

EMR Assignment - LC

by Louise Caygill

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Analysis of Electrostatic and Magnetostatic problems

Electromagnetic Radiation: ACDC5009

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Introduction

FEMM (Finite Element Method Magnetics) is a free piece of software that is able to simulate Electrostatic, magnetic, current flow, and heat flow problems [1] on a 2D plane. It is simple, yet accurate and is popular in science and engineering to study the implications or problems caused by electromagnetic fields when coming to a solution.

For this assignment it will be used to analyse the electrical properties of several given materials, and to analyse the magnetic properties of an iron core with coils of wire.

Task 1

Set Up

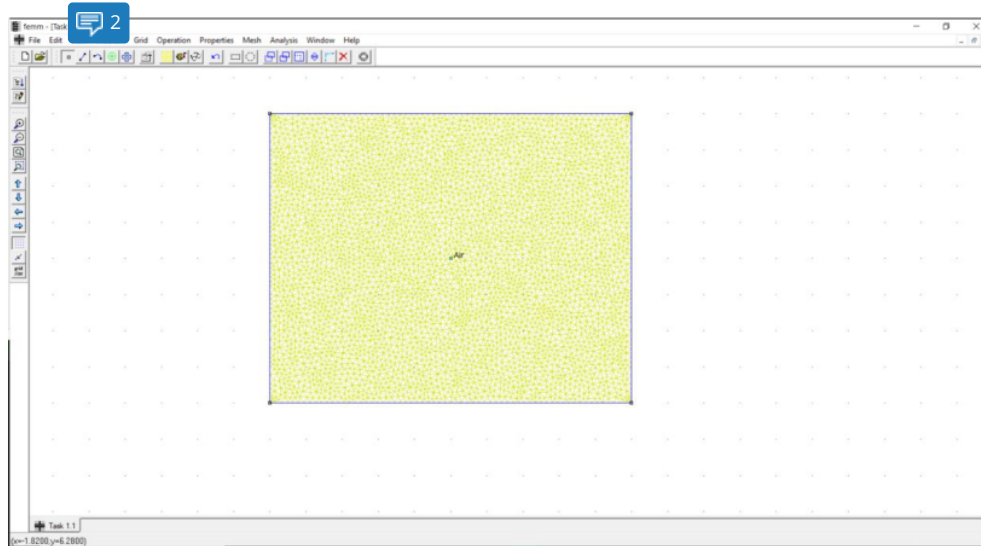


Figure 1: Simulation Set Up for Task 1

Task 1 consists of a rectangular form of 10x8cm, for an electrostatic problem. Electrostatics is the study of electric charges that are not related to motion, or the flow of current, and are instead drawn to the surface of some objects [2]. Electrostatics can be described by Coulombs law [3]. The materials to be analysed for the task are air and silicon, with the four boundaries set to either 0V or 5V. In this case the top and bottom boundary are 0V with the left and right sides as 5V. The frequency is set to 50Hz, with the dimensions in CMs.

Material Properties

Air is an electrical insulator, meaning it does not conduct electricity well. it is a naturally occurring mixture of inert gasses with little to no free electrons that are needed for electrical conduction. As such it does not permit the movement of electrons from one atom to another, rather it restricts their movement through binding them tightly [4]. Despite this, electric charges are able to pass through air when the charge is big enough, and the distance small enough, such as with lightning. In this case, it is able to discharge because the positive and negative charges that are building up in the cloud, combined with the positive and negative charges between the cloud and the ground build up enough of an opposite charge, that the insulating capacity of air breaks down momentarily, allowing the rapid discharge of lightning [5]. As air is a poor conductor, it is often used as a dielectric material [6] in electronic components such as variable capacitors [7].

Similarly, pure silicon is also a poor conductor of electricity. However, as silicon is a semiconductor, it is able to conduct under the right circumstances [8]. A semiconductor is a material which allows electricity to flow as its temperature is increased [9]. Due to this characteristic, silicon is used in electronics as the makeup of solid-state components, such as diodes. In this case the pure silicon is doped with small amounts of elements such as boron and gallium [10], which control its electrical properties and allow the movement of electrons in such a way to conduct electricity as desired.

Simulation Results and Analysis

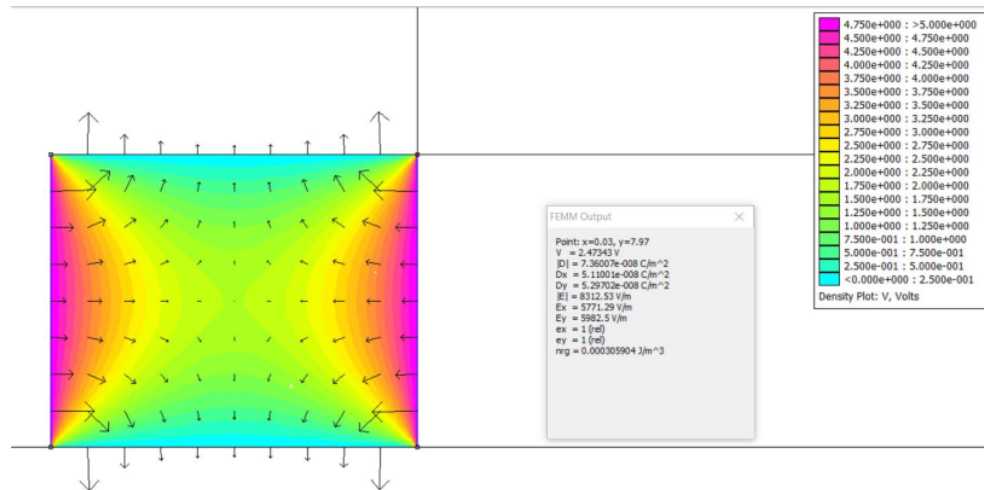


Figure 2: Air Simulation with Density Plot

Figure 2 shows voltage density plot of the electrical conduction of air, using a coloured gradient, with purple being the higher voltage, and light blue being 0V. As stated previously the right and left boundaries are +5V, with the top and bottom being 0V. This creates a draw for the electrons that the electrons are attracted to, thus they will move from the positively charged boundary to the 0V boundary. This draw is demonstrated by the vector plot in the figures, which can be seen moving from +5V to 0V. However, because air is a poor conductor, the charge is not able to maintain its strength, and as shown by the decreasing size of the arrows of the vector plot, it begins to diminish quickly as it moves away from the positive charge. It may also be observed that the flux lines are

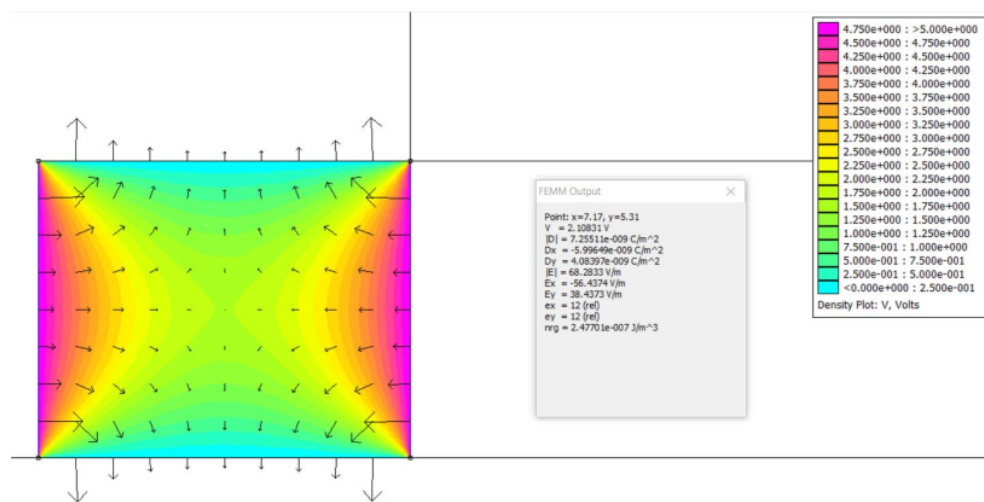


Figure 3: Silicon Simulation with Density Plot

uniform and regular, due to the uniform material presented in the simulation.

The next material to be analysed is silicon, as with air previously, the boundaries are again 0V and 5V in the same configuration. As shown in Figure 3 above, it is noticeable that it has produced the same output as air, due to the similarities in the materials. The electrons are again drawn to the 0V boundary through electrostatics, and the charge diminishes as soon as it leaves the positively charged boundary to travel to the 0V.

To further explore the similarities Figure 7, Figure 4, Figure 6, and Figure 5 below, show a voltage measurement at co-ordinates X=5,Y=4 and X=9,Y=4. For the former, both air and silicon have a reading of 1.74V. With the latter position, again, both materials produce the same reading of 3.88V, thus proving that silicon and air conduct electricity in the same manner and behave the same when exposed to the same type of charge when at the same temperature. These figures also show the

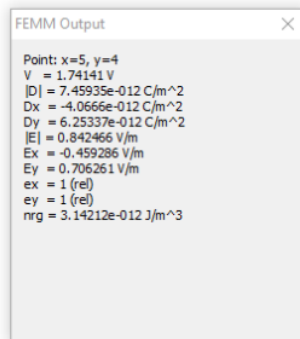


Figure 7: Air Simulation Mid-Point Reference

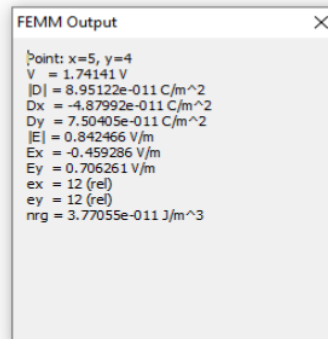


Figure 4: Silicon Simulation Mid-Point Reference

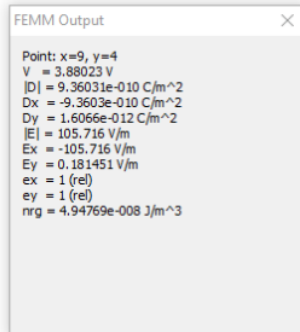


Figure 5: Air Simulation Edge Point Reference

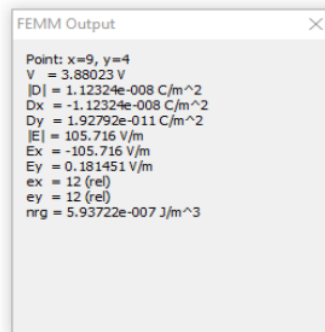


Figure 6: Silicon Simulation Edge Point Reference

permittivity of the two materials, Air has a relative permittivity of 1, whilst Silicon has a relative permittivity of 12. Using these two figures and Coulombs law, the magnitude of the force exerted by the charged particles in the materials can be calculated.

$$F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$$

Equation 1: Coulombs Law

Using the formula in Equation 1, it can be seen that Silicon has a higher magnitude than Air in the simulation. The magnitude of Silicon is 12 times higher than air, as the relative permittivity of silicon is 12 times higher. Thus, silicon stores 12 times more charge than air. The current flow is

proportional to conductivity, again, as silicon has a slightly better conductivity than air, especially when heated, it is a better conduit for the current to flow through.

The voltage tables overleaf in Figure 8 further demonstrate the similarities in the materials, and how they behave under positive charges. The two labelled "DIAGONAL" are taken from a diagonal reference line from the bottom left corner to the top right. As shown on the tables, the voltage starts at just above +2V, with a trough in the middle of just under +2V. The two labelled "BOTTOM" are taken from a reference line that runs along the bottom boundary, as such it starts at +5V, before immediately dropping to 0V for the length of the shape, returning immediately to +5V when the right-hand boundary is met. Finally, the two labelled "HORIZONTAL CENTRE" are taken from a reference line that starts at the bottom left corner, before moving up to the centre point and running along the shape centre to the right-hand boundary. These two show the same start as the ones that follow the bottom boundary in that they start at +5V and drop immediately to 0V (this is due to the fact there was no centre point, and the line had to be started at the bottom before moving to the centre), before rising again to +5V, with a trough seen at the centre of just under +2V and rising back to +5V at the other end.

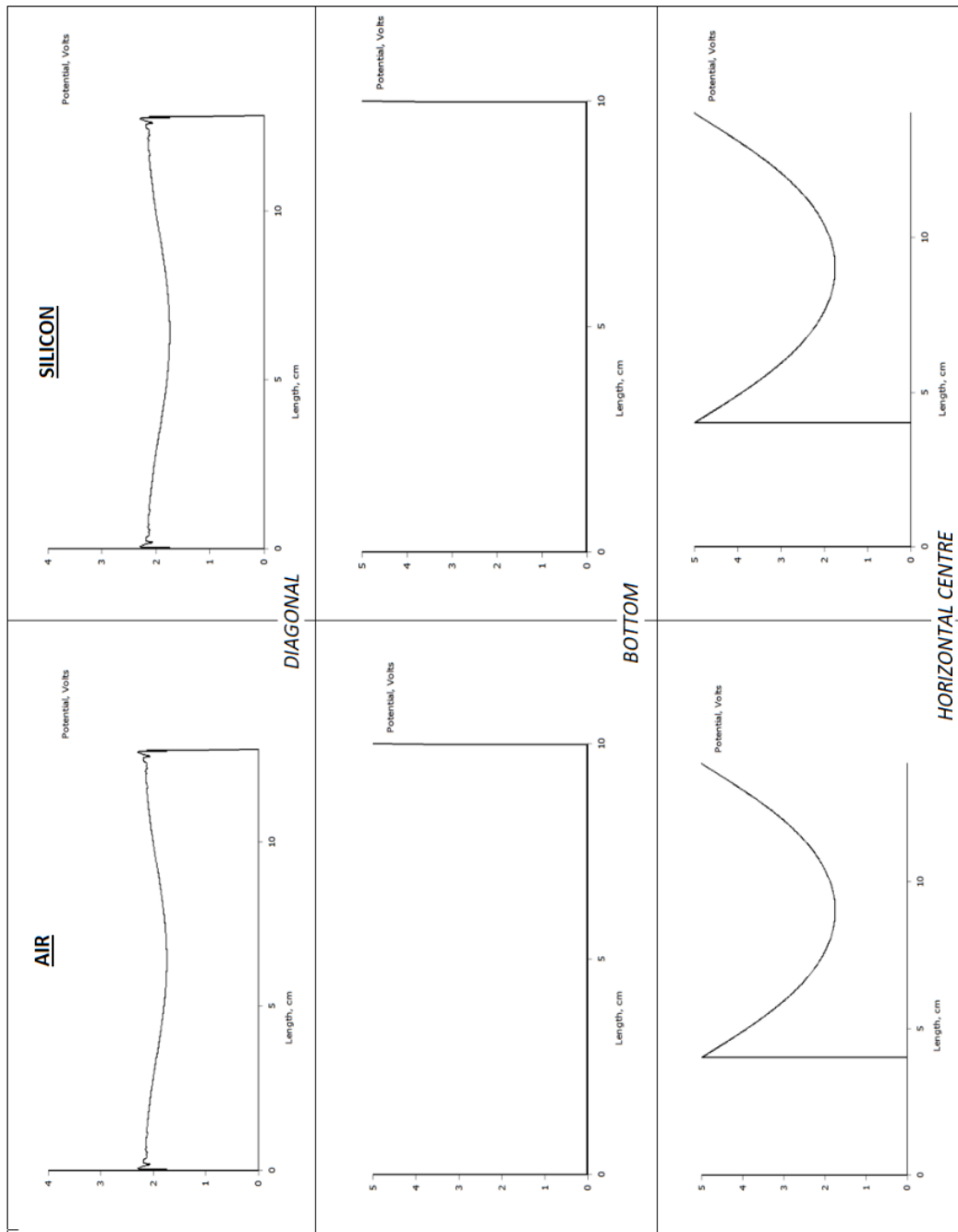


Figure 8: Voltage Comparison Tables

Task 2

Set Up

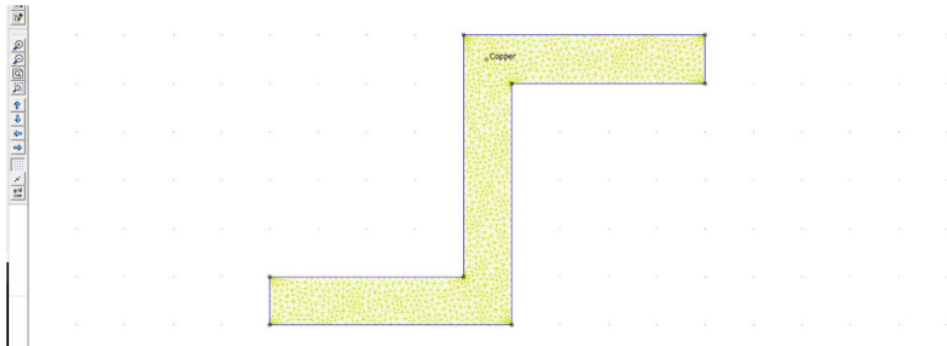


Figure 9: Task 2 Set Up

Task 2 is a current flow analysis on a backwards “Z” character. For this problem the frequency is set to 60Hz, dimensions in CM and all boundaries, bar the furthest left and furthest right are set up as insulation, meaning they have a surface current density of 0V. The remaining two being both 5V.

Material Properties

Copper is a soft, malleable material that is easily bent and shaped. It is also an excellent conductor of heat and electricity and as such is used extensively in electrical wiring, as well in construction and plumbing. Aluminium is also a soft, non-magnetic, light-weight material with high electrical and thermal conductivity. It is commonly used in packaging and in mirror coatings [11]. Whilst copper and aluminium share many likenesses, copper is ultimately stronger than aluminium, and expands

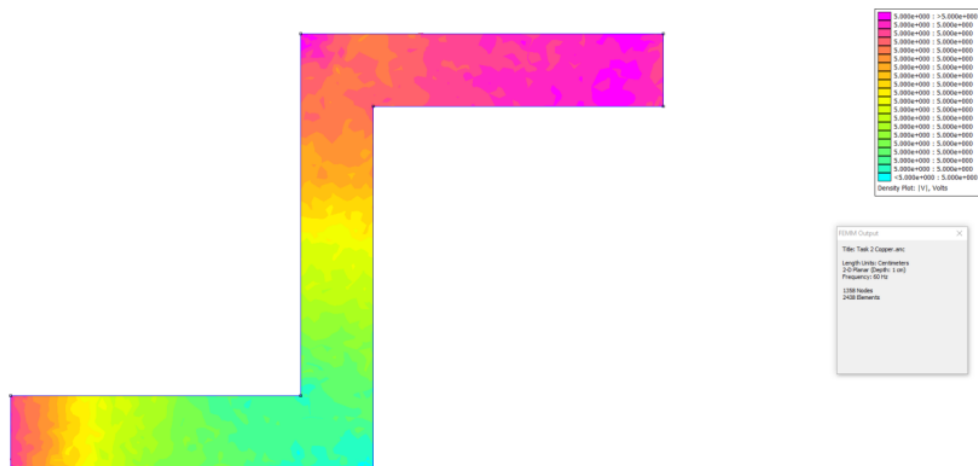


Figure 10: Copper Simulation

less under heating. Aluminium may also be subject to creep if left under continuous force, which is why copper is more popular for construction and electrical installations. Additionally, copper is more dense than aluminium [12], this is due to the atoms in copper being heavier and denser than the atoms in aluminium.

Simulation Results and Analysis

As shown in Figure 10 with the charges applied at the ends and the rest of the boundaries set to simulate insulation, there is no negative connection or ground, therefore the entire conductor is charged equally, and the current is unable to travel the length of the conductor. As the two positive charges are the same voltage, they create a patchy effect where the current flow is bounced around inside the conductor. This effect is demonstrated in Figure 11 below, using the vector plot function, where the direction of the current is non-uniform, meaning it does not point in any one direction, and instead bounces around the conductor. Also demonstrated in the two figures, is that there is a "trough" along the bottom of the shape, where the voltage is ~ 4.9 .

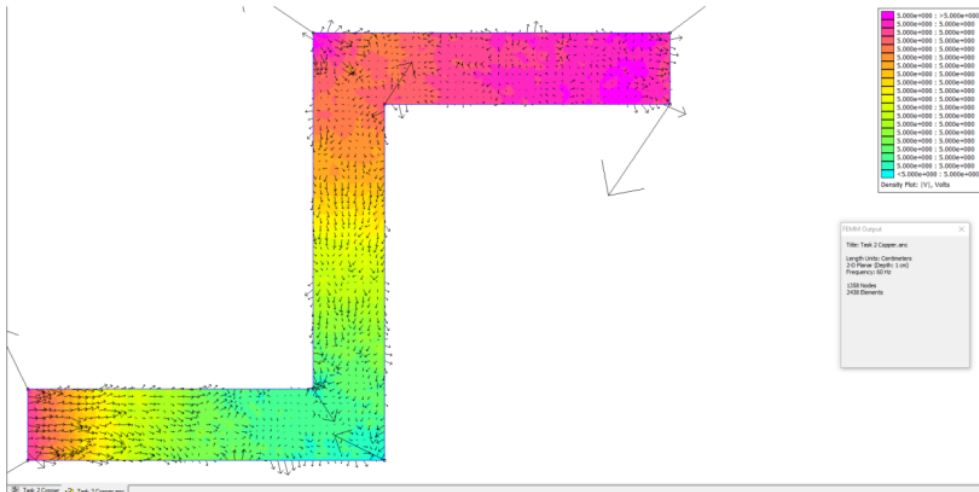


Figure 11: Copper Simulation with Vector Plot

When the voltage of one of the ends of the conductor is changed by even 1V, the result is a uniform flow of current towards the lower voltage, as demonstrated in Figure 12 below. Again using the vector plot function to show which direction the current is flowing.

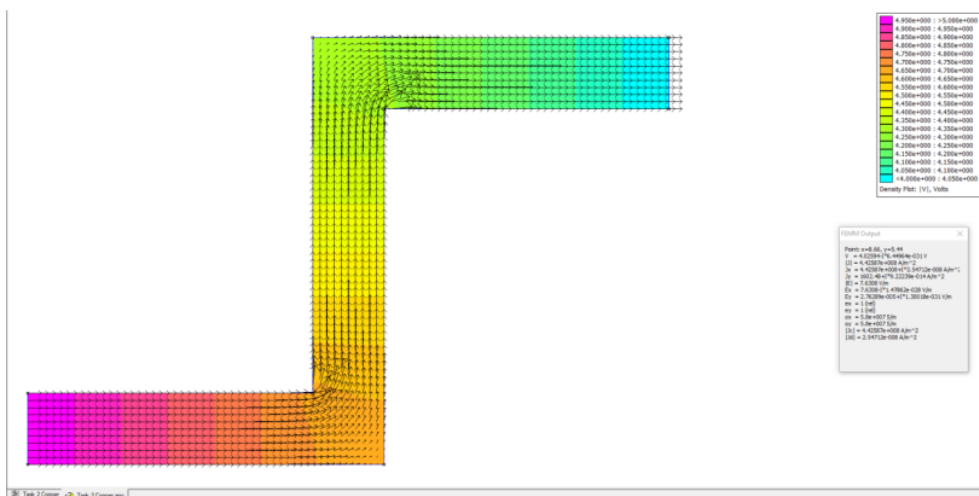


Figure 12: Copper Simulation with Different Voltage

Due to the similarities in the metal properties the two metals perform largely the same under electrical conduction, the main difference being that copper is generally able to carry a current with half the width needed for the same current in aluminium [13]. For example, a current of say 1A will require an aluminium wire that is double the thickness of the copper wire carrying 1A. As both of the simulations show, both of the metals have indeed performed almost exactly the same. There is a high current charge at the left- and right-hand connections, which is quickly dispersed into the rest of the material, with the electrons flowing from this positive connection, to the outer negative areas.

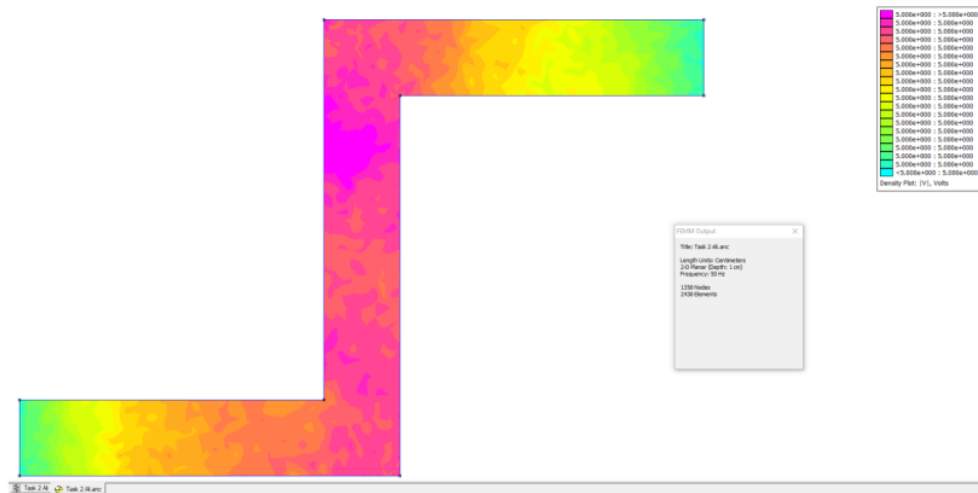


Figure 13: Aluminium Simulation

Despite the similarities in the material, when exposed to the same conditions in the simulation software, aluminium appears to have the opposite reaction to the copper. As shown in Figure 13 the trough is this time a peak, with the edges connected to the +5V being shown as lower current. Lower

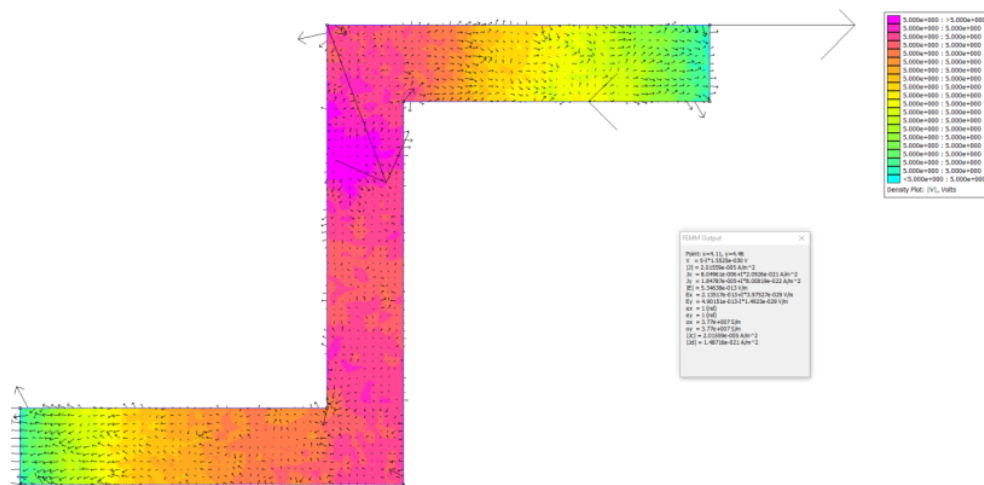


Figure 14: Aluminium Simulation with Vector Plot

here meaning 4.9 compared to 5V.

Using the block integral function of FEMM it is possible to see where the materials differ. When it is applied to copper in Figure 17 below the resultant power is 9.10903×10^{-21} . Applying the same to aluminium yields a result 5.92789×10^{-21} , shown in Figure 16. This demonstrates that copper is a better conductor than aluminium, as it has a higher wattage. Normally, this power can be calculated using Ohms law, however, as the two ends of the conductor are the same voltage, the results will be slightly skewed. The formula for Ohms Law is in Equation 2 below; P is Power in Watts, I is current in Amps and V is Voltage in Volts.

$$P = IV$$

Equation 2: Ohms Law for Power

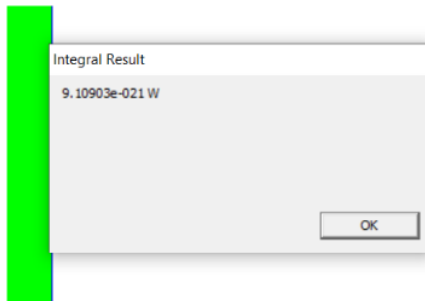


Figure 15: Copper Block Integral

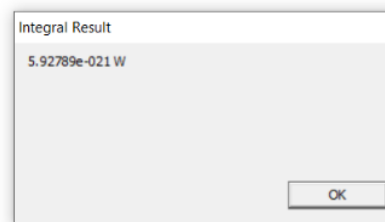


Figure 16: Aluminium Block Integral

The voltage graphs in Figure 18 overleaf demonstrate that despite copper being a moderately better conductor, both the materials behave in the same manner in the simulation. In both plot orientations, the materials are shown to remain at +5V along the entire conductor, the troughs in the graphs are from the plot values coming from outside the conductor.

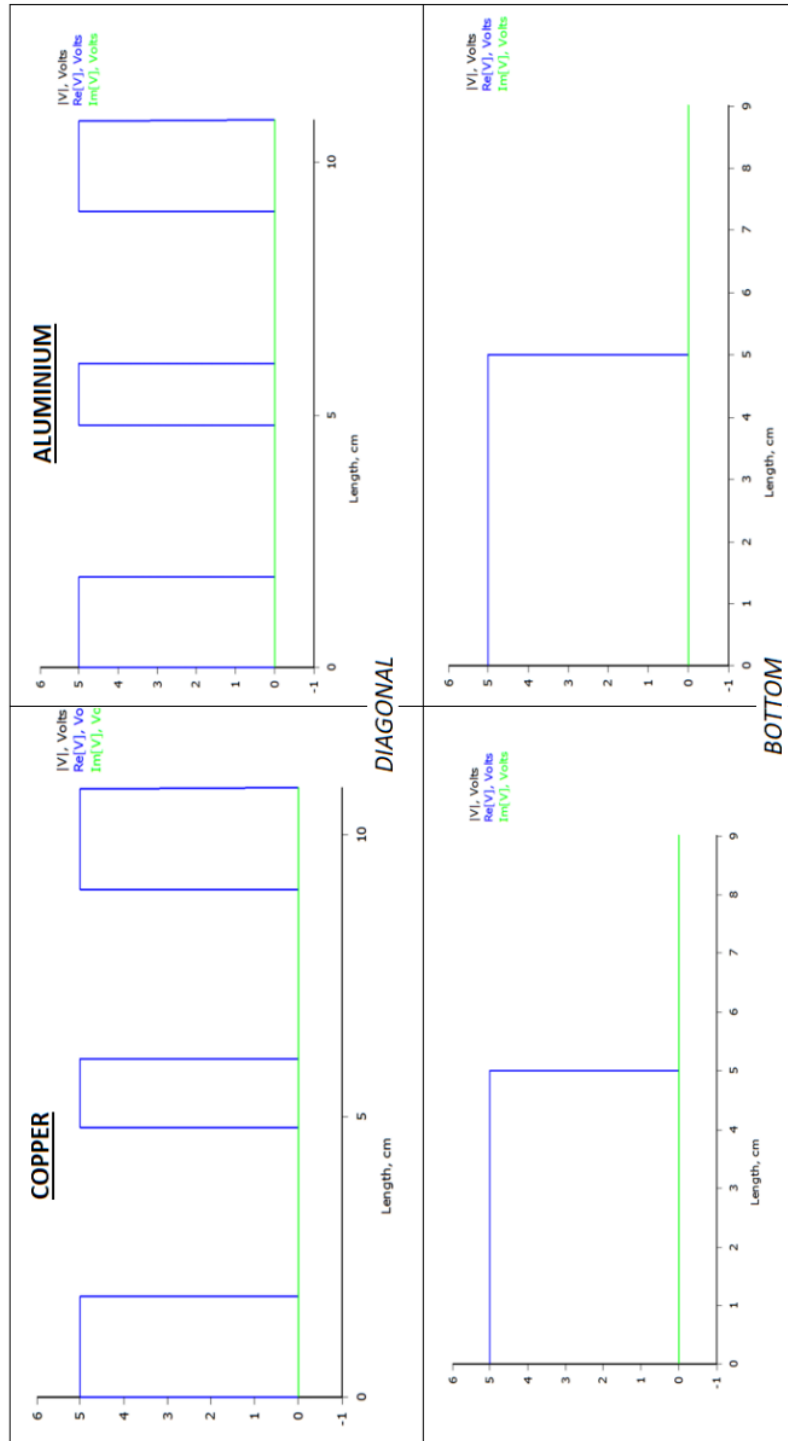


Figure 17: Voltage Graphs for Task 2

Task 3

Set Up

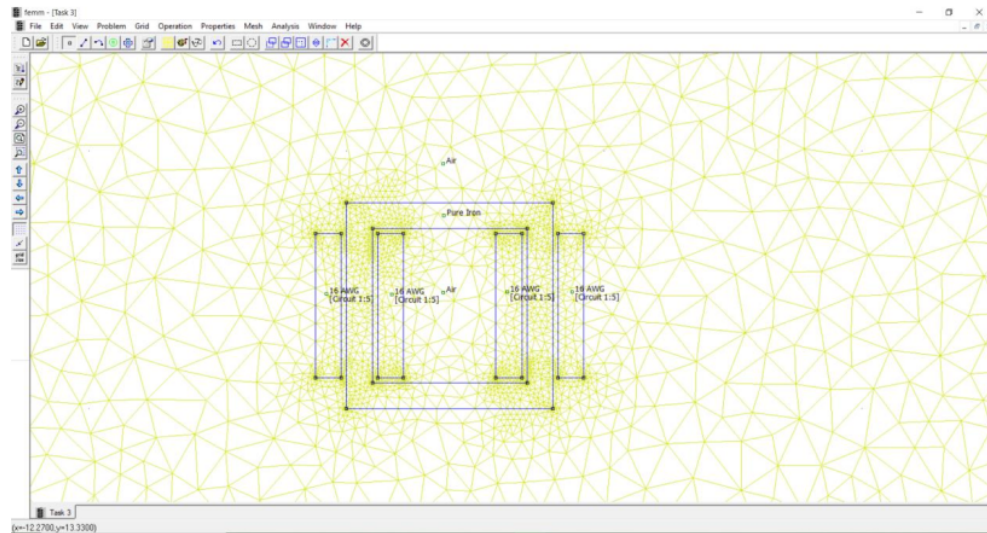


Figure 18: Task 3 Set Up

Task 3 is a magnetostatic problem based on a square conductor made of iron, with coiled wire carrying a current wrapped around the left- and right-hand side. The conductor is an 8x8cm square, creating a 6x6cm internal square. The coils are represented by rectangles of 6.6x1cm. The construction itself is placed inside a large ~90x90cm square, in which a node with material type air is placed. This is to provide the outside coils the same conditions as the coils inside the conductor, to get a more accurate representation. Each coil is made up of 5 turns, with a current of 200.

A magnetic field is a field around a magnetic object in which a force acts on other magnetic objects. The density of this field is how strong the magnetic force is. This density is measured in Webers per metre squared and is depicted by flux lines. These lines show the direction of the flow of energy, the closer the lines are and the greater the number, the stronger the field of force is. The lines will never cross and will travel from North to South.

A solenoid is a wire that is coiled into a spiral shape, which when a current is applied acts as an electromagnet. This magnetic field is stronger than it would be in a single wire, and with each additional coil it gets stronger [14]. This happens through flux linkage creating mutual inductance. This flux linkage is proportional to the current flowing through the coil. The ratio of the current to

Equation 3 below [15]. L is the inductance in Henrys, μ is the permeability of free space, N is the number of turns, A is the cross-sectional area, I is the current in the wire, and l is the length.

$$L = \frac{\mu N^2 I A}{l(I)}$$

Equation 7 Inductance in Solenoid

Material Properties

Iron is a magnetic, ductile metal, that whilst it is able to be worked, it is not as soft as aluminium or copper and is generally worked under heat, through forging or casting. It is an incredibly abundant material and is commonly used in construction, vehicle manufacture and domestic appliances, due to its low cost and high availability [16].

Iron is a good conductor of electricity, for the qualities that make air a bad conductor, iron instead has metallic bonds which allow the electrons to move freely as they are not tightly bound. With regards to metals, Iron is not the best electric conductor due to its relatively high resistance. As such it has many uses in heating elements for example [17]. Within electronics, due to iron's ability to concentrate magnetic fields, it is commonly used in transformers, generators, and electromagnets [18].

Simulation Results and Analysis

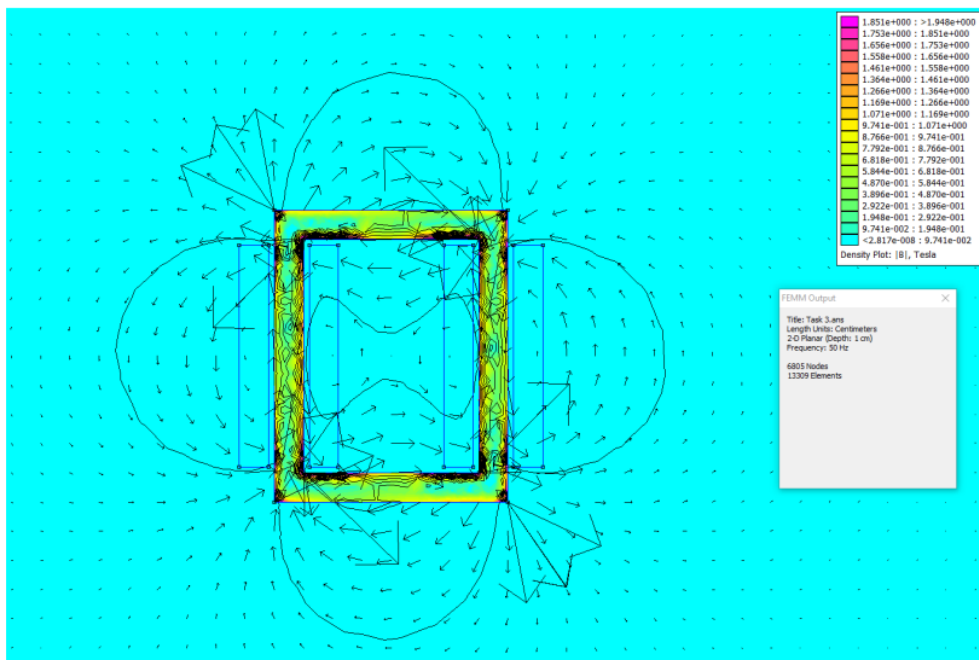


Figure 19: Task 3 Output with Vector Plot

When this task is analysed, it produces the construction shown in Figure 20. The solenoid induces an electric current in the iron, causing the set up to behave as a transformer, where the eddy currents flow from the primary to the secondary coil [19]. Because both of the coils carry a charge there are two north and two south poles created by the coils. When the current in the secondary coil is removed, only one magnetic field is produced by the primary coil. This can be seen in Figure 21 overleaf, where both coils are still in position, but the magnetic field is only created by the left-hand coil. This then induces current in the iron core and carries it to the secondary coil, acting as a transformer.

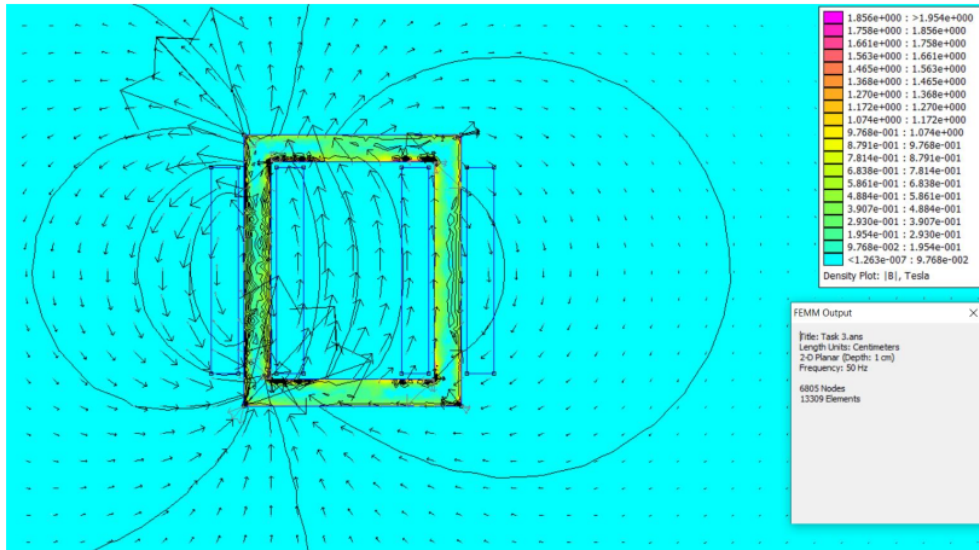


Figure 20: Task 3 with Single Wire Supply

The intensity, or strength $\vec{H}$ and density, the amount of flux lines, $\vec{B}$ of the magnetic field are linked, the intensity is measured in Newtons/Weber (N/Wb), whilst the density is measured in Weber per square meter (Wb/m^2). The analysis shows that the density of the magnetic field is quite high. The permeability of the material is calculated using the two figures. The permeability is the ability of the conductor to force the magnetic flux into the region around the conductor [20]. This Permeability is denoted by μ and measured in Henrys per meter (H/m). The formula in Equation 4 below is used to calculate permeability.

$$\vec{B} = \mu \vec{H} = \mu_0 \mu_r \vec{H}$$

Equation 4: Magnetic Permeability

For all Nonmagnetic mediums $\mu_r = 1$, and will be greater than unity for magnetic materials, such as the iron core used in the simulation. μ_0 is the denotation for free space and carries a value of $4\pi \times 10^{-7}$.



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EMR Assignment - LC

GRADEMARK REPORT

FINAL GRADE

79/100

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. It would have been better to have more reference from reputable academic publishers and articles from peer reviewed journals.

Knowledge and Understanding Skills: Marks: 16/20

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

Cognitive and Intellectual Skills: Marks: 15/20

Excellent critical evaluation and analysis of concepts and principles leading to logical, evidence-based, reasoned arguments and judgements. Can analyse new and/or abstract data and situations without guidance

Practical Application Skills: Marks : 26/30

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

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

Can communicate well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised. Would have benefited from a more formalised layout, such as breaking down the

assignment into more detailed numbered and named sections.

Overall total: 79/100

PAGE 1

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PAGE 3



Comment 1

Table of equation should be in the next page

PAGE 4

PAGE 5



Comment 2

Start with a description and then the figure



Comment 3

It is better to number the sub headings

PAGE 6



Comment 4

It is better interpret the FEMM output

PAGE 7



Comment 5

It is better interpret the FEMM output



Comment 6

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Comment 7

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PAGE 17



Comment 8

It is better to have a conclusion a the end.

PAGE 18



Comment 9

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

PAGE 19
