose nor gain electrical potential energy. Similarly to contour lines showing elevation on a map, these are useful for demonstrating where the field changes in real distance.

Permittivity:

Permittivity is the measurement of how well a material can be altered by an electric field to create separations between electric charges (called electric dipole moments) [5].

All materials have electrical permittivity to differing degrees, and the difference between them is compared with “relative permittivity”, in which a material is given a number comparing its permittivity to air. A material with a relative permittivity of 2 is twice that of air, and similarly a material with a relative permittivity of 0.5 is half that of air.

A similar plot was made replacing the air with silicone. Silicone differs from air significantly with a much higher permittivity (relative permittivity of 11.68 times air) [2]:

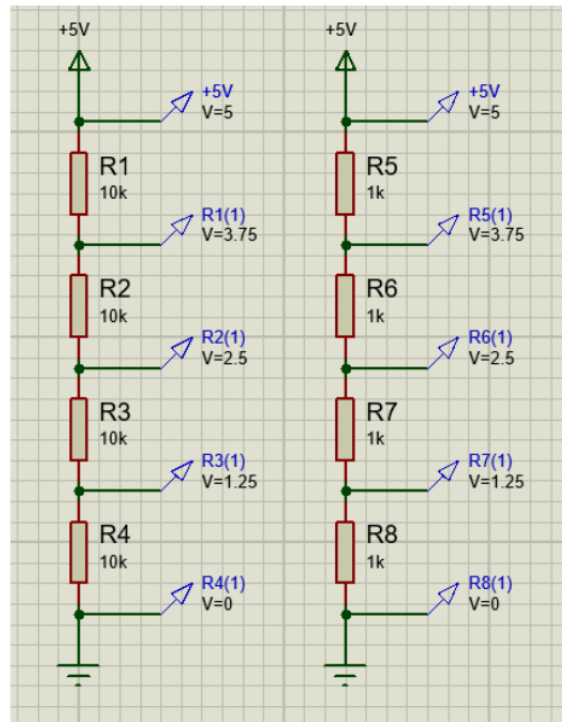


Above, left: Fig. 4, Rectangular electric field filled with Silicone.

Above, right: Fig. 5, Corresponding plot key



Both plots show a similar pattern, as the electric field is dissipated across the same distance. This can be rationalised by considering the distribution of electrical potential across two ladders of resistors with differing resistance (shown below in Fig.6):



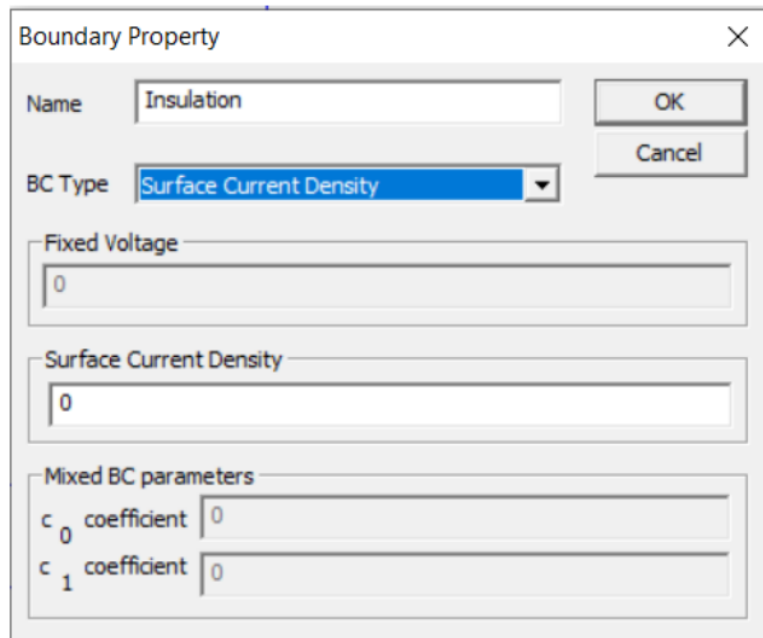
Above: Fig.6, Potential dividers of differing resistance.

Despite the differing resistance of both potential dividers, the electrical potential is distributed identically. Consider the air or silicone as an infinite ladder of individual resistors where the material property determines their resistance. The electric field still spreads out according to the same pattern.

Task 2

Finite element modelling can also be used to analyse current flow problems. Task 2 sets out such a problem for an S-shaped conductor with insulation on all sides except for 5V at the rightmost boundary and 0V at the leftmost boundary.

Creating a new boundary to characterise the insulation, the surface current density would be set to 0 Cm^{-2} as the ideal insulator has no current flow.



Above: Fig.7, Insulation properties for the current flow problem



Above: Fig.8, The electric field within the "S-shaped" conductor

With 5V at the rightmost end of the conductor, and 0V at the leftmost end, the difference in electrical potential is distributed evenly through all straight sections. The consistent width and material properties of each section means they share the same electrical resistance, and therefore the same share of the voltage (as with identical resistors in series).

As the conductor turns a corner, the cross-sectional area increases, reducing its resistance, given by:

$$R = \rho \frac{L}{A}$$

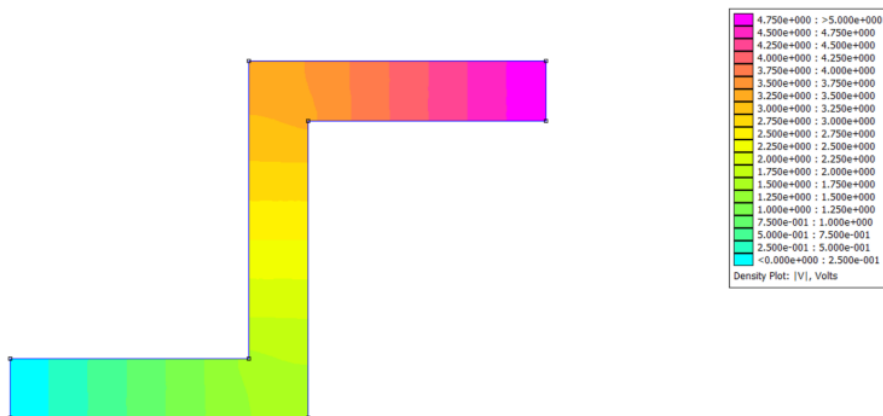
Above: Eq.6, Electrical resistance as defined by resistivity, length, and cross-sectional area [6].

When the voltage on the left of the conductor is changed from 0V to 1V, the same pattern is demonstrated with slightly smaller steps in voltage:



Above: Fig.9, The electric field within the “S-Shaped” conductor, and the leftmost boundary set at 1v.

Even when the material is changed to aluminium, the distribution of electrical potential is the same:



Above: Fig. 10, The S-shaped conductor current flow with Aluminium as the material.

As with problem 1, this is conceptualised by considering the potential divider ladders of differing resistance in Fig. 6.

Task 3

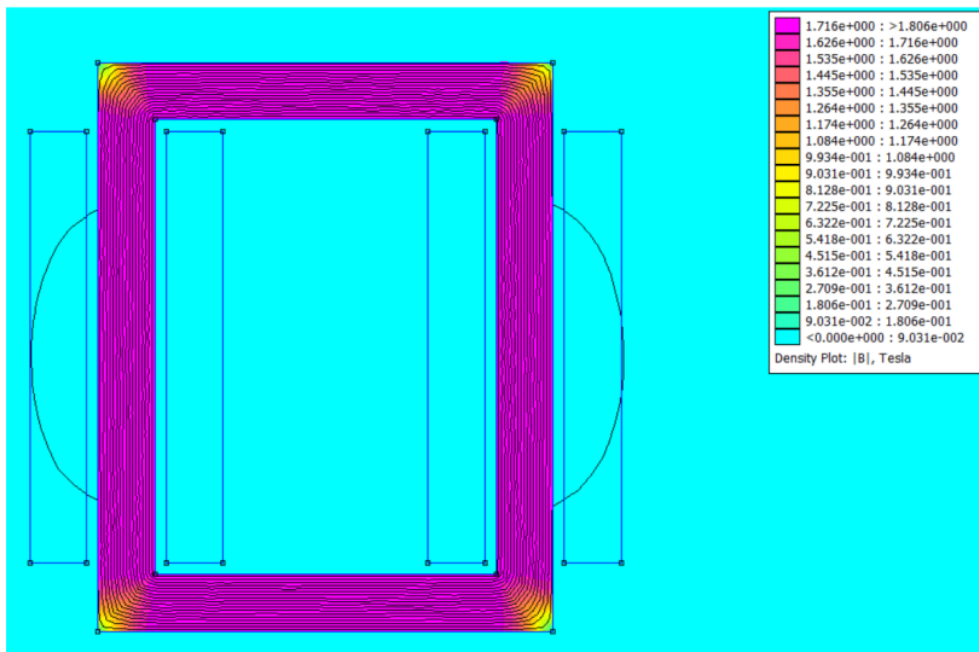
Specifying the problem:

Simulating an electromagnet can also be done in FEMM. A soft iron core 10mm thick, and 100 x 80mm long and wide was drawn. Four rectangles were plotted surrounding the long side of the iron core to simulate coils of wire.

The coils and core were surrounded with air, bounding the outermost border to 0V.

Selecting Wire Gauge:

The brief specified 200A of current flowing through each coil, although the highest-current-rated wire available for modelling was 10AWG (rated for only 15A [7]). In reality, either the current would need to be reduced, or a larger wire gauge would need to be used.



Above: Fig.9, An electromagnet modelled in FEMM.

Mathematical categorisation

The coils on either side of the soft iron core induce a magnetic field in the core.

This magnetic field induces a current through the iron core, given by:

$$emf = \frac{-d\Phi}{dt}$$

Above: Eq. 7, Faraday's Law of Induction [9].

The current induced has equivalent magnitude and opposite polarity to the rate of change of flux linkage. Flux linkage is given by:

$$\Phi N = BAN$$

Above: Eq. 8, Formula for Flux Linkage [10]

And by differentiating, the following is derived to find rate of change of flux linkage:

$$\frac{d\Phi}{dt} N = \frac{dB}{dt} AN$$

Above: Eq. 9, Formula to find rate of change of Flux Linkage.

The unit for magnetic field strength is given by:

$$B = \frac{\mu_0 I}{2\pi r}$$

Above: Eq. 10, Magnetic Field Strength. [8]

By differentiating again, the formula for rate of change of magnetic field strength can be found:

$$\frac{dB}{dt} = \frac{\mu_0}{2\pi r} \cdot \frac{dI}{dt}$$

Above: Eq. 11, Formula for rate of change of magnetic field strength



Since the current is the same at all points in the core, the magnetic field induced is the same at all points in the core. The exception to this would be the corners where the cross-sectional area increases, reducing the resistance of that part of the coil. This then reduces the current flowing through each node, reducing the rate of change of magnetic flux linkage and therefore the magnetic field.



References/Bibliography

References:

[1]	M. Navhi PhD, J. Edminster, Schaum's outlines Electromagnetics (Fifth Edition) p.47, McGraw Hill, New York. 2019
[2]	Wikipedia, 2023. [Online] Available: https://en.wikipedia.org/wiki/Relative_permittivity [Accessed May. 9, 2023].
[3]	The Efficient Engineer, 2021. [Online] Available: https://youtu.be/GHjopp47vvQ [Accessed May. 9, 2023].
[4]	Mikail Ansari, "FEMM/Finite Element Analysis Tutorial - Quick Overview" 2013. [Online] Available: https://youtu.be/5LvWE1JscO4 [Accessed May 9, 2023].

[5]	"IEEE Standard Definitions of Terms for Radio Wave Propagation," in <i>IEEE Std 211-1997</i> , vol., no., pp.1-44, 30 Nov. 1997, doi: 10.1109/IEEESTD.1997.8638365.
[6]	Libre Text Physics, "9.4: Resistance and Resistivity" LibreTexts. [Online] Available: Link [Accessed May 9, 2023].
[7]	American Wire Gauge, "American Wire Gauge (AWG) Table 1" Shopify.com. [Online] Available: Link [Accessed May 9, 2023].
[8]	Toppr, "Magnetic Field Strength Formula". [Online] Available: Link [Accessed May 9, 2023].
[9]	Brittanica, "Faraday's law of induction". [Online] Available: Link [Accessed May 9, 2023].
[10]	SaveMyExams, "7.9.2 Magnetic Flux Linkage". [Online] Available: Link [Accessed May 9, 2023].
[11]	M. Navhi PhD, J. Edminster, Schaum's outlines Electromagnetics (Fifth Edition) p.5, McGraw Hill, New York. 2019
[12]	Rice University, "Symmetry in Finite Element Simulations". [Online] Available: https://www.clear.rice.edu/mech403/HelpFiles/model_symm.pdf [Accessed May 9, 2023].

Bibliography:

Number:	Description:	Link/Reference:
1	Equipotential lines	Link
2	FEMM Tutorial	Link

FINAL GRADE

72/100

GENERAL COMMENTS

Instructor

Engagement with Literature Skills: Marks: 7/10

Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.

Knowledge and Understanding Skills: Marks: 15/20

Exhibits very competent critical understanding of the well-established concepts and principles of the electromagnetic magnetic field, which is evident through task 1, 2, and 3.

Cognitive and Intellectual Skills: Marks: 15/20

Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments. Ability to communicate ideas and evidence accurately and convincingly.

Practical Application Skills: Marks : 21/30

From task 1 to task 3, it is evident that the author has a very good application of a range of established methods, tools and techniques. Need more detail on making well-developed links between the theory and practical

Transferable Skills for Life and Professional Practice: Marks : 14/20

Generally well laid out and presented. Would have benefited from a more formalised layout, such as breaking down the assignment into more detailed numbered and named sections that follow the 1.1 1.2 2. Style

PAGE 1



Comment 1

Good work

PAGE 2

PAGE 3



Comment 2

Good introduction and Background study

PAGE 4

PAGE 5

PAGE 6



Comment 3

The response graphs are missing in this report

PAGE 7

PAGE 8

PAGE 9

PAGE 10



Comment 4

Initial design figures are missing



Comment 5

It would have been better if the obtained output results were analysed with the basic theories

PAGE 11



Comment 6

The response graphs are missing in this report



Comment 7

It is better to end the report with a conclusion