Investigations into Matching Mediums for Microwave Brain Imaging

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***Abstract*—This paper presents results from a theoretical model of wave propagation in a anatomic realistic head phantom for the purpose of determining an effective permittivity of a matching medium to facilitate increase intracranial electromagnetic transmission.**

***Index Terms*—Microwave imaging, brain modeling, medical diagnosis.**

I. Introduction

Recently it has been proposed that microwave electromagnetic radiation could supplement current diagnostic methods for intracranial trauma (stroke, hemaorrage etc); and that it may potentially provide a fast, cost effective and portable detection system [1]. This was based upon recent studies that demonstrated tissue malignancies, blood supply, hypoxia, acute ischemia, and chronic infarction significantly change dielectric properties of the effected tissue [1] [2]. Probing the brain could work by exposing tissues to low-levels of electromagnetic energy at microwave frequencies and capturing the scattered electromagnetic energy. Subsequently the estimation of the dielectric profiles of the imaged body are constructed or significant scatterers directly located. Applying either method to probe the brain presents some obvious difficulties. At microwave frequencies (0.3 - 30GHz), the brain is surrounded by a high contrast dielectric shield comprising of the skin ($\epsilon_r \sim 31-73$), skull ($\epsilon_r \sim 3-15$) and cerebral fluid ($\epsilon_r \sim 52-88$). Relatively high microwave frequencies, such as those used in ultra-wideband breast cancer detection (3-11GHz), although high resolution may lack the required penetration into the brain. Lower frequencies ($<$ 3GHz) however, would allow for a higher penetration but would be insensitive to small regions of dielectric changes. Initial simulations by the author in [3], Semenov *et al.* in [2], Trefna and Persson in [4], have shown a frequency region between 0.5-2GHz produce scattered fields external to the head phantom that are perturbed by a moderately intracranial anomaly (an emulated stroke).

This work investigates the efficacy of using a matching medium applied external to the head in order to facilitate increased electromagnetic radiation into the gray and white matter. Recent articles into microwave brain imaging, see for example [4] and [5], have made use of matching medium in their research however, we assert no dedicated analysis has been hitherto presented.

A 1-D theoretical model and a 1-D finite difference time domain simulator are used to conduct the experiments with dielectric profiles obtained from a realistic phantom head. In this work, we have chosen not to primarily rely on a 3-D full wave electromagnetic simulation for two reasons. First, the simulation time is quite long (several hours) and second, we have observed a majority electromagnetic energy rides along the contours of the skin and avoids any penetration into the regions of interests [3]. Thus making it hard to quantify the efficacy of the matching medium.

II. Cascaded Dielectric Layers

A theoretical model used to investigate the optimal medium matching can be developed by considering the problem as a cascade of M dielectric layers with a plane wave impinging normal to the dielectrics. Such a configuration results in $M+1$ dielectric interfaces. An example of this configuration is given in Figure 1. The electric field at the different dielectric interfaces can be resolved as a forward traveling wave with magnitude E_i^+ and a reflected wave with magnitude E_i^-. Propagation through these cascaded dielectric layers can be be mathematically described as [6]:

$$\begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix} = \mathbf{P}'_1, \ldots, \mathbf{P}'_M \frac{1}{(1+\rho_{M+1})} \begin{bmatrix} E_{M+1}^+ \\ E_{M+1}^- \end{bmatrix} \tag{1}$$

where the individual propagation matrices $\mathbf{P}'_i$ for each layer is given by:

$$\mathbf{P}'_i = \frac{1}{e^{\alpha_i \ell_i}(1+\rho_i)} \begin{bmatrix} e^{j\beta_i \ell_i} & \rho_i e^{-j\beta_i \ell_i} \\ \rho_i e^{j\beta_i \ell_i} & e^{-j\beta_i \ell_i} \end{bmatrix} \tag{2}$$

where $i \in \{1, \ldots, M\}$. α_i, β_i and ρ_i are the attenuation constant, phase constant, and reflection coefficient respectively for the ith layer which has a thickness of ℓ_i. Expressions for the attenuation and phase constant for lossy dielectrics although approximates, are well known and will not be given here for brevity. The matching medium effects the first and last interface and are used directly in the calculation of ρ_1 and ρ_{M+1} as shown in Figure 1; here η_a and η_b denote the intrinsic impedance of the entry and exit matching medium. The permittivity of the matching medium is denoted ϵ_m; in this instance $\eta_a = \eta_b = \sqrt{\frac{\mu_o}{\epsilon_o \epsilon_m}}$. With the multiplication of

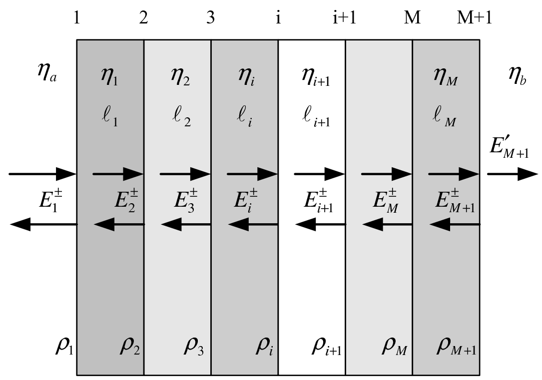

Fig. 1: Illustration of the cascaded dielectric layers.

the propagation matrices the total transfer matrix relation can be derived as:

$$\begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{21} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} E'_{M+1} \\ 0 \end{bmatrix} \tag{3}$$

where E'_{M+1} is the amplitude of the wave exiting out of the multi-layered structure as shown in Figure 1. From equation 3 it can be seen the transmission coefficient is simply $1/T_{11}$ while the reflection coefficient is simply T_{21}/T_{11}.

III. Experiment

A. Setup

Using a tissue/dielectric profile obtained from a detailed MRI scan of a human head [7] and the above method, an analysis was done on the efficacy of the matching medium with an $\epsilon_m \in [1, 100]$. The dielectric constant and conductivity of each tissue were obtained from [8] for 1GHz, 2GHz and 3GHz excitation signals. The tissue profile was a central, transverse slice across the phantom. The profile is symmetrical with the first half including: matching medium, skin layer, parietal bone (skull), fat layer, cerebral fluid and the gray and white matter. This setup is equivalent to having a transmit and receive antenna on opposite sides of the head.

B. Results

Figure 2 gives the transmission coefficient as a function of ϵ_m for a particular slice (42mm below the crown of the head) of the head phantom. These results show an optimal matching medium for 1GHz and 2GHz is when $\epsilon_m = 7$ giving a $0.64dB$ and $2.5dB$ increase respectively compared to free-space. At 3GHz it was found an optimal matching is when $\epsilon_m = 94$ giving a 12.5dB increase compared to free-space. A comparison to a 1-D finite difference time domain program is also given in Figure 2 for when the excitation signal had a frequency of 3GHz. The comparison showed a a reasonable good agreement between the two methods. The discrepancy can be explained by the ill approximated α and β parameters of brain tissues which do not meet the lossy dielectric criteria

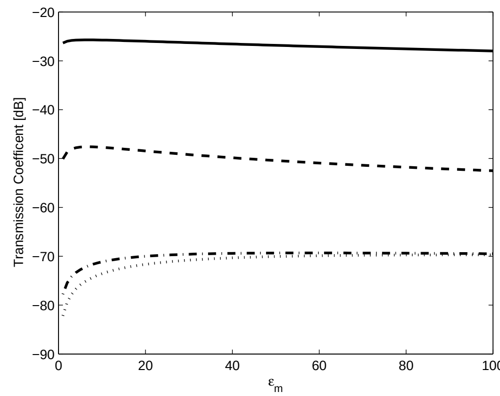

Fig. 2: Transmission coefficient as a function of ϵ_m.(-) 1GHz; (- -); 2GHz (..); 3GHz; (-.) FDTD comparison at 3GHz

i.e $\frac{\sigma}{\omega\epsilon} << 1$. This is particularly seen in the cerebral fluid which has high permittivity and high conductivity.

IV. Conclusion

This paper has presented a theoretical method for evaluating the reflection and transmission coefficient for a cascade of dielectric layers. It was subsequently used for the determination of the optimal matching medium for a slice of brain tissue. From this, evidence was given to show that a matching medium may be used to increase the electromagnetic transmission between the head for the microwave imaging of intracranial anomalies. The complete body of work will further include an analysis on multiple layers of the phantom and comparisons to solutions obtained from full 3-D wave simulations.

References

[1] Y. Serguei Y. Semenov and Douglas R. Corfield, "Microwave tomography for brain imaging: feasibility assessment for stroke detection", *International Journal of Antennas and Propagation*, vol. 2008, Article ID 254830, 8 pages, 2008. doi:10.1155/2008/254830.

[2] S. Y. Semenov, R. H. Svenson, V. G. Posukh, A. G. Nazarov, Y. E. Sizov, A. E. Bulyshev, A. E. Souvorov, W. Chen, J. Kasell, and G. P. Tatsis, "Dielectrical spectroscopy of canine myocardium during acute ischemia and hypoxia at frequency spectrum From 100 kHz to 6 GHz", *IEEE Transactions on Medical Imaging*, Vol. 21, No. 6, June 2002.

[3] D. Ireland and M. Bialkowski, "Feasibility Study on Microwave Stroke Detection using a Realistic Phantom and the FDTD Method", Accepted into the proceedings of the Asia-Pacific Microwave Conference, December 2010.

[4] H. Trefnam and M. Persson, "Antenna array design for brain monitoring", *Antennas and Propagation Society International Symposium*, (AP-S 2008), San Diego, Ca, July 2008.

[5] A. Fhager, T. McKelvey and M. Persson, "Stroke detection using a broadband microwave antenna system", EUCAP2010, 4th European Conference on Antennas and Propagation, April 12-16, Barcelona, Spain, pp. C13P1-2.

[6] S. J. Orfanidis, "Chapter 6 - Eletromagnetic Waves and Antennas", Available: http://www.ece.rutgers.edu/ orfanidi/ewa [Accessed: 22th Novemember 2010] c

[7] I.G. Zubal, C.R. Harrell, E.O. Smith, Z. Rattner, G. Gindi and P.B. Hoffer, "Computerized three-dimensional segmented human anatomy", *Medical Physics*, 21(2):299-302, 1994.

[8] "Dielectric properties of body tissues in the frequency range 10 Hz - 100 GHz". [Online]. Available: http://niremf.ifac.cnr.it/tissprop/ [Accessed: May 26th, 2010].