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Non-Invasive Breast Cancer Assessment Using Magnetic Induction Spectroscopy Technique

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Abstract: Breast cancer has become one of the main concern for all human being especially women. Most breast cancer happen in women because women have denser breast tissues than men and breast cells of women are always exposed to changes in hormones, including oestrogen, which increase the risk for women to get breast cancer. The common breast cancer imaging modalities have their own limitations which could be one of the reason for increasing number of breast cancer reported beside unawareness for the disease from the patients themselves. Therefore, early detection and treatment which involve non-invasive technique is more encouraging for its lesser physical and mental harm to patients. This paper describes single channel magnetic induction technique as an alternative method for breast cancer assessment. The simulation was done to investigate the most feasible shape of sensor coil and best range of frequency value to detect breast cancer. The study has found that the circular coil performs better than square coil and the applied frequency range must be high for detecting the conductivity property distribution of breast tissues. The study has proven that magnetic induction spectroscopy technique can be used for breast cancer assessment.

Keywords: breast cancer, magnetic induction spectroscopy, Comsol Multiphysics

1. Introduction

Breast malignancy is one of the most common cancer worldwide together with lung cancer and prostate cancer. Breast cancer is resulted from abnormal proliferation of a specific group of cells that originate from the breast area of the human body [1]. Each year, approximate 5,000 Malaysian women are diagnosed with breast cancer. One out of nineteen women in Malaysia is at risk [2]. According to breast cancer survival statistics 2015, more than 90% of ladies diagnosed with breast malignancy at the earliest stage survive their illness for no less than 5 years compare with around 15% for ladies diagnosed with the final phase of breast malignancy [3]. This study had shown that if breast lesions able to be detected in the early stage, it can help to increase the cure rates of the disease.

Traditional breast cancer imaging modalities include mammography, breast ultrasound and magnetic resonance imaging (MRI) have some shortcomings when they come to sensitivity and specificity [4]. These imaging modalities involve breast contact during diagnosis which cause discomfort and inconvenience to patients. Patients are exposed to a small amount of ionizing radiation as mammography uses x-rays to produce images of the breast [4]. For ultrasound, the allergic reaction may occur due to the gel applied to patients' skin. MRI uses high magnitude of magnetic field which is not suitable for patients with pacemaker or ferromagnetic implants [4]. Therefore, a technique which is safe, robust, low cost, non-invasive, ionizing radiation free and causes lesser physical harms to patients is needed to back up the previous scan technologies. Consequently, magnetic induction spectroscopy (MIS) technique is proposed as the alternative to the current technology. The successful of this MIS technique provides opportunity for Magnetic Induction Tomography (MIT) imaging in the future.

In this research, MIS system is modelling and simulating by using COMSOL Multiphysics software to detect breast cancer. Phase shift measurement is utilised to distinguish between normal breast tissues and breast tumour. This paper is organized by firstly presenting an overview of breast cancer, followed by magnetic induction spectroscopy, methodology, result and discussion and finally the conclusion of the study.

2. An Overview of Breast Cancer

The breasts are present in both sexes but women have denser breast tissue than men and breast covers over the pectoral muscle of the chest. Female breast is mostly comprised of lobules which are the glands that produce milk, ducts that convey the milk to the nipple, connective and fatty tissues, lymphatic and blood vessels [5][6].

Breast cancer may happen when breast's cells develop and divide without ordinary control. As a result, a lump or mass called a tumour will be formed. There are two types of tumour which are malignant (cancerous) and benign (not cancerous) [1]. The cancerous cells are most likely develop in milk-producing glands and ducts. Breast cancer can be categorised into two board categories which are invasive and non-invasive [6]. Invasive breast cancer is the harmful cells that get through ordinary breast tissues boundaries and spread to surrounding tissue

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or other parts of the human body through the circulation system and lymph vessels [7]. Non-invasive breast cancer is the destructive cells that stay in a specific region of the breast, without spreading to surrounding lobules, ducts or tissues [1]. About 80% of all breast cancers reported are invasive ductal carcinomas. Breast malignancy is also categorised based on the region in the breast the disease began. Lobular cancers are cancer cells that developing from lobes while ductal cancers are cancer cells that developing from ducts. Some less common cancer types are Paget disease of the nipple, phyllodes tumour, angiosarcoma, tubular carcinoma, medullary carcinoma, inflammatory cancers and mucous carcinoma [1]. According to the Union International Cancer Control (UICC), the stages of breast cancer can be explained mainly based on tumour size [8].

The common breast cancer symptoms and signs include change in breast's size and shape, change in the appearance of one or both nipples, nodes or lumps felt on the breast, fluid coming from the nipple other than breast milk, pain on any area of the breast and redness, swelling, or other noticeable contrasts in one or both breasts. Breast cancer can be due to many risk factors include age, female sex, family history, obesity, early puberty, ionizing radiation, hormone replacement therapy during menopause, late menopause and no child or late first pregnancy [9]. Other expected factors are smoking, drinking alcohol, lack of physical exercise, consumption of contraceptive pills, abortion and no breastfeeding.

3. Current Breast Cancer Diagnosing Techniques

3.1 Mammography

Mammography is a specific technique that utilises low dose x-rays to examine the breast for the early detection of breast lesion [10]. During mammography, patient's breast will be positioned in the mammography unit and compressed by 2 plates of the mammography machine. Compression of the breast is necessary to spread the breast tissues apart so that small abnormalities are less likely to be covered up by overlying breast tissues. This permits the utilization of a lower x-ray dose since a thinner layer of breast tissues is being imaged [11]. Mammography involves exposing patient's breast to a small dose of ionizing radiation to produce pictures of the inner structure of the breast. Therefore, mammography only recommended for women who above 45 years old. Three recent advances in mammography include computer-aided detection, digital mammography and breast tomosynthesis.

With the help of mammography, the number of early-stage breast cancer cases is increased. This will prompt to a decrease in advanced breast cancer rates and thus reduce the breast cancer mortality rate [12]. One of the limitations of mammography is that patients are exposed to a small amount of ionizing radiation as mammography uses x-rays to produce images of the breast. Besides that, mammography involves breast compression which may cause physical discomfort to the patient [12].

3.2 Breast Ultrasound

Breast ultrasound forms images of the internal structures of the breast by reflection of megahertz frequency sound waves. The most broadly utilised method in breast ultrasound is brightness mode (B-mode) grey scale [13]. During ultrasound examination, the ultrasound gel is applied directly to the patient's skin and a small transducer is used. Ultrasound depends on the transmission of sound waves in a direction that is perpendicular to the surface of the transducer. The different tissues in the breast have diverse acoustic properties. The transducer detects the echoes from these tissues and utilized the echoes to reconstruct a picture [14]. Various tissue structures are shown in varying shades of grey depend on the amount of the returning echoes.

Breast ultrasound is safe as there is no radiation exposure to the patient. Ultrasound is widely available, non-invasive, easy-to-use, painless and less expensive than other imaging techniques. Besides that, ultrasound imaging can help detect lesions in women of any age with dense breasts [15]. This is because mammography is less sensitive for tumour identification in the dense breast and women with dense breasts tend to have high risk of developing breast cancer. However, ultrasound does not replace the role of annual mammography. Many cancers are not obvious on ultrasound due to numerous calcifications seen on mammography cannot appear on ultrasound.

3.3 Magnetic Resonance Imaging (MRI)

MRI uses radio emissions from nuclear spins to generate image [4]. A powerful magnetic field and radio waves are used to produce detailed images of the structures within the breast. During MRI examination, radio waves adjust the arrangement of hydrogen molecules that normally exist inside the body while the patient is in the scanner without bringing about any substance changes in the body tissues. The hydrogen particles discharge energy that varies depend on the type of body tissues. Magnetic field is produced when an electric current passing through wire coil of MRI unit. Other coils which located in the machine transmit and detect radio waves, generating signals that are received by the coils [16]. Then, a computer processes the signals and produces a series of images, each of which demonstrates a thin slice of the body.

MRI does not involve exposure to ionizing radiation like x-ray examination. MRI plays an important role in detecting and staging breast cancer when other imaging tools fail to provide adequate information. Besides that, MRI is useful in evaluating women at high risk for breast cancer. However, MRI is not suitable for patients who have cardiac pacemakers or internal ferromagnetic objects as powerful magnetic field is used in MRI [15].

4. Magnetic Induction Spectroscopy

Spectroscopy techniques are widely applied in several fields such as biomedical, agriculture, food science, industry and others [17][18][19]. The various types of spectroscopy techniques include Raman spectroscopy (RS), near infrared spectroscopy (NIRS), mid-infrared spectroscopy (MIRS), bio-impedance spectroscopy (BIS) and magnetic induction spectroscopy (MIS)[19][20]. MIS technique is better than other spectroscopy techniques because it can eliminate the several difficulties arising from the electrode-sample interface. This is because MIS applies entirely contactless inductive coupling between the sample and sensors [21].

Magnetic induction spectroscopy (MIS) technique is a totally contactless and electrodeless framework which applies the phenomena of magnetic induction concept in its measurement. The frequency used for biological tissue is within the range of beta-dispersion region which from 10 kHz to 10 MHz [22][23]. This is because alpha-dispersion region which from 0.1 kHz to 100 kHz is depend on outer cell membranes impedance while gamma-range which occurs around 20 GHz is mainly related to the water dispersion in the tissues [24]. Because of the conductivity of biological tissue is low, the measurement is fully based on the phase shift approach which the phase delay of the signal when flow across the biological tissue is detected [21]. MIS provides contactless measurement of the passive electrical properties (PEPs) which are permeability (μ), conductivity (σ) and permittivity (Ɛ) [25][22]. The conductivity of breast tissue is the main concern in this study as conductivity is a dominant parameter in biological tissues. Hence, MIS technique is useful for breast cancer detection in the research field.

From Figure 1, it shows the basic working principle of MIS technique. In MIS system, an object is well positioned in the middle of the excitation coil and receiving coil. Alternative current is applied to excitation coil and generates an oscillating magnetic field which also known as primary field. An eddy current is induced in the object by primary magnetic field. Then, eddy current generates its own secondary field or magnetic perturbation field which will be sensed by receiver coils. The collected signal from the receiving coil which contains required information is then sent to phase detector circuit and amplifier. The generated phase shift spectroscopy is used to determine the condition and progress of measured tissues.

The advantages of using MIS technique for breast cancer detection are it provides a faster, non-complicated, low cost diagnostic and a system which is easy to design and implement. MIS technique involves contactless and electrode-less measurement scheme which does not need to apply galvanic coupling between device and object during measurement [26]. Thus, the practical difficulties arisen from electrode-skin interface can be avoided. MIS technique is safe as it does not involve exposure to ionizing radiation [22]. On top of that, the necessities for the electrical safety and protection are easier to achieve and patients will not get infected easily due to the non-skin contact method.

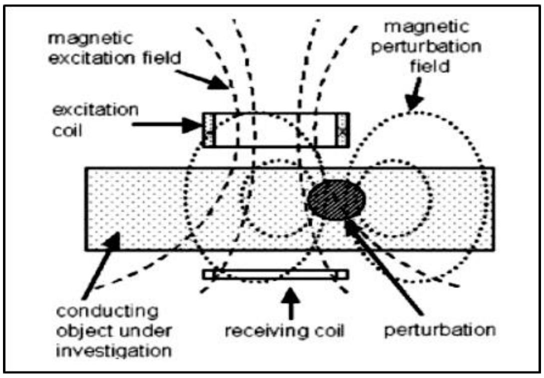

Figure 1 Principle of MIS technique [26].

5. Methodology

In this study, Comsol Multiphysics software is used for modelling and simulating single channel MIS system to determine the correct location and size of any cancerous lesions which are deep inside the breast tissues. Comsol Multiphysics software is a universally useful software platform, used for modelling and simulating physics-based problems based on advanced numerical methods [27]. A single channel MIS system mainly consists of one transmitter coil and one receiver coil. The breast sample is placed between transmitter coil and receiver coil. Transmitter coil which also known as excitation coil will produce primary magnetic field with the applied current of 1 Ampere and receiver coil of 0 Ampere. Magnetic field will propagate across the medium sample of breast which contains tumour in it. The changing of conductivity greatly affected by frequency applied across it which will influence the relative magnetic permeability in the output of result. The output is caused by the perturbation because of the radiation force coupled with the interaction between radiated energy and tissue as a function of wavelength in the sample at test [28].

Figure 2 and 3 show 2 different designs of MIS system that are designed by using Comsol Multiphysics software. Figure 2 is the MIS system with circular shape of transmitter and receiver coils while Figure 3 is the MIS system with square shape of transmitter and receiver coils. The breast sample with tumour is placed between the transmitter and receiver coils. The air medium is used as the insulator material for the constant environment value. Due to the frequencies from β dispersion region are suitable to be applied on biological tissues, the range of working frequency is from 1MHz to 10 MHz [29]. The simulation of the single channel MIS system is done for two different frequencies which are 1 MHz and 10 MHz to compare between them and choose the best frequency which able to detect any tumour in the breast tissue. Besides, MIS systems with different shapes and number of turns of transmitter and receiver coils are simulated to identify suitable transmitter-receiver pair for optimum signal measurement. The diameter of breast is 12cm which is the average diameter of female breast [30]. Table 1 shows the list of parameters involved in the project while Table 2 shows the permittivity and conductivity for normal breast and tumour tissue at different frequencies [31]. After designing the model for MIS system, the model will be meshed by the meshing process. Meshing process is applied to mesh the partition of the geometry model into small units of simple shapes. The finer the mesh applied on the model, the higher the accuracy to evaluate the simulation result.

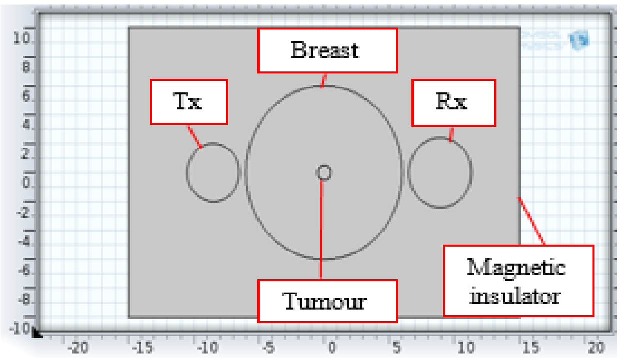

Figure 2: First design

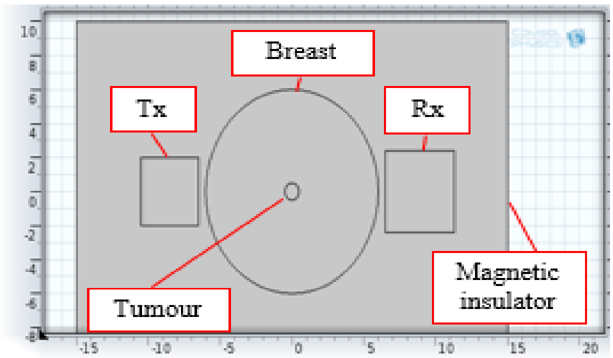

Figure 3: Second design

Table 1 List of parameter.

No	Parameters	Values
1.	Current applied at sensor coils	Excitation coil: 1 A Detecting coil: 0 A
3.	Coil type	Linear
4.	Material of coils	Copper
5.	Diameter/width of sensor coils	Excitation coil: 0.040 m Detecting coil: 0.048 m
6.	Number of turns of coils	Excitation coil: 5 turns Detecting coil: 12 turns
7.	Radius of breast	0.060 m
8.	Magnetic insulator	0.3 m x 0.2 m
9.	Diameter/Size of tumours	0.010 m and 0.020 m
10	Position of tumours	Left side, center, right side
11.	Frequencies applied	1 MHz and 10 MHz

Table 2 Dielectric properties of breast and tumour at different frequencies [30][31].

Frequency	Breast		Tumour	
	Conductivity	Permittivity	Conductivity	Permittivity
1 MHz	3.0 mS/cm	25	6.3 mS/cm	1100
10 MHz	3.2 mS/cm	12	8.2 mS/cm	300

6. Result and Discussion

6.1 Fixed Frequency with Different Shape of Transmitter and Receiver Coils

MIS technique with both circular and square shape sensor coils are simulated at 10 MHz by using Comsol Multiphysics software. Figure 4 and 5 show the magnetic field intensities of circular and square shape sensor coils respectively. The magnetic field intensity of circular shape sensor coils is higher compared to square shape sensor coils.

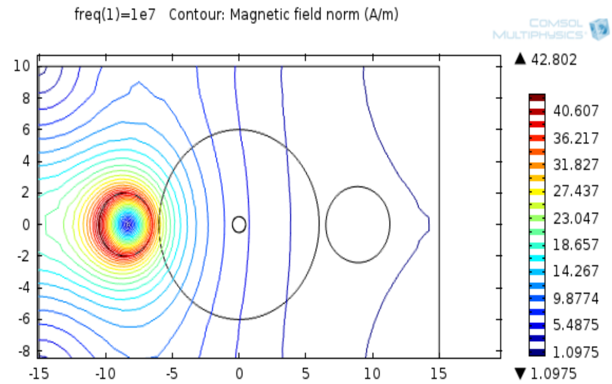

Figure 4 Circular shape of transmitter and receiver coils at 10MHz.

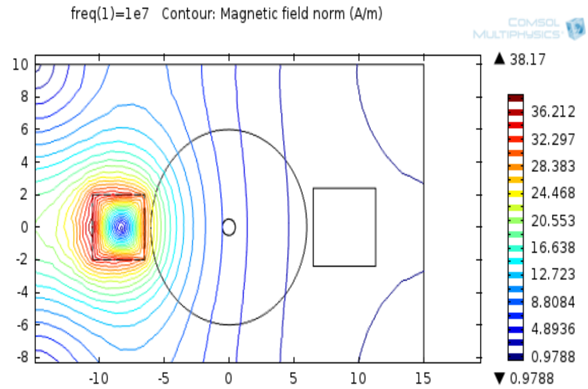

Figure 5 Square shape of transmitter and receiver coils at 10MHz.

The highest attainable magnetic field intensity for circular shape sensor coils is 42.802 A/m while the highest attainable magnetic field intensity for square shape sensor coils is 38.17 A/m. The average magnetic field intensity at circular shape transmitter coil is 26.66 A/m which is higher than square shape transmitter coil with only 23.30 A/m. Circular shape sensor coils perform better than square shape sensor coils because circular shape transmitter coil able to produce more magnetic flux across the sample to generate higher eddy current which result in higher secondary magnetic field received at receiver coil.

6.2 Circular Shape Sensor Coils with Different Frequencies

By compare the eddy current density graphs in Figure 6, 7, 8 and 9 below, the results show that higher eddy current density is induced in the sample when frequency of 10MHz is applied to the MIS system. The maximum eddy current density induced at frequency of 10MHz is 28 A/m^2 while the maximum eddy current density induced at frequency of 1MHz is only 2.6 A/m^2. Therefore, the induced eddy current density increase when the applied frequency increase. This is because higher frequency applied on the transmitter coil able to generate a stronger primary magnetic field across the sample to induce higher eddy current and stronger secondary magnetic field will be received at receiver coil. Based on the current density graph, the diameter of breast is 12cm which located from -6cm to 6cm on the x-axis while the diameter of the tumour is 1cm which located at the center of the breast. The conductivity of breast and tumour tissues are different. Therefore, an eddy current was induced from -6 cm to 6 cm (breast sample) and another eddy current was induced at the tumour in the centre of the breast.

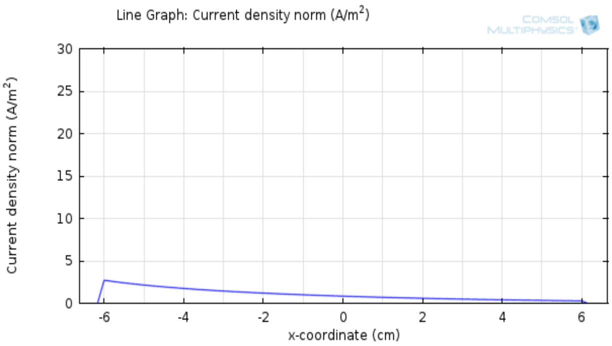

Figure 6 Eddy current density graph for sample without tumour at 1MHz.

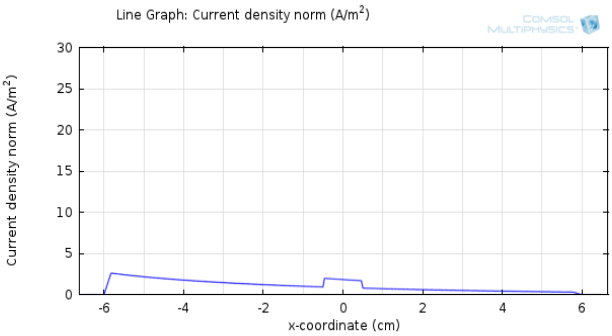

Figure 7 Eddy current density graph for sample with 1cm tumour at 1MHz.

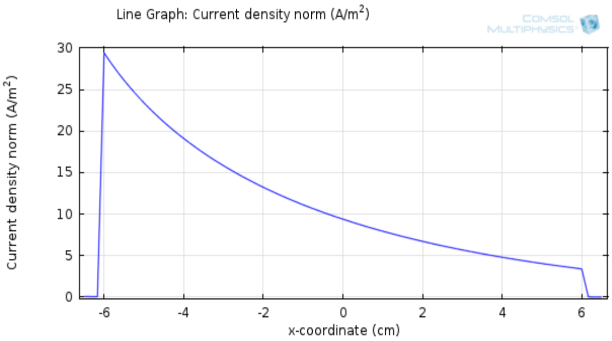

Figure 8 Eddy current density graph for sample without tumour at 10MHz.

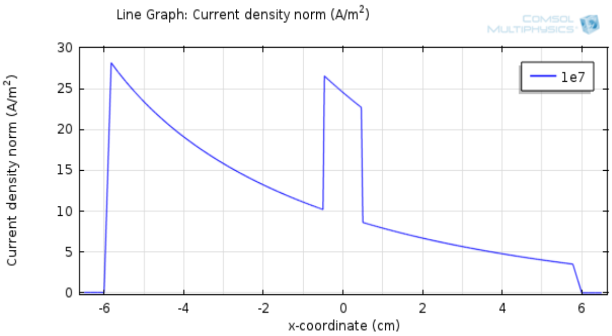

Figure 9 Eddy current density graph for sample with 1cm tumour at 10MHz.

6.3 Tumour with Diameter of 1 cm at Different Locations

Figure 10 shows that the eddy current density of 1 cm tumour located at the left side of breast is approximate 45 A/m^2 which double the eddy current density of 1 cm tumour located at the center of breast. The eddy current density is decreased to 16 A/m^2 for 1 cm tumour located at the right side of breast as shown in Figure 11. This is because as the tumour is located nearer to excitation coil, higher magnetic field strength is exerted on the tumour and result in higher induced current density. The magnetic field strength becomes weaker as the tumour is far away from excitation coil.

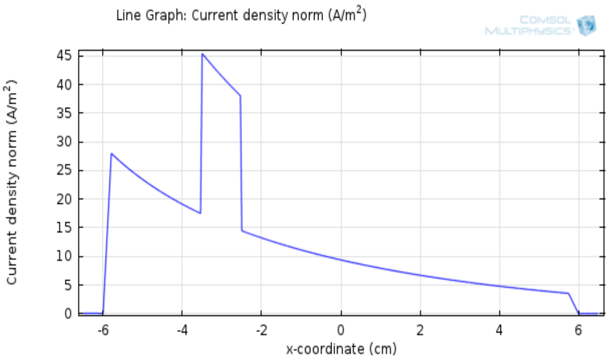

Figure 10 Eddy current density graph for 1 cm tumour at the left side of breast.

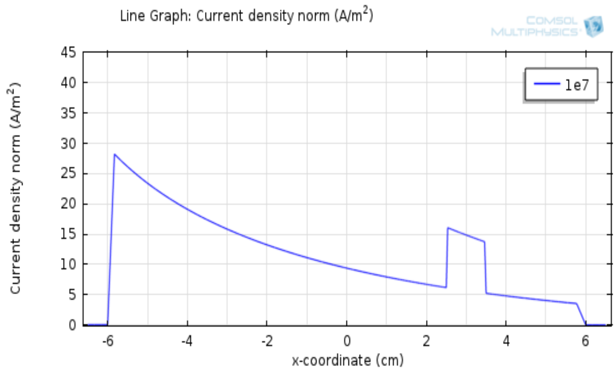

Figure 11 Eddy current density graph for 1 cm tumour at the right side of breast.

6.4 Tumour with Diameter of 1 cm and 2 cm

Figure 12 and 13 show the current density graph for tumour with diameter 1cm and 2 cm respectively. Both tumours are located at the centre of the breast. Based on the graph, the induced eddy current density at 2cm tumour is 28.4 A/m^2 which is slightly higher than the induced eddy current density at 1cm tunour, 26.5 A/m^2. This is because there was higher magnitude of primary magnetic field flow across larger size of tumour compare to smaller tumour. As a result, the eddy current density at larger tumour is higher than smaller tumour. This is also in line with the study done by C. A. Gonzalez et al [32].

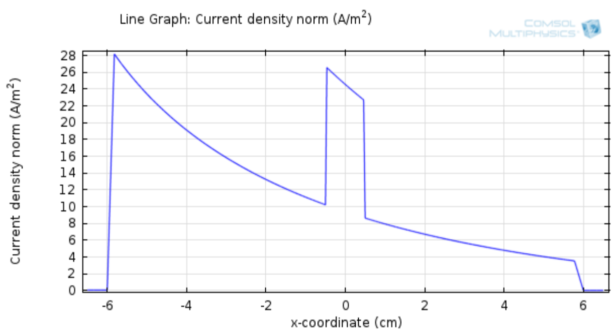

Figure 12 Eddy current density graph for 1 cm tumour at the centre of breast.

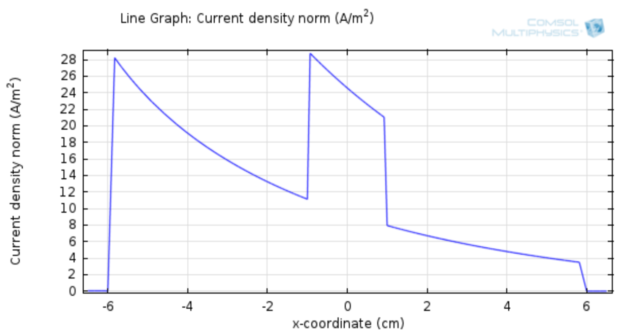

Figure 13 Eddy current density graph for 2 cm tumour at the centre of breast.

This study has proven that MIS technique has the capability to detect the location of the tumor inside the breast, either in left side, center or right side of the breast. MIS technique also has the capability to detect breast cancer at early stage as the size of tumour at stage 1 breast cancer is not more than 2cm [8].

7. Conclusion

As a conclusion, magnetic induction spectroscopy (MIS) technique is proved can be used to measure biological tissue non-invasively. Higher frequency range is required to induce stronger secondary magnetic field. Circular shape sensor coils perform better than square shape sensor coils as it generates stronger primary magnetic field. The potential of MIS setup to determine the location of tumour makes it an excellent non-invasive technique for breast cancer assessment. The successful of this MIS technique provides opportunity for Magnetic Induction Tomography (MIT) imaging in the future.

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