Finite Diference Time Domain Analysis of Energy Flow in Amplified Total Internal Reflection

Zhen Chen[1], Keely Willis[2], John B. Schneider[1], and Susan C. Hagness[3]

[1] School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA

[2] AWR Corporation, Mequon, WI

[3] Department of Electrical and Computer Engineering University of Wisconsin, Madison, WI

For over four decades there has been disagreement over whether or not the reflection coefficient associated with total internal reflection (TIR) from a gainy material can have a magnitude greater than unity. Previously, FDTD simulations have shown the reflection coefficient can indeed have a magnitude greater than unity, i.e., amplified TIR is possible [Willis *et al.*, *Optics Express*, **16**(3):1903–1914, 2008], and yet the disagreement has persisted.

We revisit this problem by analyzing the time-domain behavior of the Poynting vector, i.e., analyzing the flow of energy in the time domain. The analysis entails two-dimensional FDTD simulations where a pulsed beam originates in a lossless dielectric half-space. The pulse encounters a planar interface with a second dielectric half-space such that the incident angle is beyond the critical angle. The simulations employ a direct discretization of Maxwell's equations and make no *a priori* assumptions related to the reflection coefficient.

The magnetic components from the FDTD grid are averaged in both time and space. The resulting vector is crossed with the electric field to obtain the Poynting vector. By tracking the flow of energy in the time-domain, one arrives at a plausible explanation for a mechanism that supports amplified TIR. The Goos-Hänchen effect is found to be present whether the medium beyond the interface is lossy, lossless, or gainy. (The Goos-Hänchen effect is a shift in the axis of the reflected beam relative to the axis of the incident beam as measured at the interface between the media.) Thus, fields must "travel" within the second medium to account for the shift of the reflected beam relative to the incident beam. When the second medium is gainy, this "travel" provides the opportunity for the fields to grow so that ultimately the reflected field is larger than the incident field.

Furthermore, the FDTD simulations demonstrate that the fields adhere to causality. There is a distinct delay between when the fields enter the second medium and when they depart (with gain).