Performance evaluation of medium-matched waveforms and pulse shaping for application in ultrawideband intra-body technologies

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***Abstract*—In this letter we analyze the use of medium-matched signals and pulse shaping techniques to improve the performance of intra-body technologies. Firstly, we describe the evolution of the Brillouin precursor fields through human tissues by using a frequency-domain analysis technique and a multi-pole Cole-Cole model to characterize the dielectric properties of the human body tissues, in a frequency band designated by the FCC for UWB medical applications, 3-20GHz. A 3D representation of the body has been achieved by cuboids with a resolution of 8mm^3. The dispersive propagation is analyzed for purposes of radar imaging and intra-body communications. The performance of a classical rectangular and a medium-matched waveform, the Brillouin pulse, are described.**

I. Introduction

The dispersive propagation affects many usual and emerging systems and applications, and in human tissues it is particularly of great importance. High-resolution systems as the ones used in medical imaging require the use of ultra wideband waveforms and for such pulses the medium is inherently dispersive [1,2]. This situation will unavoidably lead to the formation of the Brillouin or Sommerfield precursors, not always in a visible form [3]. The ability to use the precursor waveforms would greatly enhance the image quality at much larger distances within a given medium. Hence, the medical imaging applications could improve the signal-to-noise (SNR) ratio once the received level is larger.

For the intra-body communications, the form and shape of the information-bearing transmitted signal is also an important factor to consider [3,4]. Since the transmitted signal influences the formation and performance of the resulting precursor we can conclude that a medium-matched signal can lead to an optimal performance by combining the benefits of the precursor formation (larger amplitude) with minor impairments (lesser time duration broadening). Pulse shaping [5] is usually applied to the transmitted signal as a way to avoid the pulse distortion after travelling through tissues. However, it has been theoretically stated [1,3] that waveforms specifically designed to match the medium properties offer a better performance in terms of pulse shape retrieval. The Brillouin pulse is postulated as a near-optimal candidate [3].

We introduce the formulation developed to analyze the dynamical evolution of a signal travelling through a dispersive medium. Additionally, we describe a 3D human-model developed to obtain a realistic interaction of precursors. We also present the selection of the parameters to setup a Brillouin pulse and a medium-matched waveform in order to achieve an optimum performance in the dispersive media considered. Finally, we present some simulation results: dynamical evolution and field intensity.

II. 3D Human Body Simulation

In order to realistically analyze the interaction of precursor waveforms, a 3D human body of 1.80m height has been implemented for this work following a simplified human body model described in [6] and depicted in Fig 1. This 3D human body representation is ideally suited to analyze the evolution of precursor waveforms with plausible application in radar imaging and intra-body communications.

The human body model is parameterized in order to consider different heights and postures. In this particular case, the human body is divided into 8mm^3 cuboids leading to over 1500 horizontal planes and over 9000 transversal planes.

The multi-pole Cole-Cole dielectric model described in [7] is used to characterize most of the human tissues. The different parameters for each type of tissue are summarized in [7]. For the purposes of this research work, we have considered the two horizontal cut planes shown in Fig 1, for a height of 1.20m and 1.35m, in which several organs such as the stomach, pancreas zone and heart are visible.

The material parameters have been computed from 3GHz to 10GHz, considering the frequency-dependent complex relative dielectric permittivity and conductivity for each organ of the respective cut planes.

III. Theoretical Analysis And Results

In Fig. 2 we show the amplitude level of the backscattered field for the transversal plane (2) indicated in Fig. 1. We observe the differences in the received amplitude level for both the Brillouin (left) and rectangular (center) pulses with respect to the third case (right) for which only the carrier component at f_0 was considered. In Fig. 3 we plotted the normalized intensity $I(z,t)=|E(z,t)|^2$ of the electric field $E_T(z,t)$ at any given location (z,t) [8], for a Brillouin pulse through a single layer of muscle. We observe that the two cycles of the pulse do not overlap.

We observe the large shape distortion, as well as the early extinction of the carrier component. This result is particularly important for intra-body communications. It implies that UWB transmission will be severely affected by the dispersive propagation and robust input signals jointly adjusted to the proper frequency spectrum windows must be chosen. We have demonstrated the large improvement in terms of SNR for medical imaging, for instance. This result indicates the likely need to review the dosimetry given that a larger energy is to be absorbed.

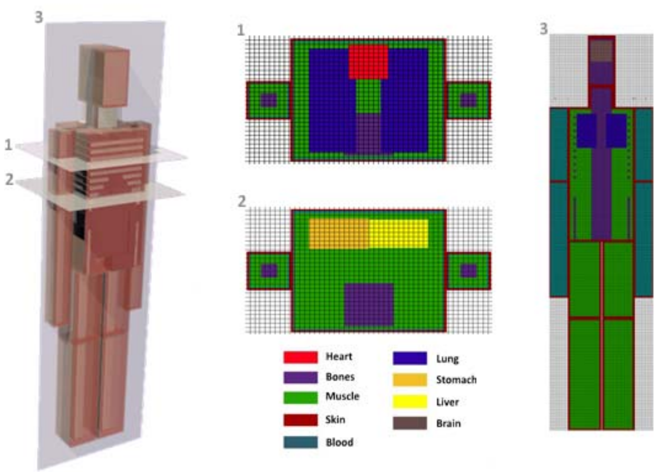

Figure 1. Schematic representation of the implemented human body model, with longitudinal (1,2) and transverse (3) planes.

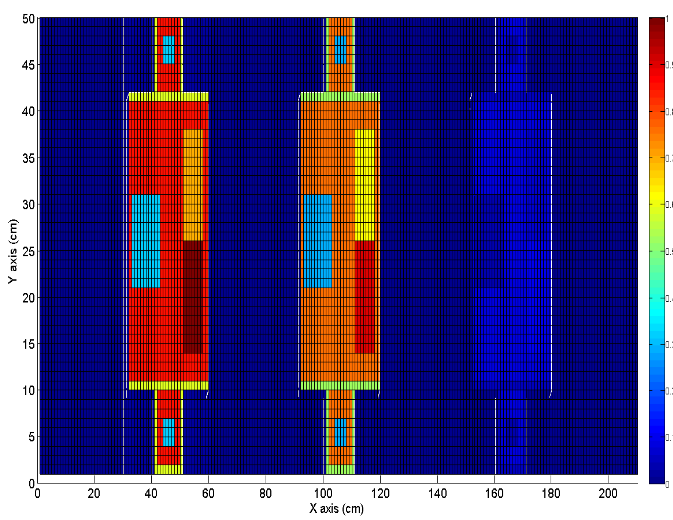

Figure 2. Comparison of peak amplitude levels detected for a backscattered signal for transversal plane at 135mm for rectangular (left) and Brillouin (center) pulses and for a non-dispersive version of the medium (right, carrier component).

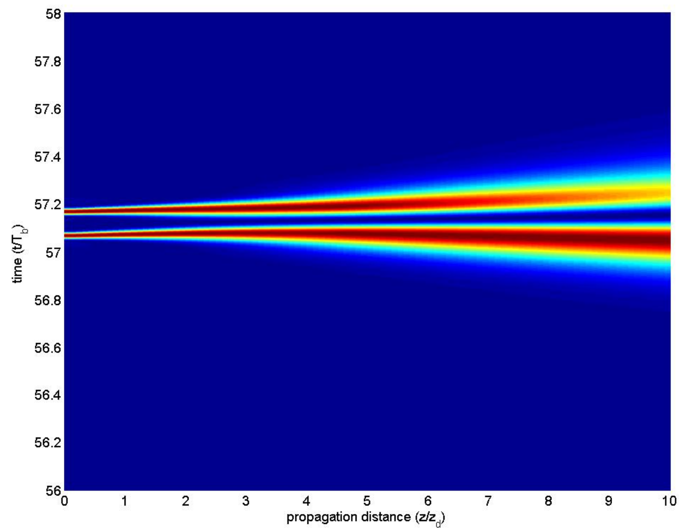

Figure 3. Spatial evolution of the normalized electric field intensity distribution through a dielectric slab of muscle at f_0=6.5GHz for a Brillouin pulse BP_{211}[3,9].

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