FDTD Investigation of a Microwave Link for Data Telemetry in Retinal Prosthesis Applications

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1 Introduction

Retinitis Pigmentosa (RP) or Age-related Macular Degeneration (AMD) are leading causes of blindness worldwide. It has been shown that patients suffering from diseases like RP and AMD could recover partial vision by means of controlled electrical stimulations of the retina. Thus, a retinal prosthesis can be developed where the functionality of permanently damaged retinal photoreceptors is replaced by a 2–D array of electrodes, which can provide electrical stimulation on the surface of the retina. Various experimental studies on human subjects [1], have reported perception of simple shapes and forms corresponding to the pattern of electrical stimulation provided, thus restoring a limited form of vision.

In this paper, a new approach facilitating high bandwidth wireless data telemetry in data-intensive biomedical applications is proposed and its application to a dual-unit retinal prosthesis device to restore partial vision in the blind is investigated.

The electronic device consists of extraocular and implantable intraocular units. Extensive work has been reported on the design aspects of the extraocular unit. Current designs propose both power and data transfer on the same carrier at low frequencies ranging from 1–10 MHz via an inductive link providing sufficient bandwidth for the amount of data communication necessary for a 10×10 electrode array at the requisite modulation scheme [2]. However, advances in the array design and miniaturization technology may make a far more compact and dense electrode array a reality for prosthetic devices, which makes it imperative to design data communication links with high bandwidths.

Here, mutually exclusive power and data transfer is proposed where the intraocular unit receives power through a low frequency inductive link whereas data transfer is accomplished via a high frequency microwave telemetry link. A pair of microstrip antennas separated by 25 mm act as the data transmitting and receiving elements for the extraocular and intraocular units respectively as shown in Figure 1. A 3–D head model with a high spatial resolution of 0.25 mm has been developed and the Finite-Difference Time-Domain (FDTD) method employed with material independent absorbing boundary conditions to compute the performance of the data telemetry link both in the presence and absence of the 3–D eye model. It is shown that an implantable microstrip antenna of dimensions 6 x 6 mm can achieve a relatively large bandwidth (30 MHz) and sufficient coupling (-30 dB) to the externally mounted radiating device. The proposed dual frequency telemetry will also allow powering the intraocular unit with a signal at a frequency lower than 1 MHz by means of a surrounding coil, thus reducing the risk of exceeding electromagnetic safety standards associated with the operation of the device.

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2 Methods

2.1 Antenna Design Considerations

Due to the nature of the application, the transmitting external unit had to be designed to fit comfortably on a pair of glasses to be worn by the patient. Hence, the extraocular antenna was restricted in size to 23 × 23 mm. Anatomically, the most appropriate location for the receiving element was hinged in between the sclera muscles of the eye (approximately 5 mm from the surface of the cornea) and its size was restricted to 6 × 6 mm. The ease of achieving a compact, planar and robust radiating structure with a sufficient gain capable of meeting all the stringent size restrictions led to the selection of a pair of microstrip patch antennas as the radiating elements. These antennas were designed to operate in the frequency range of 2–2.5 GHz. Two major considerations led to the selection of this frequency range: (i) Due to the most stringent size restrictions in place for the receiving antenna element, a lower frequency of operation was deemed unsuitable to realize a resonating antenna. (ii) At higher frequencies, with the increase in the conductivity of the eye tissues and the surrounding region, the penetration depth decreases and the attenuation increases, implying the need for extremely sensitive receiver architectures for the subsequent signal processing. Hence an intermediate frequency range of 2–2.5 GHz was chosen.

A high dielectric constant of $\varepsilon_r = 9.2$ was used to design the antennas. The transmitting antenna was designed with dimensions of 21.5 × 20.75 × 1.25 mm and a shorting pin was placed strategically to restrict the dimensions of the implanted receiving antenna to 6 × 6 × 1.5 mm. Both the antennas were initially designed individually to resonate at 2.44 GHz in free space. When modeled together in the same FDTD spatial domain to examine the coupling issues (at a separation of 25 mm), both in free space as well as in the presence of the eye model, a considerable alteration of the resonant frequency was observed especially in the case of the receiving element. This can be attributed to their relative proximity. Modifications were implemented (in the form of changing the ε_r of the substrate or size slightly) to make both antennas resonate at the same frequency so as not to compromise on the coupling efficiency in the frequency band of interest. When modeling to examine the coupling efficiency, the receiving element was terminated at its resonant impedance for maximum power transfer.

2.2 Head Model and FDTD Modeling

A complete set of cross-sections of a 3–D head model with a resolution of 1 mm were obtained from the National Library of Medicine (NLM) "Visible Man Project" [3]. In order to represent the small physical space to be simulated along with the tissues of eye and head with a high degree of detail and accuracy, it was necessary to increase the spatial resolution of the model. This was achieved by developing a software application that discretized the available model further—reaching a spatial resolution of 0.25 mm (64 times the original one) using a method of interpolation in all three dimensions. Shown in Figure 2 is the section that was extracted from the head model and utilized in the computational domain. The dielectric properties of the body tissues have been obtained from the online database compiled and organized by the Electromagnetic Wave Research Institute of the Italian National Research Council (IROE-CNR) [4]. The dielectric properties of the tissues were computed at 2.44 GHz corresponding to the intended frequency of operation for the telemetry system. Since properties for some of the tissue types were not explicitly available on the online database, they were substituted by the properties of a tissue type that most closely matched the physiological characteristics of the unlisted tissue type in terms of its material composition and water content [5].

A 150 × 150 × 175 cell uniform grid representing a spatial resolution of 0.25 mm was used as the computational domain and the entire system modeled and simulated using the FDTD method [6]. The transmitting and receiving antennas were separated by 25 mm as shown in the 2–D view in Figure 1. The lens was removed from the anterior portion of the eye and the receiving antenna placed in between the sclera muscles. The PML absorbing boundary condition was used so as to facilitate the proper truncation of the model posterior to and surrounding the lens region of the eye by immersing the portion in the PML layers [7].

3 Results

The radiation pattern plots for both the antennas (Extraocular and Intraocular) in presence of the model are shown in Figure 3 and their return losses are shown in Figure 4. A single simulation run lasted approximately 50 hours on a Pentium III– 933 MHz, 2 GB RAM machine.
Coupling for the following two cases was investigated.

1. Free Space: The eye model was removed and the antennas were separated by 25 mm in free space. Both the antennas were made resonant at the same frequency and power coupling computed and observed to be -26 dB at 2.44 GHz.

2. In the presence of the model: The receiving antenna was embedded in the eye model in the lens region–again at a distance of 25 mm from the external transmitting antenna. The antennas were again made resonant at the same frequency and the computed power coupling observed to be -30 dB at 2.44 GHz. The decrease in coupling is attributed to the absorption in the anterior portion of the eye.

4 Conclusion

A high bandwidth (of up to 30 MHz) microwave data telemetry link for a retinal prosthesis is computationally investigated. A pair of appropriately sized microstrip patch antennas (extra- and intraocular) are designed. A high spatial resolution (0.25 mm) head-eye model developed and coupling between the extraocular and intraocular units computed both in free space as well as with the receiving antenna embedded in the model. It is observed that a power coupling of -30 dB is obtained with the receiving antenna embedded in the model and -26 dB of coupling is obtained in free space. It is anticipated that future work geared towards modifying the current antenna designs to improve their gains will lead to a definite enhancement in the coupling efficiency. It is also evident that such high bandwidth data telemetry links need not be restricted to retinal prosthesis applications alone, since this research can contribute to other potentially data intensive bio-medical applications requiring chronically implanted electronic prosthetic devices.

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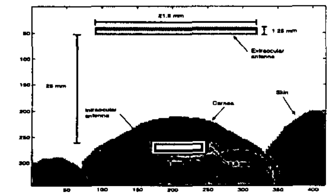

Figure 1: A 2–D view of the model showing the relative location of the Extraocular and Intraocular antennas.

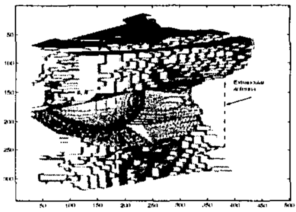

Figure 2: A 3–D view of the portion of the head model used in the simulation.

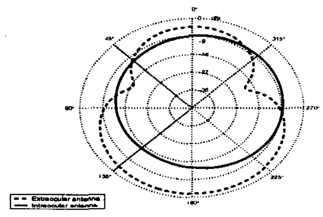

Figure 3: H-plane patterns.

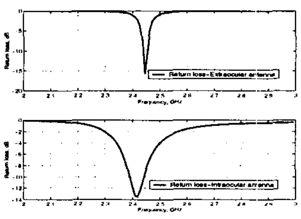

Figure 4: Return loss.

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