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Creation and Development of a Next Generation Simulation Model for Spacecraft Charging

Brian P. Beecken
beebri@bethel.edu

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Creation and development of a next generation NUMIT-type model that handles changing conductivities and varying electrode configurations

Brian P. Beecken, Thomas R. Greenlee, and Robert M. Hoglund

Department of Physics, Bethel University, St Paul, MN 55112, USA

Abstract

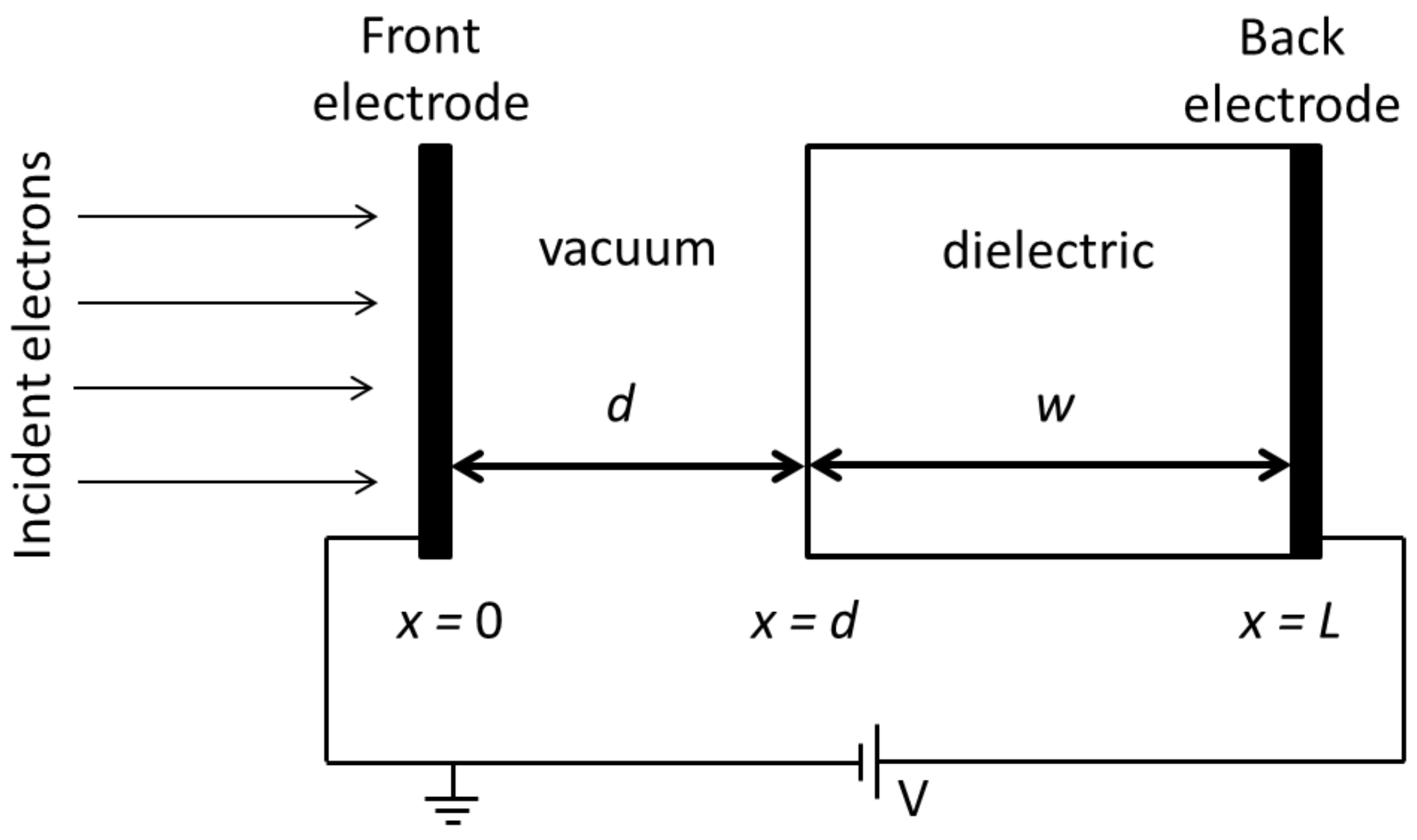
Dielectrics in spacecraft change as they age and as the temperature varies, resulting in changing radiation induced conductivities and dark conductivities. Unfortunately, these changes are not understood sufficiently well to develop comprehensive models that would represent a variety of materials for a wide range of temperatures and time periods—limiting the usefulness of NUMIT-type modeling. Also, NUMIT models assume dielectrics are "sandwiched" between two electrodes—a significant limit on modeling scenarios both for spacecraft and laboratory testing.

AF-NUMIT3 has the ability to model changing conductivities, allowing the user to run more flexible simulations that can explore a greater range of situations and aid in identifying worst-case scenarios. Furthermore, AF-NUMIT3 can model a configuration with one electrode on the back of the dielectric and the other either on the front surface or at any distance from the front surface. A variety of laboratory testing configurations and spacecraft systems can now be modeled.

Background

The NUMIT family of simulation models

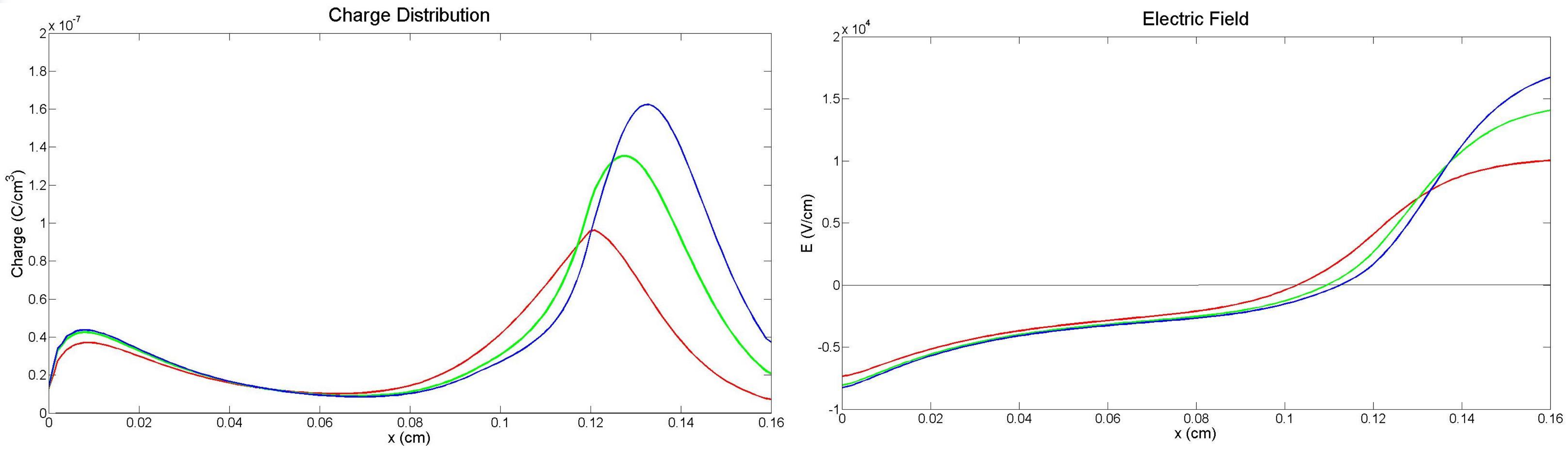
In the 1970's, Frederickson developed a computer model called NUMIT that used electrodynamics to keep track of how incident electrons move within a dielectric. It required inputs such as electron beam energies and densities plus dielectric mass densities and strengths. It used Tabata's EDEPOS to determine where the energy was deposited, thereby determining conductivity due to RIC. The code tracks changing charge distribution. The result is a calculation of the electric field, current, and charge density as a function of time and position. Electric field strength within the dielectric appears to be the major factor in determining discharge events.



Two limitations of NUMIT simulation models

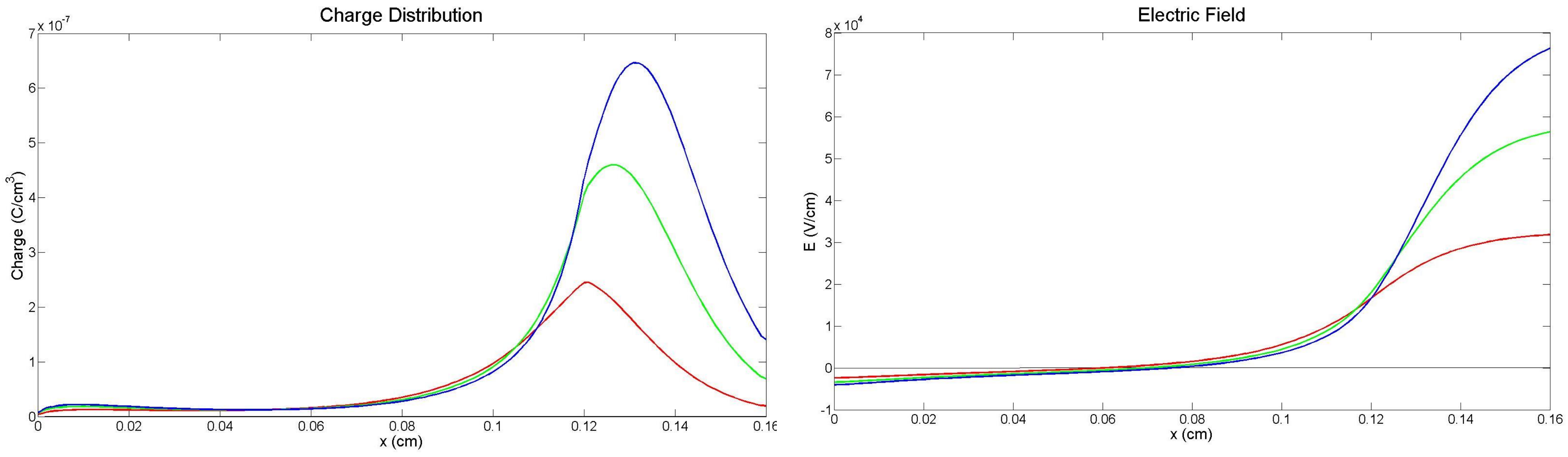
1) *Only modeling dielectrics that have an electrode on both the front surface and back surface.* The "sandwich" approach, illustrated above when d = 0, is crucial to the calculation of the electric fields that drive the transport of charges within the dielectric.
2) *Unchangeable RIC.* It is well-known that RIC changes, particularly due to aging and temperature changes

Varying placement of front electrode



Front electrode on surface

A 500 keV beam was simulated incident on Kapton®. Shown is the charge distribution and electric field resulting from 1 hr (red), 2 hrs (green), and 3 hrs (blue). Note the charges in the dielectric are pulled both to the front and the back by the induced charge on the electrodes. At the back, however, the charge builds up as there is almost no RIC.



Front electrode as far from surface as dielectric is thick

Same as above except large vacuum gap exists between front electrode and surface, *d* = *w*. Very little charge is drawn towards front surface due to few induced charges on distant electrode. Therefore, more charge is pulled towards the back electrode where more induced charge resides. Result is much greater electric field near rear of dielectric.

Theory

Induced charge on surface electrodes

For the NUMIT models to calculate electric fields within the dielectric, first the induced charge on the electrodes must be known. For surface electrodes, the equations are:

$$\sigma_{\mathrm{F}}(t) = -\frac{\epsilon V}{L} + \frac{1}{L}\int_0^L (x-L)\rho(x,t)\,dx$$

$$\sigma_{\mathrm{B}}(t) = \frac{\epsilon V}{L} - \frac{1}{L}\int_0^L x\rho(x,t)\,dx$$

Induced charge with variable distance to the front electrode

In AF-NUMIT3, the calculation was redone. Now, when $d \neq 0$ the equations are:

$$\sigma_{\mathrm{F}}(t) = \left(\frac{d}{\epsilon_0} + \frac{w}{\epsilon}\right)^{-1}\left[-V + \int_d^L \left(\frac{x-L}{\epsilon}\right)\rho(x,t)\,dx\right]$$

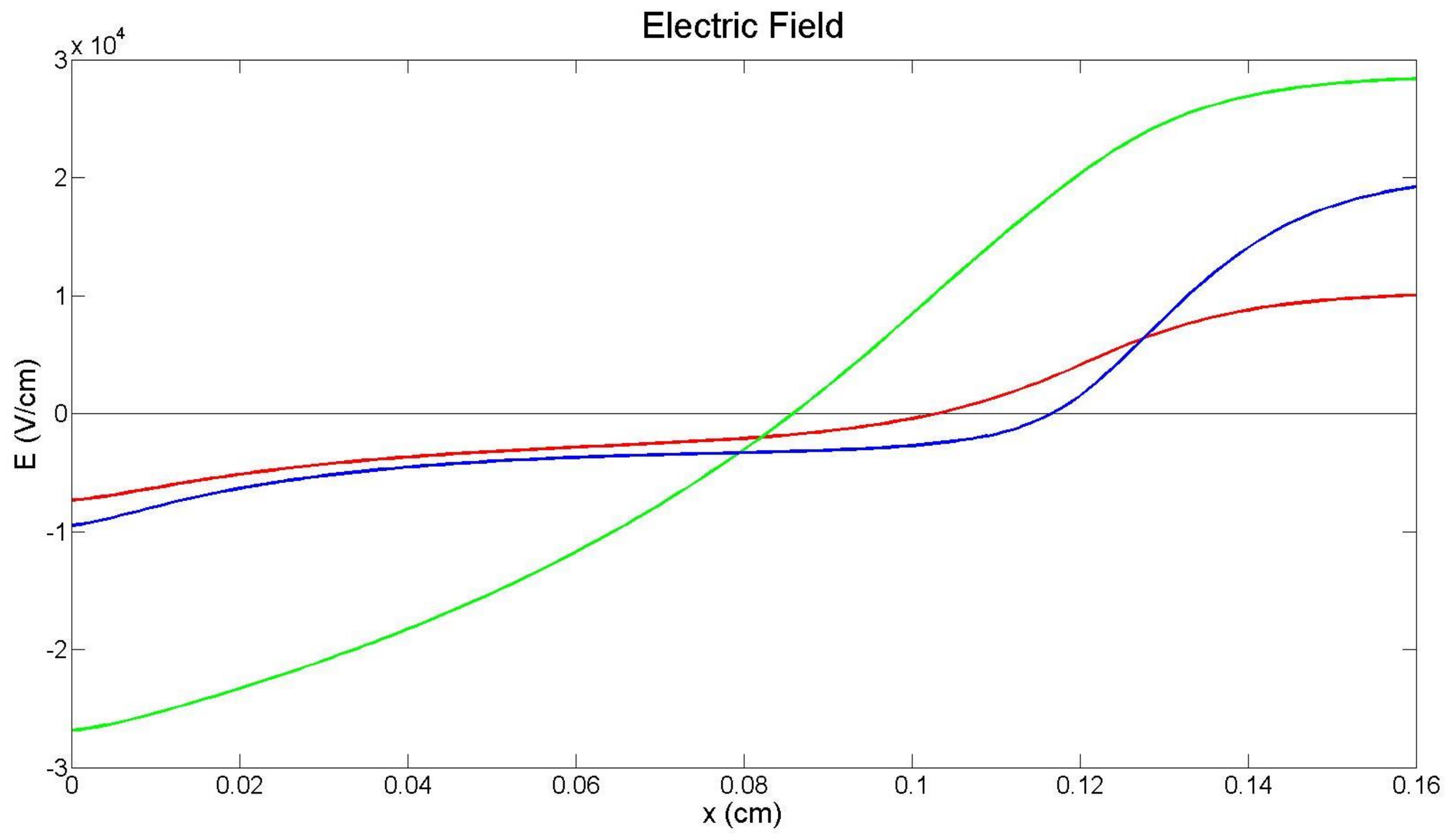
$$\sigma_{\mathrm{B}}(t) = \left(\frac{d}{\epsilon_0} + \frac{w}{\epsilon}\right)^{-1}\left[V - \int_d^L \left(\frac{x-d}{\epsilon} + \frac{d}{\epsilon_0}\right)\rho(x,t)\,dx\right]$$

Input of varying RIC coeficients

AF-NUMIT3 provides for the input of different RIC coefficients for various lengths of time.

Changing RIC

The same simulation was done as before: a 500 keV beam incident on Kapton® with a front surface electrode. This time, however, the RIC coefficient started at 5×10^{-16} sec/(Ω cm rad) for the first hour, changed to 2×10^{-17} for the second hour, and then went back to the original value for the third hour of simulation modeling. Note the rapid build-up of electric field during the hour of smaller RIC.



Acknowledgements

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