Internal Charging Characterization: AE9 Model Framework and EMA3D-Internal

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Introduction

- Spacecraft charging is a well-known problem for space vehicles
- Previous evaluation techniques of spacecraft charging threats, particularly for internal charging, require drastic simplifications and assumptions regarding both the environment and the geometry
- We present a new approach for performing a thorough evaluation of spacecraft internal charging risks

EMA3D-Internal

- EMA3D-Internal is a comprehensive tool for evaluation of internal spacecraft charging in a fully three dimensional and time dependent way
  - Spectrum Integration
  - Geometry
  - Monte Carlo Particle Transport
  - Electrodynamic Electric Field Solution
  - Computational Efficiency

Spectrum Integration

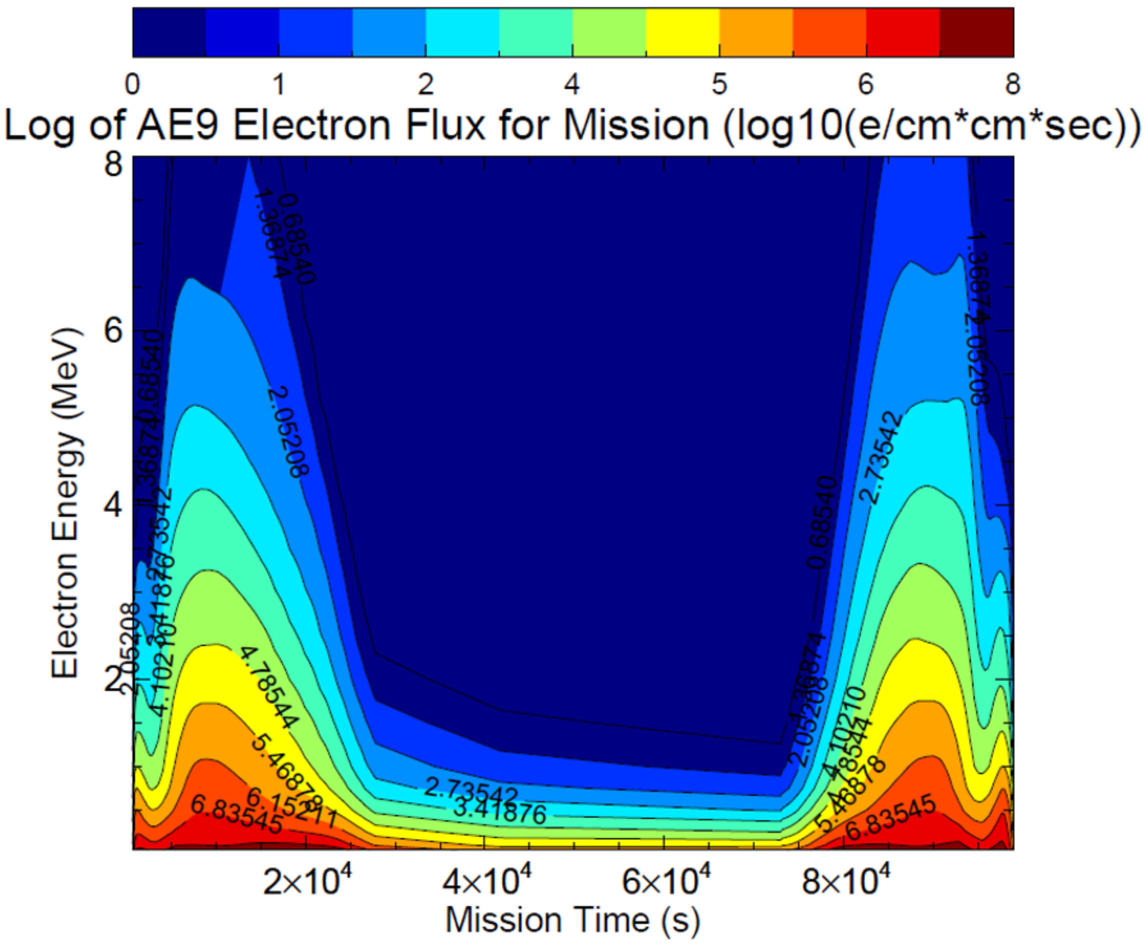
- EMA3D-Internal is very flexible in terms of allowing the user to provide the electron spectrum based on actual mission ephemeris
- The environment interface was designed with AE9 in mind
- There is no limit to the number of time steps or energies in the spectrum (apart from computer memory limits)

Spectrum Integration

- Modeling the radiation belt environment
  - Tough to do→highly dynamic region; greatly expands and/or contracts depending on many factors
- AE9/AP9 is an environment framework that accurately accounts for space weather dynamics
  - Provides models describing population of electrons and ions vs energy at varying confidence levels (75%, 95%, 99%, etc.)

Spectrum Integration

AE9 aggregate mean environment



AE9 Woes

- Data coverage
  – Very good coverage for electrons from LEO to GEO for 0 to 63 deg inclinations
    - Some data exists for higher inclinations, but not with high fidelity
    - For such missions, must use much more conservative environments (from data sources with higher fidelity) than ideal
  – More coverage (and higher fidelity data) for polar orbits (LEO to GEO) would greatly improve AE9/AP9 statistics
    - But, publicly available data is very hard to come by!

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Total number of sources:
1

Total number of particles fired per time step
1000000

Total number of time steps
7650

Total number of spectrum energies
21

Time        0 (Total current, A/m^2, and duration, s):
 1.0000e-008 30.00

Spectrum (MeV and weighting):
 0.0400      0.4200
 0.0700      0.2200
 0.1000      0.1500
 0.2500      0.1000
 0.5000      0.0700
 0.7500      0.0300
 1.0000      0.0080
 1.5000      0.0020
 2.0000      0.0000
 2.5000      0.0000
 3.0000      0.0000
 3.5000      0.0000
 4.0000      0.0000
 4.5000      0.0000
 5.0000      0.0000
 5.5000      0.0000
 6.0000      0.0000
 6.5000      0.0000
 7.0000      0.0000
 8.5000      0.0000
10.0000      0.0000
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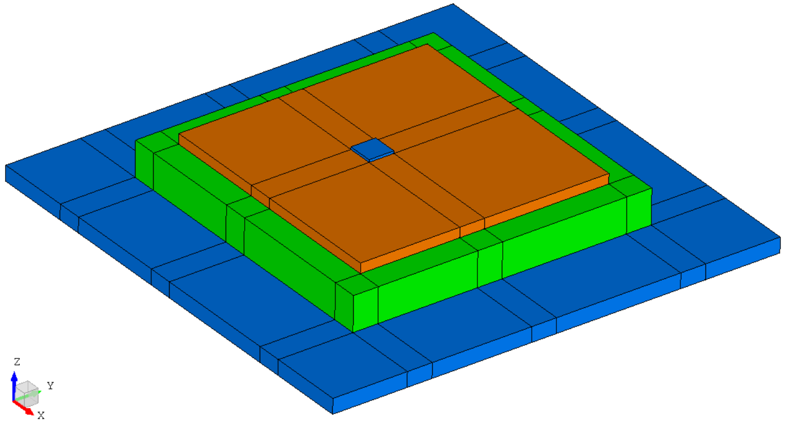
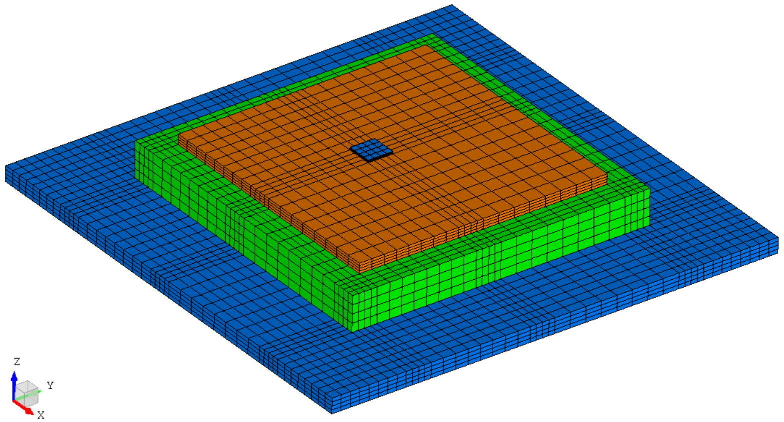
Spectrum Integration

- Our spectrum is shown at the left. It is a pulsed spectrum applied over about a week.
- It consists of a repeating pattern of 1500 seconds of a constant spectrum (taken from AE9 for a fictitious orbit) followed by 2400 seconds of zero flux.
- We divide the non-zero flux intervals into smaller time steps to avoid artificial ‘hot spots.’

Geometry

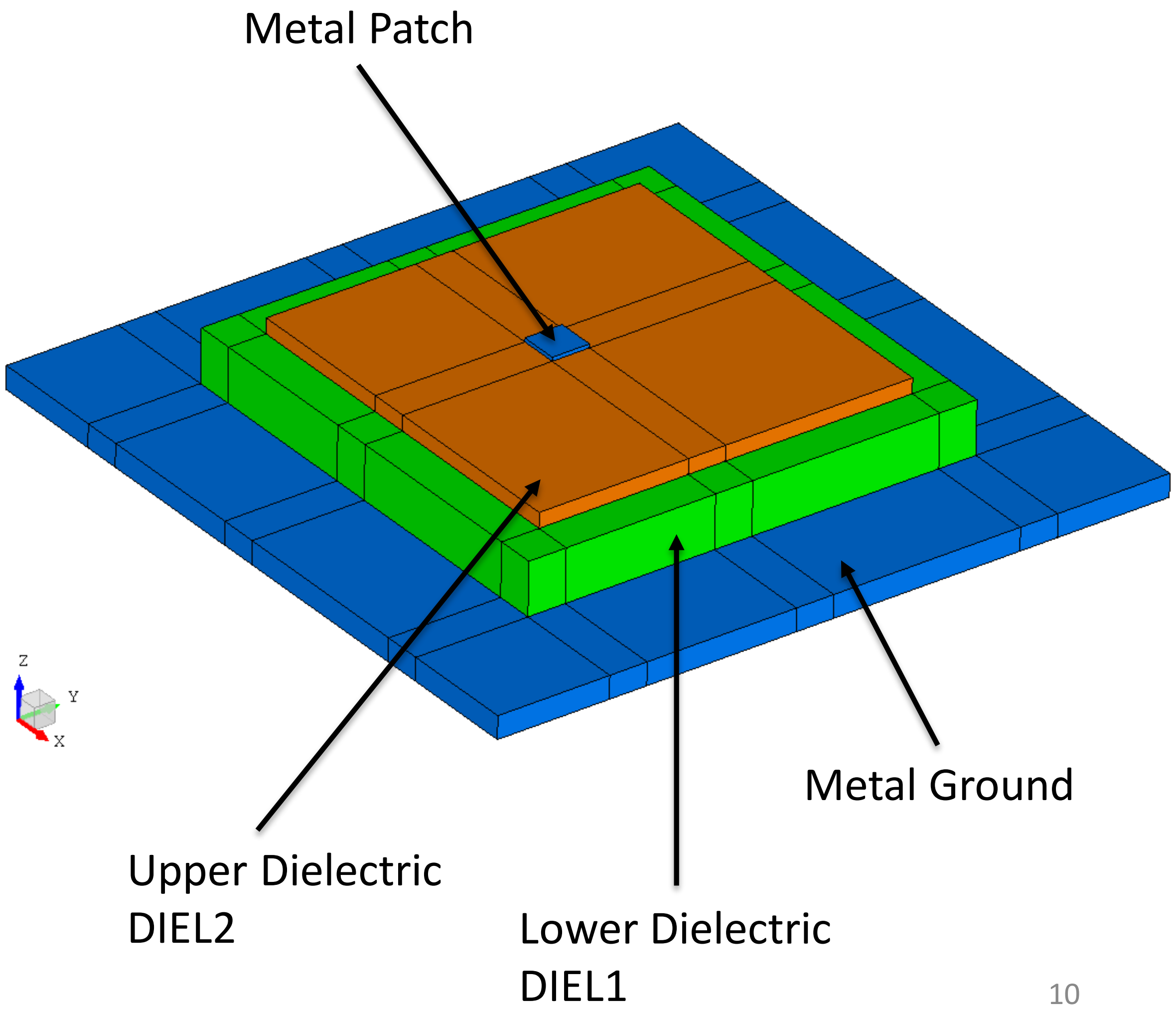
- EMA3D-Internal enables sophisticated 3D models to be built or imported via native CAD and developed in a GUI environment
- Material assignment and model mesh are controlled in this framework
- Here we examine an antenna mounted on the spacecraft





Geometry

- The dielectric materials are examined with the following properties:
  - DIEL1
    - Sigma = 1e-10 S/m, RIC = 0
    - Density = 2000 kg/m3
  - DIEL2
    - Sigma = 1e-18 S/m, RIC = 0
    - Density = 1800 kg/m3
- We run the simulation in a pulsed environment for about 7 days with a planar beam



Monte Carlo Particle Transport

- The user provided spectrum (AE9) serves as the basis for the Monte Carlo particle transport analysis to obtain the source of charge and energy deposition due to electron irradiation
- EMA3D-Internal interfaces with GEANT4 to perform the Monte Carlo particle transport simulation
- Geometry mesh is converted into GDML format
- Spatiotemporal charge and energy deposition profiles are recorded through tracking and stepping utilities

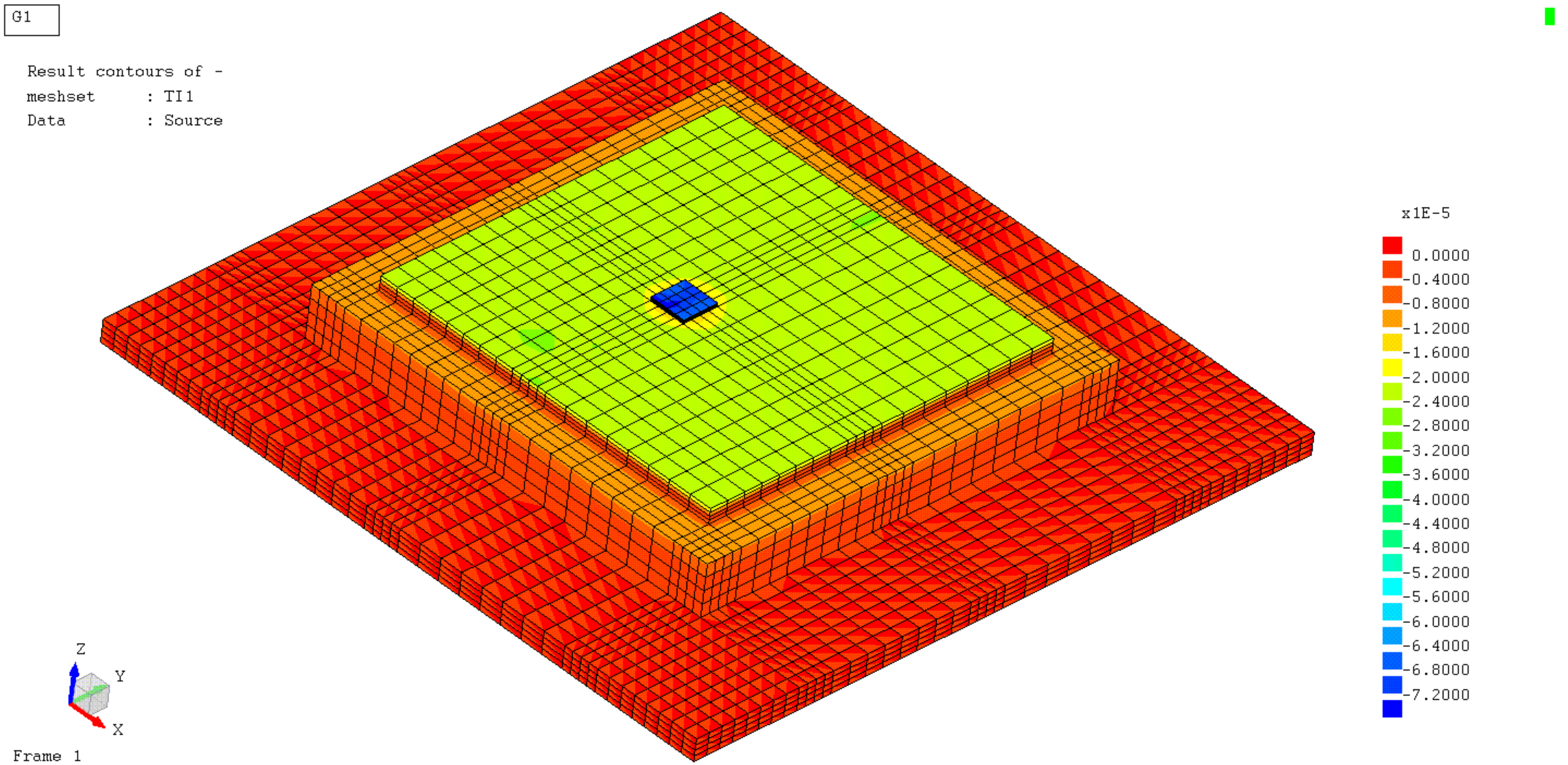
Electrodynamic Electric Field Solution

- The charge and energy deposition is the source for the electrodynamic field solution
- EMA3D-Internal uses a Finite Element approach to solve for the electrodynamic field (Elmer Multiphysics)
- The spatiotemporal charge and energy deposition profiles from the particle transport analysis are directly coupled into the electrodynamic evaluation

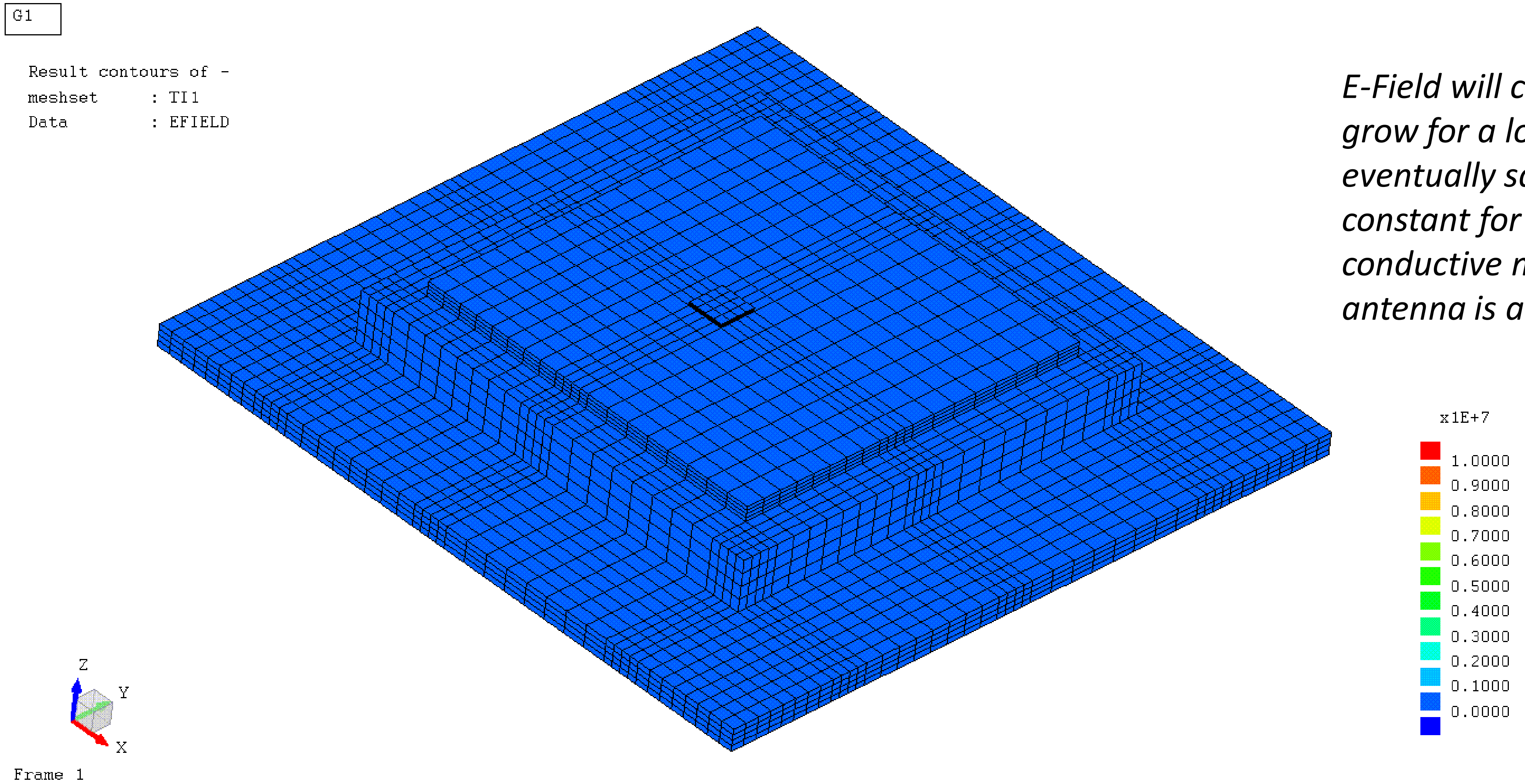
Computational Efficiency

- EMA3D-Internal is set up to provide efficient numerical computation for complex problems
- The interface with Elmer Multiphysics implements a hash-table motivated data structure to quickly access the source for electric field generation
- The simulation is performed with parallel computing methods, enabling high powered computation for difficult problems

Particle Source Animation



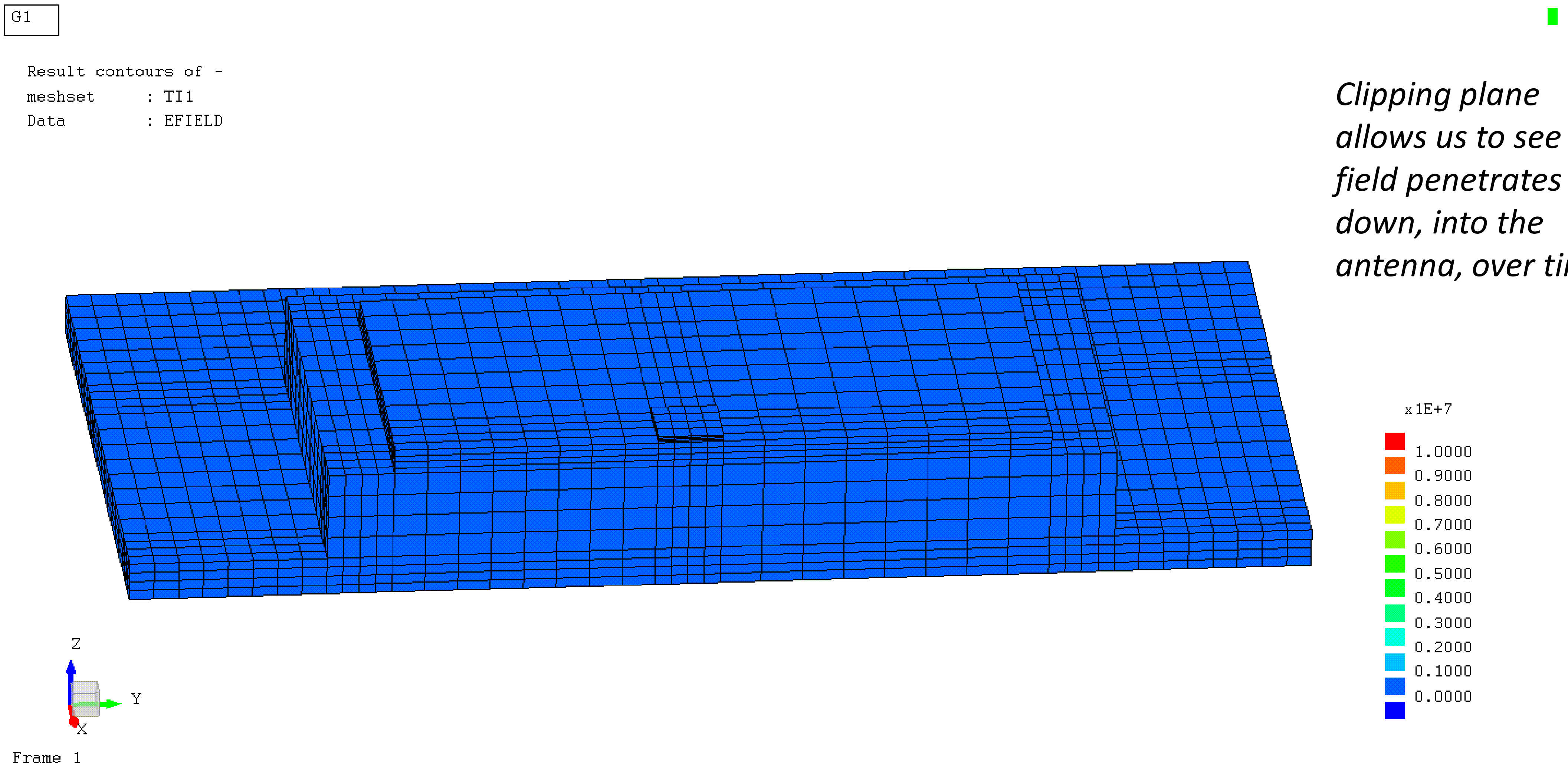
Results Animation: Absolute Value E-Field



E-Field will continue to grow for a long time and eventually saturate. Time constant for least conductive material in this antenna is about one year.

Electro Magnetic Applications, Inc.

Results Animation: Absolute Value E-Field



Clipping plane allows us to see the field penetrates down, into the antenna, over time.

Conclusions

- AE9 environment characterization is the preferred method for environment input into EMA3D-Internal charging model
  - Limited data coverage for high inclination orbits requires more environment conservatism in model than desired
- Combination of AE9 software and EMA3D-Internal present a highly relevant analysis to assist in the mitigation of internal spacecraft charging
- We have introduced the first commercial 3D internal charging software for use in the spacecraft charging community, and examined the susceptibility of a generic antenna in a space radiation environment using EMA3D-Internal