Extraction of Electrical Characteristics Using an Ultra Wide Band Pulse for Biological Tissue Differentiation

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The present work demonstrates a novel technique for tissue differentiation where the frequency dependent electrical parameters contrast vastly between healthy and diseased states. The methodology is based on transmission and reflection of an ultra wide band UWB pulse in multiple dispersive layers of biological tissue. The field that is scattered from the multiple layers of tissue contains the reflected pulses that can be identified with respect to each layer. Using the finite difference time domain technique (FDTD), an UWB pulse is allowed to propagate through layers of tissue (fig.1). The electrical characteristics of tissues (dielectric permittivity $\hat{\varepsilon}_r$ and conductivity σ) are modeled with a single-pole Debye model.

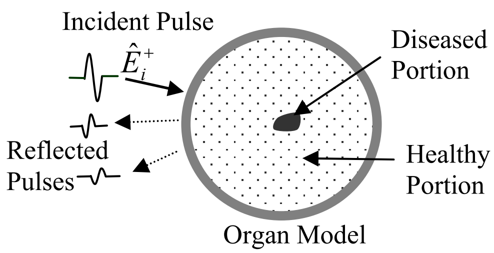

Fig.1: model of multiple layered-regions

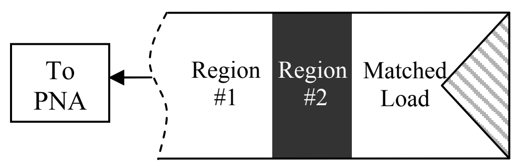

Fig.2: 1-d Experimental Setup

Because of the electrical contrast between the different regions, a portion of the incident UWB pulse ($\hat{E}_i^+$) is reflected back ($\hat{E}_r$), and the remainder is transmitted through the second region. This process is repeated for each region. The reflection pulses at each boundary that are separated in time are analyzed to obtain the group velocity and therefore the thickness of each layer. The reflection coefficient is found as follows.

$$\hat{\Gamma}(\omega) = \frac{\Im\{E_r(t)\}}{\Im\{E_i(t)\}} \tag{1}$$

Where $\Im$ represents Fourier transform and the incident and reflected signals are referenced to the same start time. The intrinsic impedance of each region, and hence the frequency dependent permittivity and conductivity can be extracted.

In order to verify our model, a 1-dimensional feasibility experimental study has been realized. A phantom similar to human tissue with an oil-in-gelatin composition (M. Lazbenik, E. L. Madsen, G. R. Frank and S. C. Hagness, Phys. Med. Biol. 50 2005) is constructed with dispersive dielectric properties that range from typical values of diseased to healthy states. To simulate a dispersive region, the biological phantom is placed in a rectangular waveguide. Using a PNA, a frequency sweep with 201 samples is performed and the reflected S_{11} signal is measured and transformed to the time domain. From the reflected pulse, the dielectric permittivity $\hat{\varepsilon}_r$ and conductivity σ are extracted and compared to the characteristics of the phantom model.