Development of the BLT Equation in the Time Domain for Transmission Line Networks

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Recent developments in electromagnetic (EM) sources producing high power microwave (HPM) or ultra wide-band (UWB) transient signals have led to a concern about the effects of these environments on modern digital systems, and have spawned several research programs, including a university MURI program (U.S. DoD MURI grant F49620-01-1-0436 with University of Illinois at Chicago and other participating universities). Such environments, which collectively are referred to as high power electromagnetic (HPEM) fields, could be inadvertent, like the environment produced by a search radar illuminating a nearby aircraft, or intentional, such as a deliberate attack on a system by an adversary using an electromagnetic weapon. In either case, the effects of these HPEM fields may include system upset, and in some cases, permanent damage.

A useful tool for assisting in the analysis of EM effects on complex electrical systems is transmission line modeling and the resulting Baum-Liu-Tesche (BLT) equation. This equation is described in the literature (see Tesche, F. M., et. al, "Example of the Use of the BLT Equation for EM Field Propagation and Coupling Calculations", Radio Science Bulletin, No 312, March 2005, Gent, Belgium). This is a frequency-domain equation that is formulated by writing the scattering and transmission relationships for line voltages and/or currents at every node in the network and combining these with the appropriate wave propagation relationships on each of the transmission lines in the network, to form a single large matrix equation for the node responses.

The BLT equation has been used for many different analysis efforts involving large transmission line networks, its frequency domain formulation makes the treatment of networks with nonlinear loads difficult. Thus, it is desired to formulate a time-domain counterpart to the BLT equation, and this is the topic of the present paper.

Starting from the conventional frequency-domain BLT equation, the inverse matrix involving propagation and reflection terms is expanded in a power series and the resulting equation is expresses in the time domain using convolution operators of the surge impedances of the lines and loads in the network. The transient analysis of the network responses is straightforward for linear loads, However, for nonlinear loads, the convolutions must be performed in a time-marching procedure, with a solution to a nonlinear matrix equation being made in every time step. Details of this solution will be explored in this paper.