SAR Performance of Rectangular Microstrip Antenna for Breast Cancer Hyperthermia Treatment with Different Period of Treatment Procedure

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Abstract. Cancer treatment using hyperthermia techniques recently become the interest among researchers in investigating and improving certain deficiencies of the treatment since this treatment has the potential to denaturate cancer into necrotic tissue. Hyperthermia uses high heat from 41°C to 45°C at a certain period of time. It is difficult to control the focus position distance of heat distribution on the treated tissue. Therefore, this paper presents the rectangular microstrip as hyperthermia applicator, which deliver the heat on the targeted treated breast cancer tissue with different period of time in order to obtain sufficient heat or SAR distribution. Sim4LifeLight software simulator is used to design, simulate and generate the specific absorption rate (SAR) distribution on the treated tissue. Three frequencies of 434MHz, 915MHz and 2450MHz are used to be compared. Based on the results, 2450MHz shows better performance than the other two frequencies. However, there is a certain limitation, such as skin burn and unwanted hotspots, that need to be further improved. The cancer is sufficiently heating at different operating frequencies at different periods of procedures.

1. Introduction
Statistics from International Agency for Research on Cancer (IARC) in December 2020 shows that breast cancer is the highest occurs cancer case throughout the world [1]. From World Health Organization (WHO) web page, it is reported a large number of breast cancer patients detected, where 1 out of 5 people globally will develop cancer, and it will increase further every year [1][2]. Breast cancer is the most prevalent occurring cancer among women [3]. According to the WHO, 2 million women were diagnosed with cancer in 2018, and the numbers have been increased to 2.3 million in 2020 [3][4][5]. Furthermore, breast cancer caused 627,000 deaths globally in 2018, and the numbers were raised to 685,000 fatalities in 2020 [3][4][5]. The increasing numbers of women been diagnosed with breast cancer, as well as the high mortality rate among breast cancer patients, making it the biggest concern among the researcher, scientists and society in identifying various treatments for killing cancers, and one that have been discussed a lot is the hyperthermia procedure.
There are several popular conventional methods such as surgery, radiotherapy and chemotherapy, which have been used for a long time to treat breast cancer patients. Meanwhile, hyperthermia is an alternative method for breast cancer treatment. It can work alone and combine with radiotherapy and chemotherapy [6][7][8]. Hyperthermia has fewer side effects during and after the execution of the procedure on the treated tissue [9][10]. Hyperthermia uses high temperature which is around 41°C to 45°C, to heat, kill and destroy the malignant tissues [11][12]. Hyperthermia has some deficiencies that need to be improved in order to present promising treatment for cancer. Difficult to control focus position distance is one of the main disadvantages of hyperthermia, where it may introduce a wide area of unwanted hot spots, which then lead to other adverse health effects on the surrounding healthy tissue. The main aim of the hyperthermia procedure is to heat the targeted treated tissue with 5mm in order to ensure cancer areas are sufficiently heated. The treated tissues which are hit by high heat denaturation treated tissues into necrotic tissues, which later causes malignant tissue to die or obstruct its future growth [6][13]. This paper emphasizes on non-invasive hyperthermia techniques, where the applicator is placed outside of the patient body [14].

After the ethical approval has been obtained from the referred hospital, ground truth is conducted with the radiologist. Thirty-six (36) breast cancer mammogram images of patient’s data have gone the ground truth process, where it classified into three main categories, which are macrocalcification, spiculated and lobulated. The classification is made based on the shape of cancer. The most active is spiculated cancer shape which is more aggressive than other shapes. The measurement is taken from two-dimensional mammogram images position, which is based on medio-lateral oblique (MLO) and crano-caudal (CC) view. This is the standard view of mammogram images[15]. MLO is the angle view of 45° to 60° from the above position of the breast phantom [15][16]. CC is the top-down view from the above of breast phantom [15][16]. The location of the malignant tissues is divided into four quadrants, which are upper inner, upper outer, lower inner and lower outer[17]. MLO determines the location, either it is in the upper or lower part. Meanwhile, CC determines either the malignant tissue is located at the inner or outer part. The inner part is considered when it is near to chest wall, while the outer part in which it opposes the chest wall. The antenna is used to deliver heat toward the treated tissues. This is an essential element to be designed properly to ensure the heat can penetrate malignant tissues. A rectangular shape is used with different frequencies are compared and analyzed based on the resulting SAR distribution on the treated tissue. Specific absorption rate (SAR) is the measured amount of absorbed energy by biological tissues and is expressed in W/Kg or mW/g. The formula for SAR is shown in Equation 1 and Equation 2 [18].

\[
PD = \frac{\sigma}{2} |E|^2 = \rho \cdot \text{SAR} \tag{1}
\]

Electrical conductivity, \(\sigma\) expressed in (S m\(^{-1}\))
Tissue density, \(\rho\) expressed in (kg m\(^{-3}\))

\[
\text{SAR} = \frac{C \Delta T}{\Delta t} \tag{2}
\]

Specific Heat Capacity of tissue, \(C\) expressed in (J kg \(^{-1}\) °C)
Primary time derivative of tissue temperature, (\(\Delta T/\Delta t\))

2. Methodology
This section covers simulation experiments to investigate and compare the SAR distribution of rectangular microstrip applicators with different operating frequencies at different periods of procedures. Data obtained from the referred hospital are analysed using DICOM software and presented in the graph as shown in Figure 1. The analysis is mainly to get the required penetration depth and focus position distance for the cancer. Therefore, the rectangular microstrip antenna, which uses as the hyperthermia applicator is developed and designed to achieve this required cancer depth and focus position distance. After the analysis, breast phantom development and design of antenna are carried out. Industrial, scientific, and medical (ISM) frequencies of 434MHz, 915MHz, and 2450MHz are used as
the operating frequencies in hyperthermia treatment [19][20][21]. These three band frequencies are the International Telecommunication Union (ITU) basic recommendations frequency for non-communications application[20]. Details on the methodology are provided in sub-section 2.1 to 2.2.

2.1. Breast Phantom Development
The experiment starts with the measurement and analysis of the size and depth of cancer using DICOM software. Ground truth check is conducted with the radiologist to confirm the cancer area before the analysis is commenced. The next step is the initial development phase of the breast phantom and cancer cells based on the analysis that has been carried out. Breast phantom diameter is set to 100mm. Cancer diameter size is based on the average value of most occurs size of cancer for all the 36’s data which is 17 mm. Breast phantom consists of breast fat and breast cancer as presented in Figure 1. Sim4LifeLight V 6.2.0.4280 software simulator is used to model the breast fat, cancer cells and hyperthermia applicator, which shown in the following figures, Figure 2 to Figure 4. While, the electro-thermal properties of breast fat and cancer are as shown in Table 1 [11][22], which are then provided in the software simulator to perform the simulation execution.

![Figure 1. Inner and surface depth of cancer cells.](image)

**Table 1.** Breast Fat and Cancer Electro-Thermal Properties

| Antenna | Relative Permittivity, $\varepsilon_r$ | Electrical Conductivity $\sigma$(Sm$^{-1}$) | Density (mm) | Radius | Specific Heat Capacity (J/Kg/K) |
|---------|--------------------------------------|---------------------------------|-------------|--------|-------------------------------|
| Breast Fat | 5.14                                | 0.125                           | 911         | 50mm   | 3060                          |
| Cancer  | 5.14                                | 0.125                           | 1911        | 17mm   | 3060                          |

2.2. Design of Antenna
An antenna is designed in a rectangular shape with 3mm thickness of FR4 substrate. The parameters for the proposed antenna are tabulated in Table 2. Since, different operating frequencies are used, different sizes of the rectangular antenna are then developed and designed. Furthermore, the size of the antenna is significantly depended on the used frequency.

**Table 2.** Parameter of Antenna Design using FR4

| Antenna | Frequency (MHz) | Substrate Thickness (mm) | Patch Width (mm) | Patch Length (mm) | Ground Width (mm) | Ground Length (mm) |
|---------|----------------|--------------------------|------------------|------------------|------------------|-------------------|
| A1      | 434            | 3                        | 218              | 174              | 236              | 192               |
| A2      | 915            | 3                        | 104              | 86               | 163              | 146               |
| A3      | 2450           | 3                        | 39               | 31               | 57               | 49                |

Figure 2, Figure 3 and Figure 4 show the design of antennas with three (3) different frequencies; 2450MHz, 915MHz and 434MHz, respectively. Based on the figures, the higher the frequency resulted in the smaller the size of antennas. After the completion of the breast phantom and rectangular microstrip antenna development, the EM simulation is then executed to obtain the SAR distribution on the treated cancer tissue. The EM simulation is carried out using Sim4LifeLight, which is based on the electromagnetic Finite Difference Time Domain (EM-FDTD) solvers[23][24].
3. Result and Discussion

In Figure 5, it shows the measurement and analysis of data, which are performed from DICOM software. Based on this Figure 5, the size of malignant tissues for this study mostly occurs at the range of 11mm to 40mm. The average size of malignant tissue is selected from the three largest occurrence sizes of the malignant tissue. Malignant tissue dimensions range from 11mm to 20mm, 21mm to 30mm, and 31mm to 40mm, as presented in Figure 9, 11 and 13, respectively.

Figure 5. Size of Malignant Tissues.

Figure 6 to Figure 8 show the return loss of three (3) different frequencies. The return loss should be below -10dB in order to ensure the antenna is operated well with no back reflection. This -10dB
represents 10% of signal reflection and 90% signal power entered the antenna [11][25]. The shifted of the frequency from initial setting frequency of 2450MHz, 915MHz and 434MHz due to the fringing field effect around the antenna [25]. All three (3) frequencies have met the requirement of good antenna signal transmission with the return loss is less than -10dB.

![Figure 6. Return loss -37dB.](image)

![Figure 7. Return loss -15dB.](image)

![Figure 8. Return loss -13dB.](image)

As for SAR distribution, the SAR physical view and plot viewer of three (3) frequencies are shown in Figure 9 to Figure 14. A microstrip rectangular applicator with 2450MHz frequency has performed more uniform heating distribution on the treated cancer. It covers more area of cancer compared to the other two frequencies. In addition, lower SAR value has provided more heat if compared to higher SAR value. The highest SAR is 2.304W/kg, which followed by 2W/kg and 138.1 W/Kg for 2450MHz, 915MHz and 434MHz respectively. The results showed the higher the frequency the deeper the heat may penetrate at different SAR values at different period of hyperthermia execution. When heat interacts with cancer, the cancer is then denatured into necrotic tissue at a specific temperature range with a certain period of hyperthermia execution.

The estimation times for three different operating frequencies with 3060J/Kg/K specific heat capacity [22] are as follows:

- 2450MHz 10W antenna:  \( \text{Time} = \frac{3060(8)}{(2.3 \times 3600)} = 2.95 \text{ hrs} \)
- 915MHz 10W antenna:  \( \text{Time} = \frac{3060(8)}{(2 \times 3600)} = 3.4 \text{ hrs} \)
- 434MHz 10W antenna:  \( \text{Time} = \frac{3060(8)}{(138 \times 3600)} = 0.058 \text{ hrs} \)
Figure 9. 2450MHz SAR physical view.

Figure 10. 2450MHz SAR plot viewer antenna.

Figure 11. 915MHz SAR physical view.

Figure 12. 915MHz SAR plot viewer antenna.

Figure 13. 434MHz SAR physical view.

Figure 14. 434MHz SAR plot viewer antenna.
4. Conclusion
The analysis of 36 patient data received from the hospital has been done using DICOM software. From the data analysis, most of the size cancer cells are within 11mm to 40mm. The average size is calculated to develop cancer cells inside the breast phantom. A frequency of 2450MHz has shown better SAR distribution. Apart from that, the size of the antenna for 2450MHz is much smaller if compared to the other two frequencies and is more suitable to treat cancer with near position to skin. 915MHz antenna shows longest time followed by 2450MHz antenna and 434MHz with 3.4hrs, 2.95hrs and 0.058hrs respectively. The results show that different frequencies have different period of hyperthermia execution in order to provide sufficient heat in destroying the cancer cell. Further research is required to obtain the comparison of hyperthermia execution with and without the addition of the water bolus at a certain period of hyperthermia execution.

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References
[1] Breast cancer now most common form of cancer: WHO taking action, 2021 [Internet] Retrieved from https://www.who.int/news/item/03-02-2021-breast-cancer-now-most-common-form-of-cancer-who-taking-action.
[2] Tsuji W and Plock J A 2017 Breast Cancer Metastasis, Intro. to Cancer Metastasis, 13–31.
[3] Bray F, Ferlay J, Soerjomataram I, Siegel R L, Torre L A, and Jemal A 2018 Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries CA. Cancer J. Clin. 68 6 394–424.
[4] Breast cancer https://www.who.int/news-room/fact-sheets/detail/breast-cancer.
[5] Tan K F, Adam F, Hami R, Shariff N M, and N M M Mujar 2020 Review of breast cancer in young women Malaysian J. Med. Heal. Sci. 16 4 370–378.
[6] Behrouzkia Z, Joveini Z, Keshavarzi B, Eyvazzadeh N, and Aghdam R Z 2016 Hyperthermia: How can it be used Oman Medical Journal 31 2 89–97.
[7] Debnath O B, Saito K, Ito K, and Uesaka M 2017 Interstitial Hyperthermia in Combination with Radiation Brachtherapy for Treatment of Breast Tumor Therm. Med. 33 2 53–62.
[8] Curto S, Garcia-Miquel A, Suh M, Vidal N, Lopez-Villegas J M, and Prakash P 2018 Design and characterisation of a phased antenna array for intact breast hyperthermia Int. J. Hyperth. 34 3 250–260.
[9] Hassan M M 2020 A Review On Water Bolus Structure Integration For Non-Invasive Hyperthermia Treatment IARET 11 7 524–532.
[10] Baskaran D and Arunachalam K 2019 Computer simulations of 434 MHz Electromagnetic Phased Array for thermal therapy of locally advanced breast cancer 2019 URSI Asia-Pacific Radio Sci. Conf. AP-RASC 2019 2019–2022.
[11] Lias K, Bunuiyamin N and Nariah M Z A 2016 Simulation study of an EBG-M applicator towards non-invasive breast hyperthermia cancer procedure J. Teknol. 78 5–6 75–81.
[12] Singh S, Sahu B, and Singh S P 2017 Hyperthermia performance of conformal applicator for limb tumor in presence of water bolus 2017 International Symposium on Antennas and Propagation (ISAP) 1–2.
[13] Debnath O B, Ito K, Saito K, and Uesaka M 2015 Design of invasive and non-invasive antennas for the combination of microwave-hyperthermia with radiation therapy 2015 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications IMWS-BIO 2015 71–72.
[14] Elsaadi M, Aid Y, Abbas M, Embarek A, and Salih K 2019 Hyperthermia for Breast Cancer Treatment Using Slotted Circular Patch Antenna Circuits Syst. 10 03 37–44.
[15] Chiracharit W and Kongkachandra R 2008 Clustered microcalcification classification using CC-MLO-view corresponding shape and distribution features Proc. SICE Annu. Conf. 29–34.
[16] Bekker A J, Shalhon M, Greenspan H and Goldberger J 2016 Multi View Probabilistic Classification of Breast Microcalcifications *IEEE Transactions on Medical Imaging* 35 2 645-653.

[17] Head J F, Lipari C A and Elliot R L, 2001 Determination Of Mean Temperature Of Normal Whole Breast And Breast Quadrants By Infrared Imaging And Image Analysis *International Conference of the IEEE Engineering in Medicine and Biology Society* 3 2823–2825.

[18] Pathak P P, Tripathi H, and Kumar V 2010 Specific Absorption Rate Calculation and Rate of Temperature Change in Tissues Due to Radio Antenna *Int. Trans. Appl. Sci.* 2 4 739–747.

[19] Luna A and Marwaha A 2014 Hyperthermia Applicator for Electromagnetic interaction with Human tissue at 434 MHz *Journal of Electrical and Electronics Engineering* 9 4 32-36.

[20] Gas P 2015 Multi-frequency analysis for interstitial microwave hyperthermia using multi-slot coaxial antenna *J. Electr. Eng.* 66 1 26–33.

[21] Habash R W Y 2018 Therapeutic hyperthermia *Handb Clin Neurol.* 157 853-868.

[22] Lozano A, Hayes J C, Compton L M, Azarnoosh J and Hassanipour F 2020 Determining the thermal characteristics of breast cancer based on high-resolution infrared imaging, 3D breast scans, and magnetic resonance imaging *Sci. Rep.* 10 1 1–14.

[23] Sim4life Light, Zurich Med Tech. 2018 [Internet] Retrieved from https://zmt.swiss/academic/s4l-academic/sim4life-light/.

[24] P-EM-FDTD, Zurich Med Tech. 2021 [Internet] Retrieved from https://zmt.swiss/sim4life/physics-models/p-em-ftd/.

[25] Microstrip (Patch) Antennas [Internet] Retrieved from https://www.antenna-theory.com/antennas/patches/antenna.php.