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NEC - NUMERICAL ELECTROMAGNETICS CODE* FOR FREQUENCY DOMAIN ANALYSIS

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Introduction

The Numerical Electromagnetics Code (NEC) is a computer program for analyzing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. The analysis is accomplished by the numerical solution of integral equations for induced currents.

The code combines an integral equation for smooth surface with one specialized to wires to provide for convenient and accurate modeling of a wide range of structures. A model may include nonradiating networks and transmission lines connecting parts of the structure, perfect or imperfect conductors, and lumped-element loading. A structure may also be modeled over a ground plane that may be either a perfect or imperfect conductor.

The excitation may be either voltage sources on the structure, an incident plane wave of linear or elliptic polarization, or the field due to a Hertzian dipole. The output may include current and charge density, near or far zone electric or magnetic fields, and impedance or admittance. The program is suited to either antenna analysis or scattering and EMP studies.

The Numerical Electromagnetics Code (NEC) has been developed at the Lawrence Livermore Laboratory under the sponsorship of the Naval Ocean Systems Center and the Air Force Weapons Laboratory. It is an advanced version of the Antenna Modeling Program (AMP) developed in the early 1970's.

Integral Equation Formulation

The NEC program uses both an electric-field integral equation (EFIE) and a magnetic-field integral equation (MFIE) to model the electromagnetic response of general structures, since each has advantages for particular structure types.

The EFIE is well suited for thin-wire structures of small or vanishing conductor volume. Of course, the thin wire approximation concerning no circumferential currents nor circumferential variation of axial currents and the use of the thin wire kernel holds.

The MFIE, which fails for the thin wire case, is more attractive for voluminous structures, especially those having large smooth surfaces. The EFIE can also be used to model surfaces and is preferred for thin structures where there is little separation between a front and back surface. Although the EFIE is specialized to thin wires in this program, it has been used to represent surfaces by wire grids with reasonable success for far-field quantities but with variable accuracy for surface fields. For a structure containing both wires and surfaces the EFIE and MFIE are coupled. This combination

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of the EFIE and MFIE was proposed and used by Albertsen, Hansen, and Jensen at the Technical University of Denmark (ref. 1) although the details of their numerical solution differ from those in NEC. A rigorous derivation of the EFIE and MFIE used in NEC is given by Poggio and Miller (ref. 2).

Numerical Solution Method

The integral equations in NEC are solved using the method of moments. In particular, collocation is used with subsectional basis functions, i.e., the equations are enforced at specified points while the currents are defined over subregions of the overall structure.

The current on each wire segment in NEC is represented by

$$I_j(s) = A_j + B_j \sin k(s-s_j) + C_j \cos k(s-s_j) \quad s\epsilon\Delta s_j$$

where s_j is the center of the j^{th} segment with length Δs_j. The current is constrained to have continuous amplitude and derivative at segment junctions.

The surface current density for surfaces in NEC is expanded in a set of pulse functions so that each "patch" has two pulses of arbitrary amplitudes representing the two components of surface current density.

Additional Features of NEC

Documentation: One of the strong points of NEC is its extensive documentation which consists of three volumes:

Part I: NEC Program Description - Theory (Describes the equations, numerical methods, and general theory in NEC.)

Part II: NEC Program Description - Code (Describes the coding in detail.)

Part III: NEC User's Guide (Contains instructions for using the code, including preparation of input and interpretation of output.

Extended Thin Wire Kernel: The accuracy of the thin-wire approximation for a wire of radius a and length Δ depends on ka and Δ/a. Studies have shown that the thin-wire approximation leads to errors of less than 1% for Δ/a greater than 8 (Ref. 3). The extended thin-wire approximation (Ref. 3) is applicable to short and thick segments, resulting in errors less than 1% for Δ/a greater than 2.

Ground Effects: The effect of a realistic ground on the electromagnetic response of a structure was regorously defined by Sommerfeld but is cumbersome and lengthy, even for computer evaluation. An approximation based on the Fresnel plane-wave reflection coefficients is used in NEC. Although inaccurate for structures very near to the ground, it provides a time-savings of up to two orders of magnitude. The range of validity is demonstrated in the NEC documentation by comparison with results obtained with the Sommerfeld formulas.

The effects of radial wire ground screens have also been included in NEC by using the surface impedance derived by Wait [4] and the reflection coefficient method.

Junctions of Unequal Radii: At a junction of two or more segments or unequal radii, the continuity of current is generalized to Kirchoff's current law. The linear charge density on each wire at the junction is assumed to be given by

$$\left.\frac{\partial I}{\partial s}\right|_{\text{at junction}} = \frac{Q}{\ell n(\frac{2}{ka}) - .5772}$$

where a is the wire radius and Q is realted to the total charge in the vicinity of the junction.

Free Ends of Finite Radius: At free wire ends, the current can be assumed to be zero or, if one allows current to flow onto the end cap, one can have

$$I(s)\Big|_{\text{end}} = \frac{1}{k}\frac{J_1(ka)}{J_0(ka)}\left.\frac{I}{s}\right|_{\text{end}}$$

Thus, at a free end one has a relationship between the linear current and its derivative.

Matrix Equation Solution: The matrix equation in NEC is solved by the Gauss Doolittle method which involves a factorization into upper and lower triangular matrices, and a solution via a forward and then backward substitution.

Evaluation of Impedance Matrix Elements: The numerical integrations in NEC for the thin wire computations are performed using a Romberg variable interval width technique. In the surface computations a simple rectangular rule is used.

Symmetries: Computation time can be reduced substantially by making use of symmetries of the structure, either symmetry about a plane, or symmetry under rotation. For either rotational or plane symmetry, the procedure requires factoring or plane symmetry, the procedure requires factoring M matrices of order N_c rather than one of order MN_c.

Sources: NEC allows for several difference sources. The excitation can be in the form of an incident electric field of linear or elliptical polarization, or the field can be generated by a Hertzian source. Also, antennas can be locally excited by a voltage over a finite gap or a more localized source can be introduced in the form of constraints on the derivative of current by using a biconical transmission line approximation near the source.

Non-Radiating Networks: Lumped circuit networks and transmission lines interconnecting various segments in NEC are allowed. They merely serve to modify the interaction matrices.

Lumped or Distributed Loading: The structures in NEC are usually assumed to be perfect electric conductors. However, NEC also allows segments to be loaded by impedances which is equivalent to placing dependent sources in the structure. For distributed impedances (finite σ wires) an expression is used to account for the limited field penetration.

Radiated Field Calculation: NEC can evaluate the far zone field, the power gain, the input power to an antenna, the directive gain, and the total radiated power.

Near Field Calculations: The near zone electric or magnetic field can be calculated in NEC.

Ground Wave Field: The radiated field is modified by an imperfect earth and is rigorously modeled using Sommerfeld's expressions. However, approximations at practical distances are needed and although far zone results are easily obtained, those somewhat closer and at grazing angles are dominated by the ground wave. NEC makes use of the Norton formulas for this case.

Out of Core Capabilities: When the impedance matrix is too large to be contained in core, NEC has the option of storing portions out of core.

Numerical Green's Function: The impedance matrix for a structure may be referred to as a self interaction matrix. With NGF the self interaction matrix for the fixed environment may be computed, factored for solution, and saved on tape or file. Solution for a new antenna then requires only the evaluation of the self interaction matrix for the antenna, the mutual antenna to environment interactions, and matrix manipulations for a partitional matrix solution.

Inter-Antenna Coupling: The Tinville method is used in NEC to evaluate coupling between antennas.

Geometry Specification: Several options exist in NEC, e.g., a wire or arc can be automatically broken into a number of segments, a portion of structure can be linearly translated or rotated, or a patch can be specified by its center point, area, and normal.

Synopsis

The user oriented computer program NEC will be described and its broad applicability will be illustrated. The various options in the program will be defined. Timing estimates for NEC and sources for the program and its documentation will be provided. Overall, potential users will be given an overview of its capabilities.

References

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