FINAL REPORT

A Research Program on Ultrawideband Electromagnetic Pulse Propagation Through the Ionosphere

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1. Accomplishments

The research done under the AFOSR grant "A Research Program on Ultrawideband Electromagnetic Pulse Propagation Through the Ionosphere" lies in the following three areas: The description of ultra-wideband pulse propagation through a homogeneous, lossy plasma. Ultra-wideband pulse propagation through a material whose dielectric permittivity may be characterized as a Debye model with static levels of conductivity. The effect of conductivity on the peak amplitude of the Brillouin precursor. The significant work accomplished in each of these areas is presented in the following summary.

UWB Propagation in a Homogeneous, Isotropic, Lossy Plasma. In our previous grant of the same title (AFOSR grant FA9550-07-1-0112), closed-form uniform asymptotic expansions were derived that describe a step modulated sine wave of fixed carrier frequency that propagates through a homogeneous, isotropic, lossy plasma. This type of material describes the ionosphere under the assumption that the ionization is independent of altitude, the Earth's magnetic field is ignored, and the collision frequency of electrons is assumed constant. Under the present grant, these results were collected into the manuscript "Ultra-wideband pulse propagation through a homogeneous, isotropic, lossy plasma," which was then published in the journal *Radio Science* [1]. These closed-form solutions may be used to calculate the propagated field at any distance into the material, unlike computer simulations that require small step sizes thereby rendering large propagations distances computationally impossible. In this work, the propagated field of the pulse is expressed as the sum of three terms: the Sommerfeld precursor, the Brillouin precursor, and the signal contribution. The peak amplitudes of the Sommerfeld and Brillouin precursors were shown to

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The research done under the AFOSR grant "A Research Program on Ultrawideband Electromagnetic Pulse Propagation Through the Ionosphere" lies in the following three areas: The description of ultra-wideband pulse propagation through a homogeneous, lossy plasma. Ultra-wideband pulse propagation through a material whose dielectric permittivity may be characterized as a Debye model with static levels of conductivity. The effect of conductivity on the peak amplitude of the Brillouin precursor. The significant work accomplished in each of these areas is presented in the following summary.

15. SUBJECT TERMS

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decay algebraically as $z^{-3/4}$ and z^{-2}, respectively, for large, yet finite, propagation distances z, whereas the signal contribution decays exponentially with propagation distance.

UWB Propagation in Dielectric Material with Static Levels of Conductivity. The second research area considered was UWB pulse propagation through dielectric material with static levels of conductivity σ_0. Specifically, the material considered is one in which the dielectric permittivity may be described by a Debye model with static levels of conductivity. Such materials include water, blood, and concrete. The input pulse is a step modulated sine wave of fixed carrier frequency. An asymptotic approximation to the propagated field is then sought. In this problem, there are three relevant saddle points of the complex phase function whose locations in the complex plane move in a region about which there are branch cuts of the complex phase function. Only nonuniform asymptotic expansions have been obtained thus far. For a plane wave that is a step function modulated sine wave of fixed carrier frequency $\omega_c = 1 \times 10^9$ rad/s, nonuniform expansions have been provided for low levels of static conductivity (which roughly satisfies the inequality $0 \leq \sigma_0 \leq 10^{-9}$ S/m) and for high levels of static conductivity (which roughly satisfies the inequality $\sigma_0 > 1 \times 10^{-2}$ S/m).

The research accomplishments in this area were published in the Proceedings of the 2009 International Antennas and Propagation and USNC/URSI National Radio Science Meeting [2] and presented at European Electromagnetics (EUROEM) 2008 in Lausanne, Switzerland, the Joint Mathematics Meeting 2009 in Washington, DC, as well as at the 2009 International Antennas and Propagation and USNC/URSI National Radio Science Meeting in Charlotte, SC.

The Effect of Conductivity on the Peak Amplitude of the Brillouin Precursor. It is known from previous research [3, 4, 5, 6] that when an UWB pulse travels through a causal, dispersive, dielectric material, the propagated field consists of the Brillouin precursor and, if present, the Sommerfeld precursor and the signal contribution. The peak amplitude point of the Brillouin precursor decays algebraically with propagation distance, whereas the Sommerfeld precursor and the signal contribution decay exponentially with propagation distance. This attribute of the Brillouin precursor makes it an ideal candidate for improving interrogative technologies such as radar. However, the decay rate of the Brillouin precursor in materials with conductivity had not been studied. In this work, asymptotic analysis was used to show that the presence of conductivity does decrease the decay rate of the Brillouin precursor. This is because the conductivity introduces a pole at the origin in the complex phase function via the dielectric permittivity. This pole prohibits a saddle point of the complex phase function from crossing the origin, which is the point that gives rise to the nonexponential decay of the peak amplitude point of the Brillouin precursor. For practical purposes though, this decay rate remains less that of the signal contribution so that again, the Brillouin precursor may be better suited for application purposes.

The research accomplishments in this area were presented at the Progress in Electromagnetics Research Symposium (PIERS) 2008 held in Cambridge, MA.

References

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