MUTUAL VALIDATION OF THREE PROGRAMS FOR NUMERIC ANTENNA COMPUTATIONS *)

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ABSTRACT. The numerical results obtained by three different codes, GALNEC, WARAN and NEC-2 are compared for thin dipoles and thick ones with hemispherical end caps and for arrays of such collinear dipoles. The electric field integral equation and Galerkin's method are used in the code GALNEC where solid thick dipole bodies are implemented. Mei's (1965) integral equation and collocation technique are used in the code WARAN, where thick dipoles are simulated as arrays of thin wires. Good agreement has been obtained for current distributions and input and mutual impedances.

1 INTRODUCTION

Validation of every new numerical algorithm is an obligatory and quite complex step of its elaboration. This problem is especially difficult in computational electromagnetics in view of well-known reasons. The code NEC [1] which is used for many antenna modelling applications has been verified very carefully several times. There are many reports available which confirm its reliability ([2], for example). That is why this code can be used as a standard for testing subsequent projects in this field. The present paper reports efforts of the authors to validate two original computer programs named GALNEC and WARAN. Numerical results are compared with each other and with data obtained by the code NEC-2. On the other hand, GALNEC implemented for solid thick antennas and permitting many narrow segments and sectors is used to show the adequacy of wire grid models used for such configurations in NEC-2.

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2 DESCRIPTION OF THE CODE GALNEC

The computer code named GALNEC [3,4,5] has been designed for numerical simulation of thick dipoles and antenna arrays consisting of such elements. The aim was to avoid several of the approximations used in the implementation of NEC-2 [1] rendering stable input admittances for large numbers of segments and sectors. The geometry of an array of two antennas is shown in Fig.1. Each dipole has hemispherical end caps and may be excited by a homogeneous tangential electric field, which is applied to a cylindrical zone of length g along the cylindrical part of the dipole. The following electric field integral equation for the unknown surface current density distributions [6] was used:

$$\vec{n} \times \vec{E}_e = \tag{1}$$
$$= -\sum_{i=1}^{N} \frac{1}{j\omega\epsilon} \vec{n} \times \int_{F^{(i)}} df' \, [k^2 G(\vec{r}, \vec{r}') \vec{J}_F^{(i)} + $$
$$+ \, (\vec{J}_F^{(i)} \cdot \vec{\nabla}) \vec{\nabla} G(\vec{r}, \vec{r}')].$$

In this equation $\vec{J}_F^{(i)}$ labels the current on the i-th dipole and $G(\vec{r}, \vec{r}') = exp(-jk|\vec{r} - \vec{r}'|)/(4\pi|\vec{r}-\vec{r}'|)$ is the Green's Function of free space. The surfaces of integration $F^{(i)}$ are the surfaces of the dipoles. The surface current $\vec{J}_F^{(i)}$ is approximated by a sum of trigonometric subdomain basis functions uniform around each dipole. The following segmentation scheme has

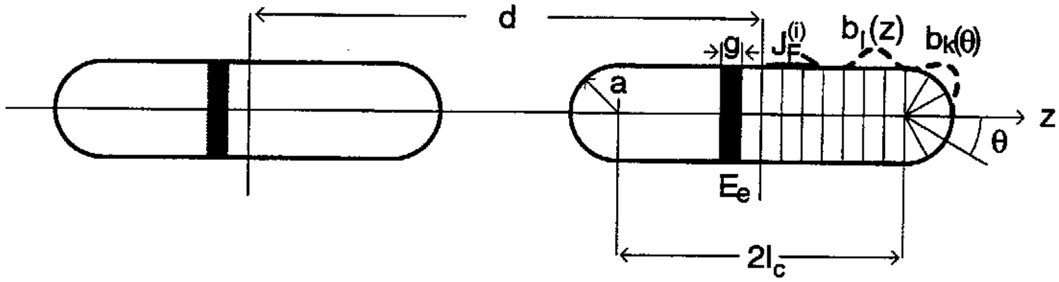

Figure 1: Geometry used for GALNEC

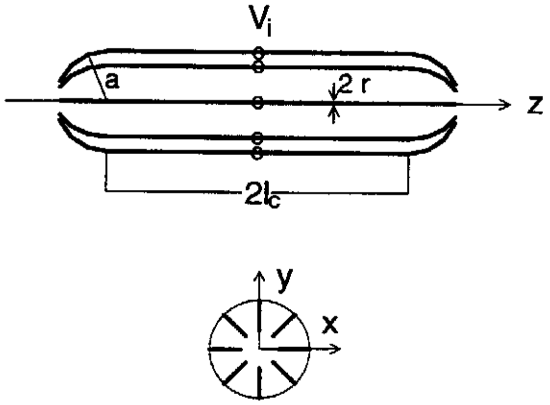

Figure 2: Geometry used for WARAN and NEC-2

been used: the cylindrical part of each dipole is divided into segments while the end caps are divided into sectors as it is indicated in Fig.1. On the cylindrical segments of each dipole the basis and test functions have the following form:

$$\vec{b}_i(\vec{r}) = \vec{b}_i(z) = \vec{e}_z \cdot \cdot [A_i + B_i \cos[k(z - z_i)] + C_i \sin[k(z - z_i)]]; \qquad (2)$$

and on the k-th sector of an end cap we have

$$\vec{b}_k(\vec{r}) = \vec{b}_k(\theta) = \vec{e}_\theta \cdot \cdot [A_k + B_k \cos(\theta - \theta_k) + C_k \sin(\theta - \theta_k)]. \qquad (3)$$

The integral equation has been solved by Galerkin's method. By calculating the moments, the integral equation (1) is transformed into a system of linear algebraic equations for the unknown current coefficients I_k

$$[Z_{ik}]\,[I_k] = < \vec{W}_i(\vec{r})^{(m)}, \vec{n} \times \vec{E}_e(\vec{r}) >, \qquad (4)$$

where $[Z_{ik}]$ is the impedance matrix.

Great efforts were made to obtain a numerical solution for the integral equation as exact as possible. Analytical expansions for the Green's function of free space were introduced and checked for accuracy; this allowed an analytical calculation of multiple integrations in some cases. Also the static singularity of the Green's function was treated analytically to guarantee a rigorous calculation of the surface integrations. The same voltage source as in NEC-2, i.e. a time-harmonic uniform tangential electric field impressed along the antenna(s) in the source region located on the cylindrical part, is used. The length of the source region can be chosen at will; this freedom is important when investigating the stability of the input impedance while refining the segmentation.

The code GALNEC has been written in Fortran and is intended for use on a UNIX workstation. It was tested on a HP 715/50. There are several versions of GALNEC; GALNEC-1 was developed by K. Lileg [3]; it is for one dipole, whose length must not exceed 0.9λ. GALNEC-1.1 is a somewhat speedier version of GALNEC-1. GALNEC-2 is an extension for two collinear dipoles of equal dimensions, whose excitation voltages and source regions may be chosen at will; GALNEC-3 is the same program for three collinear equidistant dipoles. All theory, formulae and checks employed in implementating GALNEC-1 are described in refs.[3] and [5]; there is an extensive unpublished documentation written in German. The formulae used in GALNEC-1.1, GALNEC-2 and GALNEC-3 are given in ref.[5]. For these versions there are only commented FORTRAN programs available. All these programs can be obtained from the last author (Electronic mail: schnizer at itp.tu-graz.ac.at).

3 DESCRIPTION OF THE CODE WARAN

The computer program (FORTRAN code) with name WARAN (wire arrays analysis) [7] has been written for numerical simulation of wire structures consisting of thin wires of arbitrary curvature and arrays of such elements in free space and above an infinite perfectly conducting screen. Each wire is approximated by a series of connected short straigth segments as shown in Fig.2. Each source is modelled as a voltage applied to a delta-gap.

The problem may be described by a system of integral equations for the unknown electrical current distribution $J(s_j)$ along every wire. Mei's integral equation [11] has been used:

$$B_i \sin(ks_i) + C_i \cos(ks_i) - jV_i \frac{1}{2Z_0} \sin(k|s_i|)$$
$$= \sum_{j=1}^{N} \int_{L_j} ds_j' \, J(s_j') \; \mathcal{K}(s_i, s_j'); \;\; i = 1, ..., N. \quad (5)$$

where

$$\mathcal{K}(s_i, s_j') = \sum_{m=1}^{3} \mathcal{K}_m(s_i, s_j')$$
$$\mathcal{K}_1(s_i, s_j') = G(s_i, s_j') \; (\vec{s_i}' \cdot \vec{s_j}');$$

$$\mathcal{K}_2(s_i, s_j') =$$
$$= -\int_0^{s_i} G(s_i', s_j') \frac{\partial(\vec{s_i}' \cdot \vec{s_j}')}{\partial s_i'} \cos[k(s_i - s_i')] \, ds_i';$$

$$\mathcal{K}_3(s_i, s_j') =$$
$$= -\int_0^{s_i} \left(\frac{\partial G(s_i', s_j')}{\partial s_i'} (\vec{s_i}' \cdot \vec{s_j}') + \frac{\partial G(s_i', s_j')}{\partial s_j'} \right) \times$$
$$\times \cos[k(s_i - s_i')] \;\; ds_i';$$

$$G(s_i, s_j) = \frac{e^{-jk|\vec{r}_i - \vec{r}_j|}}{4\pi \, |\vec{r}_i - \vec{r}_j|};$$

$k = 2\pi/\lambda$; $Z_0 = 120\pi$ Ohms ;
N is the total number of wires in an array;
s_i is the coordinate along the i-th wire.

A Method of Moments and a collocation technique have been used to obtain a solution of the system (5). A linear approximation of the current distribution on each segment has been used. The collocation points have been placed at the ends of each segment. The number of linear algebraic equations obtained for each wire is equal to the number of segments for this wire plus 1. The present version of the program does not support loops and wire junctions. Analytical expressions were found for all integrals where it was possible. Input impedances and all far-zone radiation characteristics are calculated using the current distributions found.

The program has been tested by MS FORTRAN 5.1 compiler under MS DOS 6.0. The code has been used mainly for various helical antennas simulations, but its potential capabilities are much wider. Using a PC under MS DOS (without DOS-extender) it is possible to analyze wire structures containing up to 200 segments. The code is available from the first author (A.A.E.).

4 RESULTS

Numerical results obtained by the computer codes GALNEC, WARAN and NEC-2 (excitation by a voltage source) have been compared for several model tasks and have given good agreement between each other. In this brief report we present only 3 samples with all input data needed, and we hope the results will be interesting for other members of the electromagnetic community.

4.1 Non-resonant thin dipole

The straight thin dipole has a length $2\,l_c = 0.7\,\lambda$ and a radius $r = a = 0.001\,\lambda$. The dipole is center-driven and it is excited by the voltage source $V = 1.0 + j0.0$ Volts. For a simulation by GALNEC the dipole was divided into

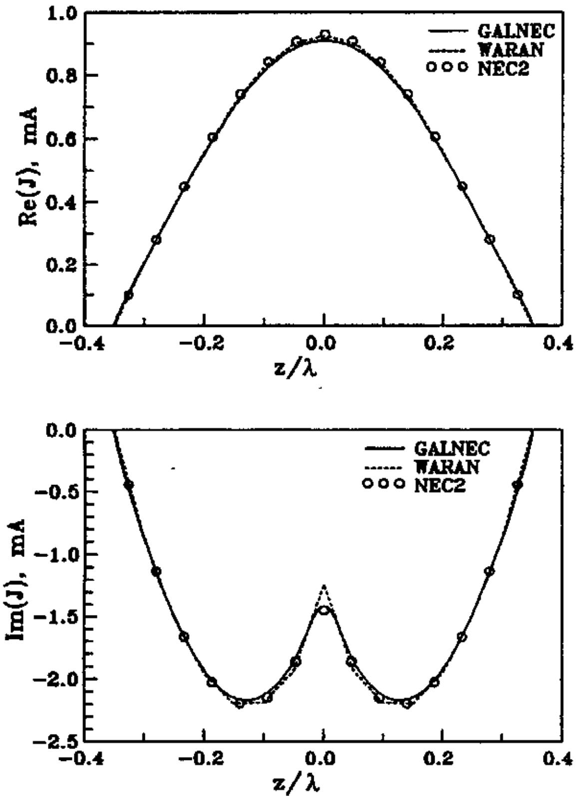

Figure 3: The current distribution along the thin non-resonant dipole

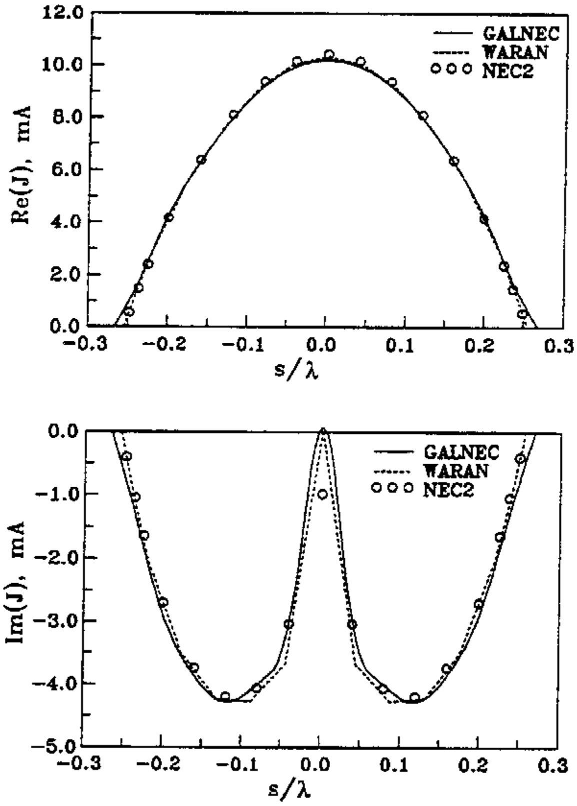

Figure 4: The current distribution along the thick resonant dipole

15 segments per cylindrical part and 3 sectors per half of each end cap. In the WARAN and NEC-2 models the dipole was divided into 14 and 15 segments, respectively. The calculated input impedances are 321.5 + j 499.8 Ohms (GALNEC), 388.2 + j 518.2 Ohms (WARAN) and 312.9 + j 488.7 Ohms (NEC-2). The calculated current distributions are shown in Fig.3.

There are some differences between the imaginary parts near the excitation point. This may be explained by the different models of excitation used in each program, as is well known [12], [13].

4.2 Resonant thick dipole

The straight thick center-driven dipole (see Fig. 1) has a length (cylindrical part) $2\,l_c = 0.44\lambda$ and a radius $a = 0.03\,\lambda$. For a simulation by GALNEC the dipole was divided into 11 segments per cylindrical part and 3 sectors per half of each end cap. In the codes WARAN and NEC-2 the thick dipole was modelled by a wire grid of 8 thin wires (see Fig.2) of radius $r = 0.001\lambda$. For each half of each end cap a 3-segment approximation was used. The wires were not connected to each other at the end caps. The straight ("cylindrical") part of each wire was divided into 10 and 11 segments for WARAN and NEC-2, respectively. Each wire was excited by the voltage source $V = 8.0 + j\,0.0$ Volts to obtain the same rate-setting of the current distribution as for the GALNEC

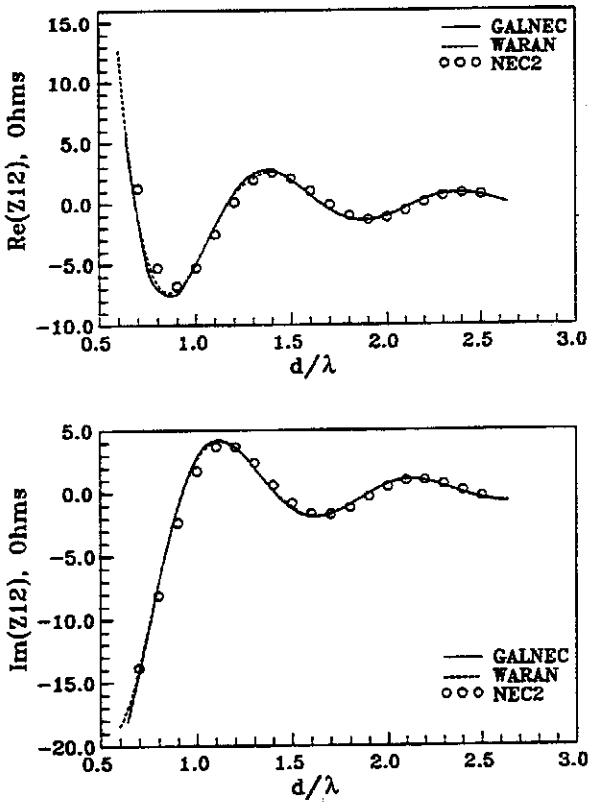

Figure 5: The mutual impedance between collinear thick resonant dipoles

model case. The calculated input impedances are 98.1 − j 0.8 Ohms (GALNEC), 96.7 − j 0.35 Ohms (WARAN) and 95.1 + j 9.0 Ohms (NEC-2). The calculated current distributions along the surface of the thick dipole (GALNEC) and along the thin wires (WARAN and NEC-2) are shown in Fig.4. Calculated and measured input impedances for single dipoles are compared in [4], [5], [9], [10]. Refs. [5] and [10] contain also comparisons with results obtained by NEC-2.

4.3 Array of thick collinear dipoles

An array (see Fig.1) of thick collinear dipoles as described in the previous case has been considered. The dependence of the mutual impedance vs the distance between the array elements (thick dipoles) has been calculated. There is very good agreement between the results obtained by all three programs (see Fig.5). Further results for dipole arrays obtained with GALNEC are reported in [5], [8] and [9].

5 CONCLUSIONS

We compared results for thin and thick dipoles and dipole arrays which were obtained by 3 programs based on different integral equations and different methods of their solution. Very good agreement of the numerical results was obtained. The wire-grid approximation used for modelling the thick dipoles in NEC-2 and WARAN gives good agreement with the exact electromagnetic approach used in GALNEC. Even for the case of a collinear array we found, that a simple wire grid model, using 8-fold rotational symmetry, yields results which agree with the exact electromagnetic approach within graphic accuracy. By comparing the results of the new codes WARAN and GALNEC to those of NEC-2 we proved the capability of these two codes to produce reliable results, which can be helpful for further tests and validations of new codes or for tests of wire grid models used in such codes (cf. also [9]).

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