The Effect of Conductivity on the Brillouin Precursor

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Ultrawideband pulses that propagate through dielectric materials have been shown to give rise to a so-called Brillouin precursor whose peak amplitude point only decays algebraically with propagation distance rather than exponentially (N. A. Cartwright and K. E. Oughstun, SIAM Review, accepted for publication, 2007). This unusually slow decay rate of the Brillouin precursor is highly desirable in radar applications where the material being interrogated is highly absorptive or in applications that require long interrogation distances. However, many physical applications require propagation of electromagnetic signals through conductive material. In this paper we present studies of a step-modulated sine wave traveling through two different types of conductive material. We show that the Brillouin precursor does exist in both models and then present the decay rate of its peak amplitude point.

In a dispersive medium, the angular frequency dependence of the electronic response of the material to an applied electromagnetic signal is given by the complex permittivity $\epsilon_c(\omega) = \epsilon(\omega) + i\sigma(\omega)/\omega$, where $\epsilon(\omega)$ and $\sigma(\omega)$ are the temporal frequency spectra of the dielectric permittivity and electric conductivity, respectively. In a purely dielectric material, $\sigma(\omega) \equiv 0$ and $\epsilon_c(\omega) = \epsilon(\omega)$ is analytic at the origin $\omega = 0$, the very point that provides the slow decay rate of the Brillouin precursor. In a conductive material, $\sigma(\omega) \not\equiv 0$ and $\epsilon_c(\omega)$ possesses a pole at the origin. The presence of this pole calls into question the existence and decay rate of the Brillouin precursor. Here, we study the propagation of a step-function modulated sine wave through two types of conductive material: the first is a Debye model with static conductivity; the second is a lossy plasma as described by the Drude model. Our method of analysis is an asymptotic approximation to the integral representation of the propagated field. This analysis provides a closed-form approximation of the Brillouin precursor which we then use to study the decay rate of its peak amplitude point as a function of propagation distance. We find that the peak amplitude point of the Brillouin precursor decays exponentially through the Debye model medium with static conductivity, and that this decay rate increases with increasing levels of conductivity. For Drude model material, we find that the peak amplitude point of the Brillouin precursor decays exponentially for small propagation distances, but algebraically for large propagation distances.