

Open-Source Simulation of Antenna Responses to Complex Electromagnetic Pulses

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This paper discusses an open-source simulation scheme for calculating the induced currents on antenna surfaces and the distribution of surrounding electric fields under the influence of various electromagnetic pulses. By designing a series of preliminary numerical experiments, the results from the open-source computations are compared with those from commercial software to verify the feasibility of the scheme. Subsequently, the open-source tools are employed for project experiments to provide references for the electromagnetic protection design of antennas. The study demonstrates that open-source electromagnetic simulation offers new possibilities for research in electromagnetic computation.

Index Terms—Open-source, electromagnetic pulse, antenna, openEMS

I. INTRODUCTION

Open-source electromagnetic simulation software enables users to access, utilize, modify, and distribute its source code freely, offering flexibility and transparency in research and development. Compared to commercial electromagnetic simulation software such as Ansys, CST Microwave Studio, and COMSOL, open-source electromagnetic simulation offers advantages such as low software costs and extensible source code. This makes it an excellent choice for individuals, academic institutions, and startups with limited budgets. Furthermore, it minimizes the impact on research reproducibility and verifiability, mitigating the risk of ‘Lock-in effect’ and fostering a more open scientific community.

II. PRELIMINARY DESIGN

In the initial phase of our project, we have concentrated on only three open-source tools to construct a comprehensive chain that includes preprocessing, solving, and postprocessing. In our assessment, these tools are particularly well-suited for the practical implementation of open-source solutions due to their interoperability: FreeCAD, openEMS, Paraview.

FreeCAD is an open-source 3D modeling software that supports parametric modeling. It can be imported as a Python module, enabling the automation of tasks and the customization of tools through Python scripts. OpenEMS, based on the finite-difference time-domain (FDTD) method, provides a Python interface and is capable of simulating a wide range of electromagnetic phenomena. Paraview is an open-source, cross-platform tool for data analysis and visualization. It supports parallel computing and includes a built-in Python interpreter, allowing users to write their own plugins to extend its functionality. It also supports the import and export of various data file formats.

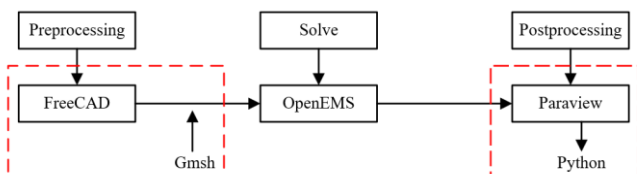


Fig.1. The open-source solution toolchain.

As shown in Fig. 1, to optimize the entire process, we employed Gmsh for the fine mesh generation and utilized the

Python programming language for the visualization of selected results.

To evaluate the suitability of open-source tools for project research, we have chosen a widely utilized commercial software in the realm of high-frequency electromagnetic simulation, as a benchmark for comparison. This paper primarily examines the official reference cases offered by openEMS, replicating the simulation configurations and computational targets of these cases within a commercial software, and subsequently comparing the outcomes derived from both simulation platforms.

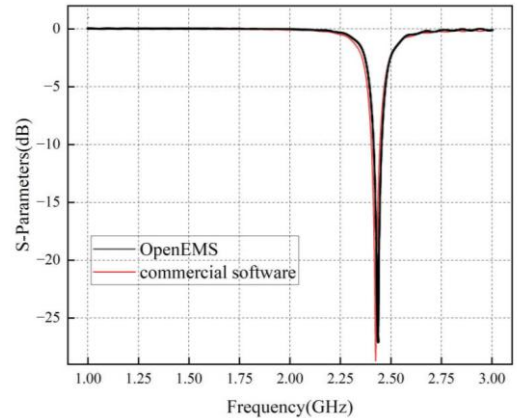


Fig.2. Normalised radiation pattern of the simple patch antenna in the E-plane. Red line: commercial software ; Blue line: openEMS.

From the comparison of simulation results of the two parameters under two simulation tools, it can be analyzed that the difference in simulation accuracy between the open-source electromagnetic simulation tool openEMS and the commercial software is within an acceptable range, and their applicability has been preliminarily verified.

III. EXPERIMENT DESIGN

Current research primarily focuses on simulating and calculating various antenna performance parameters, such as feed impedance and S-parameters, through open-source methods for antenna design purposes. However, there is limited research on utilizing open-source approaches to assess the safety impact of high-frequency electromagnetic pulse sources on antennas and applying these computational results to the electromagnetic protection design of antennas. For instance, we examine the impact on the induced currents

on the antenna surface and the distribution of the surrounding electric field.

As part of the project experiments, we analyzed the surface current distribution on the antenna and the surrounding electric field distribution when exposed to high-frequency electromagnetic pulse (EMP) radiation. The simulation results were benchmarked against established standards to determine the antenna's operational integrity and degree of potential damage. This assessment serves as a critical reference for optimizing the antenna's electromagnetic protection design.

This paper discusses electromagnetic simulations aimed at modeling the air-to-ground radiation environment. Specifically, it employs electromagnetic pulse sources with a frequency range of 1 to 10 GHz, with a propagation distance of at least 20 km. The simulation models the electromagnetic pulse emission devices on platforms such as satellites or aircraft. The receiving devices are simulated as satellite ground stations using parabolic antennas. The simulation results will indicate whether the antenna will be damaged under the influence of electromagnetic pulses and will provide insights for improving electromagnetic protection measures for antennas.

In the simulation scenario, the parabolic antenna model serving as the receiving station is modeled using FreeCAD.

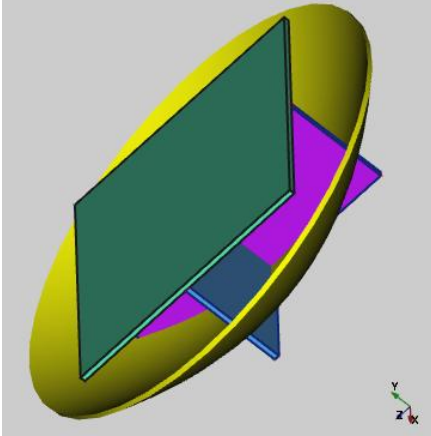


Fig.3. open-source CAD modeled parabolic antenna

This paper primarily refers to the latest series of recommendations for electromagnetic wave attenuation calculations published by the International Telecommunication Union Radiocommunication Sector. Initially, the free-space loss is calculated based on existing parameters. When the directivity coefficients of both the transmitting and receiving antennas are 1, the free-space propagation loss L_0 is given by the formula

$$L_0 = 32.45 + 20 \lg f(\text{MHz}) + 20 \lg r(\text{km}) \\ = 121.98 + 20 \lg r(\text{km}) - 20 \lg \lambda(\text{cm}) \quad (1)$$

In the formula, f represents the frequency of the electromagnetic pulse, λ denotes the wavelength of the electromagnetic pulse, and r signifies the propagation distance of the electromagnetic pulse.

If the actual electric field strength at the receiving point is E , and the electric field strength in free-space propagation is E_0 , the ratio $|E/E_0|$ is defined as the Attenuation Factor, denoted by A . Thus,

$$A = \left| \frac{E}{E_0} \right| \quad (2)$$

The corresponding attenuation loss L_F is given by

$$L_F = 20 \lg \frac{1}{A} = 20 \lg \left| \frac{E}{E_0} \right| \quad (3)$$

After considering the attenuation due to the aforementioned path, to characterize the power transmission along the path, the path loss (or fundamental transmission loss) is often introduced, denoted as L_b , which is given by

$$L_b = L_0 + L_F \quad (4)$$

The figure below shows the antenna's electric field distributions calculated with openEMS.

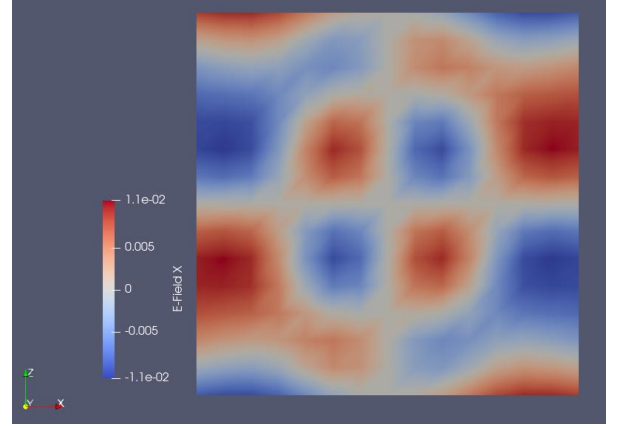


Fig.4. Electric field distribution of the antenna exposed to a 5 GHz Gaussian electromagnetic pulse

The comparative analysis reveals that open-source computational tools demonstrate principal deficiencies in domain discretization, numerical result extraction, and field visualization when benchmarked against proprietary software.

IV. CONCLUSION

This study is committed to advocating for open-source solutions in electromagnetic simulation and addressing practical challenges using open-source tools. Open-source solutions can energize research and enhance teaching in electromagnetic simulations, broadening research horizons and deepening educational insights. Future applications could include studying the response of antenna arrays under electromagnetic pulse environments and analyzing the transient behavior of antennas.

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