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Transmission and Reflection Characteristics of Electromagnetic Energy in Biological Tissues

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Abstract

When electromagnetic waves are allowed to incident on a perfect conductor they are entirely reflected. But they are transmitted completely through good dielectric. However, when they are allowed to impringe on a medium which is neither a good conductor nor a good dielectric, they are partially reflected and partially transmitted. It is easy to estimate the above characteristics on material which are homogeneous. In the case of nonhomogeneous media like a human body, the behavior of the incident and transmitted rays is complex. The reflection and transmission coefficients vary from tissue to tissue and they are dependent on permittivity, conductivity, permeability and frequency. Moreover, these fundamental parameters are also dependent on frequency. In the present paper, the analysis is made and the data on various tissues of reflection and transmission of few biological tissues are presented. The analysis is extendable for multilayers involving bio-tissues.

Keywords: Biological Tissues, Electromagnetic Energy, Reflection and Transmission Coefficient.

Introduction

Electromagnetic waves interact with different systems including bio systems. The electromagnetic radiations produced by radars, telecommunication transmitters, cellular telephones, microwave ovens etc., are electromagnetic pollutants. Human body is exposed now a days by several such emission and health hazards are created [1]. If humans are exposed to Radio Frequency (RF) energy for substantial duration, damaging biological results may develop.

When exposed to electromagnetic fields or radiation, there is no bipolar contact but energy can be deposited in the body [2]. The safety and health problems due to effects of this electromagnetic energy are the subject of controversy. However, its interaction can be effectively used provided the electromagnetic energy is properly concentrated on the tissues of the human body. Electromagnetic radiations from well defined sources have desirable effects on curing cancer [3]. In general, average RF power density level of greater than 10 mw/cm^2 is regarded as hazardous to human life and permitted exposure to this level should not exceed 1 hour. It has been observed that radiation levels below 1mw/cm^2 are safe indefinitely.

The effects of RF energy on human tissue depends upon the nature of RF (ie. Freq.), its power or radiated field intensity, exposure time, type of exposure (direct/ indirect) and also whether dominant effect is thermal or non thermal. Moreover the interaction of electromagnetic field with biological system depends on dielectric permittivity, conductivity and permeability of biological tissues. The dielectric permittivity, conductivity values vary from tissue to tissue and depend on frequency [4]. Biological materials have permeability values close to that of free space and independent of frequency.

When electromagnetic waves are allowed to incident on a perfect conductor they are entirely reflected.When they are incident on perfect dielectric they are completely transmitted.when they are incident on a biological tissue with a finite electrical conductivity and finite dielectric permittivity, they are partially transmitted and partially reflected and the behavior of incident and transmitted rays is complex [5].

Formulation

The reflection and transmission of a plane wave at a planar tissue interface depends on the frequency, polarization and angle of incidence of the wave and on permittivity and conductivity of the tissue. This paper presents a summary of reflection and transmission characteristics of a plane wave when it is incident normal to the planar biological tissue interface.

Permittivity is in general complex inlossy media. It is given by

$$\varepsilon = \varepsilon_0(\varepsilon_r - j\sigma / \omega\varepsilon_0) \tag{1}$$

Where

ε_0 is absolute permittivity of free space.

ε_r is relative permittivity of the medium.

σ is the conductivity of themedium.

If dielectric properties are closer on both sides of the interface the power reflection is small. The fraction of power transmitted is related by power transmission coefficient.

The intrinsic impedance of the medium is given by

$$\eta = \sqrt{(j\omega\mu / (\sigma + j\omega\varepsilon))} \tag{2}$$

Where μ is permeability of medium.

If intrinsic impedances of the two media are approximately equal , most of the energy is transmitted into the second medium, and the reflected field is relatively small. Conversely, if intrinsic impedances differ greatly, the transmitted field is small, and the quantity of reflected energy is large. When an EM wave is incident normally on the surface of a dielectric, reflection and transmission takes place. Reflection coefficient is defined as the ratio of reflected wave and incident wave.

Reflection coefficient for E is [6]

$$\Gamma_E = \frac{E_r}{E_i} \tag{3}$$

Reflection coefficient for H is

$$\Gamma_H = \frac{H_r}{H_i} \tag{4}$$

Where

E_r =reflected electric field,

E_i =incident electric field,

H_r =reflected magnetic field,

H_i =incident magnetic field,

Transmission coefficient is the ratio of transmitted wave and incident wave.

Transmission coefficient for E is

$$\mathrm{T}_E = \frac{E_t}{E_i} \tag{5}$$

Transmission coefficient for H is

$$\mathrm{T}_H = \frac{H_t}{H_i} \tag{6}$$

let $\varepsilon_1, \sigma_1, \eta_1$ the permittivity, conductivity and intrinsic impedance of medium 1. $\varepsilon_2, \sigma_2, \eta_2$ are the values for medium 2. We know that

$$E_i = \eta_1 H_I \tag{7}$$

$$E_r = -\eta_1 H_r \tag{8}$$

$$E_t = \eta_2 H_t \tag{9}$$

At the boundary of a dielectric, the tangential components of E and H are continuous, that is

$$E_i + E_r = E_t \tag{10}$$

Where E_t is the tangential component of E

$$H_i + H_r = H_t \tag{11}$$

Where H_t is the tangential component of H

From the above equations , we have

$$E_i - E_r = \eta_1 H_t \tag{12}$$

$$= \eta_1 H_t = (E_i - E_r) \tag{13}$$

By substituting eqn. (9) and (10) in (13) we get

$$= \eta_1 H_t = \frac{\eta_1}{\eta_2} E_t \tag{14}$$

$$= \frac{\eta_1}{\eta_2}(E_i + E_r) \tag{15}$$

$$\eta_2 (E_i - E_r) = \eta_1 (E_i + E_r) \tag{16}$$

$$\eta_2 E_i - \eta_1 E_i = \eta_1 E_r + \eta_2 E_r \tag{17}$$

$$\frac{E_r}{E_i} = \Gamma_E = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{18}$$

Reflection coefficient for E is

$$\Gamma_E = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{19}$$

Now consider $E_t = E_i + E_r$

$$\frac{E_t}{E_i} = 1 + \frac{E_r}{E_i} \tag{20}$$

$$= 1 + \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{21}$$

$$\frac{E_t}{E_i} = T_e = \frac{2\eta_2}{\eta_2 + \eta_1} \tag{22}$$

Transmission coefficient for E is

$$T_e = \frac{2\eta_2}{\eta_2 + \eta_1} \tag{23}$$

From the above equations

$$\frac{H_r}{H_i} = -\frac{E_r}{E_i} = -\frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{24}$$

$$\frac{H_r}{H_i} = \Gamma_H = \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} \tag{25}$$

Reflection coefficient for H is

$$\Gamma_H = \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} \tag{26}$$

Similarly ,consider

$$H_i + H_r = H_t$$

$$\frac{H_t}{H_i} = 1 + \frac{H_r}{H_i} \tag{27}$$

$$= 1 + \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} \tag{28}$$

$$\frac{H_t}{H_i} = \mathrm{T}_H = \frac{2\eta_1}{\eta_1 + \eta_2}$$

Transmission coefficient for H is

$$\mathrm{T}_H = \frac{2\eta_1}{\eta_1 + \eta_2} \tag{29}$$

The analysis for reflection and transmission characteristics for two layers of bio-tissues can be extended to multiple layers of tissues.For multiple layers , the reflection and transmission characteristics become complicated. Multiple reflections can occur between outer layer and subcutaneous tissue boundaries. Reflection and Transmission coefficients are modified [7]. Transmitted wave will recombine with the reflected wave to form standing waves in each layer. For the tissue model shown in Fig.1, the electric field strength in the fat layer is given by

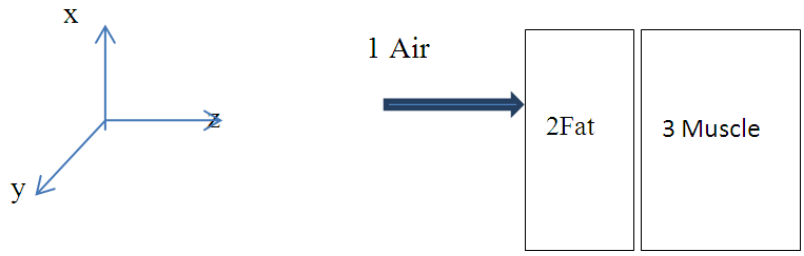

Figure 1: Plane wave impringing on a composite fat-muscle layer.

$$E_f = F_l E_0[e^{-(\alpha_2 + j\beta_2)z} + \Gamma_{32} e^{(\alpha_2 + j\beta_2)z}] \tag{30}$$

and the electric field in the muscle tissue is given by

$$E_m = F_t E_0 e^{(\alpha_3 + j\beta_3)z} \tag{31}$$

where α_2, β_2 and α_3, β_3 are the attenuation and propagation coefficients in fat and muscle, respectively. The layer function F_l and the transmission function F_t are given by

$$F_l = \frac{T_{12}}{e^{(\alpha_2 + j\beta_2)l} + \Gamma_{21}\Gamma_{32} e^{-(\alpha_2 + j\beta_2)l}} \tag{32}$$

$$F_t = \frac{T_{12}T_{23}}{e^{(\alpha_2 + j\beta_2)l} + \Gamma_{21}\Gamma_{32} e^{-(\alpha_2 + j\beta_2)l}} \tag{33}$$

Where T12 and T23 are the transmission coefficients at the air–fat and fat–muscle boundaries, respectively. Γ_{21} and Γ_{32} denote the reflection coefficients at these boundaries, respectively, l is the thickness of the fat layer.

Results

In this paper Reflection and Transmission characteristics for tissue interfaces over a frequency range of 10 MHz to 6GHz are plotted.

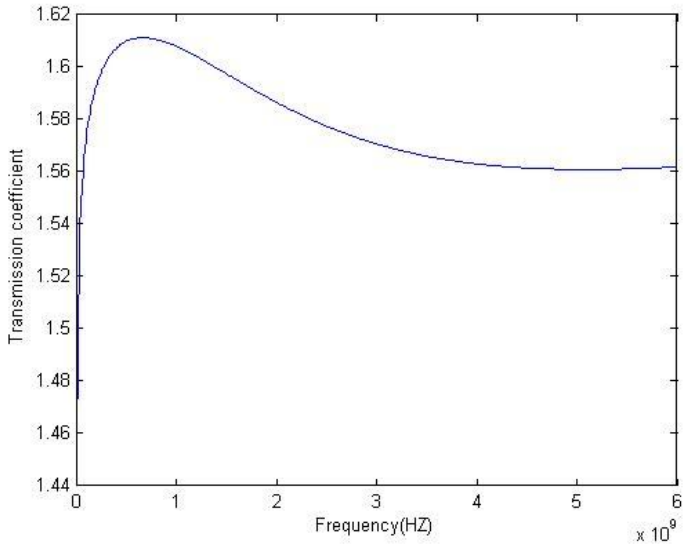

Figure 2: Variation of Transmission coefficient for Skin-Fat interface.

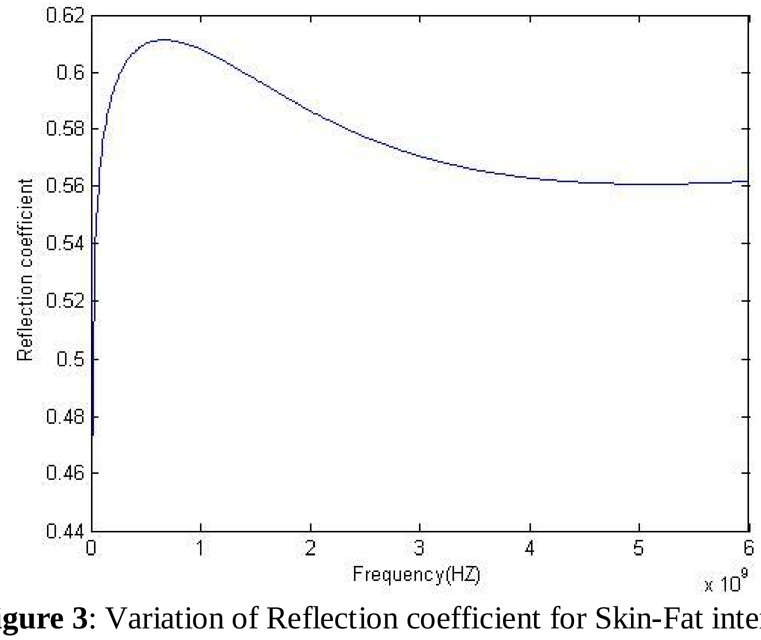

Figure 3: Variation of Reflection coefficient for Skin-Fat interface.

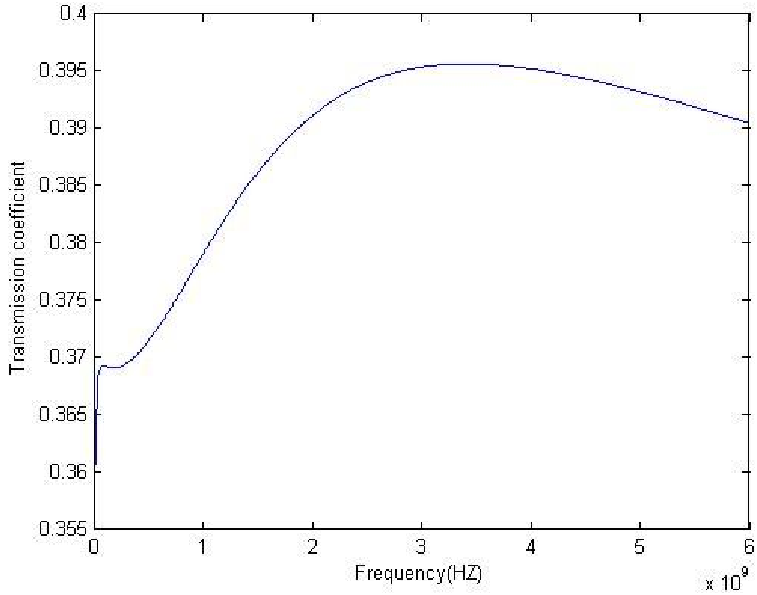

Figure 4: Variation of Transmission coefficient for Fat-Muscle interface.

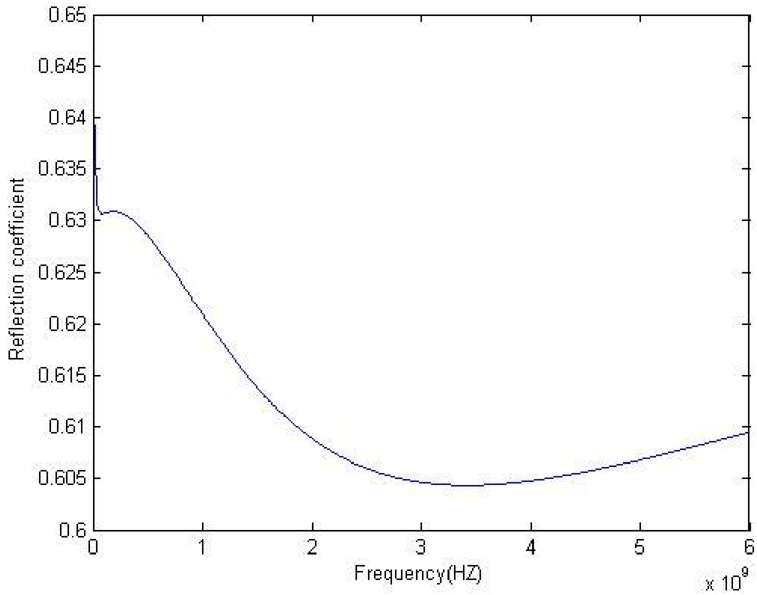

Figure 5: Variation of Reflection coefficient for Fat-Muscle interface.

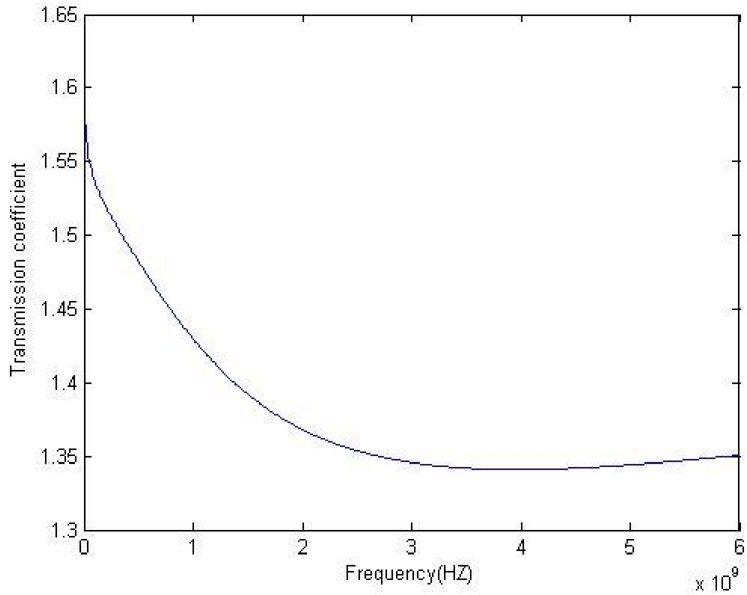

Figure 6: Variation of Transmission coefficient for Muscle-Bone interface

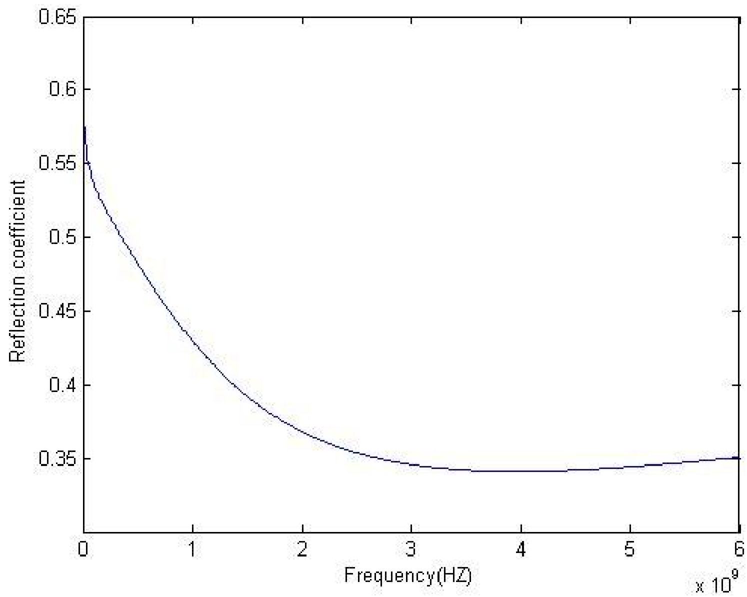

Figure 7: Variation of Reflection coefficient for Muscle-Bone interface.

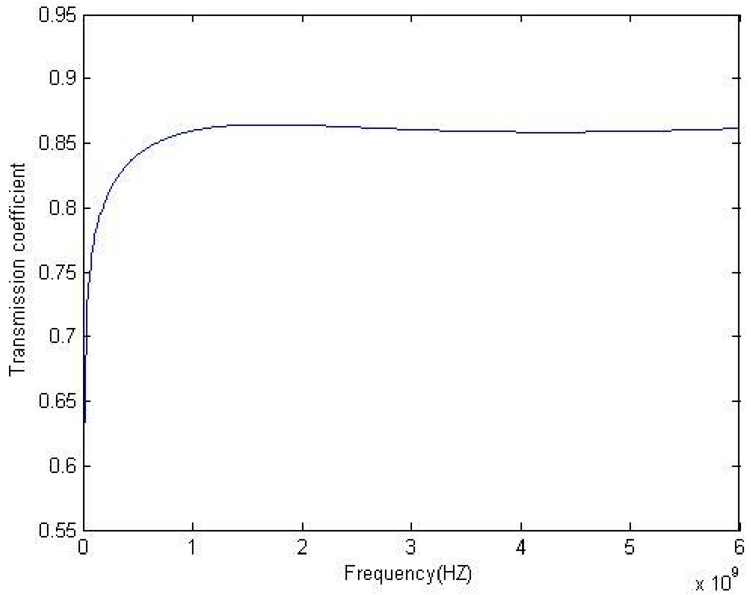

Figure 8: Variation of Transmission coefficient for Skin-Blood interface.

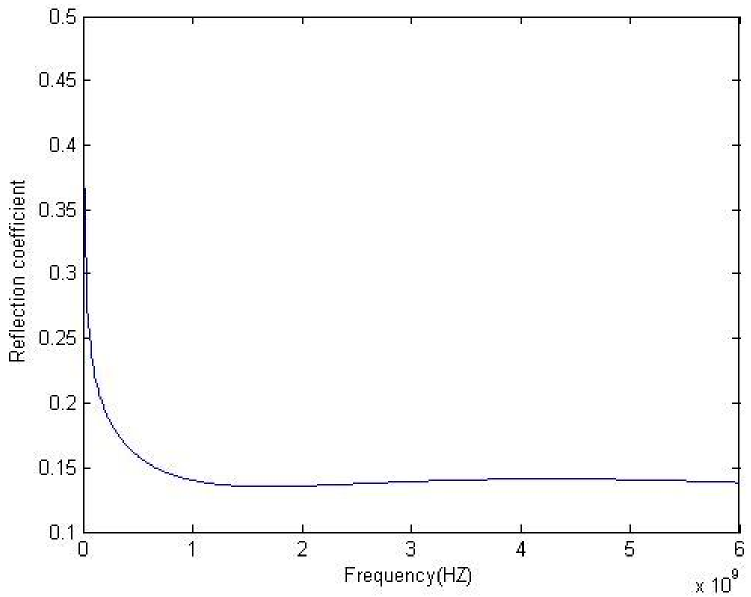

Figure 9: Variation of Reflection coefficient for Skin-Blood interface.

Conclusion

It is evident from the results the transmission and reflection coefficient for skin and fat interface exhibits overshoot that approximate about 1GHz.In case of fat-muscle interface transmission coefficient increases as frequency increases to about 3GHz and then slowly falls beyond 3GHz.The reflection coefficient falls to a value of 0.6 at about

3GHz and rises beyond 3GHz. In case of muscle and bone interface both the transmission and reflection coefficient exhibits similar behavior and they have high value at low frequencies and low at high frequencies.

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