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Theoretical Model for the EM Effects Induced By High-Energy Photons (Gamma, X-ray) in Dielectric Materials and Electronic Systems

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Introduction

During last twenty years, a number of models have been used to calculate the change of conductivity and dielectric strength in materials caused by the passage of high-energy photons, such as Gamma-rays and X-rays. In these models, the electromagnetic fields generated in the electronic system created by the high-energy photons have not been investigated. That is, the solution of Maxwell's equations has not been obtained for these kinds of problems. We constructed a theoretical model, described by a set of equations to solve such a problem. The model includes the equations that describe the physics of the recombination and generation of electron-hole pairs by the high-energy photons in the dielectric materials, the Compton electron generation rates, and Maxwell's equations.

When a beam of gamma photons penetrates into a transmission line or cables, energetic electrons and holes (carriers) are created in the metals and dielectrics of the system by the Compton and photoelectric effects. These energetic electrons and holes in turn create many low-energy holes and electrons through the interaction of the high-energy electrons with the atoms in the solids. Since the density of the solids is very high, the mean free path of the high-energy electrons is very short. In other words, they lose their energy in a very short-time, on the order of picoseconds or less. Since electronic systems typically do not respond in such a short time, we can make the approximation that the number of low-energy carriers can be determined by energy deposition by the gamma photons with the use of a Monte Carlo code and then divide the deposited energy by the average amount of energy necessary to create an electron-hole pair. Then in order to investigate how the electromagnetic wave is created by the gamma photons and its behavior as it propagates through the electronic system, we have considered the various recombination and trapping processes of the electrons and holes in the dielectric material.

We modified an implicit, two-dimensional, finite difference, time domain, electromagnetic, electron fluid computer code for the propagation of transverse electromagnetic (TEM) and transverse magnetic (TM) modes in a parallel plate transmission line in a rectangular geometry with pressure-variable air as the dielectric material. In the modified code, the single dielectric medium between the perfectly conducting metal plates is a solid dielectric with electron trapping and de-trapping, recombination, and radiation induced conductivity. Primary, high-energy electron and secondary, low-energy, conduction electron current densities are included in the modified equations. We obtained axial propagation of a primarily TEM wave when the entrance of the transmission line is obliquely illuminated with a step gamma pulse in time.

In order to model to first order in two dimensions a coaxial cable, we have also developed a radial geometry code with two different solid dielectrics between a cylindrical center conductor and an annular outer shield conductor. Both conductors are presently considered to be perfectly electrically conducting. The first problem that we considered for the gamma radiation effects is for a coaxial cable. We obtained electromagnetic wave propagation for gamma ray illumination about the axial mid-point of a two-dielectric coaxial cable model with a step pulse in time with a strong Gaussian distribution in the axial direction and gamma attenuation in the negative radial direction. Electromagnetic waves propagate out in the positive and negative axial directions. Figure 1 is a surface plot of the E_r field generated by the gamma near the axial midpoint of the two-dielectric coaxial cable at $1x10^{-16}$ sec. The cable is 0.531m long and 0.0568 cm at the outer dielectric radius. The discontinuity in the peak E_r indicates the radial discontinuity in the dielectric constant. Figure 2 is a surface plot of E_r at $1.5x10^{-9}$ sec. Two wave peaks at $r = 0.0346$ cm are seen moving toward the ends of the coaxial cable at $z = 0$ and $z = 0.531$m. The peak E_r occurs near dielectric interface at the axial midpoint.

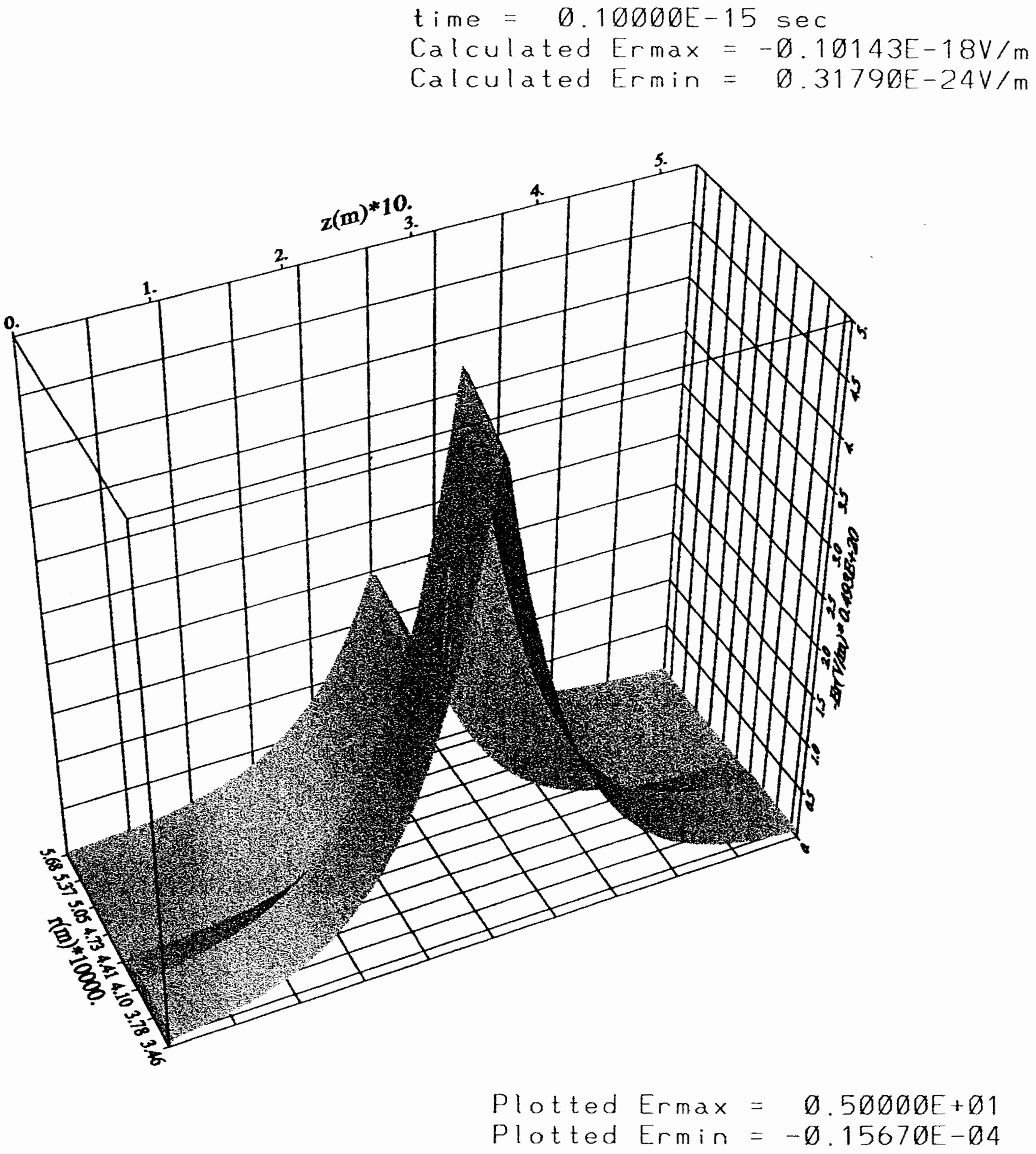
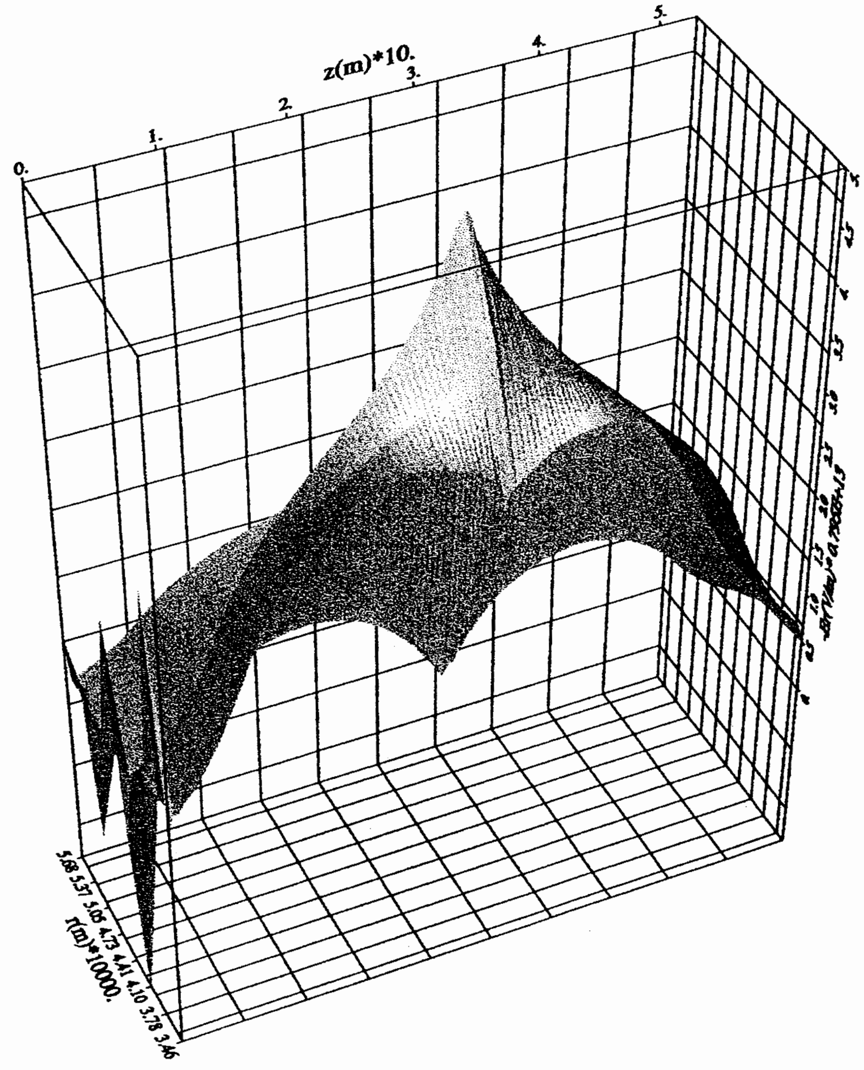


Figure 1. Surface plot of the E_r field generated by the gamma near the axial midpoint of the two-dielectric coaxial cable at $1x10^{-16}$ sec.

time = 0.15000E-08 sec
Calculated Ermax = -0.62901E-12V/m
Calculated Ermin = 0.21551E-12V/m



Plotted Ermax = 0.50000E+01
Plotted Ermin = -0.17131E+01

Figure 2 Surface plot of E_r of the two-dielectric coaxial cable at $1.5\text{x}10^{-9}$ sec.