Second Time Integral of the Impulse Response for Enhancing the Late-Time Target Response for Target Identification

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A general problem, concerning target identification via the late-time aspect-independent complex natural resonant frequencies, is the presence of the large early-time response. It would be advantageous to enhance the late-time response relative to the early-time response. In a general sense this implies some kind of frequency-dependent filter which attenuates the high-frequency parts of the waveform while providing little or no attenuation to the complex resonant frequencies of interest. Such a low-pass filter (passive and/or active) is the subject of this paper.

A desirable feature of such a filter is the temporal separation of early- and late-time responses. Furthermore we would like to be able to still use time gating (windowing) to remove some of the clutter in the signal returned to the radar. So we do not wish to introduce significant dispersion into the scattering data.

Consider first a related problem, low-frequency radiation from an antenna and its implication for pulse radiation. In [C.E. Baum, "Some Limiting Low-Frequency characteristics of a Pulse-Radiating Antenna," Sensor and Simulation Note 65, 1968] we observed that, if a step-like voltage pulse is applied to an electric dipole, the low frequency content of the radiation is proportional to $s\,(=\Omega + j\omega$, the Laplace transform variable or complex frequency). This in turn implies that the radiated pulse must have at least one zero crossing. If the late-time voltage pulse is allowed to decay to zero, then the radiated pulse must have at least two zero crossings.

Consider now the far-field scattering problem. Let the incident wave be like a delta-function, i.e., one sided, decaying back to zero with finite, nonzero area (time integral). The low frequency content of the incident field is then just the nonzero area. The scatterer is characterized at low frequencies by the induced electric and magnetic dipoles $(\vec{p}\ \textit{and}\ \vec{m})$ which are also constant vectors (in the low-frequency limit). The far field scattered by such dipoles is proportional to $s^2\,\vec{p}\ \textit{and}\ s^2\,\vec{m}$ If we multiply the Laplace transform of the far scattered field by s^2, the resulting low-frequency far scattered field is proportional to $\vec{p}$ and $\vec{m}$. In time domain this is a double time integral which goes to zero at late time since the area (the low-frequency limit of the Fourier transform) must be finite. (Note that the waveform is damped due to the radiation of electromagnetic energy.) Having applied such a filter, the various natural-frequency identification techniques such as E-pulse, matrix pencil, etc., are still applicable. In implementing the second time integral there is some advantage in using analog filters before digitizing the data. This can reduce the impact of digitization errors in the late-time data, effectively increasing the dynamic range.