Abstract

Various natural and artificial processes, such as lightning discharges and nuclear explosions, can produce a strong pulse of broad-band electromagnetic radiation, called an Electromagnetic Pulse (EMP). The large electric fields in such a pulse can cause damage to electronic and control equipment. A number of laboratories around the world have developed EMP simulators that can produce electromagnetic pulses of different types, with the objective of testing the susceptibility of systems exposed to EMP. These are generally driven by a high-voltage pulsed-power source. 'Bounded-wave' type simulators, with which this study is concerned, concentrate energy within the workspace of the system itself.

We have performed self-consistent, three-dimensional, time-domain calculations for a bounded-wave EMP simulator, including a realistic geometry and test object. The simulator consists of a constant-impedance TEM structure driven by a charged capacitor, discharging through a fast closing switch. These simulations yield the detailed 3-D electromagnetic field structure within the TEM structure, in its immediate vicinity, as well as the radiated far-field. To our knowledge, this is the first time such a detailed study has been performed.

The prepulse seen in these simulations can be explained quantitatively in terms of capacitive coupling across the switch and the known charging waveform across the capacitor. To our knowledge, this is the first quantitative explanation of prepulse through 3D simulations.

Placement of a test object within the simulator significantly modifies the electric fields within the test volume, in terms of field strength as well as the frequency spectrum. This means that, for a given simulator, larger objects would be subjected to somewhat lower frequencies. Also, regardless of the size of the test object, the waveforms match only up to the first peak in the electric field. Multiple scattering off the simulator structure and test object produces features in the simulated waveform that are markedly different from the free-space case.

Radiation leakage out of the bounded volume can result in severe electromagnetic interference with surrounding equipment. Shorter closing times for the switch, which allow access to higher frequencies, have a concomitant cost of higher radiation leakage. The use of a matched sheet termination shows significant reduction of leakage, as compared to the use of two parallel rods. For a given termination, larger test objects marginally reduce leakage. These conclusions have also been explained in terms of the distribution of Poynting flux, and in terms of the current induced in the test object. Increasing the test volume by the use of longer parallel plates offers the advantage of reduced backflow of power towards the pulser. However, this comes at the cost of increased energy leakage. The methodology used in this analysis can be extended to study leakage from essentially arbitrary combinations of bounded-wave simulators and test objects.

We have analyzed the electromagnetic mode structure inside the simulator, by the application of the Singular Value Decomposition (SVD) method to time-domain

FDTD data. This combination of two powerful techniques yields a wealth of information about the internal mode structure which cannot otherwise be obtained. The TEM mode is dominant throughout the simulator length. The TM_1 mode dominates over TM_2 over most of the length. Close to the termination, the TM_2 mode becomes stronger. This has been explained in terms of the induced current distribution in the resistive sheet and the resulting magnetic field in the vicinity of the termination.

Placement of a perfectly-conducting test object in the parallel-plate section produces major changes in the mode structure near the object. Higher-order TM modes become stronger, at the cost of the m=0 mode. This finding has considerable practical significance, since it implies that the object would be subjected to electromagnetic fields that deviate significantly from the desired m=0 form. We have provided a physical explanation for the deviation in terms of induced currents on the object and the resulting electromagnetic fields in its vicinity.

The TEM-cell radiates mainly in the forward direction, with much weaker side lobes. We have calculated the temporal cross-correlation between the modes near the termination and the forward-radiated far-field. The principal TEM mode turns out to be poorly correlated with the far-field. The dominant TM modes, viz., TM_1 and TM_2, exhibit fairly strong correlation with the far-field. TM_1 exhibits long-time correlation with the far-field, while TM_2 only shows short-time correlation. This shows that, for a given mode amplitude, higher-order TM modes are more effective in producing radiation leakage as compared to the TEM mode. We have also studied the effect on mode structure of the angle between the simulator plates, and of the switching time. The use of an optimized spatial mode filter reduces the TM_1 mode, without significantly modifying the desired TEM mode. However, the TM_2 mode remains largely unchanged. These observations could suggest ways to improve simulator design from the point of view of electromagnetic interference with surrounding equipment and the purity of the TEM mode seen by the test object.

FDTD modelling of pulsed experiments is normally done with only the load set up inside the FDTD domain, the evolution of the pulsed energy source being modelled by some other method. In order to permit a truly self-consistent study, we have also set up the capacitor and switch within the FDTD domain. Apart from self-consistency, this would also allow inclusion of distributed parameter effects in energy storage capacitors. Such effects are important when capacitors are used to drive fast-risetime experiments. The study has identified critical numerical issues that must be taken into account in such work.