Waveforms for SAR Imaging Through Dispersive Material

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As an electromagnetic wave propagates through a dispersive material in which the refractive index is a complex function of frequency, those frequencies that lie below the absorption band experience the least amount of attenuation and hence become the dominant contribution to the field for large propagation distances. Asymptotic analysis has shown that in dielectrics, this low-frequency contribution, the so-called Brillouin precursor, has a peak amplitude point that decays algebraically with propagation distance z, as $z^{-1/2}$ (Oughstun and Sherman, J. Opt. Soc. Amer. B, **5**, 817–849, 1988). It has been suggested that near-optimal pulse penetration is possible by using the Brillouin precursor as the transmit pulse, which may then have applicability to radar imaging (Oughstun, IEEE Trans. Ant. Prop., **53**, 1582–1590, 2005).

The question as to which transmit pulse produces an optimal image in synthetic-aperture radar imaging through dispersive media was addressed in (Varslot, Morales, Cheney, SIAM J. Appl. Math., **71**, 1780–1800, 2011). For large signal-to-noise ratios, their optimal waveform "closely resembles the precursor which is generate from a one-cycle sinusoid. This suggests that under certain conditions, precursors may indeed be useful as transmit waveforms in SAR imaging."

Here, we derive the low-frequency transmit precursor waveform for imaging isotropic point scatterers embedded in a Debye-type dielectric material indicative of foliage. This "scattering precursor" is derived by asymptotic methods and may be expressed in terms of modified Weber functions. In comparison to the Brillouin precursor (or the nonscattered precursor), the scattering precursor pulse consists of higher frequencies and also has a peak amplitude that decays algebraically with propagation distance, as $z^{-3/2}$.

We compare the propagation characteristics and imaging results obtained for each transmit pulse (both the nonscattered and scattered precursor waveforms, and the optimal waveform given by Varslot et al.). The spatial resolution of each transmit pulse is studied by a comparison of the bandwidth of each received pulse. It is clear from the results that which waveform is "optimal" depends upon the propagation distance from transmitter to scatterer and back, as well as the dispersive properties of the material.