APPLICATION OF BRIGHNESS TEMPERATURE DETERMINATION FOR TUMOR DIAGNOSIS

A. K. Aboulseoud , N. H. Ismail and N. M. Abou-Khatwa

Department of Electrical Engineering, Faculty of Engineering

Alexandria University, Alexandria, Egypt.

ABSTRACT

Human thermal radiation intensity emission from a multilayerd tissue has been discussed in previous papers. The radiative transfer theory is applied to get that intensity (brightness temperature) in the case of tumor free tissues . This paper is concerned with the presence of tumors with different volumes and dielectric constants (types) in a human layerd tissue. The brightness temperature is calculated and it is noticed that it depends on the thickness of each layer. In addition, it is observed that the brightness temperature is sensitive to the volume and type of the tumor.

Keywords: Thermal radiation , Passive Remote sensing in Biomedical Field , Tumor Diagnosis.

1. INTRODUCTION

One of the most important applications of passive remote sensing in the biomedical field is the measurement of human thermal radiation intensity. It is observed that the spectrum of the radiation covers a very wide range of frequencies reaching the microwave band. Particularly, at microwave frequencies the thermal intensity is directly related to the brightness temperature [1].In this paper, the radiative transfer theory is prefered to determine the brightness temperature while the blood flow effect is not taken into consideration. The developed radiative transfer theory for a layered biological medium is achieved by Ismail *et al.*[2] and the analysis procedures are shown in section 2. The case of tumors with different volumes located in a muscle layer is considered . The effective dielectric constant of the muscle is discussed and the brightness temperature is calculated as a function of tumor volume and tumor type at 0.918 MHz in section 3 . Results and discussion are presented in section 4.

2. THE MATHEMATICAL FORMULA

In the case of microwave propagation inside a biological medium , the wavelength is much larger than the cell size. Thus the scattering effect can be ignored.The radiative transfer equation becomes[2]:

$$\cos\theta \frac{dI(z)}{dz} = -k_a I(z) + k_a B_T \qquad (1)$$

where I(z) is the thermal radiation intensity as a function of z, ka is the absorption constant, B_T is the thermal emission source and θ is the angle made by I w.r. to z axis. In order to study the radiative transfer equation can be written in the j^{th} layer as:

$$\cos\theta \frac{dI_j^+(z)}{dz} = -k_{aj}I_j^+(z) + k_{aj}B_T(z) \quad (2.a)$$

$$\cos\theta \frac{dI_j^-(z)}{dz} = k_{aj}I_j^-(z) - k_{aj}B_T(z) \quad (2.b)$$

Where the (+) and (-) signs represent the upward and the downward direction respectively.

i.e.

$$I_j^+(z) = I_j(\theta,\phi,z)$$

$$I_j^-(z) = I_j(\pi-\theta,\phi,z)$$

For a multi-layered medium with different dielectric constants separated from each other by planar interfaces at z = 0,--,-dj,---,-dN-1, the radiative transfer theory will be as [2],[3]

$$\begin{bmatrix} A_j \\ B_j \end{bmatrix} = \prod_{L=j}^{N-1} \underline{C_{L,L+1}} \begin{bmatrix} A_N \\ B_N \end{bmatrix} + \sum_{L=j}^{N-1} \left(\prod_{i=j-1}^{L-1} \underline{C_{i,i+1}} \right) \underline{D_{L,L+1}} \begin{bmatrix} I_{Lp}(-d_L) \\ I_{L+1p}(-d_L) \end{bmatrix} \quad (3)$$

where Aj and Bj are the amplitude of the upward and downward intensities in the jth layer. $\underline{C_{j-1,j}}$ = U which is the unit matrix and $\underline{C_{L,L+1}}$ and $\underline{D_{L,L+1}}$ are called the propagation matrices.Their elements are determined by knowing the dielectric constants of each layer. The dielectric constants of skin ,fat and muscle are obtained at the operating frequency by [4].For the three layers; skin , fat and muscle the radiative transfer equation is [2]

$$\begin{bmatrix} A_0 \\ 0 \end{bmatrix} = \underline{C_{01}}\,\underline{C_{12}}\,\underline{C_{23}} \begin{bmatrix} 0 \\ B_2 \end{bmatrix} + \underline{C_{01}}\,\underline{C_{12}}\,\underline{D_{23}} \begin{bmatrix} I_{2p}(-d_2) \\ I_{3p}(-d_2) \end{bmatrix} + \underline{C_{01}}\,\underline{D_{12}} \begin{bmatrix} I_{1p}(-d_1) \\ I_{2p}(-d_1) \end{bmatrix} + \underline{D_{01}} \begin{bmatrix} 0 \\ I_{1p}(0) \end{bmatrix} \quad (4)$$

Where A_0 represents the intensity Io measured at the upper half space. At microwave frequencies , the thermal intensity Io is directly proportional to the brightness temperature TB as [1]

$$T_B = (\lambda^2/K)\,I_o \quad (5)$$

where K is the Boltzmann constant and λ is the wavelength.

3. THE PROBLEM OF TUMOR PRESENCE IN A MUSCLE LAYER

We assume that there is a tumor located in a muscle layer as shown in Figure (1), the muscle layer will be the host material ,and the tumor is the inclusion material. The average dielectric constant of a mixture is related to the dielectric constants of the individual substances and their orientations relative to the direction of the incident electric-field vector. Both the host and inclusion materials are assumed to have isotropic dielectric constants ε_h and ε_i respectively. Generally , the inclusion concentration is defined by the inclusion volume fraction Vi and is given by:

$$V_i = \frac{4}{3}\pi abcN \quad (6)$$

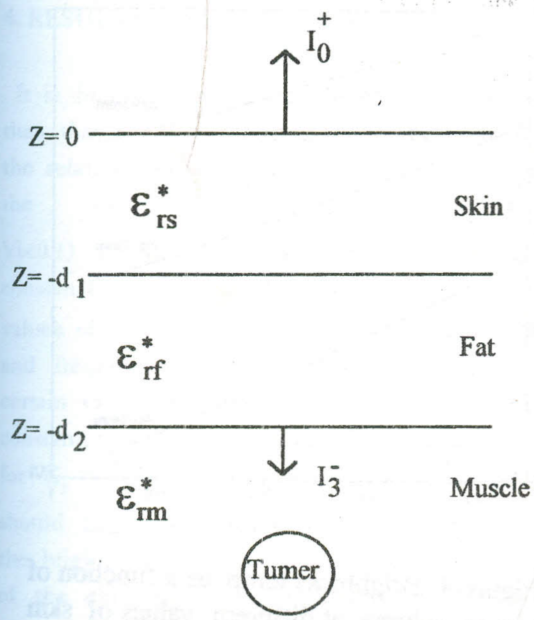

Figure 1. Skin-fat and muscle with the presence of the tumor in the muscle layer

where N is the number of ellipsoids per unit volume of the mixture and a ,b and c are the ellipsoidal particle semi- axes. The host material volume fraction Vh is written as

$$V_h = 1 - V_i$$

Since we have considered that ε_h & ε_i are isotropic dielectric constants ,therefore, the average dielectric constant of the mixture εm is anisotropic with non-zero diagonal elements [5]. An expression for the average dielectric constant is obtained by [6]

$$\varepsilon_m = \varepsilon_h + \frac{V_i(\varepsilon_i - \varepsilon_h)}{1 + A_u(\frac{\varepsilon_i}{\varepsilon^*} - 1)} \quad (7)$$

where u represents a, b or c and ε^* is the effective dielectric constant for the region immediately surrounding an included particle. While A_u is the depolarization factor of the ellipsoid along its u-axis.The depolarization factor A_u can be written as [7]

$$A_u = \frac{abc}{2}\int_0^\infty (u^2+s)^{-1}[(a^2+s)(b^2+s)(c^2+s)]^{-\frac{1}{2}} ds \quad (8)$$

where

$$A_a + A_b + A_c = 1$$

In our case we assume that the tumor has a spherical shape. Therefore,

$$A_a = A_b = A_c = \frac{1}{3}$$

For small values of the inclusion volume fraction i.e. $V_i \le 0.1$, the particle interaction may be ignored and ε^* may be taken equal to the dielectric constant of the host material εh. While for higher values of V_i, the particle is mostly assumed to be surrounded by the mixture rather than by the host material and ε^* will be equal to ε_m [7]. Thus,

$$\varepsilon^* = \varepsilon_h \text{ for } V_i \le 0.1$$
$$\varepsilon^* = \varepsilon_m \text{ for } V_i \ge 0.1 \quad (9)$$

Substituting equation (9) in (7) , we get

$$\varepsilon_m = \varepsilon_h[1 + 3V_i(\frac{\varepsilon_i - \varepsilon_h}{\varepsilon_i + 2\varepsilon_h})] \quad \text{for } V_i \le 0.1$$
$$= \varepsilon_h + 3V_i\varepsilon_m \frac{(\varepsilon_i - \varepsilon_h)}{(\varepsilon_i + 2\varepsilon_m)} \quad \text{for } V_i \ge 0.1 \quad (10)$$

If we consider the observed angle to be zero and a uniform temperature profile inside each layer, therefore, the thermal intensity in the upper half space, I_0, can be obtained by substituting equation (10) in (4). As a result, the brightness temperature which is the radiometer temperature is calculated by using equation (5).

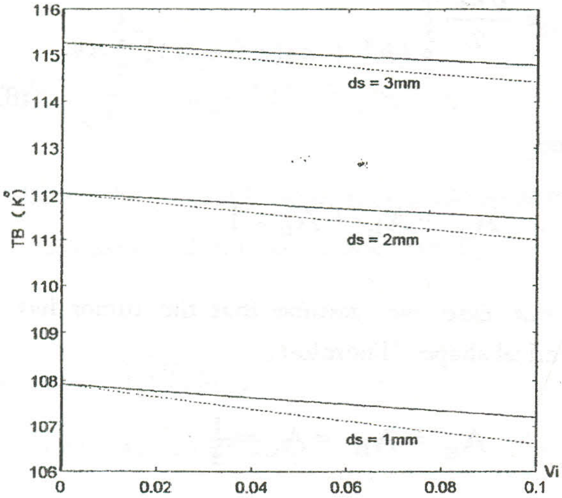

Figure 2. Brightness temp. as a function of tumor volume at different values of skin thickness for df = 1 cm at two values of tumor dielectric constants.
— $\varepsilon i = 3\ \varepsilon h$ ....$\varepsilon i = 10\ \varepsilon h$

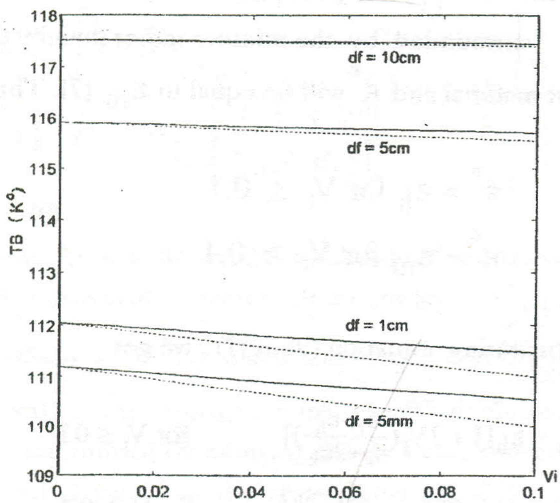

Figure 3. Brightness temp. as a function of tumor volume at different values of fat thickness for ds = 2 mm at two values of tumor dielectric constants.
— $\varepsilon i = 3\ \varepsilon h$ ....$\varepsilon i = 10\ \varepsilon h$

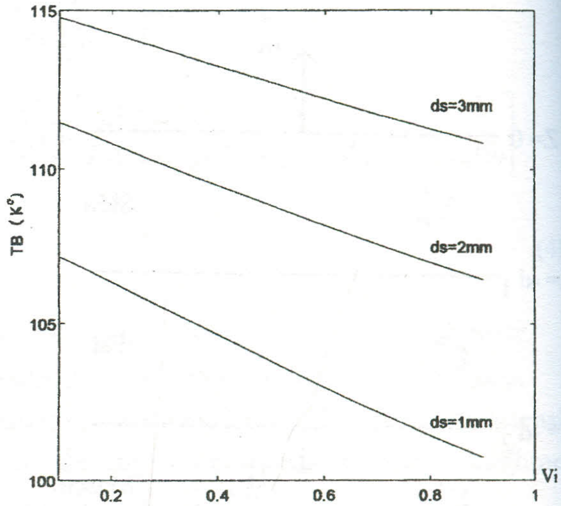

Figure 4. Brightness temp. as a function of tumor volume at different values of skin thickness for df = 1cm and $\varepsilon i = 3\ \varepsilon h$.

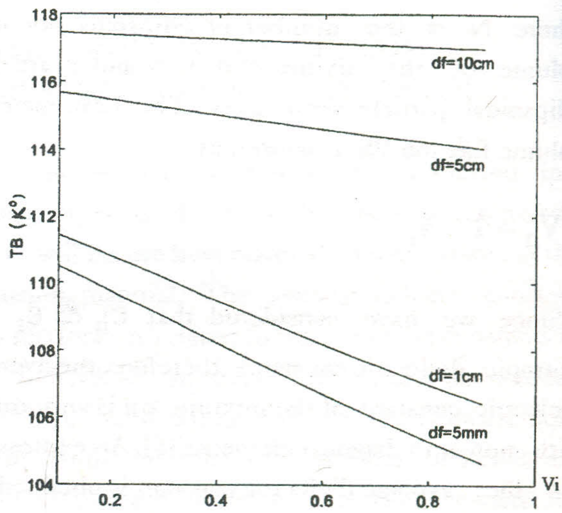

Figure 5. Brightness temp. as a function of tumor volume at different values of fat thickness at ds = 2 mm and $\varepsilon i = 3\ \varepsilon h$.

4. RESULTS AND DISCUSSION

It is found that the tumor dielectric constant is higher than that of the surrounding tissue [8]. Figure(2) shows the relation between the brightness temperature and the inclusion (tumor) volume fraction V_i (where Vi<0.1) at two different values of tumor dielectric constant $\varepsilon_i = 3\varepsilon_h$ and $\varepsilon_i = 10\varepsilon_h$ and for different values of skin thickness with a fat thickness d_f = 1cm and frequency of 0.918 MHz. It is noticed that for certain values of skin thickness and tumor dielectric constant, the rate of decrease of brightness temperature for $\varepsilon_i = 3\varepsilon_h$ is lower than that for $\varepsilon_i = 10\varepsilon_h$. It should be pointed out that in the absence of the tumor, the brightness temperature increases with the increase of the skin thickness. In Figure (3) the brightness temperature is plotted versus the tumor volume fraction for a fat thickness varying from 5mm to 10 cm, at a skin thickness ds = 2mm and for two values of tumor dielectric constants $\varepsilon i = 3\varepsilon h$ and $\varepsilon i = 10\,\varepsilon h$. It is observed that for $\varepsilon i = 3\varepsilon h$, the brightness temperature decreases with a lower rate than the case of $\varepsilon_i = 10\varepsilon_h$ for a fat thickness ,df , less than 10 cm. While for df = 10 cm the brightness temperature is almost constant for both values of dielectric constants. Figure (4) shows the brightness temperature against the tumor volume fraction Vi , 1 >Vi > 0.1, for different values of the skin thickness at df = 1 cm and $\varepsilon_i = 3\varepsilon_h$, while Figure (5) is plotted for different values of fat thickness at ds = 2 mm. It is found that the brightness temperature decreases as the tumor volume fraction increases but with a decreasing rate greater than that shown in Figures (2) , (3). The decrease of the brightness temperature due to the presence of a tumor with different volumes can be interpreted as follows;

It is known that the presence of a tumor results in a temperature increase of the region containing the tumor [8], therefore, the brightness temperature measured outside the biological tissue will be decreased than that of the free of tumor case. Figure (6) shows the brightness temperature versus the tumor dielectric constant varying from $\varepsilon_i = \varepsilon_h$ to $\varepsilon_i = 15\varepsilon_h$ for different values of Vi at ds = 2mm and d_f = 1cm. It indicates that the brightness temperature decreases as the tumor dielectric constant increases and as the tumor volume increases.

Thus , the brightness temperature measured for a certain tumor volume indicates the tumor dielectric constant which help us to identify the tumor type. This leads to discriminating malignant tumors from normal tumors.

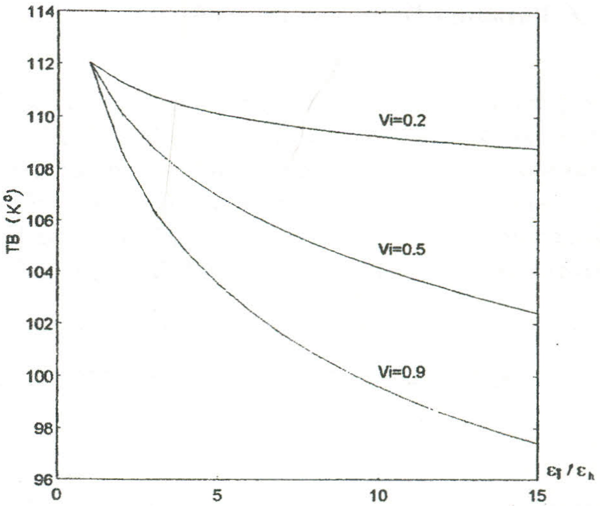

Figure 6. Brightness temp. as a function of tumor dielectric constant at different values of tumor volume fraction at ds = 2 mm and df= 1 cm.

As a result , the brightness temperature measurements outside a human layered tissue can be considered as a passive remote sensing tool or a noninvasive method could be applied successfully for tumor diagnosis.

REFERENCES

[1]L. Tsang, J.A. Kong and R.T. Shin, *Theory of Microwave Remote Sensing*, John Willey & Sons, New York, 1985.

[2]N. H. Ismail, A..K. Aboulseoud and A.E. El-Khamy, "Non-Invasive Method for the Measurement of Temperature Emission from An

Inhomogeneous Medium", *J. of Electromagnetic Waves and Applications*, vol. 5, No. 8, 1991.

[3]M.A. Karam and A.K. Fung, "Radiative Transfer Theory in a Multilayerd Random Medium with Laminar structure: Green's Function Approach", *J. Appl. Phys.* 59, No. 11, 1986.

[4]M.A. Stuchly and S.S. Stuchly, "Dielectric Properties of Biological Substances-Tabulated", *J. Microwave Power*, vol. 15, 1980.

[5]L.S. Taylor, "Dielectric Loaded with Anisotropic Materials", *IEEE Trans* ,AP. 14, 1966.

[6]G.P. de Loor, "Dielectric Properties of Heterogeneous Mixtures Containing Water", *J. Microwave Power*, vol. 3, 1986.

[7]F.T. Ulaby, R.K. Moore and A.K. Fung, *Microwave Remote Sensing Active and Passive*, vol. III, Artech House Inc., 1986.

[8]G.H. Nussbaum *Physical Aspects of Hyperthermia*, American Institute of Physics, Inc. 1982.