Efficient and Practical Pulses for Dipole Antenna UWB Link

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Introduction

Many potential communication and radar applications of UWB signals require simple, low-power circuitry and optimal use of radiated spectral power density limits. A full-wave UWB link simulator with accompanying post-processing tools has been developed to study the effects of signal waveform and antenna geometry. In this paper, we focus on analysis/synthesis of suitable UWB signaling schemes to be implemented in a low-complexity antenna/circuitry co-design. When the antenna characteristics are known, it is possible to design waveforms that optimize some aspect of a UWB link [1]. However, the optimized waveform often is complicated and difficult to implement with simple circuitry. We show below that simple windows applied to the time waveforms and frequency spectrum can produce UWB pulses that (1) control the spectral power density of radiated fields and received voltage, (2) create large peak received voltage, (3) confine received energy to a narrow time interval, and so on.

Simulation and pulse derivation technique

Method of Moments electromagnetic solvers operating in the frequency and/or time domains are used to obtain link transfer functions and antenna impedances. These full-wave solvers can evaluate the fields of arbitrary 3-D conductor structures that form antennas and nearby bodies that can disturb both the transmitting and receiving antennas. Such a UWB link with two antennas is shown schematically in Fig. 1. For EM analysis, the transmitter is represented as a voltage generator with internal resistance and the receiver is a resistive load (reactance can be included if desired). Our UWB link simulator can provide (1) electric field at an arbitrary point in space, (2) transmission between two antennas, (3) fields and/or transmission with scatterers that produce multipath, and (4) multiple sources/receivers to assess interference. In the work described here, the transmission function of the UWB link is the quantity of interest.

We obtain an efficient and practical approximation to the optimum generator pulse by applying simple window functions in the time and frequency domains to the theoretically optimum pulse. For example, the generator waveform $V_G(t)$ that produces a received voltage V_R(t) with uniform spectral power density over the frequency band $f1 < f < f2$ is obtained as the inverse Fourier transform *IFT*

$$V_G(t) = IFT\{1/T(f)\} \tag{1}$$

where *T(f)* is the voltage transfer function from the generator to the load in Fig. 1. Unfortunately, the waveforms $V_G(t)$ and $V_R(t)$ usually exist over long time intervals and may have complicated shapes that are difficult to produce with simple circuitry. By applying windowing functions that smooth the spectrum and limit the time duration of the pulse, a nearly optimum result can be obtained with waveforms that are much easier to realize

$$V_G(t) = TW(t) \cdot IFT\{FW(f)/T(f)\} \qquad (2)$$

where *TW(t)* and *FW(f)* are appropriate windowing functions in time and frequency domain, respectively. The twofold windowing is implemented through several Matlab scripts utilizing the output from the full-wave engine. Some results for a bow-tie dipole are illustrated in Figs. 2 and 3 for various generator waveforms. The signals shown here involve (1) “mathematical” shapes described by simple formula, (2) “optimal” waveforms derived directly from the transfer function, and (3) signals suitable for generation by digital circuitry.

Some results and discussion

The mathematically simple shapes of driving pulse in Fig. 2a & 3a are not well suited to UWB operation. The Rayleigh pulse applied to the bow-tie dipole results in long-ringing pulses and a narrow spectrum, Fig. 2a. The triangular pulse looks comparatively better, Fig. 3a. It is more easily generated by simple circuitry and has a better performance in terms of short pulse transmission and spread spectral power density up to 50% bandwidth [2]. Windowed versions of the optimal waveforms are depicted in Fig. 2b and 2c. These pulses efficiently utilize a wider spectrum and produce received/radiated waveforms that are localized in time. However, the generator waveforms that achieve these results are quite complicated.

The generator waveform in Fig. 2b can be quantized by using a 4-bit scheme (3 amplitude plus sign). This quantized waveform, Fig. 3b, yields a good approximation to the results obtained with the optimal waveform, Fig. 2b. Another scheme that utilizes a direct digital ±1 pulse sequence to drive the transmitting antenna is easy to implement and produces acceptable pulses and spectra, Fig. 3c. The techniques described here have produced good results for other simple antennas that are compatible with overall low-cost UWB system development.

References

[1] D. M. Pozar, “Waveform Optimizations for Ultra-Wideband Radio Systems,” accepted by IEEE Trans. on Antennas and Propagation, Vol. 51, pp. 2335-2345, September 2003.

[2] O. Boryssenko, D.H. Schaubert, Optimization Ultra-Wideband Radiation of Dipole Antennas with Triangle Driving Pulses, The AMEREM 2002 Symposium, Annapolis, MD, June 2-7, 2002.

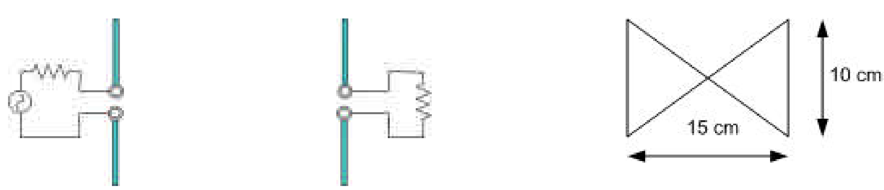


Fig.1. Schematic of simple UWB link comprised of 10x15 cm bowtie antennas.

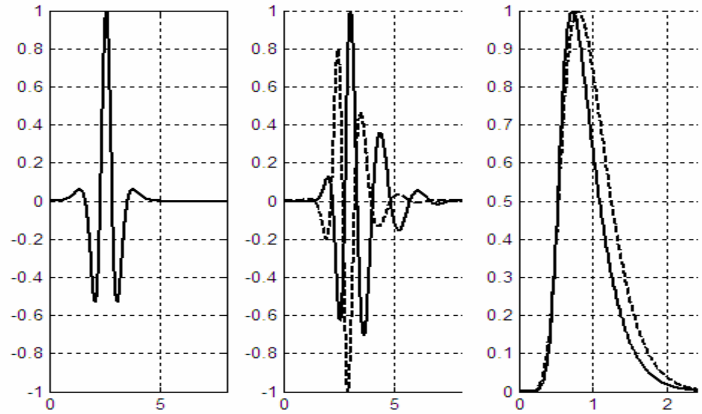
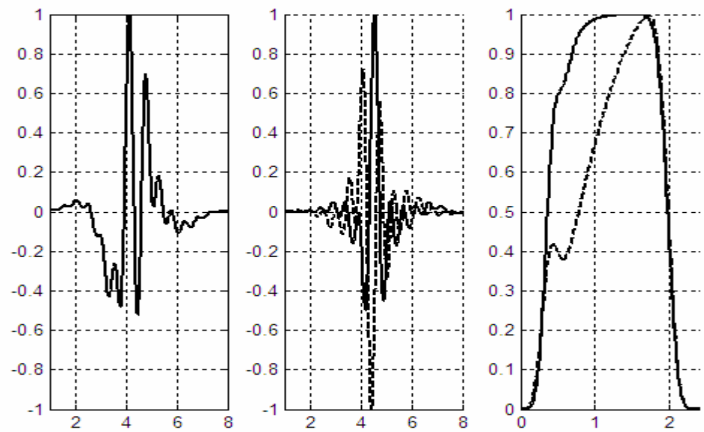
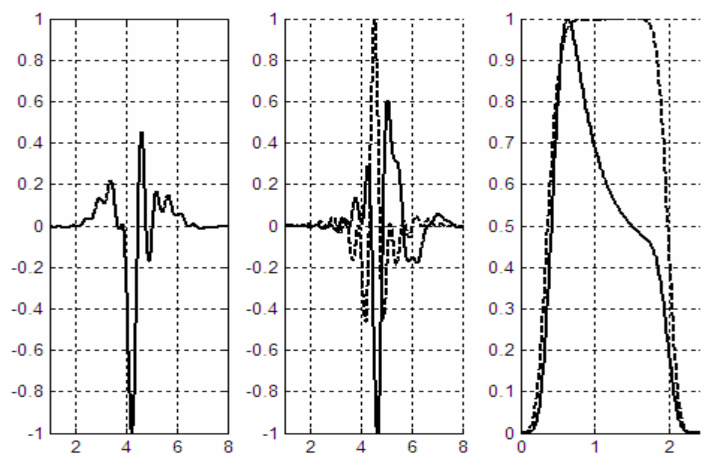
	Transmitter Generator Waveform	Received Signal (–) Radiated Field (--) Waveforms	Received Signal (–) Radiated Field (--) Spectra
(a) “Mathematical” signals, viz. Rayleigh and similar ones do not permit effective pulse shape and spectrum control			
(b) Result of optimization to support short received pulse & flat spectrum density in receiver load			
(c) Result of optimization to support short radiated pulse & accompanying flat spectrum density of radiated field			

Fig.2. Generator pulse of complex shapes for the UWB link with two 10-cm wide and 15 cm long bow-ties. 50 Ohm resistors are used in generator and load. Time is scaled in nanosecond and frequency in gigahertz. Amplitudes are normalized.

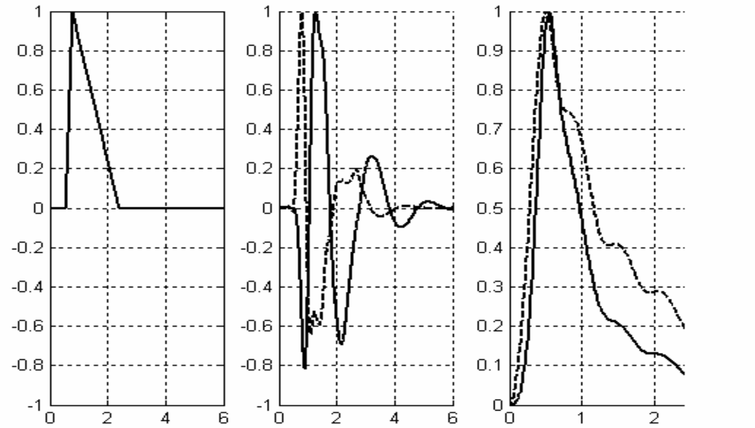
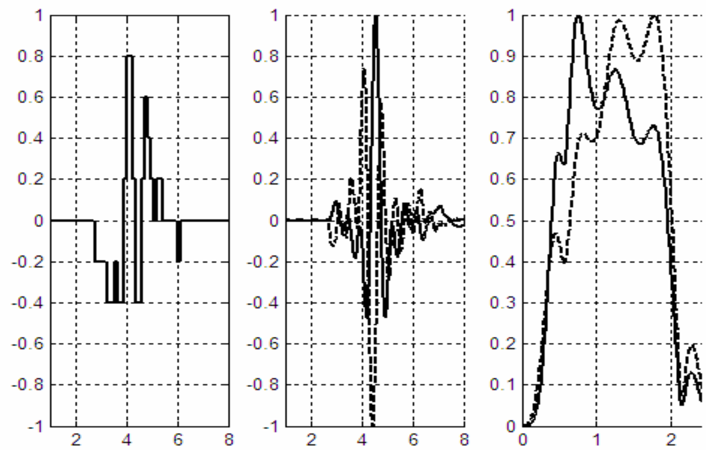
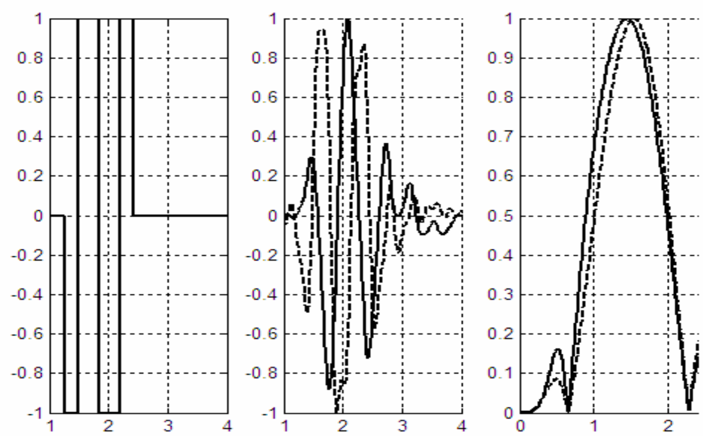
	Transmitter Generator Waveform / Received Signal (–) Radiated Field (--) Waveforms / Received Signal (–) Radiated Field (--) Spectra
(a) Asymmetrical triangular pulse of appropriate duration and skew factor can create reasonably a wide spectrum and short duration pulse [2]	
(b) Digitization with 3-bit amplitude plus sign bit resolution. 150-picosecond waveform sampling for implementation through a Direct Digital Synthesis (DSS) technique	
(c) An “optimal” code [-1-1+1+1 +1-1-1-1+1+1] with 175-ps wide ±1 V bipolar rectangular pulses for direct digital driving	

Fig.3. Simplified generator pulses for the UWB link with two 10-cm wide and 15 cm long bow-ties. 50 Ohm resistors are used in generator and load. Time is scaled in nanosecond and frequency in gigahertz. Amplitudes are normalized.