Time Domain Power Flow in Hyperbolic Metmaterial Excited by a Pulsed Dipole

Frederik Guyon[1,2], Caner Guclu[2], and Filippo Capolino[2]
(1) Commissariat à l'Energie Atomique et aux Energies Alternatives, France
(2) University of California, Irvine, California, 92697 USA

From a frequency domain point of view, the field emitted by a dipole in free space translates into two parts: the real power, that is propagating, and the reactive power. The latter is the average stored energy, in a sense that it is a stationary one. From a time domain point of view, a finite pulse results in a net propagating wave and also power flow that oscillates forward and backward or around the dipole (A Shlivinski and E. Heyman, IEEE Trans. on Antennas and Propat., 47, 280-286, 1999). Adopting a frequency domain formulation, the propagating spectrum in hyperbolic medium (HM) is indefinite, in contrast to an ordinary medium where the propagating spectrum is finite.

We present an analytic investigation that shows the impact of HM on the time domain power flow excited by a pulsed dipole. We start from the expression of the field emitted by an infinitely small dipole inside a homogeneous anisotropic medium (L.B. Felsen and N. Marcuvitz, Radiation and Scattering of Waves, IEEE press, Ch. 7, 1994). Assuming a non-dispersive medium, time domain expressions are derived and applied to a lossless "elliptic" medium. We identify the propagating and reactive properties (G. Francheschetti and C.H. Papas, IEEE Trans. on Antennas and Propat., 22, 651-661, 1974). Then, in the near-field region, we point out the role of the reactive field in the complicated behavior of the time-domain Poynting vector, arising from the circulating and radial power flow and backward/forward oscillations thereof. This oscillatory power flow results in a "waste of time" in the process of energy propagation to the far-field region.

Extrapolating the expressions to a lossless non-dispersive HM, some results are highlighted. In particular, the space is split into two regions (Rr) and (Ri) characterized by a purely real index of propagation and a purely imaginary one, respectively. Rr and Ri are separated by an impassable boundary (B). Although the instantaneous amplitude of the flow may be high in Ri, the time-average energy balance is strictly zero. This region experiences only reactive field with no net power flow. The power flow is strongly modified in Rr close to B, almost only in the radial direction, reducing the "waste of time", thus increasing the "Purcell" factor. These observations also allow to understand the impact of losses in Ri, in an easier way than with a wave vector approach in the frequency domain.

Finally, numerical simulations are performed for pulsed excitation in a dispersive lossy HM, that satisfies the causality principle. These simulations consolidate the primary observations that were based on a simplified non-dispersive approach that did not respect the principle of causality.