



## SPATIAL TEMPERATURE PATTERN OF A NON-INVASIVE 2.45 GHz MICROWAVE HYPERTHERMIA DEVICE

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### ABSTRACT

Hyperthermia is one method of tumor therapy, the goal of hyperthermia therapy is to generate enough heat (41°C-45°C) to kill the tumor cells without damaging the surrounding cells of healthy tissue. Maintain a stable temperature in the treatment is necessary, also knowing the area and the depth of penetrating by heat, especially when using microwave radiation hyperthermia type, purpose that the desired therapeutic effect can be restricted to certain area only (area contain tumor). In this research according to our developed microcontroller based 2.45 GHz microwave hyperthermia device, we investigate the temperature pattern during the exposure of microwave hyperthermia at ex vivo medium (agar phantom) based on some thermogram pictures acquired by using an infrared camera.

**Keywords:** microwave hyperthermia, temperature pattern, thermogram.

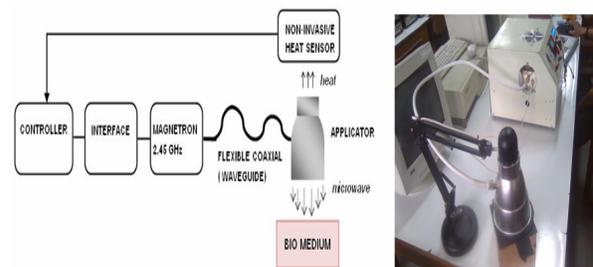
### INTRODUCTION

Hyperthermia is a method of increasing the temperature of tumour area above normal human body temperature (37°C) from 41°C to 45°C (maximum). This must be kept hyperthermia temperature range can not damage the healthy tissue surround the tumour [1, 2, 3].

There are many hyperthermia types, one is microwave hyperthermia. It is using one of ISM (Industrial Scientific and Medical) frequencies, 2.45 GHz, and suitable for superficial tumor therapy. Microwave as electromagnetic wave exposed to medium can be directly through out in lossless medium or absorbed in loss medium. SAR (specific absorption rate) is a quantity that represents the electromagnetic power absorption per unit mass in loss medium, biological medium is a kind of loss medium. The absorbed electromagnetic wave in lossy medium at a certain time can generate heat caused by molecules rotation and friction at the same time [1, 2, 4].

The temperature of microwave heated lossy medium proportional to the power of microwave source, it is important to keep the hyperthermia temperature during irradiation time by adjusting the microwave power. Another aspect in microwave hyperthermia as this research conducted is to investigate the spatial temperature distribution during microwave exposed, at the surface and the depth of the medium. As we use the conical horn type

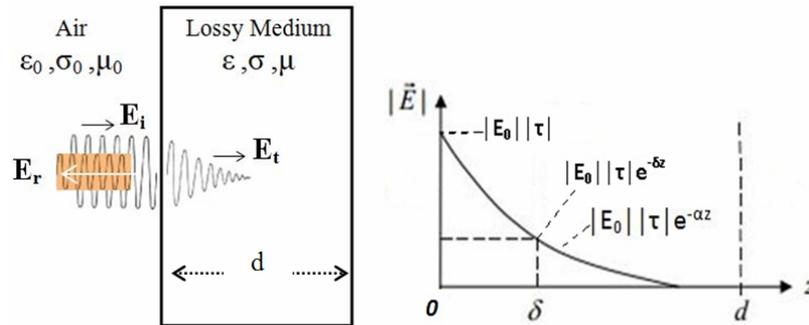
antenna with circular aperture for applicator, the temperature distribution should have relation with the aperture size of applicator, beside the medium parameters (permittivity, heat coefficient, etc.) and frequency [5, 6, 7, 11].



**Figure-1.** A schematic diagram of non-invasive 2.45 GHz microwave hyperthermia device (left) and its hardware realization (right).

### ELECTROMAGNETIC AND HEAT TRANSFER

Microwave as electromagnetic wave  $E_i$  (incident wave) exposed to biological tissue (lossy medium) can be reflected  $E_r$  or transmitted  $E_t$  as in [7, 9, 10].



**Figure-2.** Scheme of electromagnetic exposed from air to lossy medium (left) and its typical electric field profile in the medium (right).

The electromagnetic relation given by

$$E_t = \tau E_i \tag{1}$$

$$\tau = 2\eta / (\eta + \eta_0) \text{ and } \eta = \sqrt{\mu_0 / (\epsilon - j(\sigma/\omega))} \tag{2}$$

where  $E_i = E_0 e^{-\alpha z} \cos(\omega t - \beta z)$ ,  $E_0$  = initial electric field (V/m),  $\tau$  = transmission factor,  $\alpha$  = attenuation factor,  $\omega$  = frequency,  $\beta$  = phase factor ( $\beta=0$ ),  $\sigma$  = conductivity of medium,  $\epsilon$  = medium permittivity,  $\mu$  = medium permeability,  $\epsilon = \epsilon_r \epsilon_0$ ,  $\mu = \mu_r \mu_0$ ,  $\eta_0$ : free space impedance ( $\eta_0 \approx 377 \Omega$ ), and  $\eta$  = lossy medium impedance, .

The electromagnetic absorption quantities in medium have been defined with

$$SAR = (\sigma/\rho) E_t^2 \tag{3}$$

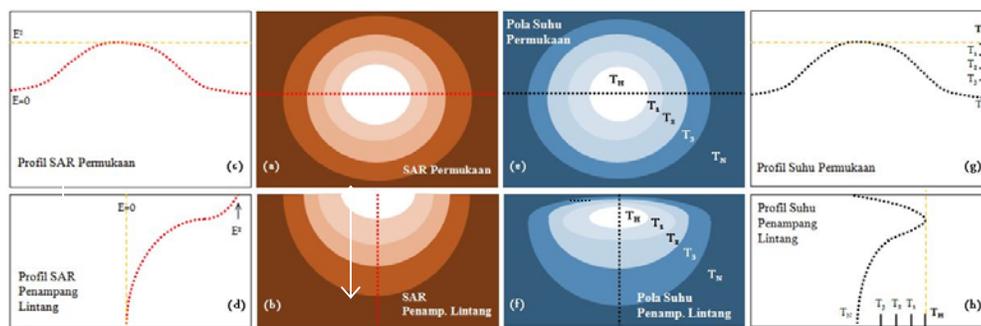
As the medium cannot keep the absorbed E and for balance mechanism, it releases the energy as heat, the

loss term mean part or mostly of EM energy become heat. The heat can be described by bio-heat transfer equation in bio-medium by Pennes.

$$\rho C \frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x^2} + Q_b + Q_m + Q_e \tag{4}$$

$\rho$  is bio-tissue density ( $\text{kg.m}^{-3}$ ),  $C$  is bio-tissue specific heat ( $\text{J.kg}^{-1}.\text{C}^{-1}$ ),  $\kappa$  is bio-tissue heat conductivity ( $\text{W.m}^{-1}.\text{C}^{-1}$ ),  $T$  is tissue temperature ( $^{\circ}\text{C}$ ),  $Q_b$  is heat transfer due to blood perfusion,  $Q_m$  is metabolic heat transfer,  $Q_e$  is external heat source from microwave radiation source and  $Q_e = \rho \text{ SAR}$ ,  $Q$  unit is in  $\text{J.m}^{-3}.\text{s}^{-1}$ .  $Q_m$  and  $Q_b$  can be ignored in ex vivo experiment as in [1, 3, 8, 9].

Figure-3 shows the theoretical SAR and temperature profile in 1D (1 dimension) and 2D (2 Dimension) after microwave heating from microwave hyperthermia applicator as in [5, 8, 11].



**Figure-3.** Theoretical SAR profiles in 2D at the surface (a) and cross section (b) of the biomedium (c) and (d) its corresponding 1D SAR profiles. The right pictures also shown the theoretical thermal image (2D) at the surface (e) and inside or cross section (f) of the biomedium, the curves (g,h) are the corresponding 1D temperature profile. ( $T_H$  is hyperthermia temperature (the highest value) and  $T_N$  is normal tissue temperature or the lowest value).

**MATERIAL AND METHODS**

This research using 2.45 GHz microwave hyperthermia device which non-invasive to the medium under microwave exposed. We use agar phantom (9gr/900ml) with 5 cm in width as representation of biological tissue.

The temperature of the agar phantom after microwave heating, both at the surface and inside, was taken by noninvasive temperature sensor, using passive thermopile array for temperature vs time only at medium surface, and using infrared camera for instantaneous time 2D temperature profile at the surface and inside the



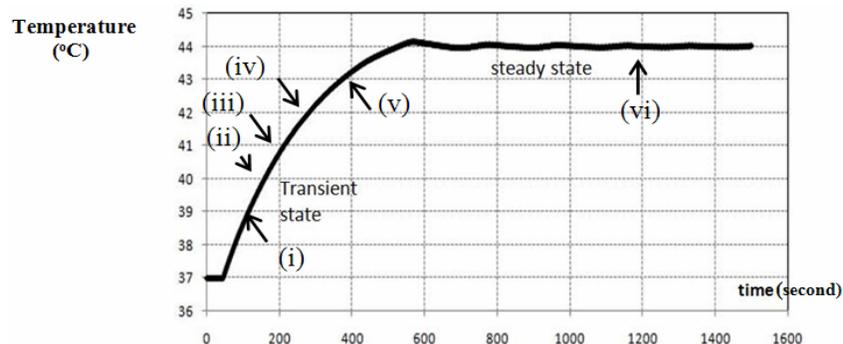
medium, this done at transient state and steady state hyperthermia temperature response.

## RESULTS AND DISCUSSIONS

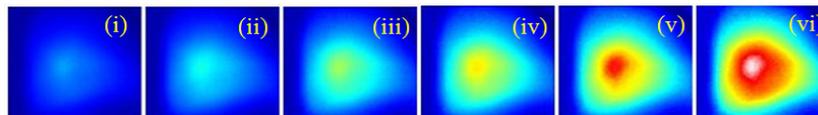
Our developed a microcontroller based 2.45 GHz microwave hyperthermia device as in Figure-1. This device generate on-off state microwave (depend on pulse width duty cycle derived by fuzzy based microcontroller)

exposed from circular aperture applicator to bio-medium or agar phantom [3].

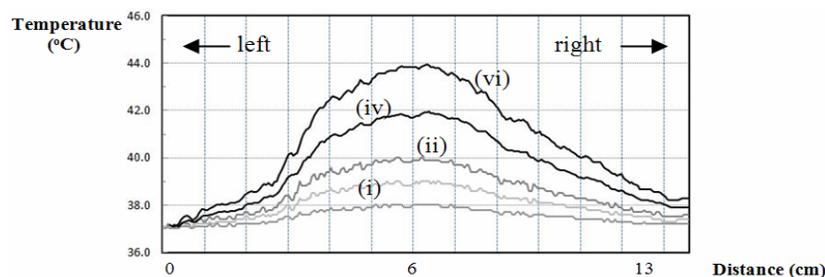
Figure-5 shown the thermograms taken by an infrared camera at different microwave exposed time from transient state (i, ii, iii, iv, v) until steady state (vi). It correspond to temperature response as seen in Figure-4, the time for (i) = 100 s, (ii) = 150 s, (iii) = 200 s, (iv) = 290 s, (v) = 390 s, and (vi) above 600s.



**Figure-4.** The 2.45 GHz microwave hyperthermia temperature response and (i), (ii), until (vi) represent the captured time of the thermograms by infrared camera.



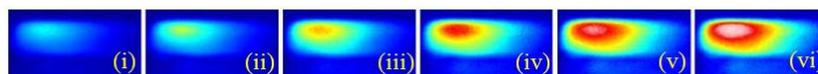
**Figure-5.** Thermograms or 2D heat patterns of the surface of the agar phantom taken at different microwave exposed duration time.



**Figure-6.** The surface (from left to right) temperature profile of the agar phantom.

The last thermogram (vi) in Figure-5 and Figure-7 is the steady state heat pattern respect to hyperthermia temperature setting (41-45°C), it represent the circular

aperture area of applicator, that shape is semicircular, because of nonlinearity of EM radiation from the circular horn antenna.



**Figure-7.** Thermograms of the cross section of the agar phantom also taken at different Time of microwave exposed.

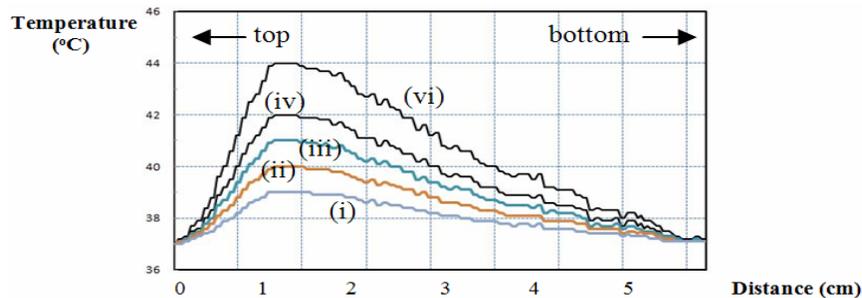
The 2D temperature profile at the surface of agar phantom follow the circular shape of the installed aperture applicator (antenna) with more than 50% area covered by hyperthermia temperature, by this temperature profile we

can estimate the beamwidth of the antenna (approximately 30°). According to 2D cross section temperature profile, it also follow the applicator type, circular horn antenna (Figure-1), we can observed the



depth of penetration of 2.45 GHz microwave exposed to agar phantom, it is around 2 cm effective coverage of hyperthermia temperature from top of the medium. By this we can also estimate the radiation pattern of the antenna, as this really near field electromagnetic exposure to the medium without any external interference.

The stability of the microwave hyperthermia device also can be shown by fact that the are same thermograms if we capture at the steady state time range (above 600s or 10 minutes).



**Figure-8.** Cross section (from top to bottom) temperature profile of the agar phantom.

## CONCLUSIONS

Our developed 2.45 GHz microwave hyperthermia device was evaluated. As the results supported by thermograms or 2D temperature measurement after microwave heating for a certain time (transient state and steady state) at agar phantom, we can conclude that this device suitable for superficial cancer treatment, with location around 2 cm below the skin and the hyperthermia temperature pattern can be restricted in a certain area only due to the circular aperture applicator that applied.

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## REFERENCES

- [1] Andras Szasz, Oliver Szasz and Nora Szasz. 2006. Physical Background and Technical Realizations of Hyperthermia. In: Hyperthermia in Cancer Treatment. A Primer (Editor): G.F. Baronzio; E. D. Hager, Landes Bioscience and Springer Science+Business Media. 27-59.
- [2] Riadh W.Y. Habash. 2008. Bioeffects and Therapeutic Application of Electromagnetic Energy. Taylor and Francis Group.
- [3] Imam Santoso, Thomas S.Widodo, Adhi Susanto and Maesadjie Tjokronagoro. 2014. Application of Fuzzy Logic for Temperature Control in Microcontroller Based 2.45 GHz Microwave Hyperthermia Devices, Int. Jour. of Applied Eng. Research. 9(6): 665-673.
- [4] Rama Jayasundar, Laurance D. Hall and Norman M. Bleehen. 1999. Magnetic Resonance, Hyperthermia and Oncology, Current Science, Indian Acad. of Science. 76(6): 794-799.
- [5] Pere J. Riu and Kenneth R. Foster. 1999. Heating Tissue by Near-Field Exposure to a Dipole: A Model Analysis. IEEE Transc. on Biomedical Eng. 6(8): 911-917.
- [6] Jan Vrba. 2005. Microwave Applicator for Medical Applications: Imaging and Thermotherapy Treatment, Microwave Review. pp. 43-46.
- [7] Radim Zajiček, Ladislav Oppl and Jan Vrba. 2008. Broadband Measurement of Complex Permittivity using Reflection Method and Coaxial Probes, Radioengineering. 17(1): 14-19.
- [8] Teerapot Wessapan, Siramate Srisawatdhisukul and Phadungsak Rattanadecho. 2011. Numerical Analysis of SAR and Heat Transfer in The Human Body Exposed to Leakage Electromagnetic Field at 915 MHz and 2450 MHz. Journal of Heat Transfer. 133: 1-13.
- [9] Yaron Alpert and Eli Jerby. 1999. Coupled Thermal-Electromagnetic Model for Microwave Heating of Temperature-Dependent Dielectric Media. IEEE Transaction on Plasma Science. 27(2): 555-562.
- [10] David M. Pozar. 2012. Microwave Engineering, 4<sup>th</sup> Ed., John Wiley and Sons, Inc.
- [11] Paolo Togni, Tomas Drizdal, Jan Vrba and Luca Vannucci. 2009. Slot-line Applicator for Microwave Hyperthermia. Journal of Microwave Power and EM Energy. 43(2): 24-30.