DESIGNING AND SIMULATING MICRO FLUXGATE SENSOR

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved:

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(Dr. John Ojur Dennis)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Muhamad Hilmi Bin Sufyan)

ABSTRACT

The objective of this project is to design a micro fluxgate sensor using Coventorware software. This project is focusing on designing a fluxgate sensor in micro scale for sensing the magnetic field. Micro fluxgate sensor can be widely applied in the conventional and potential fields, for examples, scientific research, automation, process control of industry, mineral prospecting, medical appliance and satellite missions. The collection of technical details and data regarding the harmonics of magnetic field, micro fluxgate sensor and its conditioning circuit existing in the world is done. A 3D model of micro fluxgate sensor is designed using Coventorware software in its Architect and Designer applications. A simple analysis of micro fluxgate sensor is carried out to after designing the 3D model of micro fluxgate sensor.

ACKNOWLEDGEMENTS

First and foremost, praises be to Allah S.W.T whom had poured His tremendous blessing and wisdom upon the author throughout his whole life as a student. Through Him everything is possible and this project can be completed despite of those obstacles and hardship.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

A micro fluxgate sensor is a device which measures magnetic fields utilizing the nonlinear magnetic field characteristics. This sensor is based on the fluxgate magnetometer principal. Fluxgate magnetometers were first introduced in the 1930s. The purpose of this invention in 1930s was for airborne magnetic surveys and for submarine detection during World War II. Much airborne magnetic surveying was carried out using fluxgate detectors between 1945 and 1985, and hand-held portable devices were used for making vertical-component ground measurements between 1965 and 1985 [1]. After that, this technology was further developed for geomagnetic studies (airborne, seaborne and underwater), for mineral prospecting and later for magnetic measurements in outer space. It was also adapted and developed for various detection and surveillance devices, both for civilian and military use. Nowadays, micro fluxgate magnetometer is invented and can be widely applied in the conventional and potential fields, for examples, scientific research, automation, process control of industry, mineral prospecting, medical appliance, especially in satellite missions.

Despite the advent of newer technologies for magnetic field measurement, micro fluxgate sensor continues to be successful in all of these areas, because of their reliability, relative simplicity, economy and ruggedness [2].

1.2 Problem Statement

Nowadays, magnetic field sensors are really useful devices in human life. With these sensors, human can do so many things such as geomagnetic studies and magnetic measurements in outer space. Currently, micro fluxgate magnetometer is invented and can be widely applied in the conventional and potential fields, for examples, scientific research, automation, process control of industry, mineral prospecting, medical appliance, especially in missions. But there are needs to improve its design and sensitivity for the sake of the existing technology that we have in those fields. Therefore, this project will aim to design a miniature micro fluxgate sensor with improved design and sensitivity.

1.3 Objective and Scope of Study

The objectives of this study are:

- To do research on theory of operation of micro fluxgate sensor.
- To design a rough model of micro fluxgate sensor using AutoCAD software.
- To design and simulate a micro fluxgate sensor using Coventorware software.
- To analyze simulation results.

The scope of study for this project is to investigate the characteristics and behavioral of the fluxgate magnetometer. Once knowing its characteristics, a study of micro fluxgate sensor will be done. This study its theory of operation is essential in order to design this type of sensor. A rough 3D design will be design using AutoCAD software. Once finish with the AutoCAD, a micro fluxgate sensor will be design using Coventorware software.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory of Operation of Micro Fluxgate Sensor

The understanding of the theory of operation is essential in designing a micro fluxgate sensor. The operation of this sensor is quite similar to the operation of a fluxgate magnetometer. So, understand about micro fluxgate sensor, a study about fluxgate magnetometer is done.

A fluxgate magnetometer consists of two bars of ferromagnetic material, primary coil, secondary coil, AC power supply and an ammeter. These two bars are placed closely and parallel to each other. Each bar is wound with a primary coil, but the direction in which the coil is wrapped around the bars is reversed. Primary coil is supplied with an alternating current and will produce varying magnetic field in each coil [3]. With the current flowing in the primary coil, the two cores will experience induced magnetic field that have the same strength but opposite orientations, at any given time during the current cycle. The two ferromagnetic cores and the primary coil are surrounded by the secondary coil. With existence of external magnetic field, one component of the external field will be parallel to the core axes. The external field will be parallel to the magnetic field in one core when the current in the primary coil increases. The other core will be opposite the external field and so smaller. The field will reach saturation in one core at a time different from the other core and fall below saturation, as the current decreases, at a different time [1]. The secondary coil will detect the difference occurs in the both cores. A voltage potential in the secondary coil is produced by the magnetic fields induced in the cores. Voltage detected in secondary coil would be zero without the existence of external magnetic field but will have some values in the existence of magnetic field since the behavior of two cores differs depending on the external magnetic field. Figure 1 shows the figure of a simple fluxgate magnetometer.

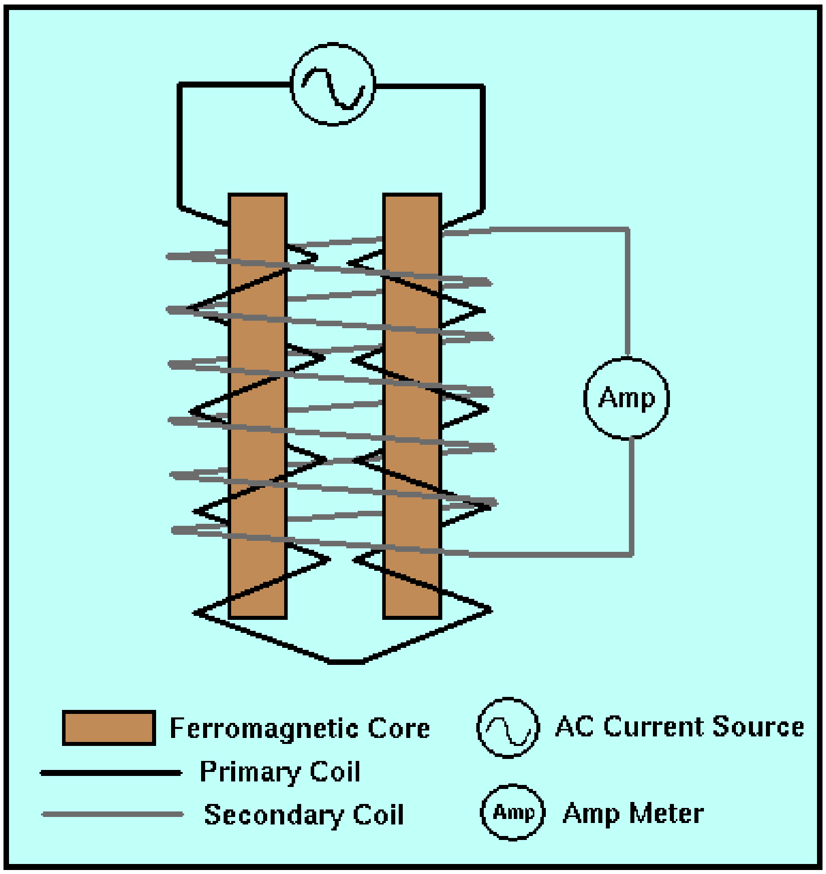


Figure 1 : A simple fluxgate magnetometer [1]

The difference between fluxgate magnetometer and micro fluxgate sensor is the size of both devices. The other difference is type of coil that will be used in designing this sensor. Planar rectangular coils will be used in this project and replace primary and secondary coil as shown in Figure 1. In Conventorware software, it is known as movable coil. The example for this type of coil is shown in Figure 2 which also represents the secondary planar rectangular coil.

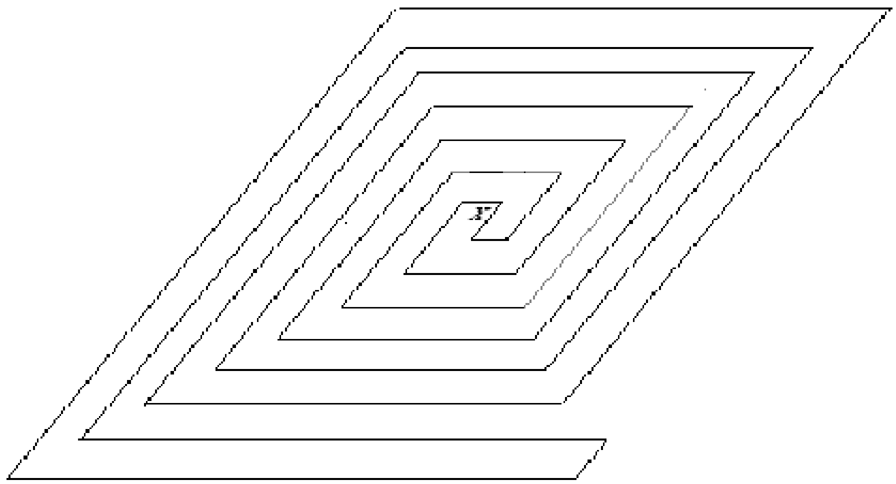


Figure 2 : Secondary planar rectangular coil

Figure 3 shows the construction of a primary planar rectangular coil.

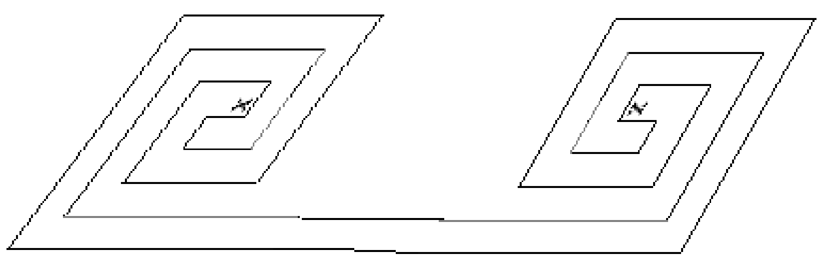


Figure 3 : Primary planar rectangular coil

Besides that, the location of the core will also be changed. Two symmetrical magnetic cores will be located on the both side of the coils. The centrally located coils magnetize the cores in opposite directions, so that the structure forms two closed magnetic paths. Since the design of this micro-fluxgate sensor has a slight difference with the design of a fluxgate magnetometer, the theory of its operation also changes. In this micro-fluxgate sensor, the current still produce magnetic field at the both primary coils but in the opposite directions. Then the magnetic field will flow through the core and make a circulation at each coil [4]. At one point, both opposite magnetic fields will meet each other. If there is no external field expose to this device, both magnetic field will be canceling each other since both of them have same magnitude but different direction. If the is an external field, one component of the external field will be parallel to either one of the direction of magnetic field and will has a greater magnitude of magnetic field and current. This phenomenon will create a difference in magnitude of magnetic field and current between the primary coils. The difference is sufficient to induce a measurable voltage in a secondary. This theory is illustrated in Figure 4.

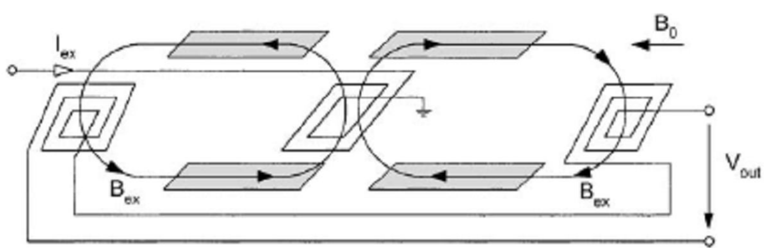


Figure 4 : Theory of operation of a micro-fluxgate sensor [4]

Micro-fluxgate sensor with symmetrical core on both sides of the planar rectangular coils has substantially improved parameters compared to its single core predecessor and almost closed magnetic path for the excitation field allows much deeper saturation of the sensor core, which reduces the perming effect, hysteresis and noise [5]. The construction of this micro-fluxgate sensor is shown in Figure 5 for the side view.

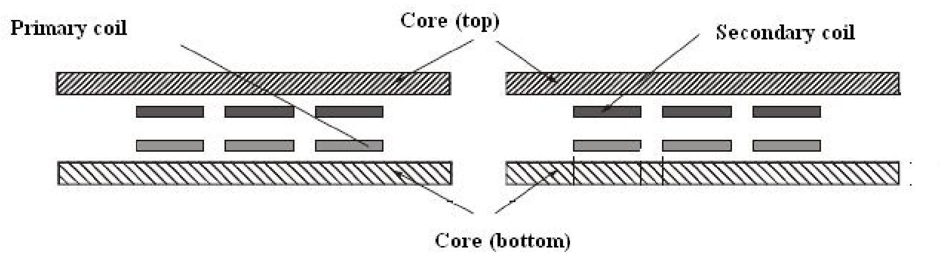


Figure 5 : Micro-fluxgate with closed core [5]

2.2 Transformer Principal

The micro fluxgate sensor is based on the transformer principal since it transfers electrical energy from one circuit to another through inductively coupled conductors. The example of circuit diagram for this sensor is shown in Figure 6.

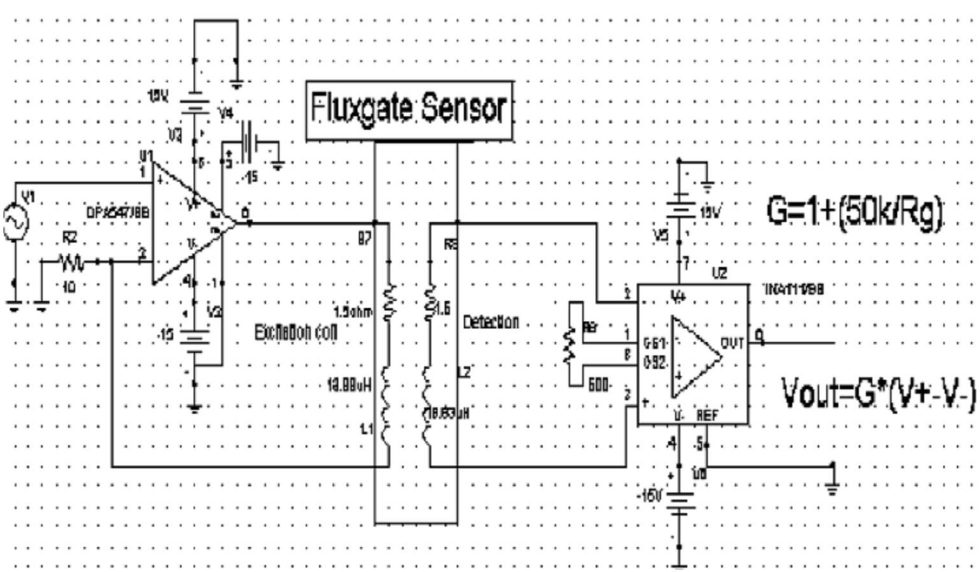


Figure 6 : Example of a circuit diagram for micro fluxgate sensor [6]

Transformer in general is a passive device which transforms alternating (AC) electric energy from one circuit into another through electromagnetic induction [7]. It normally consists of a ferromagnetic core and two or more coils (windings). The coils are commonly wound around the core, or around separate but magnetically-coupled cores. A varying current in the first or primary winding creates a varying magnetic field in the core (or cores) of the transformer. This varying magnetic field induces a varying electromotive force (EMF) or voltage in the secondary winding. This effect is called mutual induction.

2.3 Perming Effect

Perming effect is recognized as a weak point of all magnetic sensors, which contain ferromagnetic material either in form of the sensor core or in the form of the field concentrator. It is defined as the change of sensor zero (or even distortion of its characteristics) after the shock of large magnetic field and in the former case the core should be periodically re-magnetized in order to erase its magnetic history; it is usually no way how to prevent perming of the field concentrator [5]. It is a particularly serious problem in micro-fluxgate sensors incorporating flat coils, which cannot be effectively tuned.

Figure 7 shows the linear part of the single-cored sensor characteristics based on experiment conducted by [5].

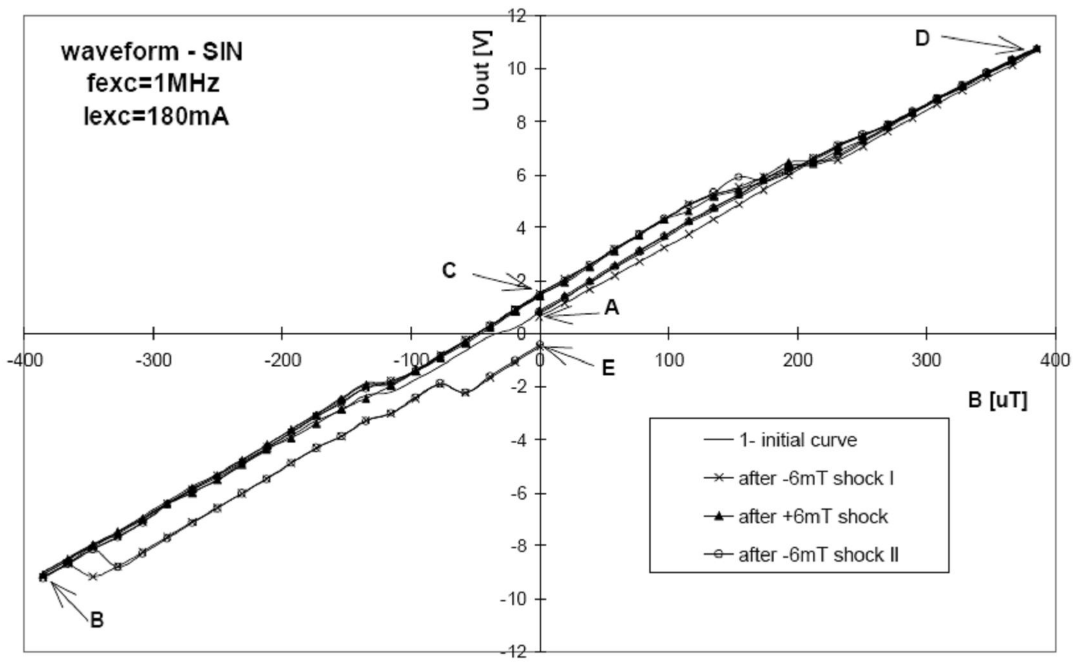


Figure 7 : Hysteresis and perming of the single-core in 400 uT range [5]

First curve (A-B-C-D-A) was measured on carefully demagnetized sensor. Its hysteresis was 20 uT. Then the sensor was subjected to the in-field axis field shock of -6 mT: the output skipped to point E, which corresponds to the gross perming effect error of 50 uT. The following characteristic is (E-B-C-D-A). After another field shock of reverse polarity (+6 mT) the characteristic is similar to the virgin one. This effect caused by low saturation of the core. As the excitation current cannot be further increased because of the temperature limitations and the coil thickness is limited by metallization technology, the only way to increase the saturation level is to decrease the demagnetization of the core by decreasing of its width [5].

Figure 8 shows the same characteristics measured for novel sensor with double-sided core (X-Y-X-Z-X).

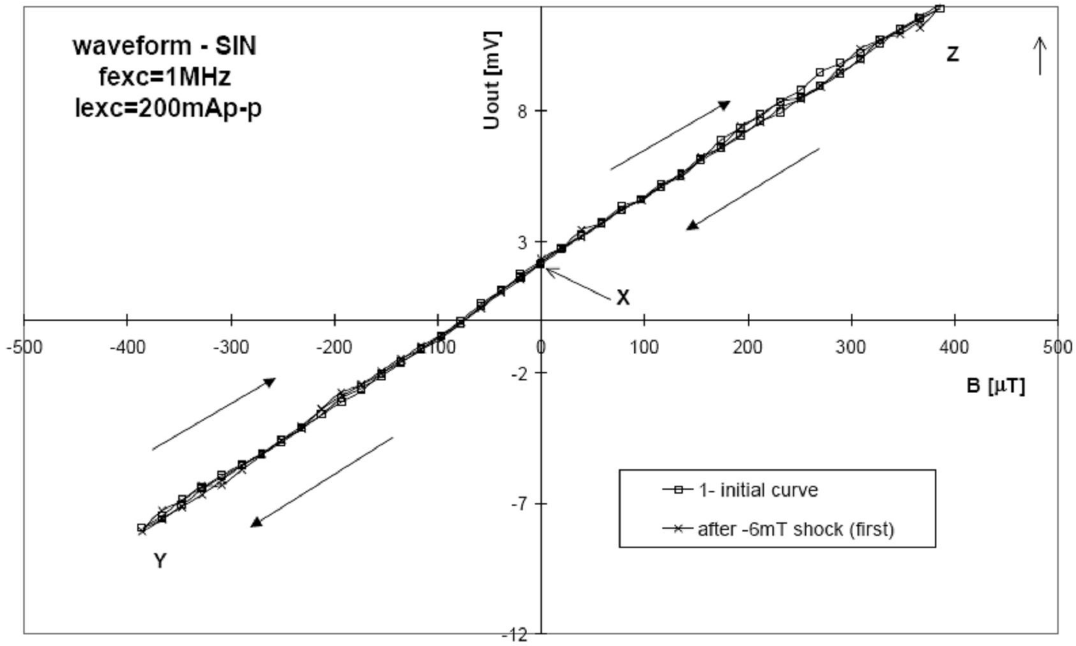


Figure 8 : Hysteresis and perming with double-sided core [5]

As the magnetic core is almost closed, the coupling between the coils and magnetic material is much stronger and the cores are saturated more deeply.

2.4 AutoCAD Software

AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting) software application for 2D and 3D design and drafting, developed and sold by Autodesk, Inc. Initially released in late 1982, AutoCAD was one of the first CAD programs to run on personal computers, and notably the IBM PC [8]. Most CAD software at the time ran on graphics terminals connected to mainframe computers or mini-computers. AutoCAD supports a number of application programming interfaces (APIs) for customization and automation. These include AutoLISP, Visual LISP, VBA, .NET and ObjectARX. ObjectARX is a C++ class library, which was also the base for products extending AutoCAD functionality to specific fields, to create products such as AutoCAD Architecture, AutoCAD Electrical, AutoCAD Civil 3D, or third-party AutoCAD-based applications [8].

2.5 Coventorware Software

This project is using software called Coventorware software. Coventorware software is a product of Coventorware, Inc. which a leading worldwide provider of 3D analysis and design automation software for the development of micro-scale and nano-scale devices and systems [9]. This software is a common platform for a broad range of semiconductor applications, provides a complete process steps with a user-friendly interface. In this software, there are some functions that are really useful in developing this sensor such as Process Editor and 3D visualizer function. The Process Editor function allows the user to define layer thickness, process steps and descriptions and the 3D visualizer enables users to view, manipulate and cross-section 3D models [9]. Coventorware software is commonly used:

- to build 3D models
- to interact with 3D visualization
- to view and save any 2D cross section
- to view complex structures in 3D at unique perspectives
- to explore process variations with metrology-capable models

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

Before proceeding with the methodology itself, steps were drawn out diagrammatically to clear out on the flow. Figure 9 shows the flow chart of procedure identification that includes:

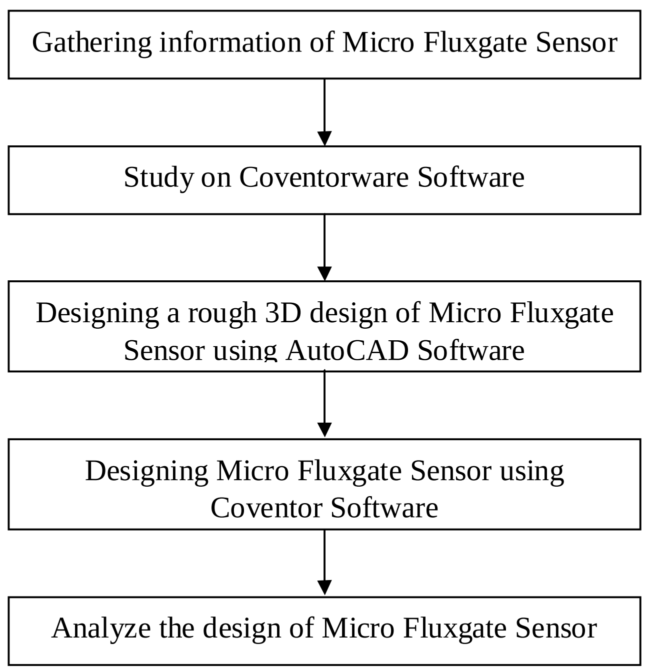


Figure 9 : Flowchart of procedure identification

3.1.1 Gathering Information of Micro-Fluxgate Sensor

First step of doing this project is to gather all the information about the micro fluxgate sensor. This research also include the study of the behavioral and characteristics of magnetic field. It is conducted by doing research through internet and books that related to this project. Information also collected from the journals and thesis that been done before.

3.1.2 Study on Coventorware Software

Since this project will be using Coventorware software, a study about this software also been done. All the information about this software are gathered from the internet and its manual. From this study, all the tools and functions to be used are identified. More understanding on this tools and functions needed to make sure the project flow smoothly.

3.1.3 Designing Micro-Fluxgate Sensor in AutoCAD Software

At this stage, a rough 3D design or sketch model is needed. Using AutoCAD software, this model can be created just to visualize what will be designed in the Coventorware software.

3.1.4 *Designing Micro-Fluxgate Sensor in Coventorware Software*

Design stage comes after all the tools and functions in the software are understood. In this stage, assistance from the master student that been using this software before is needed since this software need to be handled carefully because of its high value. A micro fluxgate sensor design is expected from this stage.

3.1.4.1 Initialization

During this initialization process, a project directory is selected and a setting file is created. To do this, Coventorware software must be started first. In the project window, a file project name *fluxgate* is entered. Then a default setting file appears on the Setting file line. This process is shown in Figure 10.

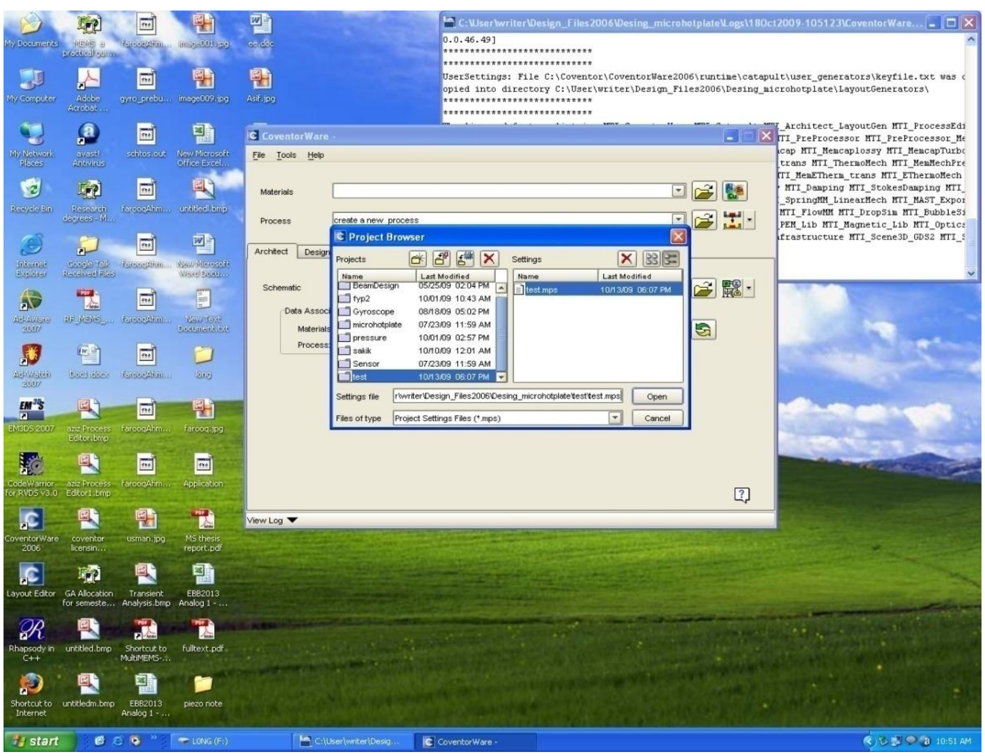


Figure 10 : Initialization in Coventorware software

3.1.4.2 Material Properties

Before starting a design, the Material Properties Database (MPD) is checked so that it has the necessary materials and the correct material parameters. The material specified in the process file will be used to assign certain material properties to the micro-fluxgate sensor schematic. The properties of these materials are determined by the parameter specified in MPD.

To start with, the Material Editor icon in the Function Manager window is selected. In the Material drop-down menu, Aluminum is selected. The material is verified as shown in Figure 11.

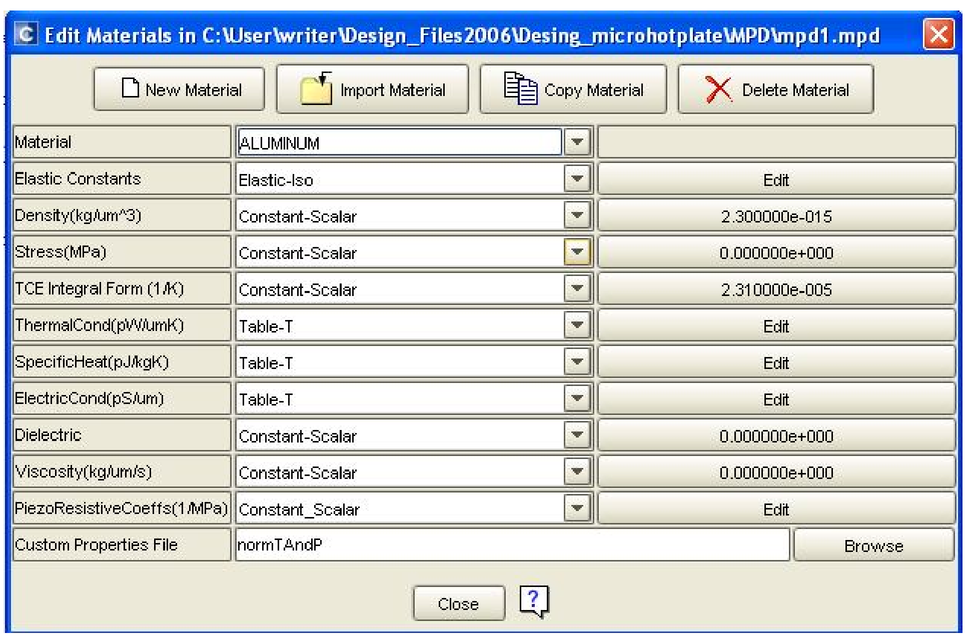


Figure 11 : Aluminum properties

Then, in the Material drop-down menu, Chromium is selected. The material is verified as shown in Figure 12.

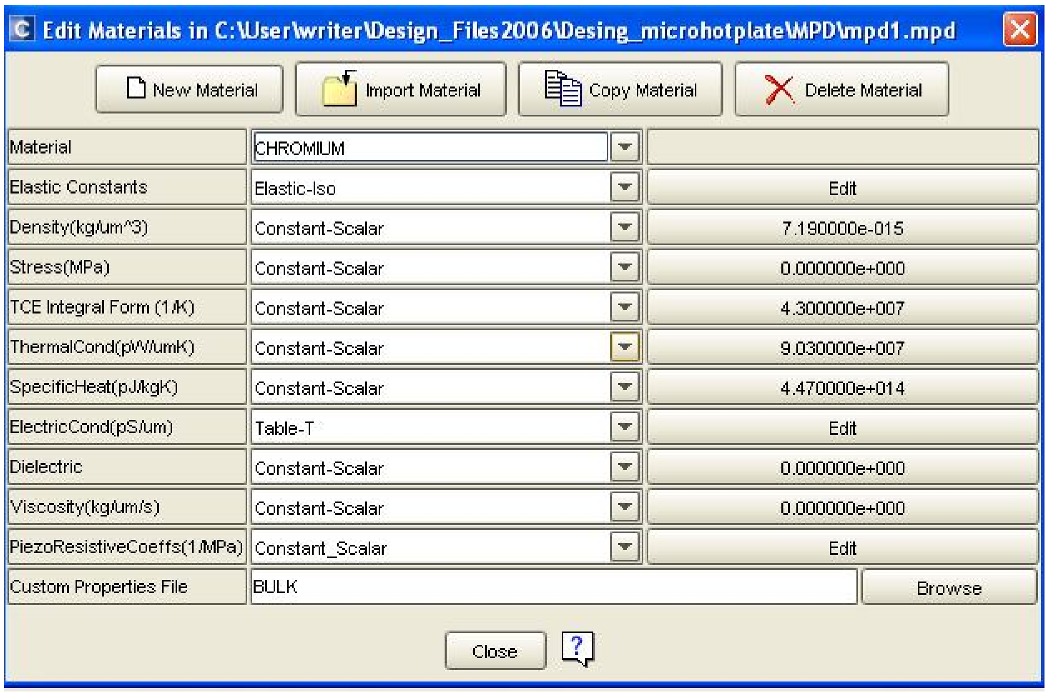


Figure 12 : Chromium properties

Once again, in the Material drop-down menu, Silica is selected. The material is verified as shown in Figure 13.

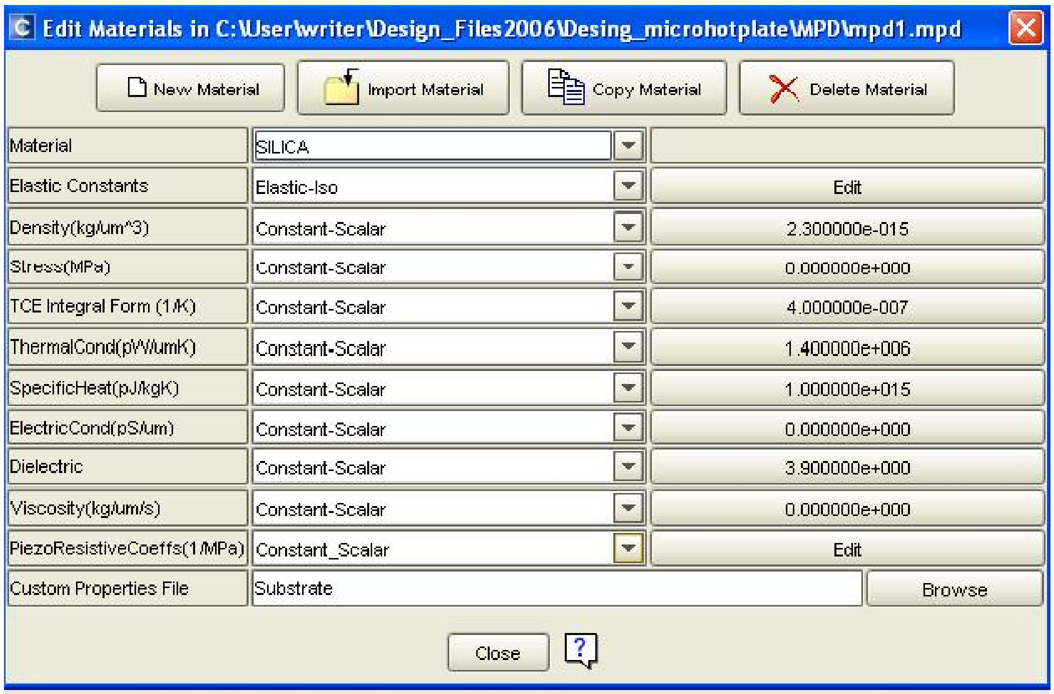
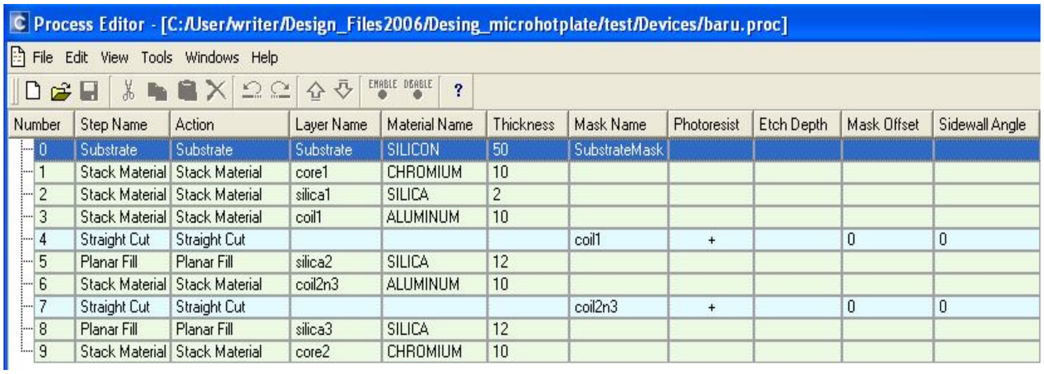


Figure 13 : Silica properties

Material Editor window is closed after all the material properties are verified. After that, Process Editor icon is clicked. In this Process Editor, layer for cores, primary coil and secondary coil is defined and they are shown in Figure 14. This file is saved as *fluxgate.proc*. The Process Editor is closed after all the information as in Figure 14 is inserted.



Number	Step Name	Action	Layer Name	Material Name	Thickness	Mask Name	Photoresist	Etch Depth	Mask Offset	Sidewall Angle
0	Substrate	Substrate	Substrate	SILICON	50	SubstrateMask				
1	Stack Material	Stack Material	core1	CHROMIUM	10					
2	Stack Material	Stack Material	silica1	SILICA	2					
3	Stack Material	Stack Material	coil1	ALUMINUM	10					
4	Straight Cut	Straight Cut				coil1	+		0	0
5	Planar Fill	Planar Fill	silica2	SILICA	12					
6	Stack Material	Stack Material	coil2n3	ALUMINUM	10					
7	Straight Cut	Straight Cut				coil2n3	+		0	0
8	Planar Fill	Planar Fill	silica3	SILICA	12					
9	Stack Material	Stack Material	core2	CHROMIUM	10					

Figure 14 : Process Editor

3.1.4.3 Schematic Creation

In this section, a schematic of micro-fluxgate sensor is assembled in one of Coventorware application that is Architect. Electrical and magneto-electrical components from the Coventorware Parametric Model Library and other provided generic components, such as voltage sources, wires and ground are used.

To start, Saber icon drop-down menu in Architect tab is clicked. New from Process is selected. A sketch window appears and is maximized. This file is saved as *fluxgate. COVENTORWARE* symbol is selected to edit its attributes. In the Name field, *plate_legth* is entered. For the Value, *4400u* is entered. The other properties that been added are shown in Figure 15.

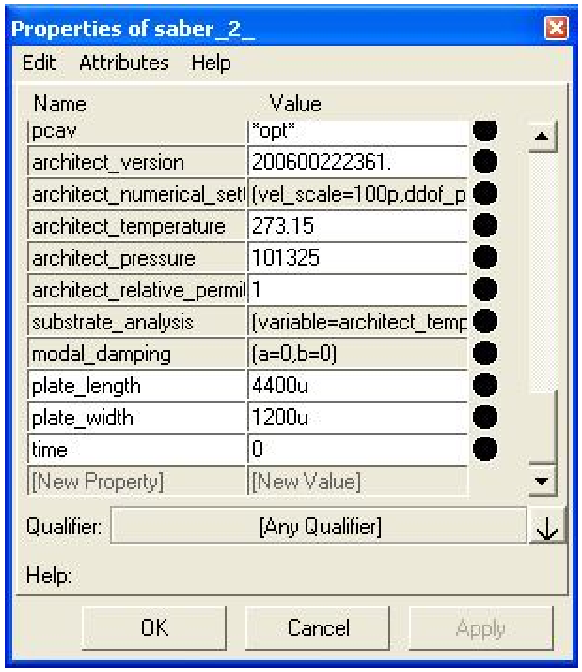


Figure 15 : Properties of COVENTORWARE symbol

After that, a *Rigid Plate* is placed in the schematic. The Rigid Plate component is located in *Coventorware Parts Library/Parametric Library/Electro-Mechanics/Rigid Plate*. It is named as *rigid plate 1*. The plate parameter is assigned as shown in Figure 16.

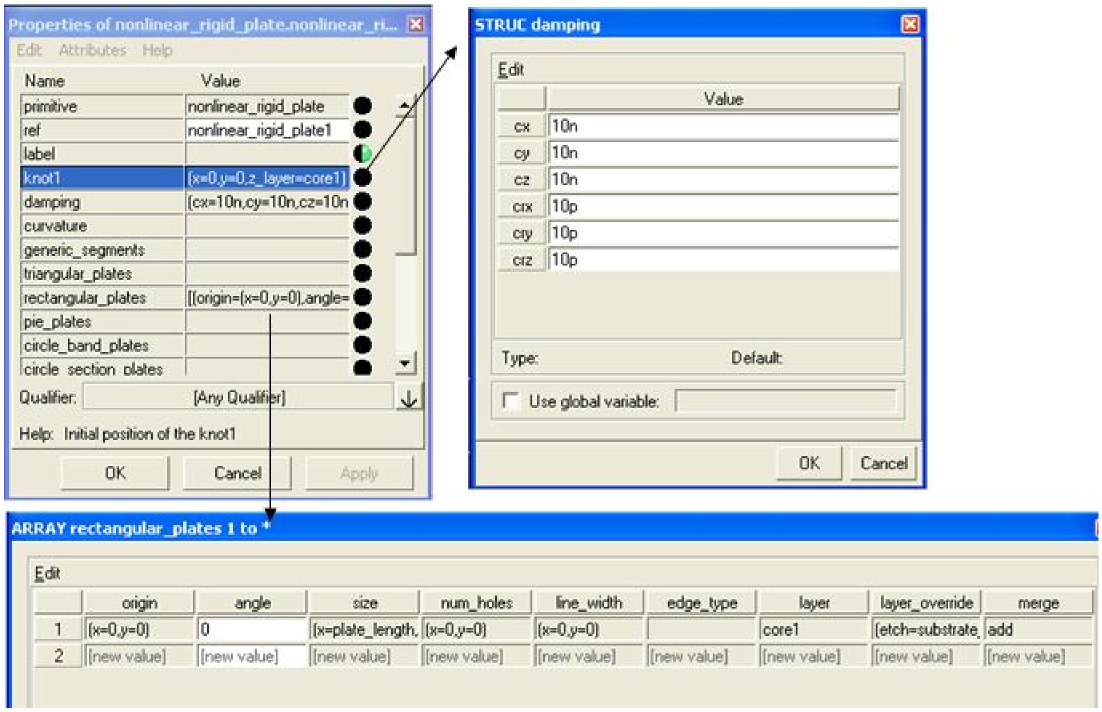


Figure 16 : Rigid plate parameters

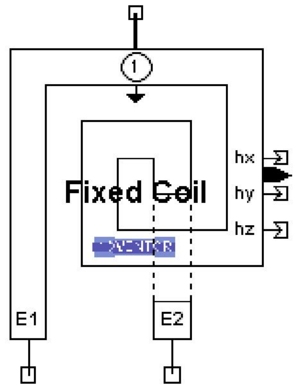
Step above is repeated but with some different parameters. It is named as *rigid plate 2*. The parameters that changed are shown in the Table 1.

Table 1 : Changes of parameter for rigid plate 2

Name	Value
knot1	x = 0, y = 0, z_layer = core2
rectangular_plate	layer = core2

Next, in the Part Gallery, a fixed planar rectangular coil bus is selected and placed in the schematic. The detail of the coil is shown in Table 2.

Table 2 : Details of fixed planar rectangular coil bus

Symbol name	Symbol	Path	Quantity
fixed_planar_rec_coil_bus		/Coventorware Parts Library /Parametric Libraries /Magneto-Mechanics /Fixed Sources of Field	3

The coils are named as *coil1*, *coil2* and *coil3*. At coil1, the properties are shown in Figure 17.

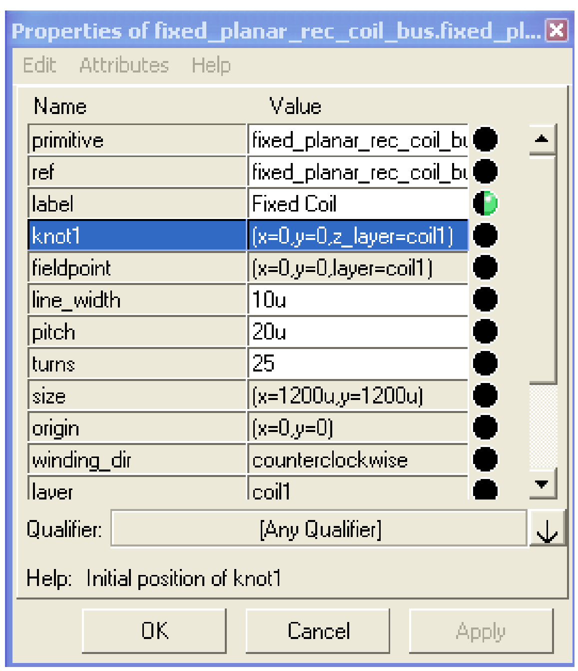


Figure 17 : Properties of coil1

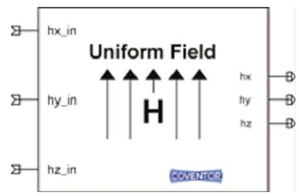
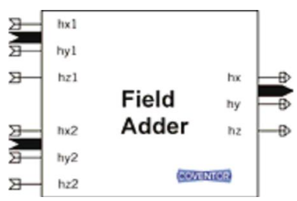
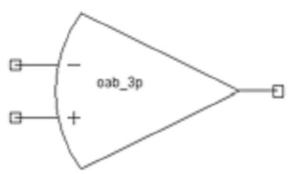
For coil2 and coil3, the some parameters have changed and shown in Table 3.

Table 3 : Changes of parameter for coil2 and coil3

	Name	Value
coil2	knot1	x = 0, y = 0, z_layer = coil2n3
	fieldpoint	x = 0, y = 0, layer = coil2n3
	origin	x = -1000u, y = 0
	layer	coil2n3
coil3	knot1	x = 0, y = 0, z_layer = coil2n3
	fieldpoint	x = 0, y = 0, layer = coil2n3
	origin	x = 1000u, y = 0
	layer	coil2n3

After changing all the coils parameters, 2 *uniform magnetic field components*, a *field adder component* and an *op-amp* are added in the schematic. The details of the components are shown in Table 4.

Table 4 : Details of uniform magnetic field, field adder and op-amp component

Symbol Name	Symbol	Path	Quantity
Uniform_mag_field		/Coventorware Parts Library /Parametric Libraries /Magneto-Mechanics /Fixed Sources of Field	2
Field_adder		/Coventorware Parts Library /Parametric Libraries /Magneto-Mechanics /Utility Parts	2
OpAmp, Ideal 3-Pin		/Mast Parts Library/Electronic/ OpAmps	1

There is no property for uniform magnetic field and field adder components but for op-amp component, the properties are stated as shown in Figure 18.

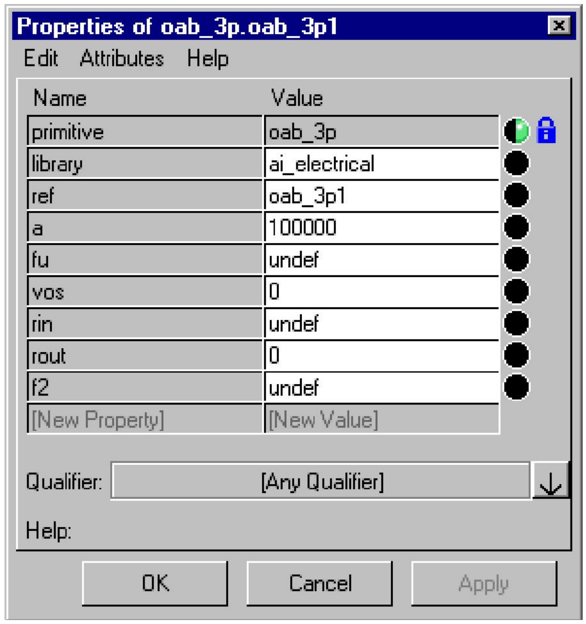
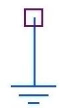
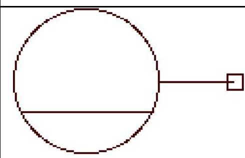
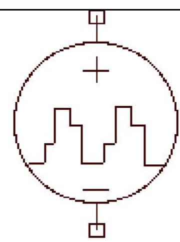


Figure 18 : Properties of op-amp

Last components inserted in the schematic are parts needed to set up the electrical stimuli components. They are *ground*, *control source (DC source)*, *resistors*, *inductor* and *voltage source (periodic PW*L) and their details are shown in Table 5.

Table 5 : Details of ground, control source (DC source) voltage source (periodic PWL), resistors and inductor

Part	Symbol	Path	Quantity
Ground, (Saber Node 0)		/MAST Parts Library /Sources, Power, Ground /Power & Ground	3
Control Source, DC Source		/MAST Parts Library /Control Systems /Continuous Control Blocks /Control System Sources	3
Voltage Source, Periodic PWL		/MAST Parts Library /Electronic/Electrical Sources /Voltage Sources	1
Inductor (-)		/MAST Parts Library/Electronic /Passive Elements/Inductors and Coupling	1
Resistor (|)		/MAST Parts Library /Electronic/Passive Elements /Resistors	4

For DC control source that will be connected to the *hz_in* terminal of the uniform field component, its *dc_value* is set to 29.4k. For the inductor, the *l* value is assigned to 1n. For all the resistors, their *rnom* values are set to 10k and their *tnom* are set to 27. The properties of voltage source (periodic PWL) are shown in the Figure 19.

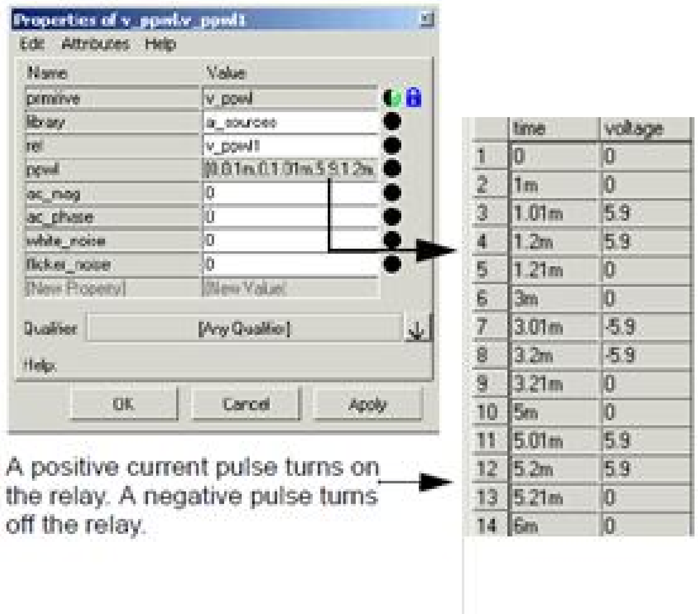


Figure 19 : Properties of voltage source (periodic PWL)

When all the components needed are placed in the schematic, they are connected and the connection is shown in the Results and Discussion chapter.

3.1.4.4 2D Layout Verification

During schematic creation, many parameters have been entered in the Properties window for each component. These parameters are carefully selected in order to maintain consistency. Inconsistencies in the design are usually difficult to find. So, to avoid these inconsistencies from happen, the schematic is netlisted using *Netlist* application in the Architect. Netlisting can often highlight hookup errors. If any errors occur, a dialog box displaying those errors will appear during the netlist procedure. If there is no error, the process can proceed to design 2D layout using *Designer* tab. In the Designer tab, *Layout Editor* icon is selected. It creates 2D layout based on the schematic created in the Architect. When the 2D layout appears, it is saved as *fluxgate1*.

3.1.4.5 Building 3D Model

To build a 3D model in Conventor software, it has to start with clicking *Start Preprocessor* icon in the Designer tab. This application creates 3D model based on the 2D layout and the schematic. After a few minutes, a solid 3D model of micro-fluxgate sensor appears in the window. Then, this file is saved as *fluxgate2*.

3.1.5 Analyze the design

The last step for this project is to analyze the design of micro fluxgate sensor. This will be done in order to verify and justify the new design of micro fluxgate sensor.

3.2 Tools and Equipment Required

3.2.1 AutoCAD Software

Using AutoCAD software, a rough 3D design of a micro fluxgate sensor can be design. This 3D design is important in order to visualize the sensor before it is designed using Coventorware software.

3.2.2 Coventorware Software

Coventorware software is the main tool that required doing this project. With this software, a 3D micro fluxgate sensor can be design. An experiment to verify the new design of micro fluxgate sensor also can be conducted using this software.

CHAPTER 4

RESULTS AND DICUSSION

4.1 Results

4.1.1 3D Model Using AutoCAD

Below are the figures of 3D model of micro fluxgate sensor that have been designed using AutoCAD software. It is considered as a rough design or a sketch model of a micro fluxgate sensor before it is designed using Coventorware software. Figure 20 shows the isometric view of micro fluxgate sensor that is designed using this software.

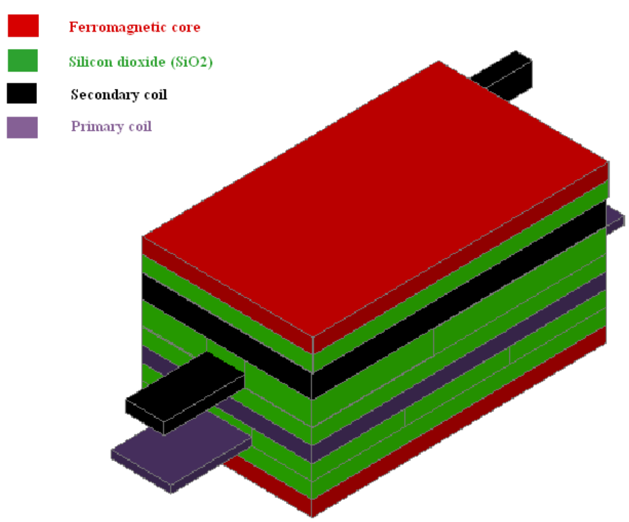


Figure 20 : Isometric view of a micro fluxgate sensor

Figure 21 (a) shows the top view and Figure 21 (b) shows the bottom view of micro fluxgate sensor in AutoCAD software.

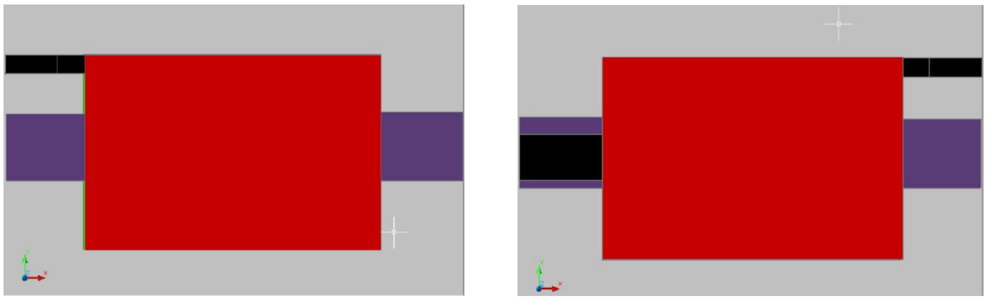


Figure 21 : (a) Top view of micro fluxgate sensor and (b) Bottom view of micro fluxgate sensor

Figure 22 (a) shows the front view and Figure 22 (b) shows the back view of micro fluxgate sensor in AutoCAD software.

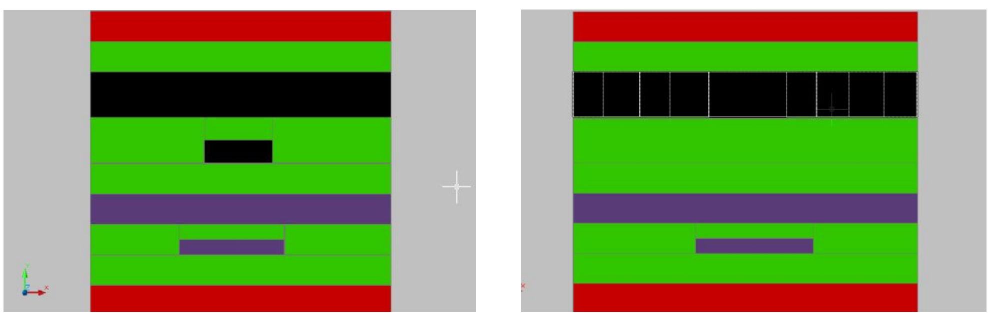


Figure 22 : (a) Front view of micro fluxgate sensor and (b) Back view of micro fluxgate sensor

Figure 23 shows the side view of micro fluxgate sensor in AutoCAD software.

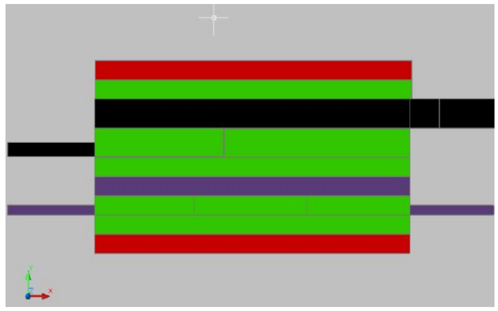


Figure 23 : Side view of a micro fluxgate sensor

Figure 24 shows the isometric view of primary coil that is designed using AutoCAD software.

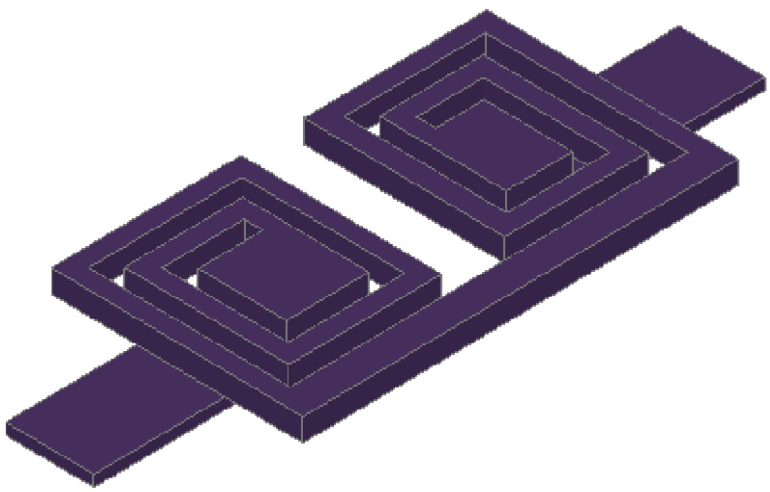


Figure 24: Isometric view of primary coil

Figure 25 shows the isometric view of secondary coil in the AutoCAD software.

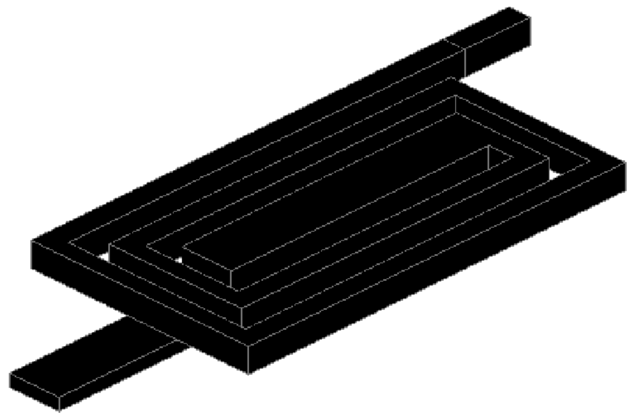


Figure 25 : Isometric view of secondary coil

4.1.2 Results In Coventorware Software

4.1.2.1 Schematic in Architect

As mentioned in Schematic Creation part (see 3.1.4.3), after all the parts are assembled in the schematic window, they are connected to create a circuit of micro fluxgate sensor. The details of the connection are shown in Figure 26.

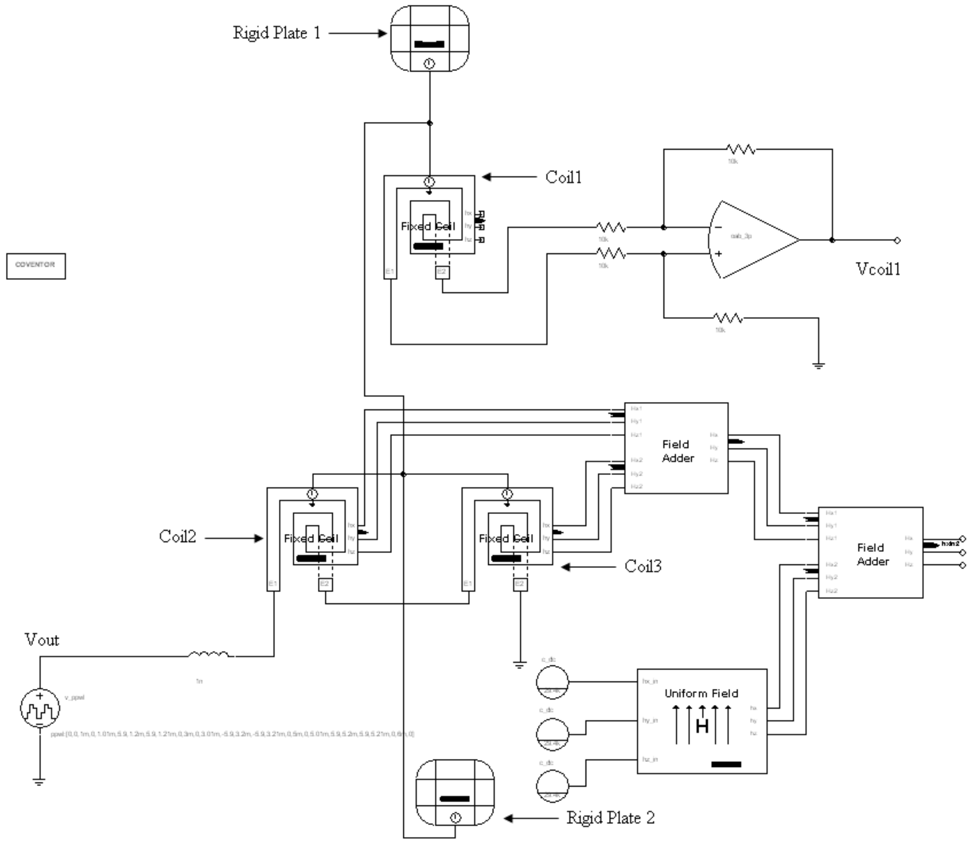


Figure 26 : Schematic in Architect

This schematic shows that the voltage supply (periodic PWL) and the inductor are connected to the coil2. Then both coil2 and coil3 are connected in a way that they can produce a different direction of magnetic field. Both of them are connected to field adder 1. Then, field adder 1 and uniform field block are connected to field adder 2. Before that, uniform field block is connected to the three DC source. When these DC source are activated, the uniform field will produce external magnetic field that can be detected by coil2 and coil3. The figure also shows how coil1 is connected to an op-amp. The difference of magnetic field at coil2 and coil3 is detected using this coil and measured at Vcoil1 at the op-amp output. After that, rigid plate 1, rigid plate 2, coil1, coil2 and coil3 are connected to each other using bus.

Figure 27 shows the signal that been measured at Vout. It represents the input signal supplied by the voltage source (periodic PWL) to coil2 and coil3.

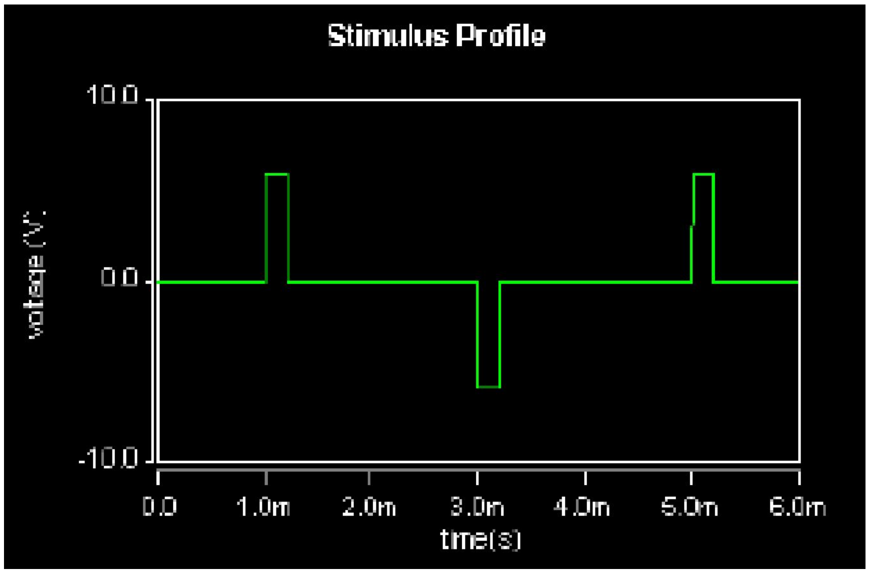


Figure 27 : Measured Vout signal

The signal shows that at it will has positive signal at 1 millisecond and 5 millisecond but at 3 millisecond the signal will have negative value.

4.1.2.2 2D Layout In Designer

After finish designing the schematic, 2D layout is designed in the Designer application. This is compulsory before proceeding with the 3D creation in the Coventorware software. Figure 28 shows the 2D layout for the micro fluxgate sensor.

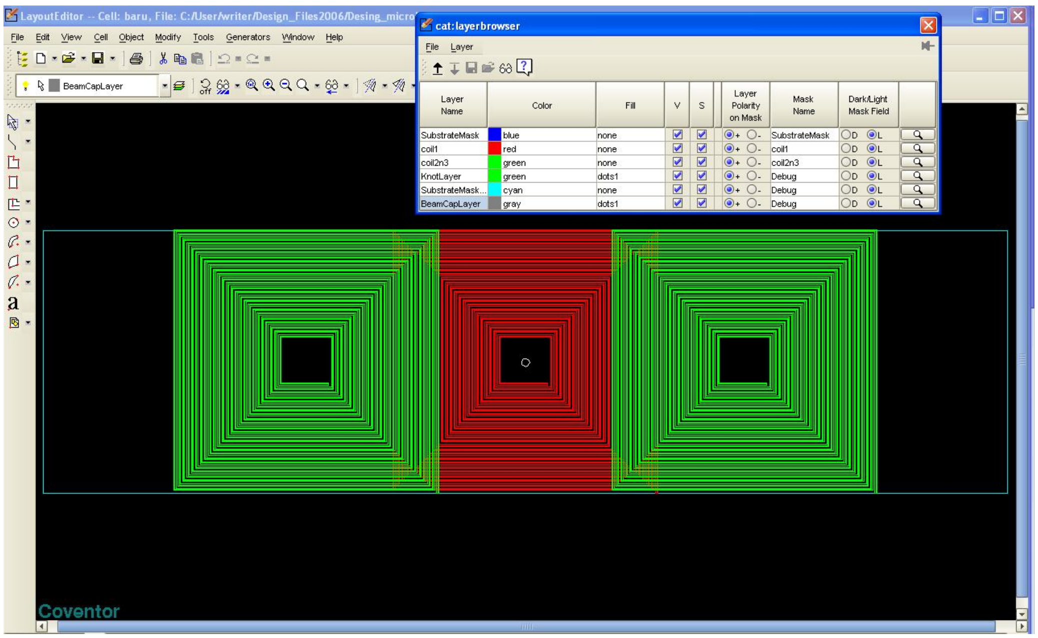


Figure 28 : 2D layout in Coventorware

As shown in the Figure 28, there are 3 coils. The red coil represents coil1 while the green coils represent coil2 and coil3. The blue rectangular represents the rigid plate 1 and rigid plate 2 which indicate the cores.

4.1.2.3 3D Model In Designer

3D model of micro fluxgate sensor is designed in the Designer application after the 2D layout is verified. This 3D model is generated based on the 2D layout created before. Figure 29 shows the 3D model that is generated in the Designer application.

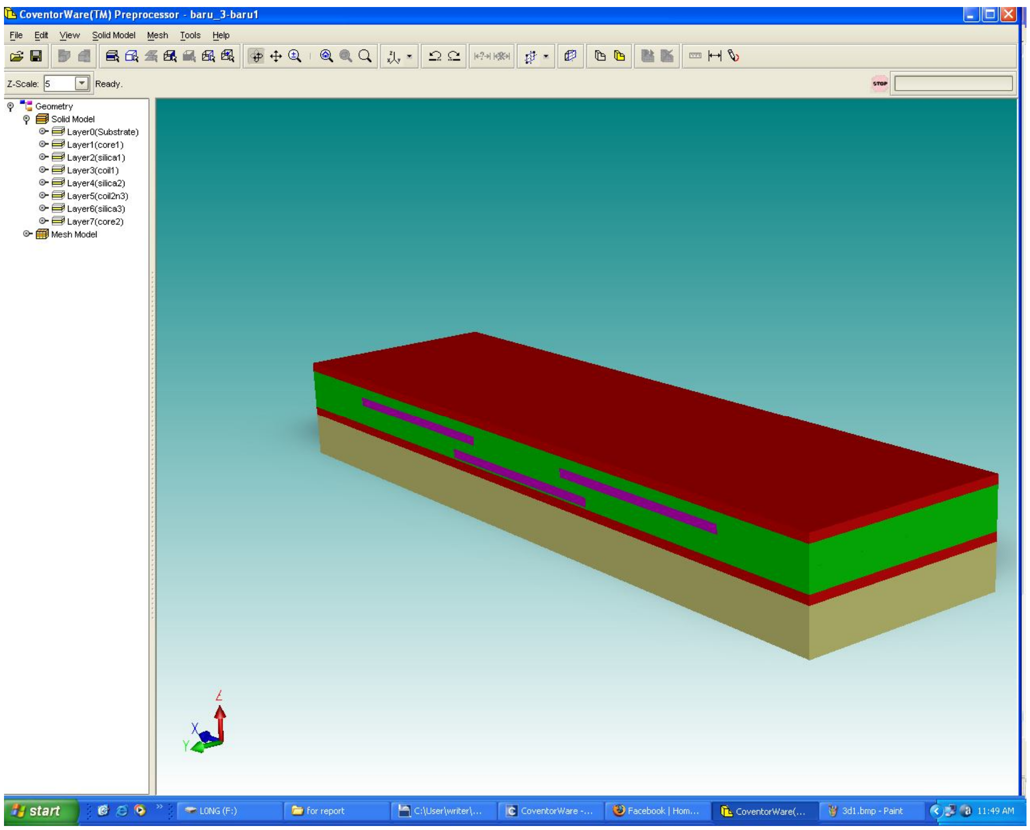


Figure 29 : 3D model of micro fluxgate sensor in Coventorware software

4.2 Discussions

Figure 30 shows the relationship between the 3D model and the schematic in the Coventorware software.

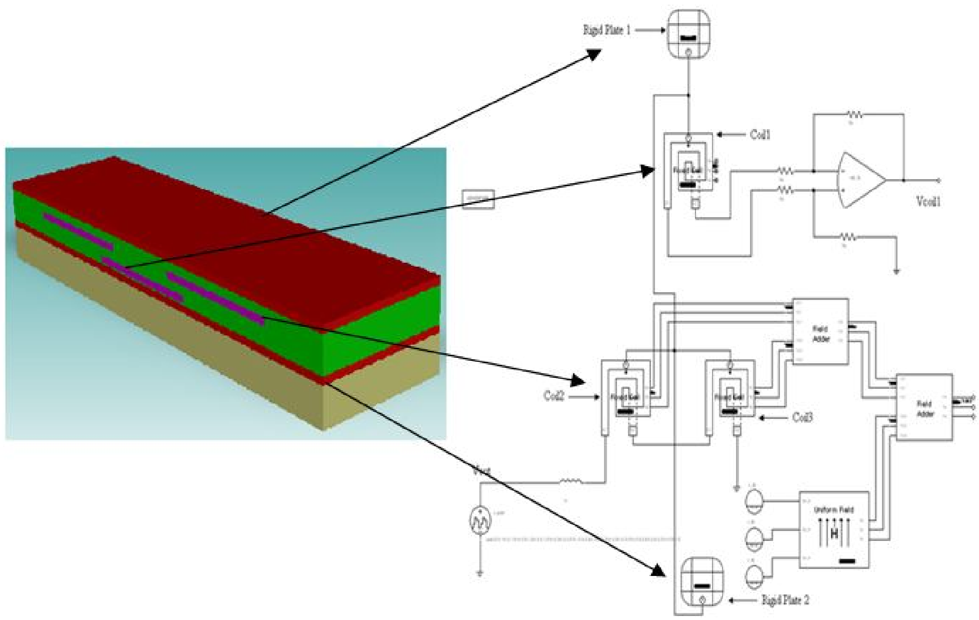


Figure 30 : Relationship between 3D model and schematic in Coventorware software

The brown layer indicates the substrate layer. The red layers represent rigid plate 1 and rigid plate 2 or the first core layer and second core layer. The green layer represents the silica layer which is acting as insulator in this sensor. The purple layer indicates the coil1, coil2 and coil3.

The schematic shows that coil2 and coil3 is supplied with voltage by the voltage source (periodic PWL). When voltage is supplied, magnetic field will be produced at both coils with same magnitude but in the different direction since the flow of the current in each coil is opposite to each other. The magnetic field will flow through the rigid plate 1 and rigid plate 2 which act as cores and make a circulation at each coil. The circulation of magnetic flow in micro fluxgate sensor 3D model is shown in Figure 31.

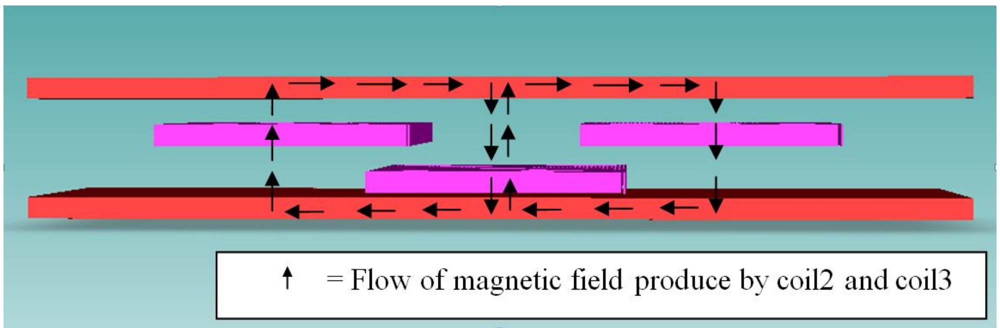


Figure 31 : Circulation of magnetic field in the micro fluxgate sensor

The function of uniform field block is to supply external magnetic field to the both coils. If external magnetic field is existed in both coils, one component of the external field will be parallel to the direction either one of coil magnetic field axes. The coil which has the same direction with the external magnetic field will have a bigger current compared to the other coil. This difference is sufficient to induce a measurable voltage in coil1 and can be measured at Vcoil1.

The following figures will show the construction of micro fluxgate sensor by each layer. They will also show how components are located in each layer. To build this sensor, firstly, a substrate layer is needed as shown in Figure 32.

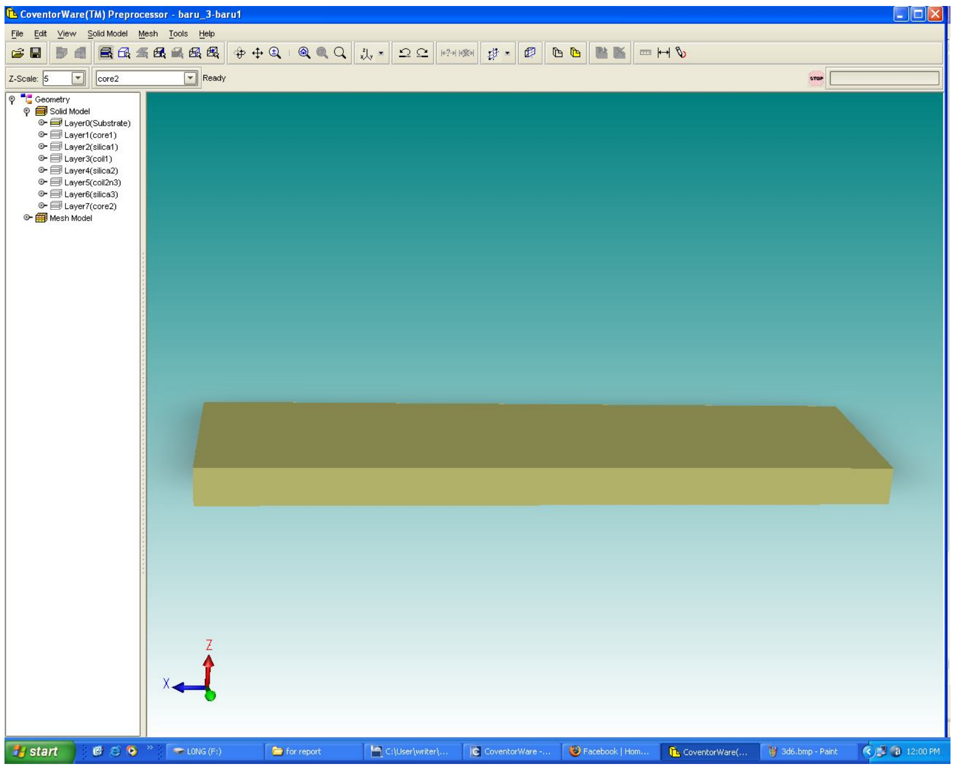


Figure 32 : Substrate layer

The substrate layer is acting as a base for the creation of this sensor. It is normal to have this kind of layer in order to design a micro-elctromechanical system (MEMs) device.

After creating the substrate layer, first core layer or rigid plate 1 is inserted above the substrate layer. It is shown in Figure 33.

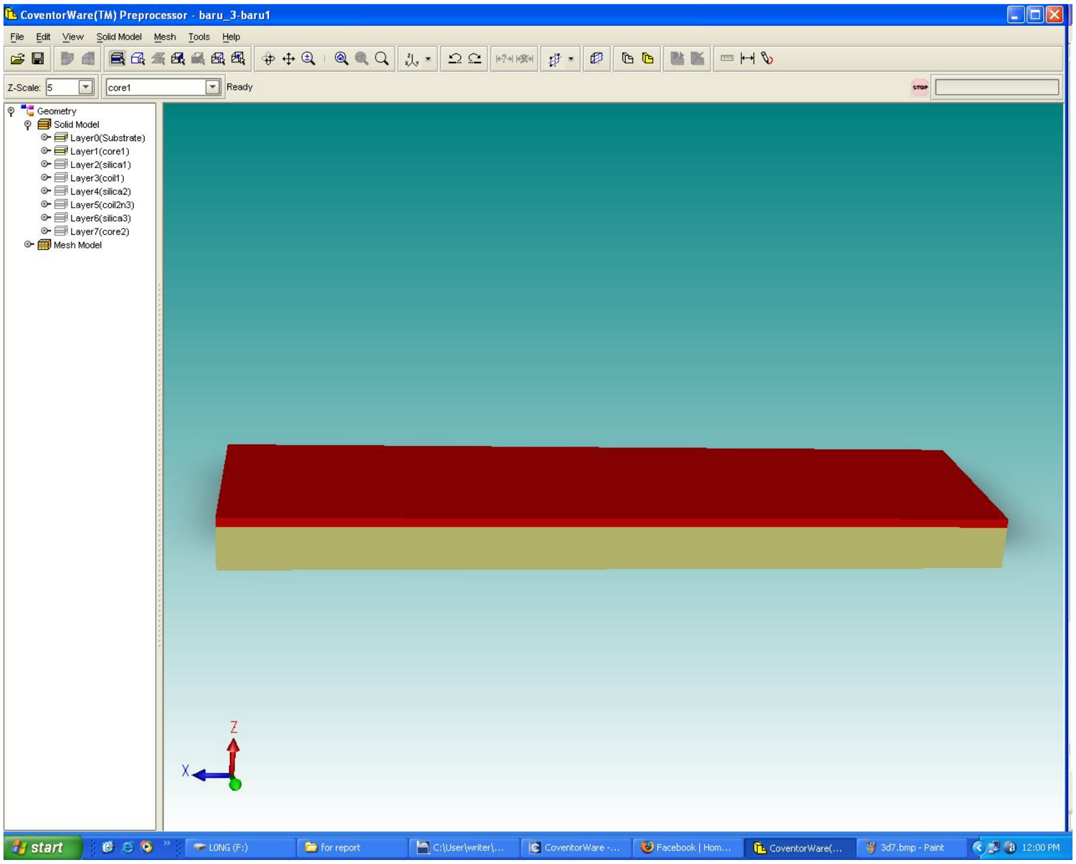


Figure 33 : First core or rigid plate 1 is inserted in the design

This layer acts as one of the core for this sensor. The magnetic field will flow through the rigid plate 1 and make a circulation at each coil1, coil2 and coil3.

Then the first silica layer is stacked on the first core layer as shown in the Figure 34.

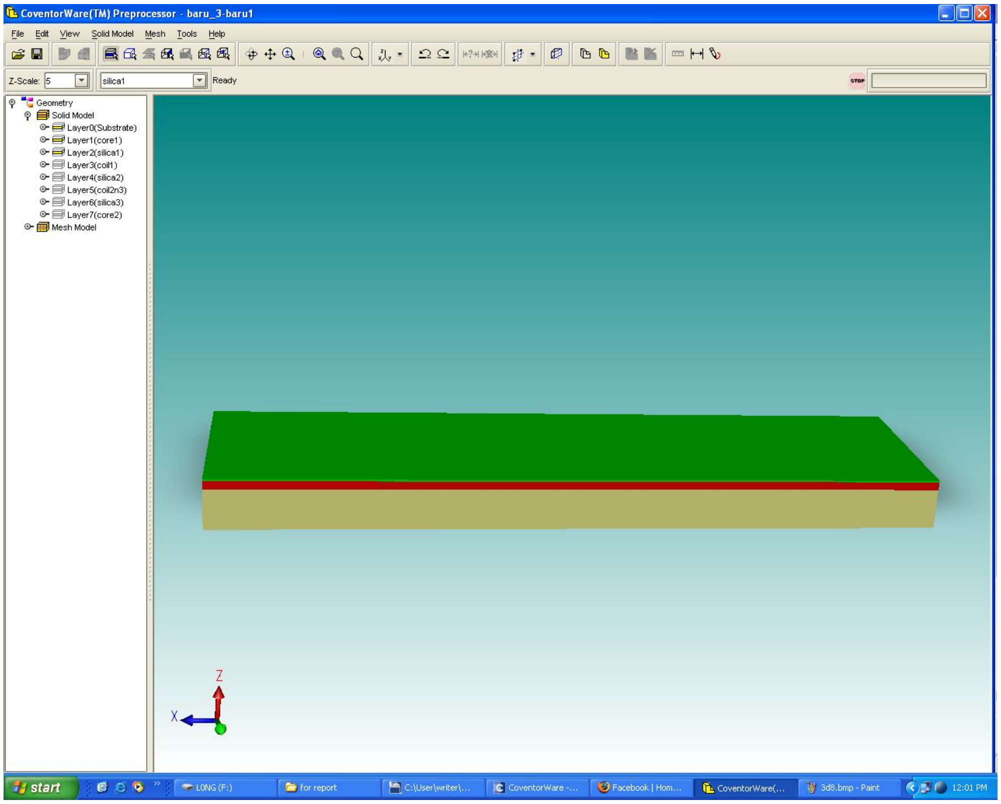


Figure 34 : First silica layer is stacked on the first core layer

This layer is inserted in order to make sure that first core layer is not directly touch the coil1 layer which will be stacked after this step since both of them is considered as conductors. If these two layers are touching each other, the sensor might not work.

Coil1 is stacked on the silica layer as shown in Figure 35.

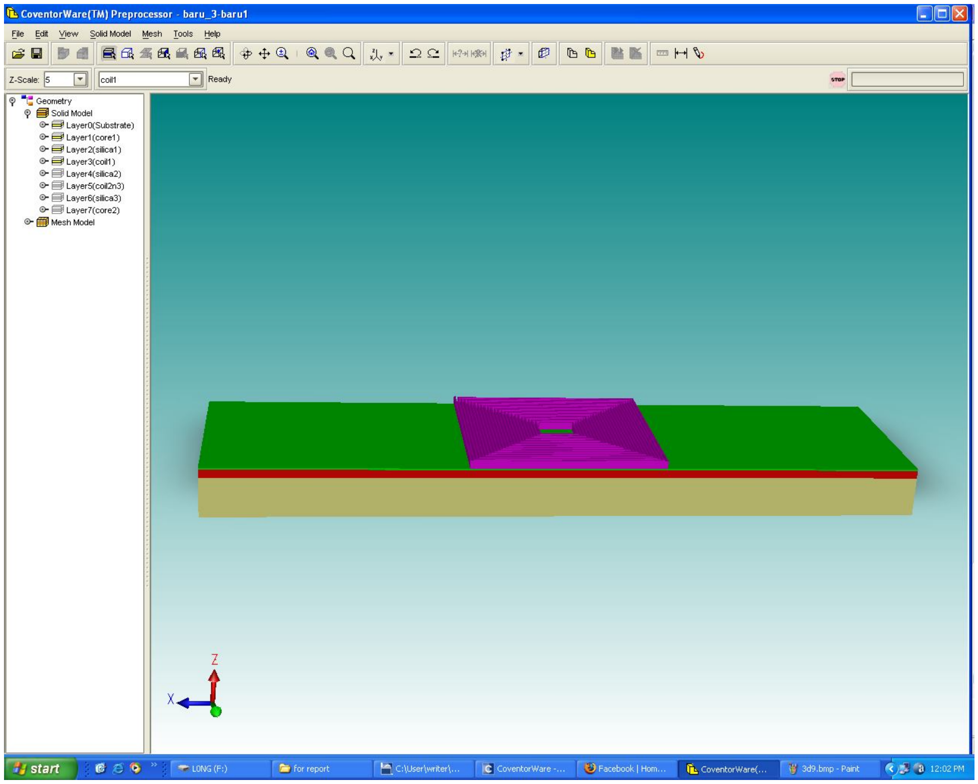


Figure 35 : Coil1 is located on the first silica layer

This layer indicates the measuring layer since coil1 is located in this layer. It will detect the difference of magnetic field magnitude occurs between coil2 and coil3 that flowing through it.

After that, the second silica layer is filled in the coil1 layer. It is shown in the Figure 36.

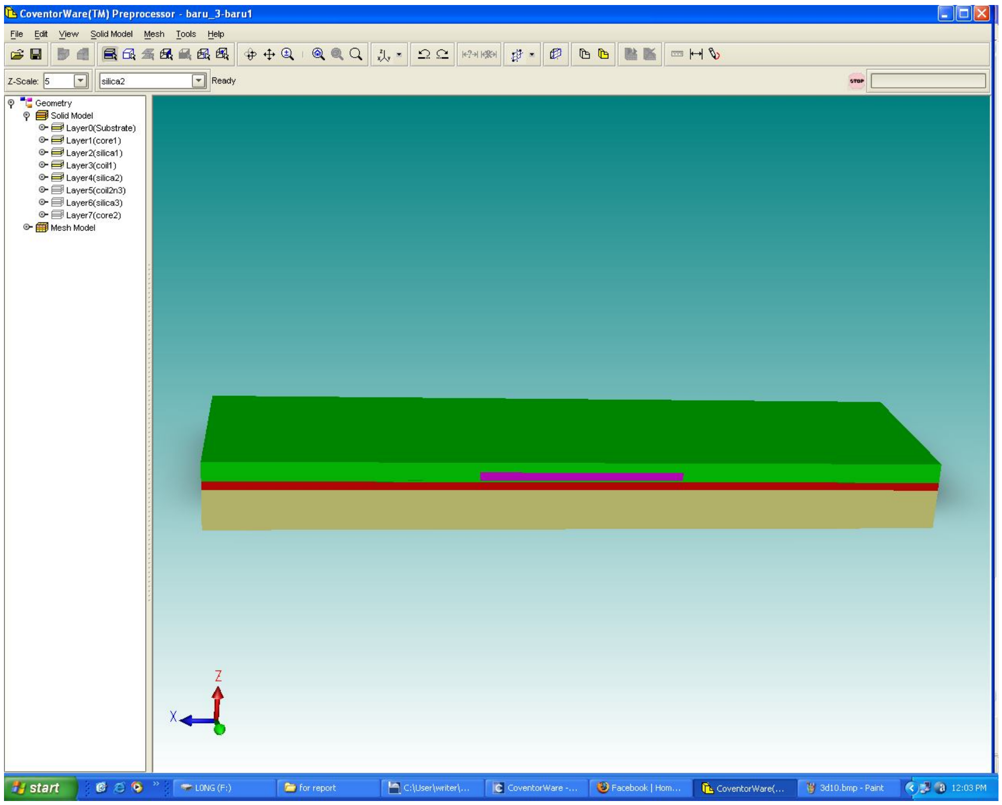


Figure 36 : Second silica layer is filled in the coil1 layer

This layer will act as insulator between coil1 layer and coil2 and coil3 layer. It can avoid those layers from directly touching each other.

Next, coil2 and coil3 is stacked on the second silica layer. Figure 37 shows how these coils are located in this layer.

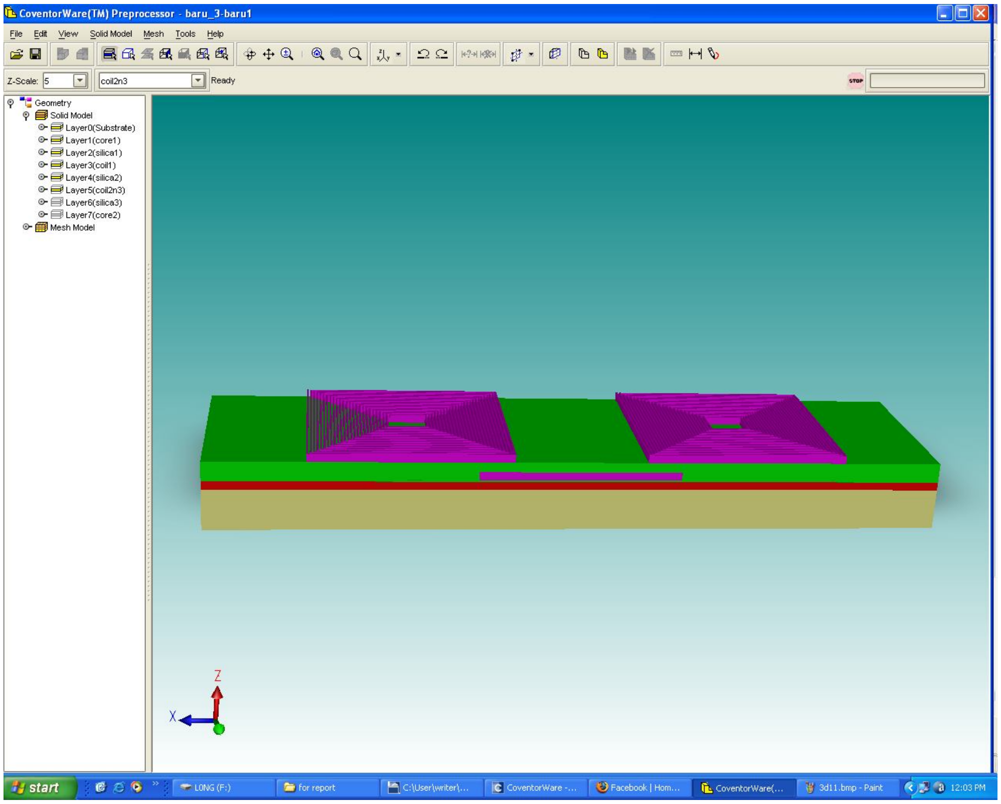


Figure 37 : Coil2 and coil3 is stacked on the second silica layer.

In this layer, magnetic field will be produced at both coil2 and coil3. These coils will act as the detecting coil whenever it is exposed to the external magnetic field. The current flows in these coils have same magnitude but different direction and these phenomena will effects the direction of magnetic field at the coil.

After stacking coil2 and coil3 layer, once again silica layer is filled in the coil2 and coil3 layer as shown on Figure 38.

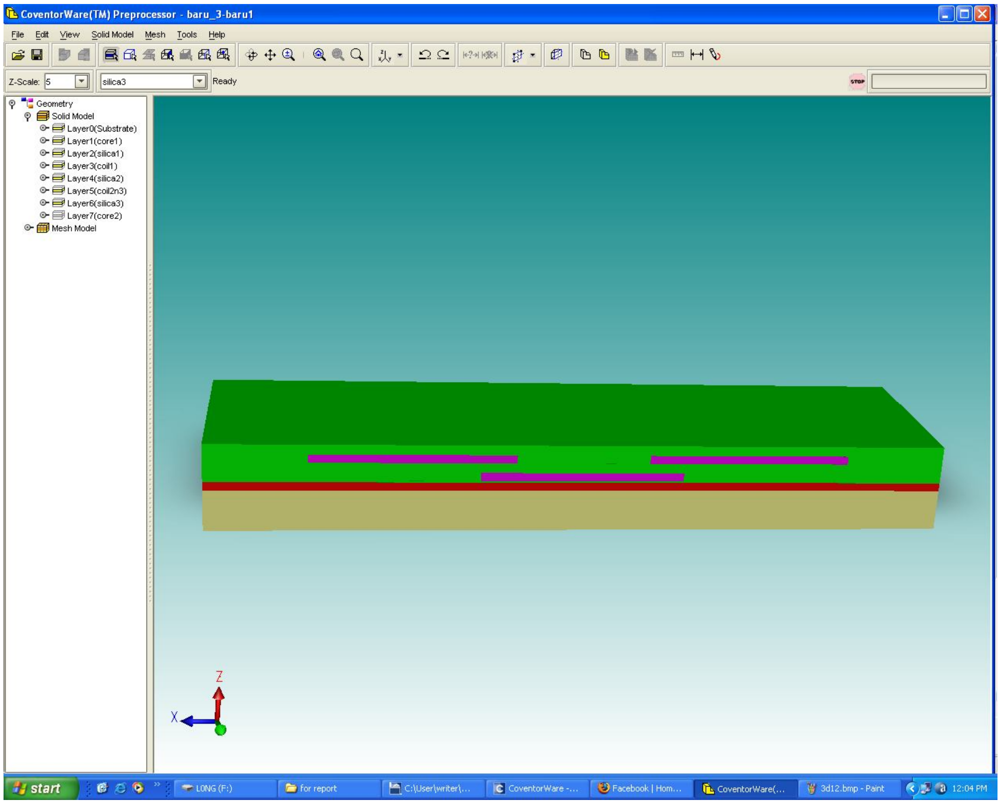


Figure 38 : Third silica layer is filled in the coil2 and coil3 layer

This purpose of this layer is same as the other silica layer that is to act as an insulator. This layer is created in order to make sure that coil2 and coil3 layer and second core layer are not directly touching each other.

The construction of second core layer is shown in Figure 39. It is stacked on the third silica layer.

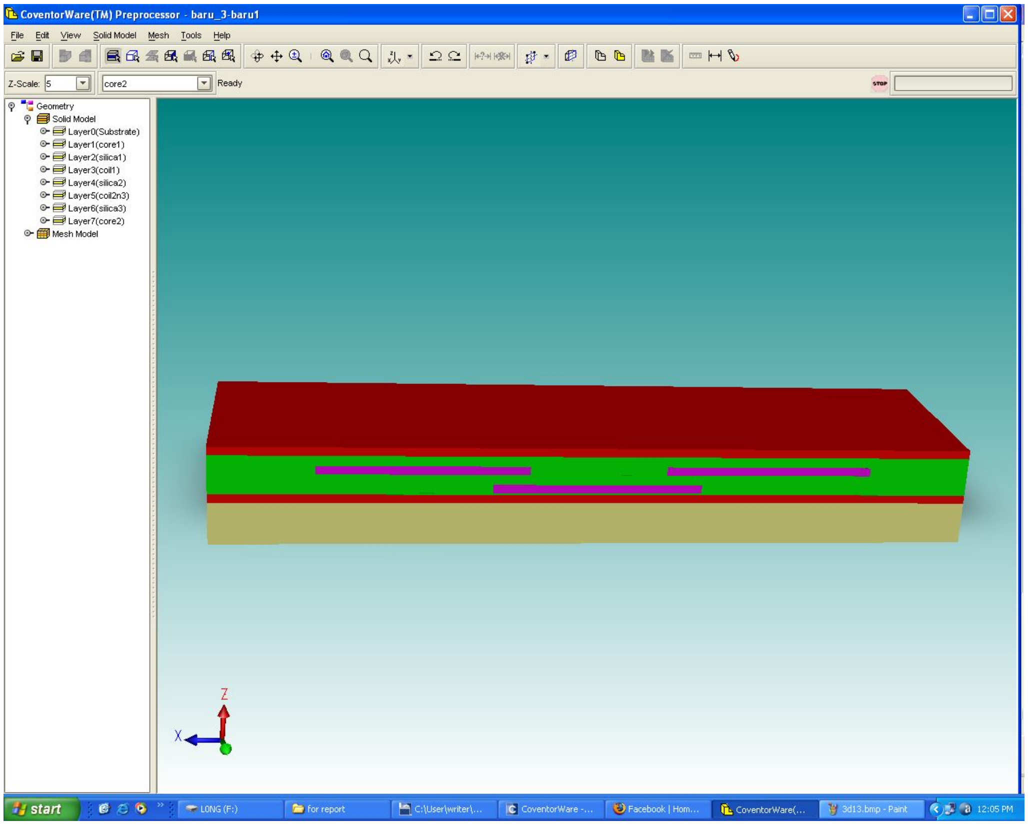


Figure 39 : Second core is stacked on the third silica layer

The second core layer or rigid plate 2 has the same function as the first core layer. The magnetic field that produced in the coil2 and coil3 will use this layer as their flow path in order to make a circulation at each coil.

Figure 40 shows the top view of the coil1, coil2 and coil3 in the Coventorware software.

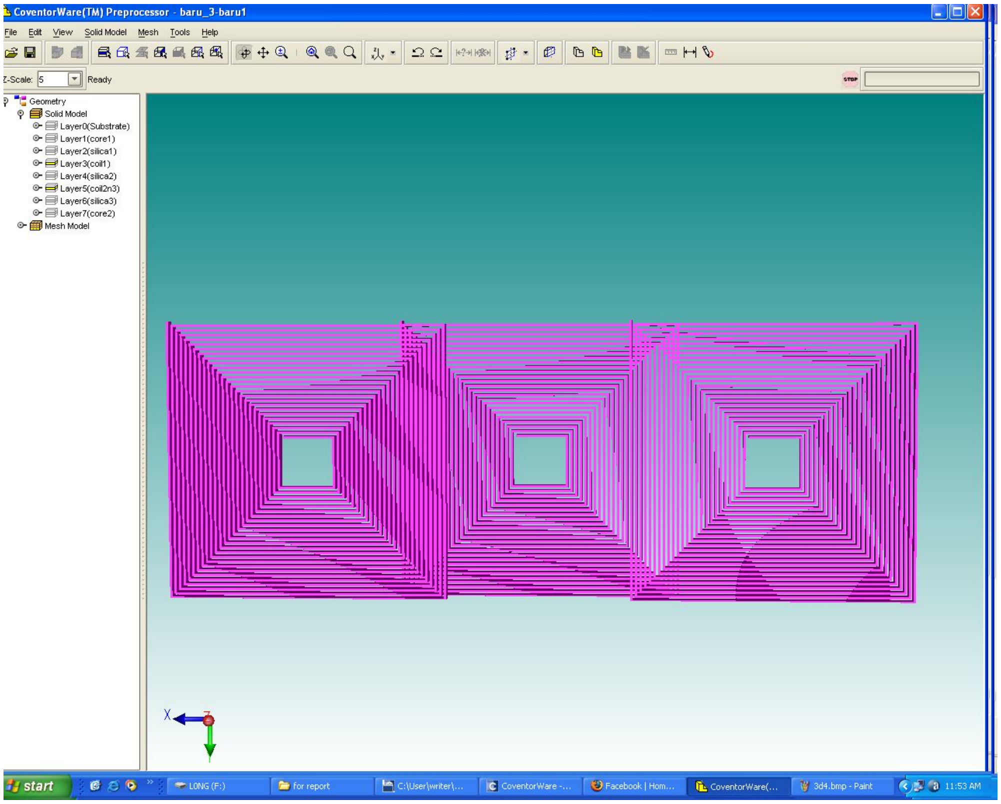


Figure 40 : 3D top view of coil1, coil2 and coil3 in Coventorware software

Coil1 is located at the origin that is at (0, 0) coordinate. For coil2 and coil3 they are separated a little bit at x-axis since their coordinate is set to (-1000u, 0) and (1000u, 0). This separation is to make sure that the magnetic field can flow smoothly through coil1 without any distraction from coil2 and coil3.

Figure 41 shows the 3D side view of coil1, coil2 and coil3 in Coventorware software.

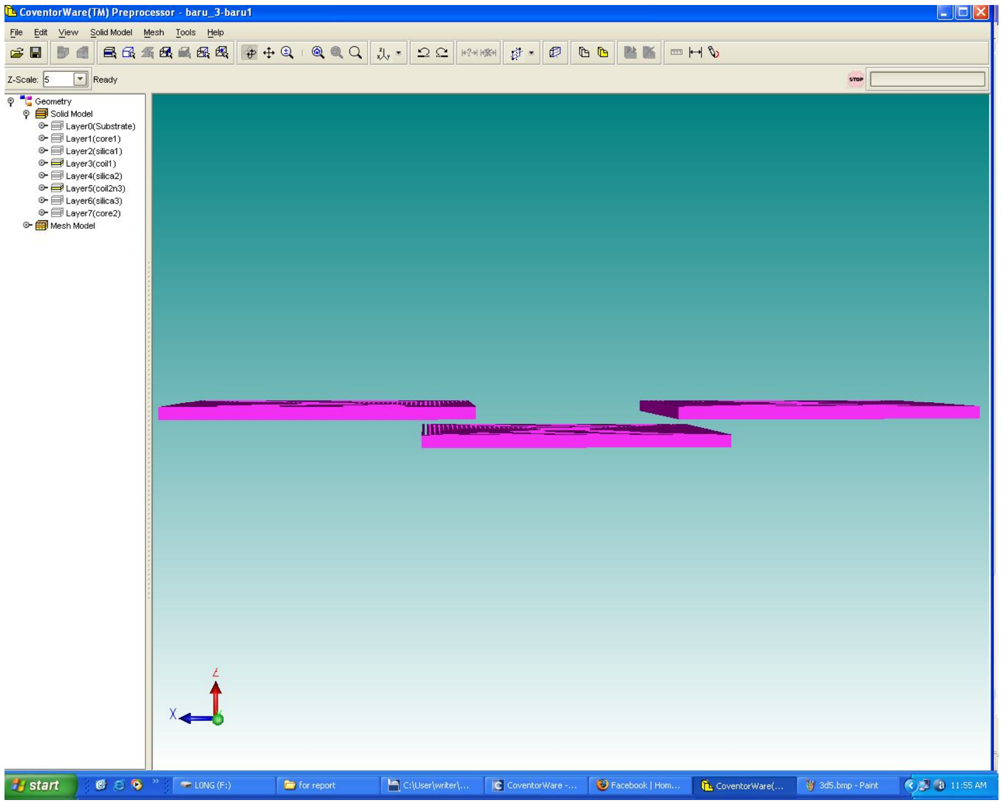


Figure 41 : 3D side view of coil1, coil2 and coil3 in Coventorware software

Coil1 layer and coil2 and coil3 layer is separated by the silica layer in the y-axis. This is because both layers are made from conductor material and if they are directly touching each other, the sensor might be malfunctioning.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Using Coventorware software, a micro fluxgate sensor can be designed using its Architect and Designer application. The schematic, 2D layout and 3D model of micro fluxgate sensor are designed using this software. This sensor should manage to detect the external magnetic field and helps in conventional and potential fields, for examples, scientific research, automation, process control of industry, mineral prospecting, medical appliance and satellite missions. However, some improvement must be implemented to this micro fluxgate sensor in the future in order to work efficiently

5.2 Recommendation

For future work, it is recommended that:

1. Fabricate the micro fluxgate sensor.
2. Analyze the fabricated micro fluxgate sensor in the real experimental condition.

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