Improved Focusing in Heterogeneous Frequency-Dependent Materials with Instantaneous Time Mirror in Electromagnetics

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Time reversal invariance is a physical principle that allows waves to travel backwards [1] producing a result similar to rewinding a video to an earlier time. A reversed propagation retraces the path of a previous forward propagation, ideally converging to a focus at the location of the source from which the forward propagation originates [1]. Many numerical and experimental studies of time reversal have been conducted exploring its application as a method to focus waves at a targeted site [2, 3].

Although reversed waves can be achieved through a disruption in space using a Time Reversal Mirror (TRM) or in time using an Instantaneous Time Mirror (ITM) [1, 4], it is known that the time-reversal symmetry breaks in lossy materials due to attenuation and dispersion [2, 5]. This leaves scope to investigate and improve the TRM and ITM approaches with respect to the spatial accuracy and resolution of the reversed foci produced.

For decades, TRM has been the standard approach due to its convenient use of transceivers, allowing the digital manipulation of the recorded signals for attenuation compensation [3, 5]. On the other hand, ITM is achieved through a direct change of the medium's propagation properties *without* transceivers. In [4], a change of effective gravity was used to reverse water waves. Based on the same theoretical concept, our work explores the use of ITM in electromagnetic waves. We use Finite Difference Time Domain simulations with a one-pole Debye model to manipulate a medium's complex relative permittivity, altering the wave speed and inducing reversed propagations.

In this paper, we propose a new method of manipulating the applied ITM which is capable of improving both the spatial accuracy and resolution of the ITM-reversed foci compared to our previous approach described in [6]. The proposed methodology is presented and discussed based on its performance in a human phantom setting, including heterogeneous and frequency-dependent propagation media. The potential of our proposed methodology is highlighted by studying cases where forming accurate reversed foci was previously deemed difficult but is possible with the new method.

References

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