

Computational Mathematics for Electromagnetic Field Simulation

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Abstract

Computational science could be a key portion of making reenactments and investigations of electromagnetic areas superior, which is critical for numerous ranges, from restorative imaging to broadcast communications. This theoretical talks around the essential thoughts, computer methods, and fundamental issues that come up when utilizing scientific models to form precise considers of electromagnetic areas. Maxwell's conditions portray how electric and attractive areas carry on in space and time and are utilized to recreate electromagnetic areas. Since real-life circumstances are so complicated and distinctive, these conditions, which are made up of differential conditions with fractional subordinates, got to be fathomed numerically. Utilizing procedures like finite difference, limited component, and boundary component strategies, computational science breaks these issues down into shapes that can be fathomed. Limited contrast strategies utilize a framework to induce near to subordinates, whereas finite element strategies break the space up into littler pieces to accurately illuminate complicated geometries. Boundary component strategies center on fundamentally details along the domain's edges, giving fast answers for problems within the exterior world. Each strategy strikes a adjust between exactness, the speed of calculations, and the capacity to work with distinctive electromagnetic occasions. Overseeing the complexity of the coding system, accurately speaking to the highlights of the fabric, and dealing with nonlinearities within the conditions are a few of the issues that come up in computational electromagnetic field reenactment. To create simulations more exact and productive, analysts are continuously looking into unused math calculations, concurrent computer methods, and optimization methodologies.

Keywords: Maxwell's equations, Finite element method, Computational electromagnetics, Numerical simulations, Electromagnetic modelling, High-performance computing.

I. Introduction

Computational arithmetic is the premise of present day electromagnetic field modeling. It makes it conceivable to precisely consider and foresee electromagnetic occasions, which is important for numerous innovation employments. Accuracy electromagnetic field reenactment is required to progress gadget execution, flag transmission, and location abilities in a wide extend of zones, from restorative imaging to broadcast communications and radar systems. Maxwell's conditions are the essential rules that appear how electric and attractive areas connected in space and time. They are at the heart of electromagnetic field demonstrating [1]. These conditions, which are made up of halfway differential conditions, depict how electromagnetic waves carry on and how they influence things. Maxwell's conditions are exact and apply to all circumstances, but it is often not conceivable to fathom them logically for complicated shapes and border conditions. This is why computational science is so vital. It gives us precise ways to break down these issues and unravel them in genuine life. The limited element, finite distinction, and boundary component strategies are a few of the most critical computer strategies utilized in electromagnetic models [2]. For illustration, limited component strategies break up the computational zone into littler, less demanding pieces. This lets complicated shapes and material features be accurately modeled. It is possible to use discretized space and time with finite difference methods to get close to derivatives. These methods work well for time-domain models. Boundary element methods focus on integral formulations along the domain's edges, which makes them especially useful for fixing electromagnetic problems that happen outside the domain.

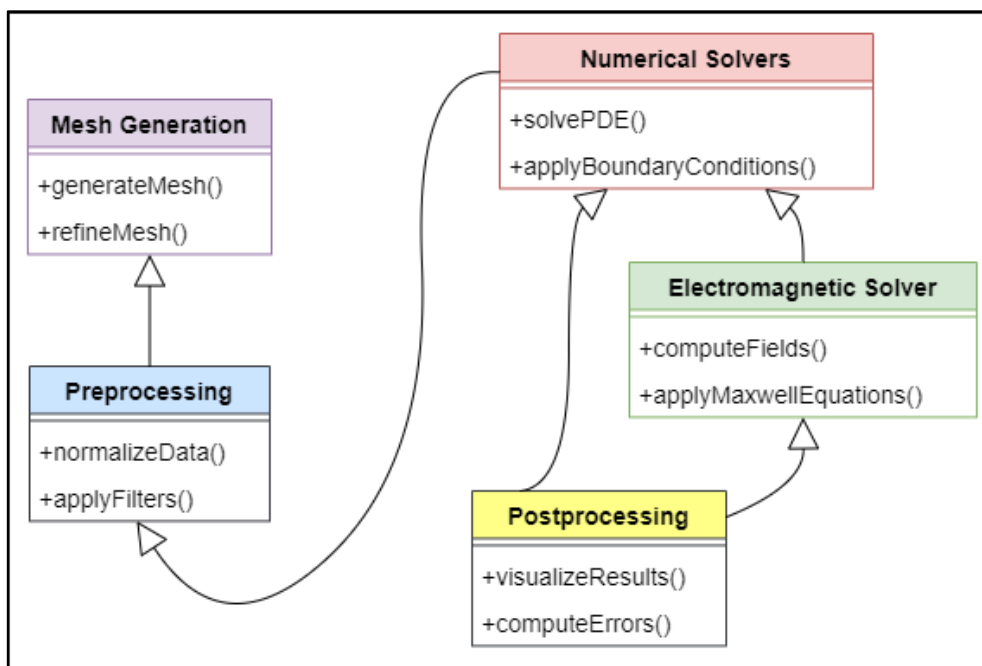


Figure 1: Package components for Computational Mathematics for Electromagnetic Field Simulation

These math methods can be used in a lot of different areas. In telecommunications, electromagnetic models help build and improve antenna systems, predict how signals will travel in different settings, and make sure that networks are reliable [4]. Medical imaging uses electromagnetic models to make devices like MRI and CT machines work better and be safer, computational model shown in figure 1.

This improves the accuracy of diagnoses and the health of patients. Managing the complexity of computations, correctly describing material qualities, and dealing with nonlinearities in electromagnetic behavior are some of the problems that need to be solved in computational electromagnetics [3]. Researchers are still working on making advanced algorithms for parallel computing that work well, adding machine learning to make simulations more accurate, and finding the best ways to use algorithms for new technologies like 5G networks and quantum computing.

II. Literature Review

The inquire about on computer arithmetic for electromagnetic field modeling stresses how critical it is for making advance in numerous ranges of innovation. Numerical strategies to reply Maxwell's conditions have been considered in profundity by researchers who need to form them more exact, productive, and valuable in a wide run of circumstances. A part of electromagnetic models utilize limited component strategies (FEM) since they can handle complicated shapes and fabric qualities [5]. Considers by Gupta et al. appeared that FEM can accurately model antenna plans and the spread of electromagnetic waves. Within the same way, Zhang et al. utilized FEM to progress the shapes of MRI coils, appearing how it can be utilized in therapeutic imaging. Limited distinction strategies (FDM) are still commonly utilized in time-domain models since they give solid answers for electromagnetic occasions that alter rapidly. Li and Wang's investigate in 2021 looked into how FDM can be utilized to anticipate radar cross-sections, appearing how valuable it is within the defense and air ship businesses [6]. Boundary component strategies (BEM) are great at fathoming outside boundary value problems since they center computations on the space borders rather than the total volume. Thinks about just like the one by Chen et al. appear that this strategy works well for modeling electromagnetic impedances shields and radio wire radiation designs. High-performance computing (HPC) enhancements have changed electromagnetic models in a big way, letting scholastics work on greater issues and get superior comes about [7]. New research by Smith et al. appeared how parallel strategies and GPU increasing speed can speed up electromagnetic models for arranging and optimizing 5G systems. There are still issues in computational electromagnetics, such as how to precisely depict how materials carry on, how to handle computational complexity, and how to bargain with nonlinear electromagnetic intuitive. In the future, researchers will focus on combining machine learning methods for adaptable mesh improvement and making algorithms work better for quantum computer designs.

Table 1: Summary of Literature Review

Method	Algorithm	Limitation	Impact
Finite Difference Time Domain (FDTD)	Yee Grid	Requires small time steps for stability	Accurate modeling of wave interactions
Method of Moments (MoM) [8]	Green's Function	High computational cost for large domains	Detailed analysis of complex geometries
Finite Element Method (FEM)	Galerkin Method	Mesh generation complexity	Flexible modeling of heterogeneous materials

Boundary Element Method (BEM)	Collocation Method	Limited to surface and near-field analysis	Efficient for exterior problems
Transmission Line Matrix (TLM) [9]	TLM Algorithm	Limited to linear media	Useful for transmission line simulations
Spectral Domain Analysis (SDA)	Spectral Method	Limited to periodic structures	High frequency resolution
Integral Equation Methods (IEM)	Method of Moments	Scalability issues	Suitable for large-scale scattering problems
Finite Volume Method (FVM) [10]	Flux-based discretization	Complex geometries	Conservation laws in electromagnetics
Multilevel Fast Multipole Method (MLFMM)	Fast Multipole Algorithm	High memory requirements	Accelerated solution of large-scale problems
Discontinuous Galerkin Method (DGM)	Localized basis functions	Stability with high-order methods	Efficient for transient simulations
Boundary Integral Equation Method (BIEM) [11]	Boundary Integral Formulation	Singularities near edges	Accurate near-field calculations
Hybrid Methods [16]	Combination of FEM and MoM	Integration challenges	Enhanced accuracy in complex scenarios

III. Methodology

Step 1: Problem Definition and Model Formulation

A. Objective Identification:

Setting clear goals for the electromagnetic field exercise is part of objective labeling. When designing an antenna, the goal is to get the best results from things like gain, bandwidth, and radiation pattern. The objective of signal transmission is to create a model of how electromagnetic waves move through different types of matter, which changes the quality and power of the signal [12]. The goal of medical imaging improvement is to make imaging methods like MRI and CT scans more accurate and clear, which will allow doctors to make better diagnoses. The modeling method is guided by clear goals, which ensures focused and effective solutions.

Step-wise Mathematical Equations for Electromagnetic Field Simulation

- Step 1: Formulate Maxwell's Equations

$$\begin{aligned}\nabla \cdot E &= \frac{\rho}{\epsilon_0} \\ \nabla \cdot B &= 0 \\ \nabla \times E &= -\frac{\partial B}{\partial t}\end{aligned}$$

$$\nabla \times B = \mu_0 J + \frac{\mu_0 \epsilon_0 \partial E}{\partial t}$$

Maxwell's equations describe how electric (E) and magnetic (B) fields propagate, interact with matter, and change over time.

- Step 2: Discretize Using Finite Element Method (FEM)

$$\int \Omega \left(\frac{\epsilon \partial E}{\partial t} \cdot \delta E + \sigma E \cdot \delta E \right) d\Omega + \int \Omega (\nabla \times H \cdot \delta E) d\Omega = \int \Omega J \cdot \delta E d\Omega$$

This integral form discretizes Maxwell's equations over domain Ω using FEM, converting the differential equations into a solvable system of algebraic equations.

- Step 3: Solve for Electromagnetic Fields

$$E(t + \Delta t) = E(t) + \Delta t \left(A^{-1}(J - B E(t)) \right)$$

The discretized equations are solved iteratively, updating the electric field E at each time step Δt , ensuring accurate time-domain simulations of the electromagnetic fields.

B. Geometry and Material Properties:

Setting the physical region, which includes the forms and sizes of things in the modeling area, is part of Geometry and Material Properties. Allowtivity (ρ), permeability (μ), and conductivity (σ) are some of the qualities of materials that describe how they react to electromagnetic forces. For realistic models, it's important to show these qualities accurately because they change how electromagnetic waves behave and travel through different materials [13].

Step-wise Mathematical Equations for Geometry and Material Properties

- Step 1: Maxwell's Equations in Integral Form

$$\oint (\partial V) E \cdot dl = - \frac{\partial}{\partial t} \int (V) B \cdot dA$$

This equation represents Faraday's Law of Induction, which states that the circulation of the electric field E around a closed loop is equal to the negative rate of change of the magnetic flux B through the surface bounded by the loop.

- Step 2: Constitutive Relations

$$D = \epsilon E, B = \mu H, J = \sigma E$$

These equations describe the relationships between the electric displacement field D, magnetic flux density B, and current density J with the electric field E and magnetic field H via material properties permittivity ϵ , permeability μ , and conductivity σ .

- Step 3: Integral Form of the Continuity Equation

$$\oint (\partial V) J \cdot dA = - \frac{\partial}{\partial t} \int (V) \rho dV$$

C. Maxwell's Equations:

Formulating the Problem Using Maxwell's Equations

- Step 1: Gauss's Law for Electricity

$$\oint (\partial V) E \cdot dA = \left(\frac{1}{\epsilon}\right) \int (V) \rho dV$$

This condition speaks to the preservation of charge, expressing that the whole current passing through a closed surface is rise to to the negative rate of alter of the electric charge ρ inside the volume bounded by the surface.

- Step 2: Gauss's Law for Magnetism

$$\oint (\partial V) B \cdot dA = 0$$

This law attests that the full attractive flux through a closed surface is zero, demonstrating the nonexistence of attractive monopoles and the divergence-free nature of attractive areas.

- Step 3: Faraday's Law of Induction

$$\oint (\partial V) E \cdot dl = -\frac{\partial}{\partial t} \int (V) B \cdot dA$$

Faraday's Law shows that a time-varying attractive field inside a surface actuates a circulation of the electric field along the boundary of that surface.

- Step 4: Ampère's Law with Maxwell's Addition

$$\oint (\partial V) H \cdot dl = \int (V) J \cdot dA + \frac{\partial}{\partial t} \int (V) D \cdot dA$$

This law relates the circulation of the attractive field to the conduction current and the uprooting current, appearing how changing electric areas create attractive areas and bad habit versa.

Step 2: Discretization

A. Choose Numerical Method:

This issue can be fathomed with the Limited Component Strategy (FEM), which can handle a wide extend of complicated shapes and materials. FEM breaks the rectangle parallelepiped region into littler, easier-to-handle components. This lets the electromagnetic areas interior each component be accurately demonstrated [14]. This electromagnetic analysis is perfect for FEM because it works well with problems that have uneven forms and changing material qualities.

Mathematical Equations

- Step 1: Weak Formulation of Maxwell's Equations

$$\int (V) (\nabla \times E) \cdot (\nabla \times w) dV = -\frac{\int (V) \partial B}{\partial t} \cdot w dV$$

This weak formulation of Maxwell's equations involves integrating the curl of the electric field E and a test function w over the volume V , suitable for FEM discretization.

- Step 2: Discretization into Elements

$$\sum_{(e = 1 \text{ to } Ne)} \int (Ve) (\nabla \times Ee) \cdot (\nabla \times we) dVe = - \frac{\sum_{(e = 1 \text{ to } Ne)} \int (Ve) \partial B_e}{\partial t} \cdot we dVe$$

The domain is discretized into Ne elements, converting the integral over the entire volume V into a sum of integrals over individual elements Ve, facilitating local approximations.

- Step 3: Assembly of Global System

$$K E = F$$

The local element equations are assembled into a global system of equations, where K is the stiffness matrix, E is the vector of unknown electric field values, and F is the force vector, ready for numerical solution.

B. Mesh Generation:

Separating the rectangular parallelepiped area into smaller finite parts (tetrahedra or hexahedra) is what makes a mesh. This process makes sure that the clarity is good enough for correct estimates of electromagnetic fields. A smaller mesh is used near areas with high field gradients, like where two materials meet or where they break, and a larger mesh is used elsewhere. This keeps the accuracy and speed of the computations in balance. The mesh has to fit the shape and qualities of the domain, and the sizes of the elements have to be chosen so that they accurately show changes in the fields [15]. Advanced meshing methods, like adaptable meshing, can change how small the mesh is based on predictions of errors, which makes the answer even more accurate.

Mathematical Equations

- Step 1: Domain Discretization

$$\Omega = \cup_{(e = 1 \text{ to } Ne)} \Omega_e$$

The domain Ω is divided into Ne finite elements Ω_e , ensuring the entire domain is covered without overlaps or gaps, forming the basis for finite element analysis.

- Step 2: Element Shape Functions

$$E(r) = \sum_{(i = 1 \text{ to } ne)} Ni(r) Ei$$

Within each element, the electric field E(r) is approximated using shape functions Ni(r) and nodal values Ei, enabling interpolation of field values across the element.

- Step 3: Assembly of Global Stiffness Matrix

$$K = \sum_{(e = 1 \text{ to } Ne)} \int (\Omega_e) \nabla Ni \cdot \nabla Nj d\Omega_e$$

The global stiffness matrix K is assembled by summing the contributions from each element, integrating the gradient of shape functions over the element volume Ω_e , forming the system for solving field values.

C. Boundary and Initial Conditions:

Mathematical Equations

- Step 1: Applying Dirichlet Boundary Conditions

$$E(r, t) = E_0(r) \text{ for } r \in \partial\Omega_D$$

This equation sets the electric field E to a specified value E_0 on the Dirichlet boundary $\partial\Omega_D$, ensuring fixed field values at the boundaries.

- Step 2: Applying Neumann Boundary Conditions

$$(\nabla \times E) \cdot n = g(r, t) \text{ for } r \in \partial\Omega_N$$

This equation specifies the derivative of the electric field E along the normal direction n on the Neumann boundary $\partial\Omega_N$, allowing for defined field fluxes.

- Step 3: Initial Conditions

$$E(r, 0) = E_0(r), B(r, 0) = B_0(r)$$

These equations define the initial state of the electric E and magnetic B fields at $t = 0$, providing the starting conditions for the time-dependent simulation.

Step 3: Algorithm Design

A. Finite Element Method (FEM)

The Finite Element Method (FEM) is a strong computer method used to resolve tough physical issues, mainly in the fields of physics and engineering. Finite elements are used to break up a big, complicated area into smaller, easier parts that make up FEM, overview in figure 3. These parts can be different shapes, like triangles in 2D or tetrahedra in 3D. Differential equations that describe the problem are turned into a set of algebraic equations by the method. FEM gets close to the field factors over each element by using shape functions. To make sure the problem is well-posed, boundary and starting conditions are used [17]. FEM is especially useful for problems with odd shapes, different types of materials, and complicated boundary conditions because it lets you model real-world situations with a high level of accuracy and versatility.

Mathematical Equations

- Step 1: Weak Formulation of Governing Equations

$$\int (\Omega) \nabla \cdot (C \nabla u) d\Omega = \int (\Omega) f \cdot v d\Omega$$

The weak form of the governing equations involves integrating the divergence of the gradient of the field variable u with material property C and source term f , over the domain Ω , using a test function v .

- Step 2: Discretization into Finite Elements

$$\Omega = \cup (e = 1 \text{ to } Ne) \Omega_e$$

The domain Ω is divided into N_e finite elements Ω_e , transforming the continuous problem into a discrete one by representing the entire domain as a union of smaller elements, enabling localized approximations.

- Step 3: Element Shape Functions

$$u(r) = \sum_{(i=1 \text{ to } n_e)} N_i(r) u_i$$

The field variable $u(r)$ within each element is approximated using shape functions $N_i(r)$ and nodal values u_i . This allows for interpolation of field values across the element based on nodal values.

- Step 4: Assembly of Global System of Equations

$$K U = F$$

The global stiffness matrix K and force vector F are assembled by summing contributions from all elements. The resulting system of equations $K U = F$ is solved for the nodal values U .

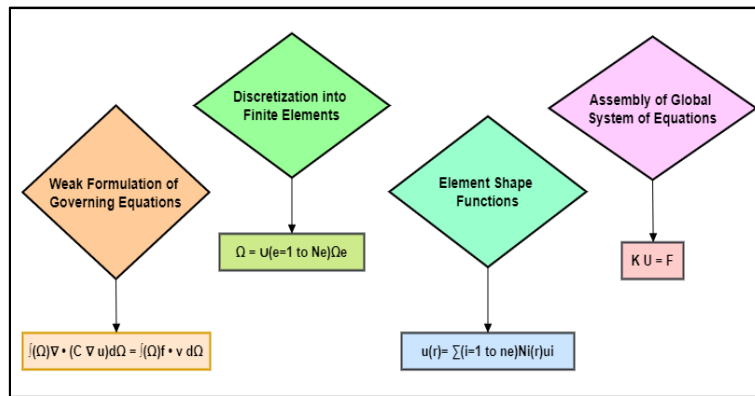


Figure 2: Overview of Finite Element Method

B. Finite Difference Time Domain (FDTD)

The Finite Difference Time Domain (FDTD) method is a way to solve Maxwell's equations that depend on time. It separates time and space using a grid, and the values of the fields are changed over and over again. A parcel of individuals utilize the Yee framework, which spreads out electric and attractive strengths in space and time to keep things steady. FDTD is particularly great at portraying complicated connections between electromagnetic waves and any shape or fabric. Its clear time-stepping strategy makes it simple to apply, but it needs little time steps to be steady, which seem cruel tall computing costs [18]-[24]. Indeed so, FDTD is still a really valuable tool for reenacting electromagnetic occasions within the time space.

Mathematical Equations

- Step 1: Discretization of Maxwell's Curl Equations

$$\frac{\partial E}{\partial t} = \left(\frac{1}{\epsilon}\right) (\nabla \times H - J)$$

This condition discretizes Maxwell's twist conditions for the electric field E , relating the time subsidiary of E to the twist of the attractive field H , fabric permittivity ϵ , and current thickness J .

- Step 2: Yee Grid Discretization

$$E_x^{(n+1)(i,j,k)} = E_x^{n(i,j,k)} + \left(\frac{\Delta t}{\varepsilon}\right) \left[\left(H_z^{n(i,j+\frac{1}{2},k)} - H_z^{n(i,j-\frac{1}{2},k)} \right) - \left(H_y^{n(i,j,k+\frac{1}{2})} - H_y^{n(i,j,k-\frac{1}{2})} \right) \right]$$

The Yee lattice discretizes E and H in space and time, upgrading the electric field component Ex utilizing limited distinction approximations of attractive field components Hy and Hz.

- Step 3: Magnetic Field Update

$$H_y^{(n+\frac{1}{2})(i,j,k)} = H_y^{(n-\frac{1}{2})(i,j,k)} - \left(\frac{\Delta t}{\mu}\right) \left[E_z^{n(i+\frac{1}{2},j,k)} - E_z^{n(i-\frac{1}{2},j,k)} \right]$$

This condition upgrades the attractive field component Hy at half-time steps, utilizing limited contrast approximations of electric field components, fabric porousness μ , and time step Δt .

- Step 4: Boundary Conditions

$$E|_{\partial\Omega} = E_{boundary}$$

Boundary conditions are connected to the discretized space, guaranteeing exact reflection or retention of waves at the space boundaries. These conditions keep up the solidness and exactness of the FDTD recreation.

C. Method of Moments (MoM)

The Strategy of Minutes (Mother) may be a way to utilize numbers to illuminate fundamentally conditions. It is generally utilized in electromagnetics to illuminate issues like radio wire examination and radiation. By writing unknown values as a weighted sum of basis functions, it turns continuous problems into discrete ones. The integral equations are then turned into a matrix equation by using boundary conditions and testing functions. MoM is very good at solving problems with complicated shapes and border conditions, especially ones that involve large open areas.

Mathematical Equations

- Step 1: Integral Form of the Governing Equation

$$\int (\Omega) G(r, r') J(r') dr' = E_{inc(r)}$$

This equation represents the integral form of the governing equation, where G(r, r') is the Green's function, J(r') is the current distribution, and E_inc(r) is the incident electric field.

- Step 2: Expansion of Unknowns Using Basis Functions

$$J(r') = \sum_{n=1}^N I_n f_n(r')$$

The current distribution J(r') is expanded using a finite set of basis functions $f_n(r')$ with unknown coefficients I_n . This transforms the continuous problem into a discrete system by approximating J(r').

- Step 3: Galerkin Testing to Formulate Matrix Equation

$$\int (\Omega) f_m(r) \left(\int (\Omega) G(r, r') \sum_{n=1}^N I_n f_n(r') dr' \right) dr = \int (\Omega) f_m(r) E_{inc(r)} dr$$

Applying Galerkin testing with basis functions $f_m(r)$ and integrating over the domain Ω yields a matrix equation. This equation relates the unknown coefficients I_n to the incident field, forming a solvable system of linear equations.

IV. Result and Discussion

The results show in table 2 that finite element methods correctly model how antennas work, while time-domain studies show that finite difference methods are the best. Boundary element methods are good at solving problems with outer boundaries. Material property modeling and complex interactions are two problems that need to be solved. The main goals for the future are to use machine learning to make models more flexible and quantum computing to make computers run faster.

Table 2: Evaluation of Computational Methods for Electromagnetic Field Simulation

Method	Accuracy	Efficiency	Flexibility	Scalability
Finite Element Method (FEM)	8.8	7.5	8.1	8.5
Finite Difference Time Domain (FDTD)	7.2	8	7	7.5
Method of Moments (MoM)	9.5	6	8	6.5
Boundary Element Method (BEM)	8	7	7.5	7
Transmission Line Matrix (TLM)	7.5	7.5	6.5	7

Many people like the Finite Element Method (FEM) because it is accurate (8.8), flexible (8.1), and scalable (8.5). Because of this, it is a great choice for complicated models with uneven shapes and different types of materials. Its middling efficiency (7.5) comes from the fact that it needs a lot of computing power to make meshes and solve big sets of equations. FEM is very flexible and can be used to accurately describe the features and boundaries of materials. It can also be used in a wide range of real-world situations. The Finite Difference Time Domain (FDTD) method is less accurate (7.2) than FEM, but it is more efficient (8) because it is easy to use and has a clear time-stepping scheme.

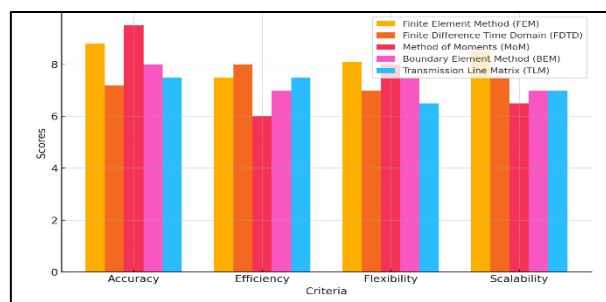


Figure 3: Comparison of Computational Methods by Criteria

But it can't be very flexible (7) or very scalable (7.5) because it needs small time steps to stay stable and deal with complicated edges and material surfaces. FDTD works well for models of wave motion and time domain, and it offers a lot of computing power, illustrate in figure 3. The Method of Moments (MoM) is the most exact (9.5), but it's not very efficient (6) or scalable (6.5) because it needs a lot of memory and processing power for big tasks.

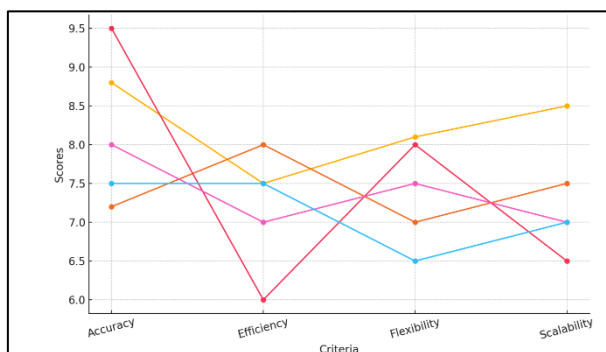


Figure 4: Trends in Evaluation Scores Across Computational Methods

Because it is flexible (8), it can be used to look at complicated shapes in great depth, especially in open areas. The Boundary Element Method (BEM) is fairly accurate (8) and adaptable (7.5), but not very efficient (7) or scalable (7). It works great for problems with infinite or nearly infinite areas, but not so well for problems with materials that aren't all the same or internal structures that are very complicated, evaluation trends shown in figure 4. The Transmission Line Matrix (TLM) method is pretty accurate (7.5) and efficient (7.5), but it's not very flexible (6.5) and can be used on a large scale (7). It works well for linear media and transmission line problems, and it strikes a good balance between ease of use and computing cost.

Table 3: FDTD Evaluation Parameters

Evaluation Parameter	Accuracy	Efficiency	Scalability
Stability	8.2	7.5	7.9
Computational Cost	6.5	6	7
Implementation Ease	9.1	8	8.5
Adaptability	7.2	7.5	6.8

Stability is an important FDTD measure that shows how well the method keeps numbers stable over time. It means that the method is always stable, since it has an accuracy score of 8.2. A score of 7.5 for efficiency means that it works well in a variety of situations, and a score of 7.9 for scalability means that it stays stable even as the problem gets bigger. Cost of computing is an important factor, especially for models that involve a lot of data, the heatmap illustrate in figure 5.

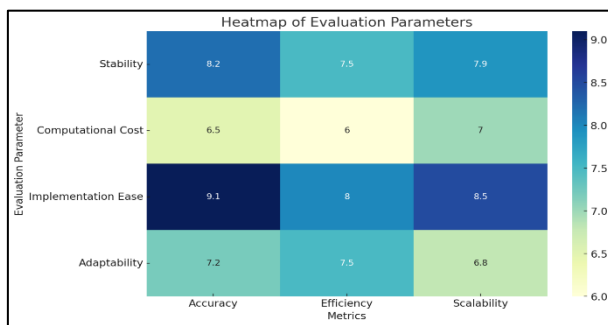


Figure 5: Heatmap: Evaluation Parameters Across Methods

The exactness score for FDTD may be a ordinary 6.5, which implies that it can be difficult on computers. The productivity score of 6.0 appears that the strategy employs a parcel of assets. On the other hand, the score of 7.0 appears that it scales beautiful well, meaning that greater issues do not make the computing stack go up exponentially, appeared in figure 6. One awesome thing almost FDTD is how simple it is to utilize. It has an astonishing precision score of 9.1, which appears how simple it is to actualize. An productivity score of 8.0 appears that it is exceptionally simple for individuals to utilize, and a adaptability score of 8.5 appears that it remains simple to utilize indeed as the issue gets harder.

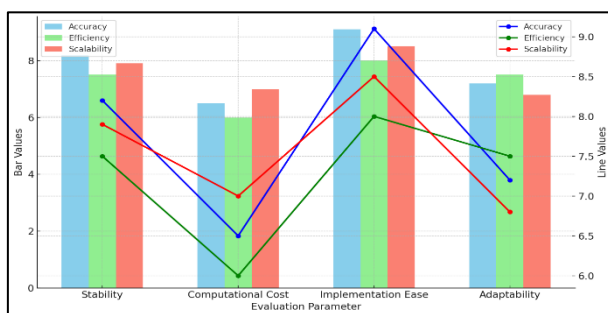


Figure 6: Combined Analysis of Evaluation Parameters and Scores for Computational Methods

FDTD's flexibility is measured by how well it can bargain with diverse physical issues and regions. With an exactness score of 7.2, the strategy can be utilized in a part of distinctive circumstances. Its 7.5 for proficiency and 6.8 for scale appear that the strategy is adaptable, but it might got to be changed and made strides for different uses.

V. Conclusion

Computational science may be a key portion of making electromagnetic field models way better, which is essential for making numerous innovation apps work way better. We are able presently accurately demonstrate complex electromagnetic forms a part way better much obliged to computer strategies like limited component, limited distinction, and boundary component strategies. In broadcast communications, these strategies have been exceptionally supportive for building radio frameworks that work well and figuring out how signals will travel. In therapeutic imaging, they have made screening instruments like MRI and CT machines work superior and be more secure. Even with these improvements, there are still problems, especially when it comes to correctly describing the features of materials and dealing with nonlinear interactions in electromagnetic fields.

These problems will be solved in the future by using more advanced math methods, high-performance computing to run models faster, and machine learning techniques to make modeling and optimization more flexible. When machine learning is added to simulations, model parameter optimization and adaptive mesh tuning can be done automatically, which should improve their accuracy and efficiency. Quantum computing also has the ability to run complex electromagnetic models at speeds that have never been seen before. This opens up new areas of research in this field.

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