Applied Engineering
2022; 6(1): 1-6
http://www.sciencepublishinggroup.com/j/ae
doi: 10.11648/j.ae.20220601.11

Integrated Lens Microstrip-Slot Applicator for Breast Hyperthermia Procedure

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To cite this article:
Kasumawati Lias, Hazrul Mohamed Basri, Wong Vei Ling, Kuryati Kipli, Wan Azlan Wan Zainal Abidin. Integrated Lens Microstrip-Slot Applicator for Breast Hyperthermia Procedure. *Applied Engineering*. Vol. 6, No. 1, 2022, pp. 1-6. doi: 10.11648/j.ae.20220601.11

Received: June 21, 2021; **Accepted**: June 29, 2021; **Published**: February 9, 2022

Abstract: Hyperthermia is an alternative procedure for cancer treatment. It has potential either used alone or adjuvant with other conventional procedures such as chemotherapy and radiotherapy to enhance the capability of chemotherapy drugs and the radiation intensity, respectively. However, since the success rate is still not significant, the requirements in improving the limitations for this alternative procedure are massively carried out. Therefore, in this paper, it is emphasised to improve the main deficiency of this hyperthermia treatment, which is focus position distance in order to reduce the possible adverse health effects due to the treatment by reducing the area of unwanted hot spots on surrounding healthy tissue. A simulation with SEMCAD X is utilised to obtain heat distribution on the treated tissue. Various rectangular microstrip-slot applicators have been modified and developed with SEMCAD X, where it is used to provide heat towards the treated tissue at a certain period of time and hyperthermia specific temperature. The outcomes showed the modified microstrip-slot with a Y shape is able to penetrate up to 80 mm with sufficient focus position distance. Finally, a water bolus is introduced to produce a cooling impact on the treated tissue, which also alters the effective field size (EFS) of heat dispersion.

Keywords: Hyperthermia, Microstrip, Slot, Focus Position Distance, Heat Distribution, SAR

1. Introduction

Hyperthermia is a safer alternative treatment for many types of cancers, especially breast cancer, liver cancer, prostate cancer and skin cancer [1]. It utilises a temperature of 41°C to 45°C at a certain period of time in order to ensure the cancer tissue is denaturated into necrotic tissue [2-4]. Hyperthermia can be used alone or [5, 6] as adjuvant therapy with other cancer therapy, such as chemotherapy and radiotherapy, in enhancing the response of the chemotherapy drugs and the intensity of the radiation for chemotherapy, respectively [2]. Notwithstanding, this hyperthermia treatment needs to be further enhanced in improving the deficiencies, such as its poor focus position distance that may contribute to wider unwanted hot spots that lead to adverse health effects on surrounding healthy tissue [5, 6]. In conjunction with that, current research on hyperthermia treatment is mostly concerned with improving the focus position distance and reducing the unwanted hot spots simultaneously. Various techniques have been proposed, where most of the works were emphasised the introduction or modification of the hyperthermia applicators in order to provide sufficient heat on the treated tissue [5-9].

In recent years, most of the research was introduced various structures of the slot, which integrated with microstrip antenna as hyperthermia applicator based elements. Examples of the research were carried out by Jianian Li, Masoud Sarabi, Divya Baskaran, and Soni Singh in [5, 6, 9-12], respectively. In short, various types of non-invasive radiative electromagnetics (EM) applicators have been presented. Based on the responses towards the treated tissue, a microstrip antenna, which was used as a base element for the hyperthermia applicator, had shown good penetration depth. It was able to provide a depth of more than 50 mm. When modification and array arrangement were carried out, it resulted in a good focus capability of specific absorption rate (SAR) distribution towards the treated tissue. However, each research that was carried out showed a variety of outcomes as different parameters had been used. This included the tissue electrical properties, different operating frequencies, different operating power and different hyperthermia applicator. The main similarities were to provide a better focus on the treated tissue that able to minimise the adverse health effects due to wider area of unwanted hot spots.

Therefore, this research mainly presents a modified rectangular microstrip-slot antenna as a hyperthermia applicator to heat a breast cancer of 100 mm depth with a 7855 mm^2 cancer area. In order to accomplish this main objective, three (3) main steps are required in this research, with some design of experiments (DoE) that need to be conducted. Details are discussed in the next Section 2.

2. Research Methods

The experimental simulation approach, which employs the software simulator known as SEMCAD X, is the mainstay of the research approach. The first stage in this study is to analyse the mammography breast cancer images that have been collected. After receiving ethical consent from the referring hospital, a ground truth with the radiologist is performed to confirm the cancer position. The depth and position of the mammography images are then measured using DICOM software in order to achieve the needed penetration depth and focus position distance of the breast cancer tissue to be heated, as illustrated in Figure 1.

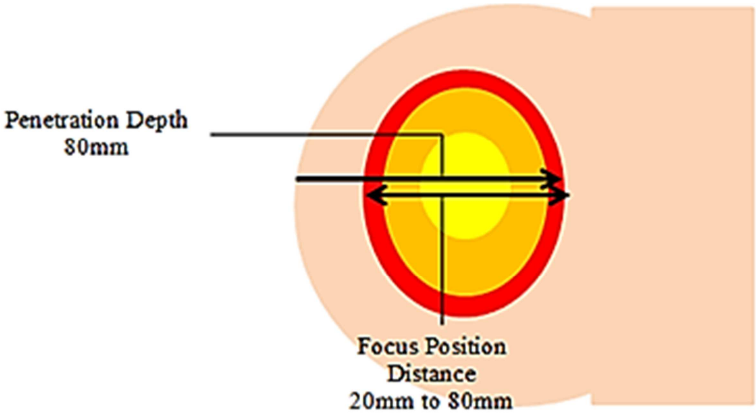


Figure 1. *Penetration depth and focus position distance.*

The basic element of the applicator is a traditional rectangular microstrip antenna, which has demonstrated good penetration depth and focus position distance with its simple form. As to produce a proposed applicator for hyperthermia breast cancer treatment, the antenna is modified by adding a rectangular corner with a Y-slot structure, which is then combined with a metal antenna lens structure.

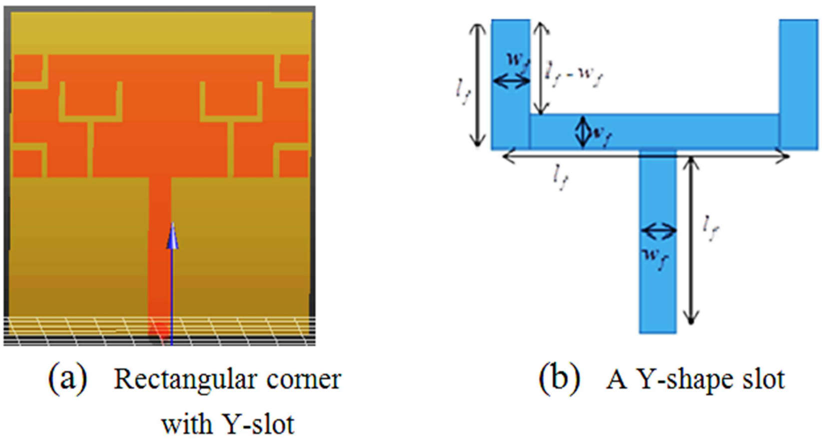


Figure 2. *Microstrip-slot (a) Rectangular corner with Y-slot (b) A Y-shape slot.*

From a basic rectangular microstrip antenna, it is then corner modified and integrated with a Y-shape slot. The width for a slot is 2 mm. It is based on $\frac{w_f}{2}$ half of the width of the microstrip feed line (w_f). As for slot structure length, it is varied in the range of $\frac{l_f}{2} \le l_s \le l_f$, where l_f and l_s is referred to as microstrip feed line length and slot length, respectively. The position of w_f and l_f are presented as in Figure 2 (b). These two Y-slots are the mirror image of each other. EM-simulation is then executed to obtain SAR distribution. An arrangement of microstrip-slot and breast phantom in SEMCAD X is set up as in Figure 3.

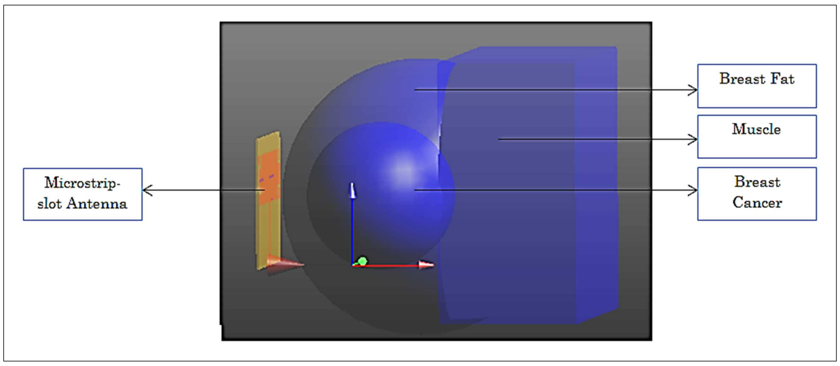


Figure 3. *EM-simulation setup for the microstrip-slot antenna.*

After that, a lens structure is used to improve the ability of the EM energy to focus on the treated tissue. In the SEMCAD X software simulator, single and multiple *n*-rectangular lens structures are modelled, integrated into the microstrip-slot, and simulated. The effect of various thickness and height constructions on the penetration depth and focus position distance on the treated tissue is examined. According to the optic principle, unwanted hot spots could be reduced with the integration of lens structure. Therefore, the penetration depth on the treated tissue is also expected to be affected. The arrangement for the EM-simulation setup is shown in Figure 4.

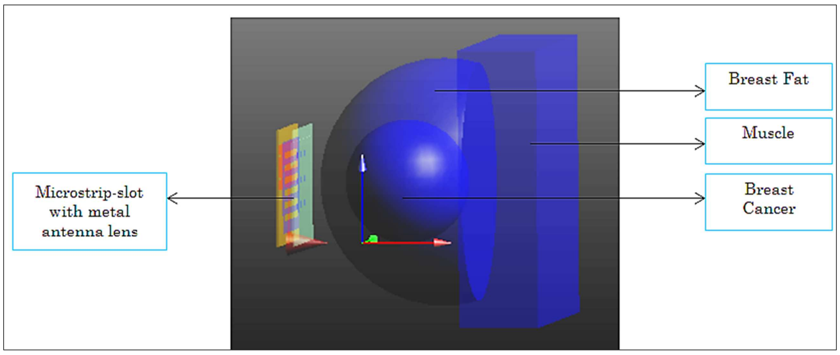


Figure 4. *EM-simulation setup with the integration of the lens structure.*

For the final research methodology, a water bolus is constructed to observe the influence of the cooling system on the radiation absorption pattern. Distilled water is utilised as a coolant fluid, having εr, ζ, and ρ values of 76.7, 5e-005, and 1000, respectively. The effects of a water bolus on SAR's effective field size (EFS) are investigated.

The water bolus is shaped in rectangular and breast shape structures. Based on previous studies [13, 14] in which most of the water boluses are developed in a rectangular shape. Based on previous studies, when water bolus is added in the treatment, it was able to improve the EFS of the heat contour of the treated tissue [15, 16]. This improvement occurred when distilled water in the water bolus has improved mismatch impedance between the EM applicator and treated tissue. By improving the impedance, it contributed to shaping or radiation optimisation, which improved EFS and reduced unwanted hot spots surrounding cancer tissues. The arrangement setup for both water boluses shapes is presented in Figure 5.

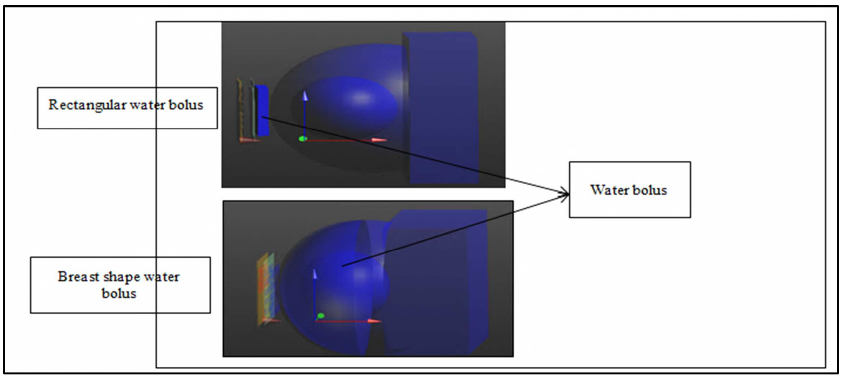


Figure 5. *EM-simulation setup for a lens integrated into microstrip-slot with rectangular and breast shape water bolus.*

Complete arrangement for EM-simulation setup is presented in Figure 6. All the results obtained from the simulation are being compared and analysed. The results from the simulation are discussed in the following Section 3.

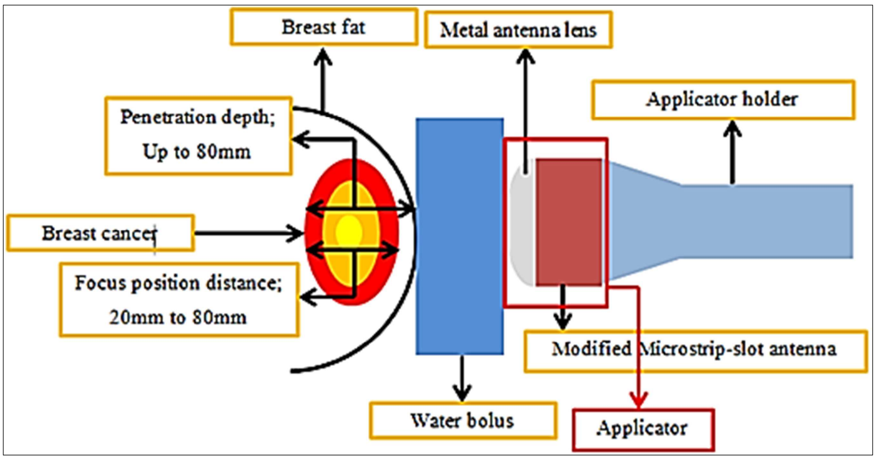


Figure 6. *EM-simulation setup for complete hyperthermia breast cancer procedure with integrated lens microstrip-slot applicator.*

3. Result and Discussion

In this section, it is explained the results of the research based on the simulation experiments carried out using the SEMCAD X simulator. The SAR is obtained in observing the penetration depth and focus position distance on the treated tissue. This SAR parameter is a measure of the rate at which energy is absorbed by a biological system when exposed to microwave (MW) or radio-frequency (RF) EM fields [17]. SAR also indicates the amount of power absorbed per unit mass of a biological body upon exposure to an EM field. In SAR measurements, the biological body is represented by a dielectric medium, which is possessed dielectric constants similar to those of the biological body and is called a phantom [18]. SAR is expressed in units of watts per kilogram (W/kg or mW/g).

SAR can be determined from either electric-field amplitude or temperature measurement and is represented as equations (1) and (2), respectively.

$$SAR = \frac{\sigma |E|^2}{\rho} \quad \text{[W/kg]/[mW/g]} \tag{1}$$

$$SAR = \frac{C\Delta T[W/kg]}{\Delta t} \tag{2}$$

Where σ is the conductivity of tissue simulant (S/m), $|E|^2$ is the electric field strength (V^2/m^2), ρ is the density of tissue simulant (kg/m^3), C is the specific heat capacity of tissue simulant (J/kg/°C), and ΔT is the change in temperature when exposed for time change of Δt.

SAR does not depend on the phase but the magnitude of the measured electric field. Besides, SAR is also known as specific loss power (SLP), whereby it is defined as mass-normalised (specific) and denotes the magnitude (power) that is absorbed/released by the treated tissue [19].

Furthermore, SAR is able to manipulate by changing the averaging volume. According to [20], the Federal Communications Commission (FCC) requires that SARs to be averaged over 1 g of tissue, while both the Institute of Electrical and Electronics Engineers (IEEE) in IEEE/IEC62704-1 and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) is specified a 10 g.

3.1. SAR Distribution of Microstrip-Y-Slot Shape

Based on the simulated results, a rectangular corner with a Y slot is able to obtain penetration depth up to 90 mm, as presented in Figure 7. These results are in line with previous research carried out by P. Surendra Kumar in [21], wherewith the integration of slot structure into the microstrip antenna was able to improve heat penetration depth on the treated tissue. By integrating the slot on the radiating patch, the surface waves are converted into space waves that are able to propagate and thus reduce the surface wave. This reduction leads to the improvement of antenna efficiency, which then contributes to deeper penetration on the treated tissue. However, poor focus position distance is observed, where the focus position distance of 20 mm to 80 mm is not achieved. The focus position distance is from 0 mm to 90 mm. There are requirements to reduce the unwanted hot spots to minimise the effect of hyperthermia on surrounding healthy tissue.

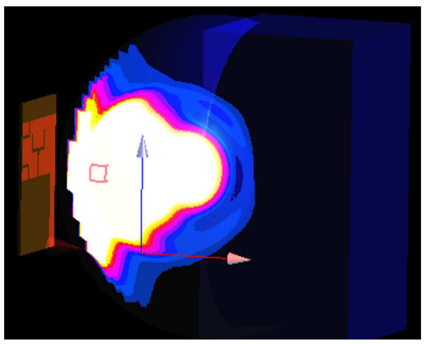


Figure 7. *SAR distribution of microstrip-Y-slot shape.*

3.2. SAR Distribution of Integrated Lens Microstrip-Y-Slot Shape

Poor focus position distance is observed in Section 3.1. With regards, the lens structure is introduced to enhance the EM energy focus capability on the treated tissue. From the simulated result, a single-lens structure with 1 mm thickness has obtained 90 mm depth and focus position distance of 0 mm to 90 mm. When the lens is thicker, the resulting penetration depth is decreased. This situation occurs because of the increase in radiation loss.

Then, when the metal antenna lens is introduced, the depth becomes lesser, but the focus position distance is improved. Metal antenna lens with metal Electromagnetic Band-Gap (EBG) 6X6 structure has presented the best focus position distance of 20 mm to 80 mm on the treated tissue. The SAR distributions for the metal antenna lens structures are depicted in Figure 8, which present SAR distribution with a penetration depth of 80 mm and focus position distance of 20 mm to 80 mm on the treated tissue.

Therefore, with the metal antenna lens, it is able to improve a focus position distance of 20 mm to 80 mm. It is in compliance with the optic theory presented by Yoshio Nikawa in [22].

3.3. SAR Distribution of Integrated Lens Microstrip-Y-Slot Shape with Water Bolus

Investigation with rectangular and breast shape water bolus is carried out. The results from the simulation are tabulated in Table 1. Based on the findings, 2 mm thickness provides better depth and focus position distance. As for width and height, the best is 105 mm and 94 mm, respectively. The selection of this structure is basically based on the ability to reduce the most unwanted hot spots between the breast skin and breast cancer. Therefore, the adverse health effect on surrounding healthy tissue can be reduced and minimised.

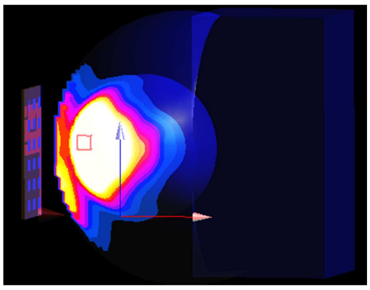
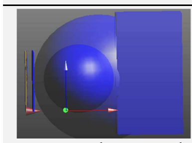
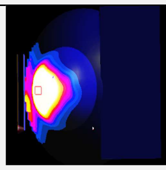
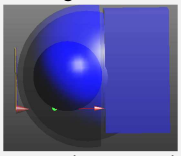
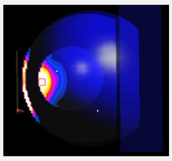


Figure 8. *SAR distribution of integrated lens microstrip-Y-slot shape.*

Table 1. *SAR distribution of rectangular and breast shape water bolus.*

Setup EM-simulation	SAR distribution	Penetration Depth and Focus Position Distance Achievement
 Rectangular water bolus with 2 mm thickness, 94 mm height, 105 mm width		Penetration Depth = 80 mm Focus Position Distance = 20 mm to 80 mm
 Breast shape water bolus with 2 mm thickness		Penetration Depth = 50 mm Focus Position Distance = 20 mm to 50 mm

4. Conclusion

The integrated lens microstrip-Y-slot shape was proposed as a modified hyperthermia applicator used to obtain the required penetration depth of 80mm and improved focus position distance of 0mm-80mm to 20mm-80mm. The design, modelling and simulation experimentation were carried out using SEMCAD X software simulator. Then, from the simulation findings, this modified rectangular microstrip applicator was successfully achieved the targeted area of the treated tissue. The wide area of unwanted hot spots on the surrounding healthy tissue was also reduced. When a water bolus was added to the treatment procedure, it was able to reshape EFS on the treated tissue.

Acknowledgements

The author would like to thank Universiti Malaysia Sarawak (UNIMAS) for supporting this research under Cross-Disciplinary Research Grant, F02/CDRG/1840/2019.

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