Improving the Performance of Applicators for use in Hyperthermia Cancer Treatment Procedure by the Introduction of LHM Lens

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Abstract—**This paper describes the improvement of applicator performance used for Non-invasive Hyperthermia Cancer Treatment Procedure (NIHCT). Current available applicators have poor focal spot when directed towards an actual tumor area. A literature review indicated that Left-Handed Metamaterial (LHM) lens when integrated with an antenna can improve focusing capabilities of the antenna to treat the cancerous area. Subsequently, a proposed modified applicator that integrates Left-Handed Metamaterial (LHM) lens with existing antenna is discussed. The applicator performance is improved by the integration of Left-Handed Metamaterial (LHM) lens to a microstrip antenna. The proposed antenna termed LHMA is expected to have an improved focusing capability which could be used to kill cancerous tissues without severely affecting surrounding healthy tissues. The goal of the research is to reduce unwanted hot-spots using the proposed applicators. The applicator for NIHCT procedure used LHM lens by adjusting the applicator distance towards the cancerous area and varying the thickness of the LHM lens. SEMCAD X simulator software was used to execute electromagnetic and thermo simulation, analysis and modification of the simulated antenna where two shapes of lens were used. The focusing abilities of the proposed applicator was evaluated using the Specific Absorption Rate (SAR) area obtained. The results shows that Cylindrical LHM lens gives better focusing effect rather than flat rectangular LHM lens.**

Index Terms— **Non-invasive Hyperthermia Cancer Treatment Procedure (NIHCT), Left-handed Metamaterial (LHM), Non-invasive, Hyperthermia, Specific Absorption Rate (SAR)**

I. Introduction

The interest in the development of antennas or sometimes termed as applicator for non-invasive hyperthermia cancer treatment(NIHCT) procedure has recently grown tremendously. This is because NIHCT could destroy cancerous cells without severely affecting patients as opposed to other cancer treatments.

Nowadays, breast cancer contributes to the highest number of cancer among women all over the year. In Malaysia specifically, according to [1], women are the most at risk of cancer involving 10,290 patients out of 100,000 people in the year 2016 where it is the highest incidence with 14.5% if compared to other types of cancer such as lung, stomach, and leukemia.

NIHCT artificially heats body tissue using electromagnetic (EM) waves by focusing the EM wave onto the cancerous cell area thus heating the selected cells to induce denaturation. One of the challenges in hyperthermia treatment is to selectively heat an area where the cancerous tissues are located to elevate the cancerous cell temperature to above 42 °C while keeping the temperatures of the surrounding healthy tissue as close as possible to normal human body temperature [3],[4]. Thus, to provide a good NIHCT is to have an applicator of the EM waves that could provide a good focusing control parameter

An alternative treatment is by the use of microwave hyperthermia which can be considered as an effective treatment for cancer therapy. Hyperthermia is also known as thermal therapy, or thermotherapy is a type of a cancer treatment in which the body tissue is exposed to high temperature. It is a treatment which requires high temperature around 41°C - 45°C to denaturize cancerous tissues which will be then induced to cell death with minimal side effects [2],[3]. Hyperthermia can work alone or commonly as an adjuvant towards chemotherapy and radiotherapy.

Hyperthermia treatment can be either invasive or non-invasive. NIHCT is a safe and effective treatment to fight against various types of cancer with less pain and injury [4]. Thus, in recent years, many researchers focused on non-invasive hyperthermia antenna/applicator development. The applicator is considered as the main part of NIHCT. It is used to deliver electromagnetic energy that transform to heat and then distributed and absorbed by the cancerous tissues at a certain level of heat and within a period of time.

The use of an appropriate antenna is very crucial as the heat generated by the antenna Electromagnetic (EM) fields will be used to kill/destroy the cancerous tissues or cells. Various researches were conducted to obtain the quality of hyperthermia treatment from the perspective of antenna design. Currently,

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research in the establishment of the antenna with the integration of metamaterial slab and lens has grown rapidly as in Figure 1.

II. METAMATERIAL

The applicator focusing ability was improvised by previous using various types of antenna structures and metamaterials in the design of antenna for hyperthermia treatment. Metamaterials (MM) are usually made of composite of material such as metal and plastic and built in various types of structures. There are two types of metamaterial lens which are Right-Handed Metamaterial (RHM) lens and Left-Handed Metamaterial (LHM) lens.

Table 1 : Advantages and Disadvantages of Metamaterial Lens.

Types of Metamterial Lens	Advantages	Disadvantages
Right-Handed Metamaterial (RHM) Lens [7]	- This lens is lossless which can give good performance without any losses.	- Has fixed and penetration depth which may be not flexible in use.
Left-Handed Metamaterial(LHM) Lens	- Gives good focussing effect towards cancerous cell and generate a heating towards cancerous cells.	- Its gives heavier loss which makes hypethermia more effective and more energy was attenuated during the process.

Table 1, shows that LHM lens provides better performance for safer and due to non-invasive procedure. It gives better focusing effect towards cancerous cells rather than RHM lens. Comparison of the LHM lens performance of from previous researchers are discussed in the next section.

A popular metamaterial known as left-handed metamaterial (LHM), has electromagnetic properties at microwave frequencies and has several unique properties such as the backward wave and the focusing effect inside it slab. The concept of LHM was initially proposed by Veselago in 1968 [5].

One of the most attractive properties of metamaterials is the negative-refractive index (NRI) slabs to focus the electromagnetic field of a source [6]. With permeability and permittivity that are simultaneously negative, LHM slab with parallel sides can be used as a lens to focus incident microwave[7].

III. LEFT-HANDED METAMATERIAL LENS

Metamaterial technology was used to develop lenses, where LHM slab can act as a lens that will focus the incident waves. *Pendry* introduced LHM lens in the year 2000. Due to its unique characteristics, *Pendry* concluded that the LHM lens is a perfect lens as it can focus microwave energy very well and thus enhance the antenna performance[6]. LHM lens is defined as an artificially designed material having several unique properties such as Backward Wave Propagation (BWP). It is also known as Double Negative (DNG) material and it lies in the third quadrant where permeability (μ) and permittivity(ε) are negative [8].

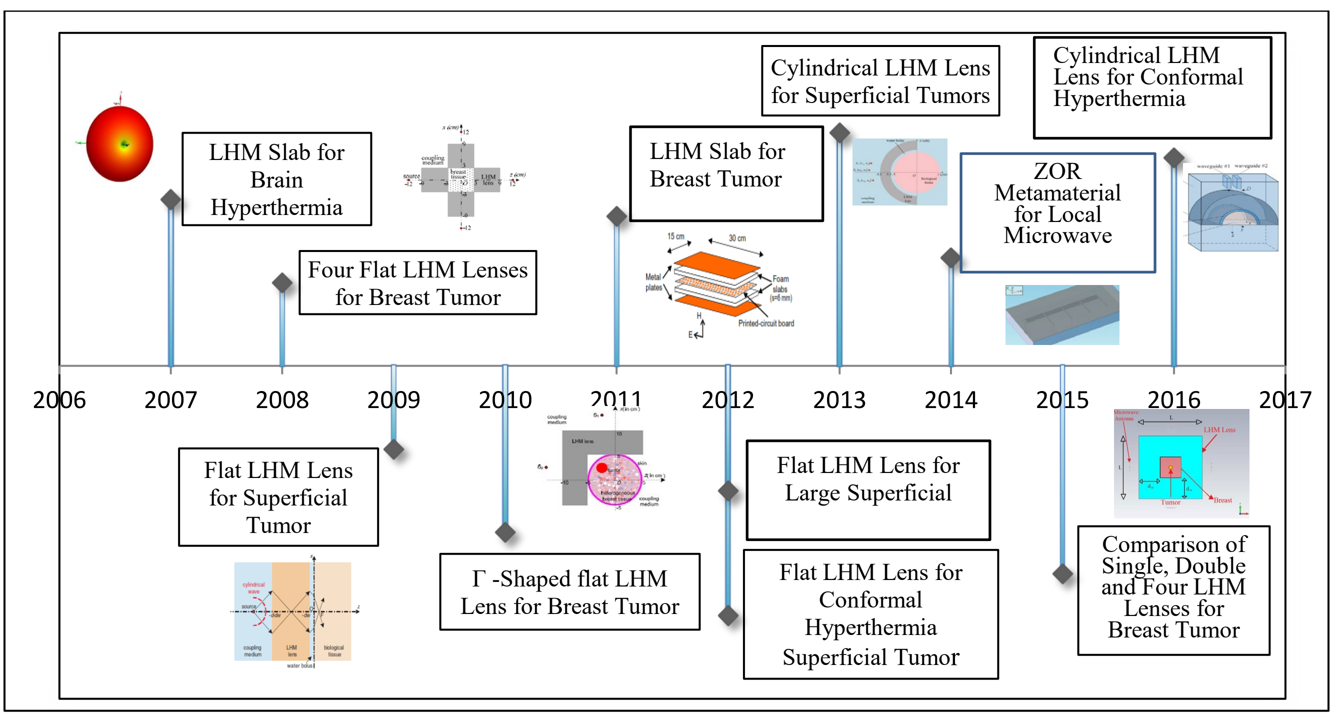


Figure 1: Timeline of Metamaterial Slab and Lens Applicators for Non-Invasive Hyperthermia Cancer Treatment

The perfect LHM lens may amplify the evanescent waves, so this may break the diffraction limit of the conventional lens to achieve better focusing resolution [9]. It has been proven by many researchers that LEFT-Handed Metamaterial (LHM) lens has shown great potential in hyperthermia cancer treatment and it shows excellent performance in microwave hyperthermia [10],[11],[12],[13] due to its ability on focusing microwave energy.

Figure 1 shows a Timeline of Metamaterial Slab and Left-Handed Metamaterial (LHM) lens applicators for hyperthermia cancer treatment. Metamaterial technology in the hyperthermia cancer treatment had been introduced since 2007. Researchers such as K. T. Karathanasis[14], M. C. Velazquez-Ahumada [15] and D. Vrba[16] are among the researchers that involve in metamaterial technology in the hyperthermia cancer treatment.

Metamaterial technology was further developed into lenses, where LHM slab can act as a lens that will focus the incident waves. The most prominent property of LHM lens is the ability of negative-refractive index (NRI) to focus the electromagnetic field of a source. Hence it can generate appropriate focusing spot in biological tissue as required in microwave hyperthermia treatment. Based on the reviews, it is proven that LHM lens gives a better focusing capabilities in comparison to metamaterial slab.

In 2008, Yu Gong [7] had introduced LHM lens in hyperthermia cancer treatment technology. A four-lens LHM applicator was proposed for breast tumor hyperthermia. By adjusting the tumor position to some extent, the results indicate that the focusing effect is less affected. One flat LHM lens has been investigated in [12] for superficial tumor, where only one source is set behind a flat LHM lens. When the position of microwave source is adjusted, the heating zone in tissue can also be easily adjusted in both lateral and depth direction in tissue as required in hyperthermia.

In [17], Γ -shaped LHM lens applicator composed of two orthogonally-deployed flat LHM lenses was suggested. Furthermore, the feasibility of multiple sources sharing one flat lens has been introduced by Y. Toa in [18], which forms a relatively large heating zone for hyperthermia for large superficial tumor and conformal hyperthermia of superficial tumor was investigated in [10]

A comparison between single, double and conformal four-lenses has been compared in [19]. It indicates that multi-lens systems had shown better alternative to produce temperature concentration within the tumors compared to single-lens. In [20], superficial hyperthermia with a cylindrical LHM lens and conformal hyperthermia of superficial tumors with a cylindrical LHM lens in [21] had been introduced. Both demonstrated that by using multiple microwave sources and properly setting the source-to-lens distance or phases, a heating zone better fit to large superficial tumors could be generated.

The current existing applicators could not focus effectively and less coverage of heat absorption can be applied at the required area (cancer cells) and the area around the tumor to be treated. Thus, the surrounding healthy cells are affected and the side effect of skin burn may occur [10],[12].[18], [17],[19],[20],[22].

A. A New LHM lens Applicator Design

Based on the previous success of using MM in the available hyperthermia applicators system, a new design of LHM lens with difference shape will be integrated to the existing applicator that is expected to improve its focusing capabilities. The improvised LHM lens is designed from the combination of the modified microstrip antenna introduced by K. Lias [23].

K. Lias proposed an electromagnetic band gap that was embedded with microstrip applicator which is known as EBG-M applicator. This proposed applicator showed a good penetration depth towards the treated cancer area, but inferior in focusing capabilities towards the treated cancer area. Therefore, LHM lens is expected to enhance the existing applicator which can give better focusing capabilities.

B. Proposed Research Framework

Using simulation software, an applicator that integrates LHM lens is developed. The software is also used to create breast phantom models based on the real data of breast cancer images collected from a hospitals' cancer department. The breast phantom model is created so that the SAR due to the application of EM wave from the developed applicator could be studied. This is a similar study to [24], who also used breast models to study the sensitivity and the strength of non-invasive hyperthermia treatment. Based on literature review, Specific Absorption Rate (SAR) is a commonly used parameter which characterize the heating of the tissue [25]. The specific absorption rate (SAR) created by the developed applicator on the phantom breast model will be analysed.

The setting of the variation of the thickness of lens and by adjusting the applicator distance towards the cancerous area will be proposed to solve the focusing problem of non-invasive hyperthermia cancer treatment. Figure 2 below shows the focusing scheme when using LHM lens, and Figure 3 shows the complete model for NIHCT applicator investigation.

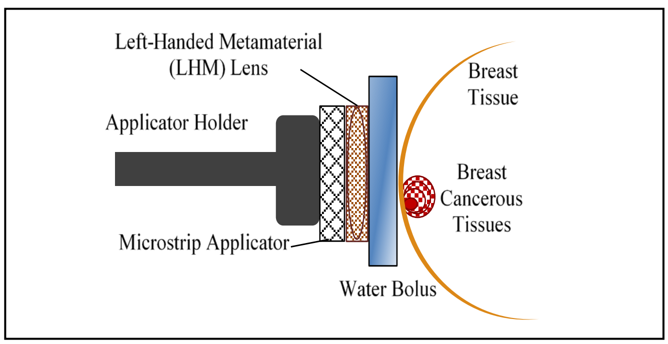


Figure 2: Model for NIHCT Applicator Investigation.

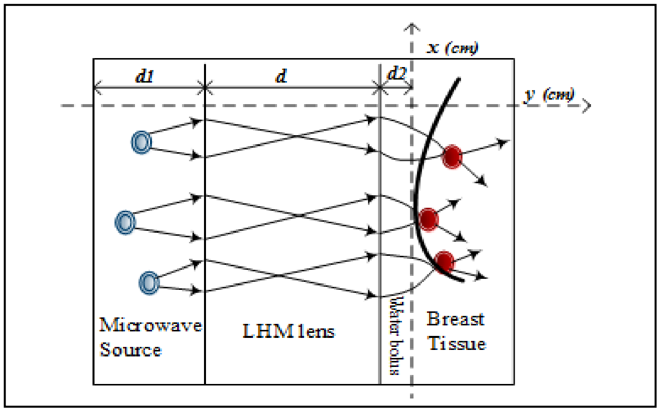


Figure 3: Focusing scheme by using LHM Lens.

C. The equation for LHM lens

LHM lens can be considered as an effective isotropic medium characterized by the relative permittivity, ε_{rLHM} and permeability, μ_{rLHM} [26] as follows:

$$\varepsilon_{rLHM}(\omega) = 1 - \frac{\omega_{pe}^2}{\omega^2 + 2j\delta\omega} \quad (1)$$

$$\mu_{rLHM}(\omega) = 1 - \frac{\omega_{pm}^2}{\omega^2 + 2j\delta\omega} \quad (2)$$

Where δ is the damping frequency, ω_{pe} the electrical plasma frequency, and ω_{pm} the magnetic plasma frequency.

D. Thermal Units

For thermal radiation, there are two most important equations; the specific absorption rate (SAR) and Penne Bioheat equation [22] as follows:

$$SAR = \frac{\sigma E^2}{\rho} \quad (3)$$

$$\rho C \frac{\delta T}{\delta t} + \nabla(-k\nabla T) = h_b(T_b - T) + \rho SAR \quad (4)$$

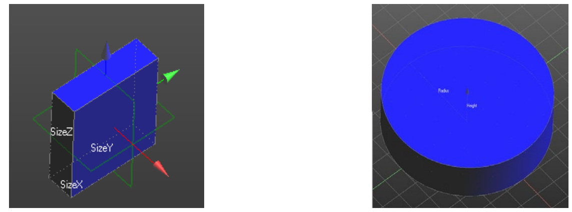
Where σ is a conductivity of tissue (S/m), E is an electric field (V/m), ρ is a density of tissue (kg/m^3), C is specific heat tissue (J/mK), k is a thermal conductivity of tissue (W/mK), T is temperature of tissue (°C), T_b is a blood temperature (°C) and h_b is a convective heat transfer coefficient (kg/m3).

SAR is a commonly used parameter which characterize the heating of tissues. It is also a good thermal dosimetry indicator. Penne Bio-heat equations show the heat transfer in the human biological system. Both equations are important in hyperthermia thermal study and they are used in research either through computational simulation or experimentation or combination of both methods to control temperature required for hyperthermia treatment.

IV. Results and Discussion

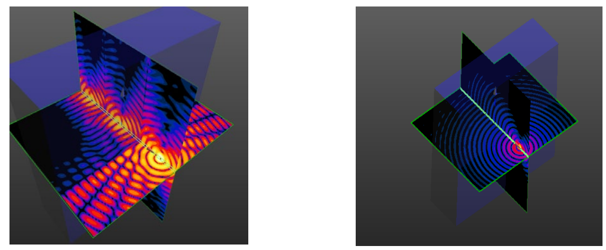
The simulation, analysis and modification step are implemented with SEMCAD X simulator by SPEAG Schmid & Partner Engineering AG, Switzerland. Two simulations setup was used. The first is an electromagnetic (EM) Simulation and the second experiment is the Thermo Simulation by utilizing Pennes Bio Heat. Two types of LHM lenses were developed and integrated with a microstrip antenna. The lenses differ in shape. The types investigated were a) flat rectangular shape and b) cylindrical shape as shown in Figure 4.

Figure 5 shows the results of SAR distribution pattern for this two lens.



(a) (b)

Figure 4 : LHM Lens with (a) Flat rectangular shape (b) Cylindrical shape



(a) (b)

Figure 5 : SAR Distribution Pattern for (a) Flat rectangular LHM lens (b) Cylidrical LHM Lens

From the observation, SAR distribution of Figure 5(a) is wider than Figure 5(b). It indicates that cylindrical LHM lens gives better focusing effect than flat rectangular LHM lens. It is proven by previous work in [10] and [27] where its shows LHM lens could gives better focusing capabilities towards the treated cancerous area especially cylindrical LHM lens compared to flat rectangular LHM lens. Futher simulations and analysis will be done to investigate the effect of the thickness to the performance of the lens.

V. Conclusion

The performance of applicators for hyperthermia cancer treatment procedure using LHM lens was presented. The literature review indicated that metamaterial slab and lens applicator have performed relatively well and achieved their planned objective, which is to provide quality hyperthermia treatment in term of focusing capabilities of an antenna towards the treated cancer area. However, the current applicator had poor focal spot towards the actual tumor area. Thus, LHM lens is introduced in this research to improve hyperthermia treatment mainly in term of improving applicator focusing capabilities to destroy cancerous tissues without giving any effect to the surrounding healthy tissues during the hyperthermia cancer treatment procedure. As observed from the results, it is shown that Cylindrical LHM lens when integrated to an antenna which gives better focusing effect towards the cancerous area rather than flat rectangular LHM lens.

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References

[1] "About 100,000 Malaysians suffer from cancer each year," *The Star*. 2016.

[2] J. Vrba, "Microstrip Applicator for Local Hyperthermia," pp. 1047–1049, 2007.

[3] O. Losito, M. Bozzetti, S. Sterlacci, and V. Dimiccoli, "E-field distribution improvement by new hyperthermia applicators," *MeMeA 2011 - 2011 IEEE Int. Symp. Med. Meas. Appl. Proc.*, pp. 1–5, 2011.

[4] K. B. Lias, M. Zulkarnaen, A. Narihan, and N. Buniyamin, "An Antenna with an Embedded EBG Structure for Non Invasive Hyperthermia Cancer Treatment An Antenna with an Embedded EBG Structure for Non Invasive Hyperthermia Cancer Treatment," 2015, no. December 2014.

[5] V. G. Veselago, "The Electrodynamics Of Substances With Simultaneously Negative Values Of And μ," *Sov. Phys. Uspekhi*, vol. 10, no. 4, pp. 509–514, 1968.

[6] J. B. Pendry, "Negative refraction makes a perfect lens," *Phys. Rev. Lett.*, vol. 85, no. 18, pp. 3966–3969, 2000.

[7] G. Yu, W. Hongjin, and W. Gang, "Microwave heating by using flat LHM lens," *META08 - Proc. 2008 Int. Work. Metamaterials*, pp. 370–373, 2008.

[8] J. Baviskar, A. Mullay, and A. Jeyakumarz, "Performance analysis of uniform meta-material lens embedded patch antennas," *IEEE Antennas Propag. Soc. AP-S Int. Symp.*, vol. 2015–Octob, pp. 1914–1915, 2015.

[9] J. B. Pendry and S. A. Ramakrishna, "Refining the perfect lens," in *Physica B: Condensed Matter*, 2003, vol. 338, no. 1–4, pp. 329–332.

[10] Y. Tao and G. Wang, "Conformal hyperthermia of superficial tumor with left-handed metamaterial lens applicator," *IEEE Trans. Biomed. Eng.*, vol. 59, no. 12, pp. 3525–3530, 2012.

[11] G. Wang and Y. Gong, "Metamaterial lens applicator for microwave hyperthermia of breast cancer.," *Int. J. Hyperthermia*, vol. 25, no. 6, pp. 434–45, 2009.

[12] J. Zhang, Y. Yin, and J. Ma, "Progress In Electromagnetics Research, PIER 96, 287–298, 2009," *Superf. TUMOR Hyperth. WITH FLAT LEFT-HANDED METAMATERIAL LENS*, vol. 96, pp. 287–298, 2009.

[13] G. Wang, Y. Gong, and H. Wang, "Schemes of microwave hyperthermia by using flat left-handed material lenses," *Microw. Opt. Technol. Lett.*, vol. 51, no. 7, pp. 1738–1743, 2009.

[14] C. Internationale, K. T. Karathanasis, I. S. Karanasiou, and N. K. Uzunoglu, "Enhancing the Focusing Properties of a Prototype Non-Invasive Brain Hyperthermia System: a Simulation Study," pp. 218–221, 2007.

[15] M. C. Velazquez-Ahumada, M. J. Freire, and R. Marques, "Metamaterial applicator for microwave hyperthermia," *2011 30th URSI Gen. Assem. Sci. Symp. URSIGASS 2011*, pp. 1–4, 2011.

[16] D. Vrba and J. Vrba, "Applicators for local microwave hyperthermia based on metamaterial technology," *8th Eur. Conf. Antennas Propagation, EuCAP 2014*, no. EuCAP, pp. 68–71, 2014.

[17] Y. Tao and G. Wang, "Influence of source offset on breast tumor hyperthermia with ??-shaped LHM lens applicator," *2010 Int. Conf. Microw. Millim. Wave Technol. ICMMT 2010*, pp. 1859–1861, 2010.

[18] Y. Tao and G. Wang, "Hyperthermia of large superficial tumor with a flat LHM lens," in *IEEE MTT-S International Microwave Symposium Digest*, 2012.

[19] L. Leggio, O. De Varona, and E. Dadrasnia, "A Comparison between Different Schemes of Microwave Cancer Hyperthermia Treatment by Means of Left-Handed Metamaterial Lenses," *Prog. Electromagn. Res.*, vol. 150, no. October 2014, pp. 73–87, 2015.

[20] Y. Tao and G. Wang, "A New Hyperthermia Scheme with a Cylindrical LHM Lens," *APCBEE Procedia*, vol. 7, pp. 32–36, 2013.

[21] D. Yin, M. Li, and J. L. Li, "Non-invasive Breast Cancer Thermotherapy Studies Using Conformal Microstrip Antennas," pp. 159–162.

[22] K.Lias, N. Buniyamin, and M. Z. B. Ahmad Narihan, "An overview of cancer thermal therapy technology based on different types of antenna exposure," in *2013 International Conference on Electrical, Electronics and System Engineering, ICEESE 2013*, 2013, pp. 96–101.

[23] K. Lias and N.Buniyamin, "Simulation Study of a Modified Rectangular Microstrip for Hyperthermia Breast Cancer Procedure with SEMCAD X Solver."

[24] P. T. Nguyen, A. Abbosh, S. Member, and S. Crozier, "Microwave Hyperthermia for Breast Cancer Treatment Using Electromagnetic and Thermal Focusing Tested on Realistic Breast Models and Antenna Arrays," vol. 63, no. 10, pp. 4426–4434, 2015.

[25] J. Vrba and B. Vrbova, "Microwave Thermotherapy : Study of Hot-Spots Induced by Electromagnetic Surface Waves," no. Eucap, pp. 3125–3126, 2013.

[26] G. Wang, J. Fang, and X. Dong, "Resolution of near-field microwave target detection and imaging by using flat LHM lens," *IEEE Trans. Antennas Propag.*, vol. 55, no. 12, pp. 3534–3541, 2007.

[27] Y. Tao and G. Wang, "A New Hyperthermia Scheme with a Cylindrical LHM Lens," *APCBEE Procedia*, vol. 7, pp. 32–36, 2013.

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