# OPTIMUM MEDICAL SIGNALS FOR TUMOR TREATMENTS

**Nour H. Ismail**
Department of Electrical Engineering, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

Optimum medical signals for a two layered biological medium are discussed. The design procedures are depicted. The design procedures are depicted and the optimum signal response is illustrated. As an application, optimum medical signal and its response at a certain location inside a fat-muscle medium are obtained. The resulting optimum signals can be used successfully to treat tumors at different locations inside the muscle layer.

## 1. INTRODUCTION

Many medical reports stated that tumors can be destroyed by raising their temperature to certain values. Those values depend on tumor type and volume [1]. The main idea of raising temperature (Hyperthermia) is to expose the malignant cells to X - ray doses or signals for different intervals. The signals may be transmitted by external antennas or implanted needles [2-8]. The disadvantage of this method is the damage that occurs in the normal cells surrounding the malignant cells.In this paper, the suggested signal which is referred to as optimum medical signal can be used to overcome this problem. Optimum signals are defined as those input signals which are propagated through a medium and maximize the received signals at certain location and time. The design approach of optimum signals is based on the matched filter technique [9]. In section 2, the problem is formulated and the transfer function, including the transmission effect from air to the biological medium, is obtained. In section 3, an optimum medical signal and its received response at a certain location inside the muscle medium is obtained.

## 2. THE TRANSFER FUNCTION OF A FAT-MUSCLE LAYERED MEDIUM

Consider an electromagnetic signals incident normally on the surface of a fat-muscle medium as shown in Figure (1). We assume that the electric and magnetic field vectors are in the y and x directions respectively. The field equations can be written as

$$E_{oy} = E_o\,(e^{\gamma_o z} + R\,e^{\gamma_o z}),\ \ z > 0 \qquad (1\text{-a})$$

$$E_{fy} = E_1\,e^{\gamma_f z} + E_2\,e^{-\gamma_f z},\ \ -d < z < 0 \qquad (1\text{-b})$$

$$E_{my} = E_o\,T\,e^{\gamma_m (z+d)},\ \ z < -d \qquad (1\text{-c})$$

$$H_{ox} = \frac{E_p}{\zeta_o}(e^{\gamma_o z} - R e^{-\gamma_o z}),\ \ z > 0 \qquad (2\text{-a})$$

$$H_{fx} = \frac{1}{\zeta_f}(E_1 e^{\gamma_f z} - E_2 e^{-\gamma_f z}),\ \ -d < z < 0 \qquad (2\text{-b})$$

$$H_{mx} = \frac{E_o}{\zeta_m} T e^{\gamma_m (z+d)},\ \ z < -d \qquad (2\text{-c})$$

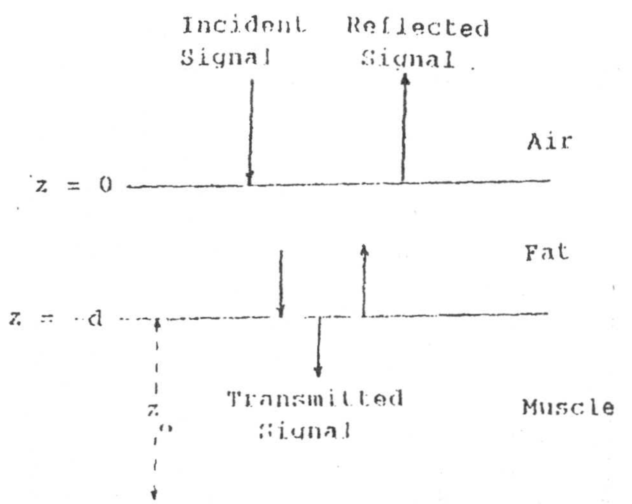


**Figure 1.** Incident and reflected signals in a fat-muscle layered medium.

where $E_o$ is the amplitude of the incident electric field and R, T are the reflection and transmission coefficients and $\gamma_o, \gamma_f, \gamma_m$ are the propagation constants in air, fat and muscle respectively. Since the relative permittivity constants of fat and muscle depend on frequency
(dispersive media), they are expressed as

$$\epsilon(\omega)=\epsilon'(\omega)-j\epsilon''(\omega).$$

Some values of $\epsilon'(\omega)$ and $\epsilon''(\omega)$ are tabulated in Table (1). $\gamma(\omega)$ is written in terms of $\epsilon(\omega)$ as

$$\gamma(\omega)=j\left(\frac{\omega}{C}\right)$$

$\sqrt{\epsilon(\omega)}$ $\zeta_o, \zeta_f, \zeta_m$ are the wave impedances in air, fat and muscle respectively. Generally, $\zeta(\omega) = \sqrt{\mu_o/\epsilon(\omega)}$. $\mu_o$ is the permeability of nonmagnetic materials.

By applying the boundary conditions at the interfaces z=0 and z = -d, we get expressions for the reflection and transmission coefficients as

$$R(\omega) = \frac{((\zeta_m+\zeta_f)+(\zeta_m-\zeta_f)e^{-2\gamma_f d}) - \sqrt{\epsilon_f}((\zeta_m+\zeta_f)-(\zeta_m-\zeta_f)e^{-2\gamma_f d})}{((\zeta_m+\zeta_f)+(\zeta_m-\zeta_f)e^{-2\gamma_f d}) + \sqrt{\epsilon_f}((\zeta_m+\zeta_f)-(\zeta_m-\zeta_f)e^{-2\gamma_f d})} \quad (3)$$

$$T(\omega) = \frac{2\zeta_m(1+R)e^{-\gamma_f d}}{(\zeta_m+\zeta_f)+(\zeta_m-\zeta_f)e^{-2\gamma_f d}} \quad (4)$$

**Table 1**. Permittivity constants for fat and muscle [10].

| Frequency MHZ | Muscle | | Fat | |
|---|---|---|---|---|
| | $\epsilon'$ | $\epsilon''$ | $\epsilon'$ | $\epsilon''$ |
| 433 | 53 | 55 | 5.6 | 0.26 |
| 750 | 52 | 42.4 | 5.6 | 0.46 |
| 915 | 51 | 34.74 | 5.6 | 0.59 |
| 1500 | 49 | 25.1 | 5.6 | 0.945 |
| 2450 | 47 | 19.06 | 5.5 | 1.385 |
| 3000 | 46 | 17.69 | 5.5 | 1.6 |
| 5000 | 44 | 17.5 | 5.5 | 1.97 |
| 5800 | 43.3 | 18.16 | 5.05 | 1.99 |
| 8000 | 40 | 20.25 | 4.7 | 1.92 |
| 10000 | 39.3 | 22 | 4.5 | 1.76 |

The transfer function which represents the transmission from air to any depth in the muscle layer, in frequency domain, can be written as

$$H(\omega,z_o) = T(\omega)e^{-\gamma_m(\omega)(z_o+d)}, \quad z_o < -d$$

The magnitude and phase of $H(\omega,z_o)$ are plotted in Figure (2).

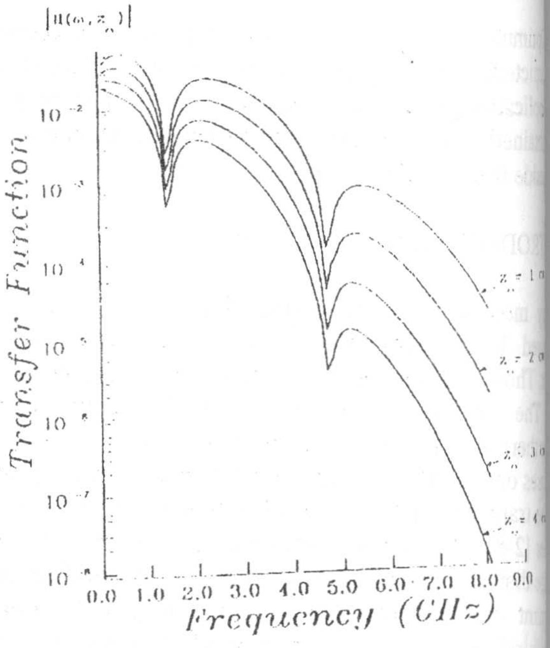


**Figure 2-a**. The magnitude of the transfer function of a fat-muscle medium. Assume the tumor location $z_o$=1,2,3,4 cm. d = 2 cm.

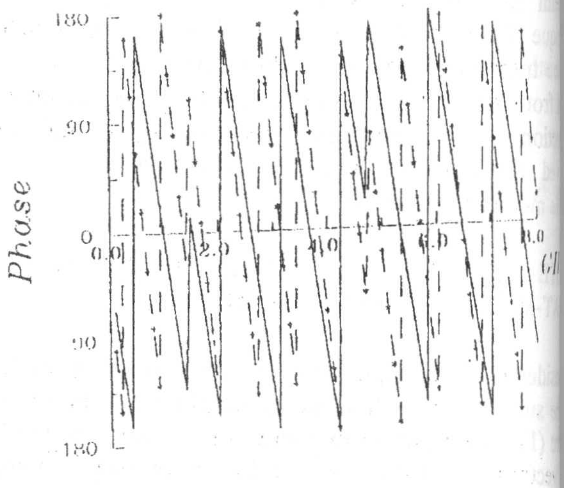


**Figure 2-b**. The phase of the transfer function of muscle medium --- $z_o$ = 2 cm ---- $z_o$ = 4 cm.

## 3. OPTIMUM MEDICAL SIGNALS

The optimization criterion considered is the maximization of the received signal amplitude at a certain location z and an arbitrary time $t_o$. This is equivalent to applying the matched filter theory . The optimum medical signal is that signal which matches a filter of a transfer function $H(\omega,z_o)$ given by equation (5). It can be written as [9]

$$\zeta_{op}(t,z_o) = A\, h^*(t_o - t,z_o) \tag{6}$$

where A is a constant which determine the required energy. h(t,z) is the filter impulse response and equals to the inverse Fast Fourier transform of $H(\omega,z)$. The received signal at any location z corresponding to the optimum signal can be obtained by applying the convolution theory as follows,

$$\zeta_r(t,z) = \zeta_{op}(t,z_o) * h(t,z) \tag{7}$$

Figures (3) show the optimum medical signal and its received signal at a depth $z_o = 4$ cm inside the muscle layer as functions of the shifted time $(t_o - t)$.

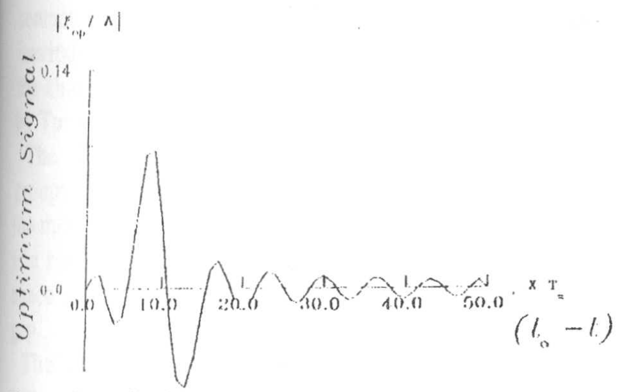


Figure 3-a. Optimum signal for a tumor at $z_o = 4$ cm in the muscle layer. $T_s = 50 \times 10^{-12}$ sec.

## 4. DISCUSSION AND CONCLUSION

The results show that the amplitude of the transfer function $H(\omega,z)$ represents a low pass filter and it has local minimum values at several frequencies. The existence of such modes would be expected since the incident and reflected fields oppose each other in each layer and form standing waves at those frequencies. Also, it is observed that the optimum signal has a shape close to sin x / x function . Furthermore, it is seen that the optimum signal response is a narrow pulse with a peak value at $t = t_o$ . This means that the energy of the response signal is also maximized at $t = t_o$ and at $z = z_o$ (the tumor location). Therefore, the heat effect is maximized at the tumor location. The calculations of power absorption due to the optimum signal response are postponed to a future paper.

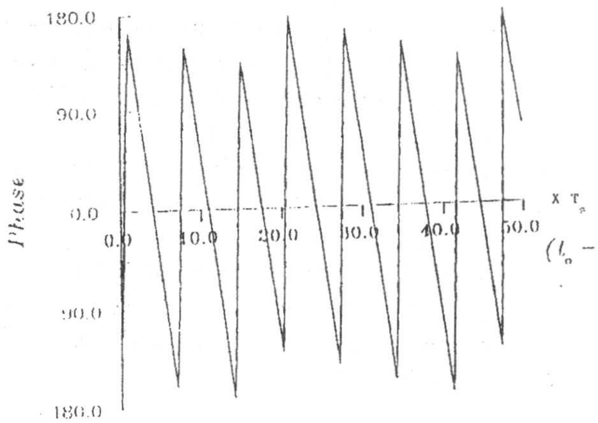


**Figure 3-b**. Optimum signal phase for a tumor at $z_o$=4cm in the muscle layer.

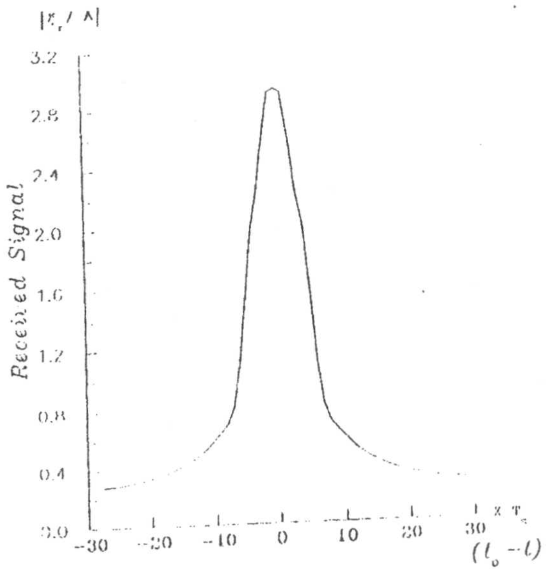


**Figure 3-c**. Received signal at $z_o = 4$ cm in the muscle layer.

As a result, the optimum medical signal can be used successfully to destroy a tumor at a known depth without severe

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