VALIDATION OF THE MININEC3 CODE FOR COMPLEX RADIATING STRUCTURES

K.P.Murray and B.A.Austin
Department of Electrical Engineering and Electronics
University of Liverpool
PO Box 147
Liverpool L69 3BX
United Kingdom

Abstract

The ability of the MININEC3 code to accurately model complex radiating structures was previously unknown because computer compiler constraints limited the size of analyzable configuration. With the conversion of the code from BASIC to FORTRAN however it is now feasible to use it to simulate such structures. This paper presents the results of a validation exercise aimed at assessing the code's suitability for modelling configurations which involve hundreds of segments.

1 Introduction

The MININEC moment method code is sometimes considered erroneously to be merely a more compact version of the widely known Numerical Electromagnetics Code (NEC). There are though significant differences between the algorithms used in the two codes. Of particular importance are the expansion and testing functions used in the representation of the current distribution. MININEC uses a modified Galerkin approach with pulse expansion and testing functions whereas NEC's employs constant-sine-cosine expansion functions and delta testing functions. In certain moment method applications however it is desirable to use a code where the same expansion and testing functions are employed in the representation of the current distribution. One particular application, of interest to the authors, is the calculation of the so-called characteristic modes (Harrington 1975) of a radiating structure. This is facilitated by the solution of a weighted eigenvalue equation involving its generalized impedance matrix [Z]. If a Galerkin or modified Galerkin moment method code is used in the initial determination of [Z] then reciprocity between segments is enforced and the matrix is symmetrical. This is highly advantageous as it ensures that the characteristic modal currents and their associated eigenvalues are real, giving them a clear physical meaning and hence allowing greater insight into a structure's radiation characteristics.

The results presented in this paper relate to a research program concerned with the investigation of the characteristic modes of complex vehicular structures (Murray and Austin 1993) at HF and VHF frequencies. This involved the use of a moment method code with the ability to model such configurations accurately. The need also for identical expansion and testing functions effectively eliminated the use of NEC. Hence the MININEC code was chosen as the basis of the work. A useful feature of NEC and MININEC is the similarity of geometry definition which means that the wide range of available NEC pre- and post-processors could be employed with minimal modification. The one major drawback of using MININEC was that it had not previously been used to model complex geometrical configurations because it was written in BASIC and compiler constraints imposed severe segmentation limits. Conversion of the code to FORTRAN however, as described by Miller (1989a), effectively removed this constraint but its ability to model complex structures accurately was unknown. This paper addresses this issue by showing the results of a MININEC3 validation exercise. Three approaches were adopted using appropriate analytical, NEC-generated and available experimental data.

2 Development of the MININEC3 Code

The Mini-Electromagnetics Code (MININEC) was initially developed by Julian *et al* (1982) as a Method of Moments code for the analysis of simple, relatively small (in terms of wavelengths), antenna structures. The original purpose of the code was to provide a tool for the rapid analysis of such simple antennas on small micro or desktop computers. It allowed the computation of a number of the basic characteristics such as current distribution, input impedance and far-field pattern of an antenna situated in either free space or over an infinite, perfectly conducting ground-plane. There were many limitations to the initial version of MININEC. Point reactive loading was available, although this was not allowed for wire segments intersecting the perfectly conducting ground plane. Also any wire that did intersect the ground plane had to do so at an angle of 90°. In addition computer technology of the time introduced further constraints. Computer memory and the available BASIC compilers limited the size of analyzable geometries to around 30 segments. This meant that the maximum size of antenna that could be handled confidently was of the order of 1 wavelength.

A second version of the code was developed by Li *et al* (1983) which addressed some of the ground plane constraints listed above. The next major step in the progression of the code however was the development of MININEC3 by Logan and Rockway (1986), together with the rapid development of computer technology. Although the program was still written in the BASIC language, compilers were available that could address up to 64k of memory, enabling antenna structures of up to 125 segments or of the order of 8 wavelengths to be analyzed. The relative increase in desktop computer speed also made the analysis of such structures feasible within a reasonable period of time.

This third version of MININEC also included many more of the features that are available with the mainframe NEC code. As with the previous codes, current distribution and hence input impedance, along with far field patterns could be calculated. The feature of point loading the antenna was improved to include the ability to add either fixed or frequency dependant s-domain loading. The antenna could now be situated in either free space or over a perfect or finite conducting ground plane. This feature used the Fresnel reflection coefficient approximation to allow five changes in ground impedance with distance using either circular or linear boundaries. Near fields were also computed, if required.

Other variants of the MININEC code have been developed that have improved the interface with the user and also presented improved routines for the display of calculated data. Such codes are described by Lewallen (1991) and include The MININEC System (Logan 1988), MN4 (Beezley 1992) and ELNEC (Lewallen 1991). Although not improving the capabilities of the basic algorithm or speed, they present an attractive, "user friendly" interface and rapid methods for displaying calculated data graphically.

The algorithms used in the MININEC3 code and its variants provide a reliable, stable method for the calculation of generalized antenna characteristics. There is no theoretical limit to the size of geometry that can be analyzed using these algorithms, although it is limited by two external factors. Firstly, as discussed above, the size of core memory that a BASIC compiler can address limits the physical size of the problem. Secondly, the speed of operation of the computer on which the software is mounted places a further practical constraint on the time available.

The first of these constraints was addressed with the implementation of a version of MININEC3 in FORTRAN as described by Miller (1989a). The FORTRAN programming language overcomes all the inherent constraints of BASIC compilers. There is no theoretical limit to the size of memory that can be addressed and the greater efficiency of the language for numerical calculations improves execution time. Also the code may be used with a wider range of computers including mainframes.

3 Validation of MININEC3

Three different approaches will be used in the assessment of the ability of MININEC3 to model complex antenna structures. Firstly the analytical results for the input impedance of a V-dipole antenna are examined. This configuration, with an acute angle between two conductors, has been reported to produce erroneous impedance results with some moment method codes (Austin 1993). Since wire grid models of complex structures frequently contain such acute angles it is therefore important that the ability of MININEC3 to model the situation is considered. Secondly MININEC3 was used to calculate the radiation characteristics of a number of complex wire grid models representing continuous surfaces. These are compared to the results obtained using NEC. Finally the experimentally-determined input impedance of a monopole mounted on a conducting box is compared to the results obtained with MININEC3.

4 The V-dipole Antenna

The input impedance of a centre-fed V-dipole antenna in free space was determined analytically by Jones (1976). His results showed excellent agreement with experimentally determined data for a base fed monopole antenna positioned at various angles over a large conducting ground plane. The antenna configuration used by Jones is shown in figure 1. He varied the angle Ψ between the two wires from 30° to 180° in 30° increments.

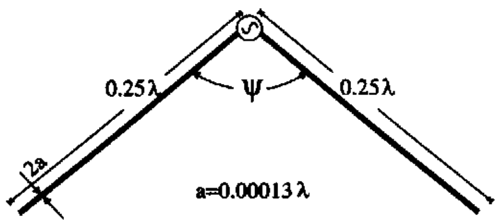


Figure 1. V-dipole antenna.

For the MININEC3 model three uniform and one tapered segmentation scheme were employed and are shown in table I. Schemes 1, 2 and 3 are the uniform segmentation configurations. Notice that schemes 2 and 3 involve higher densities than the generally accepted MININEC3 "rule of thumb" of 20 segments per wavelength of wire. Scheme 4 is the graded segmentation case. This consists of dividing each wire into two equal sections. For the section including the feed-point a higher segmentation density was employed. Figures 2 and 3 then show the predicted input impedances obtained using these four schemes and compares them to those of Jones.

Table I. V-dipole segmentation schemes.

Scheme	1	2	3	4
Total segments	12	20	40	30
Segmentation density (per wavelength)	24	40	80	80 - Region 1 40 - Region 2

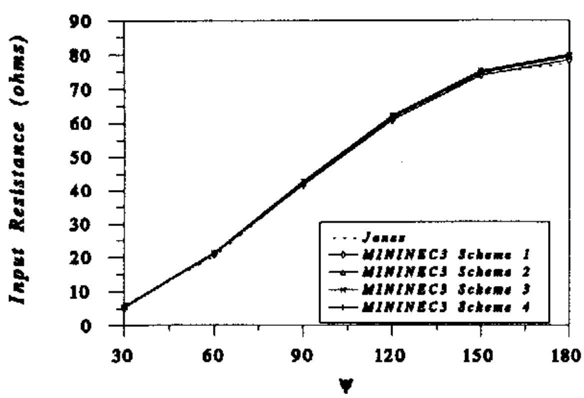


Figure 2. Comparison of analytical and MININEC3 predicted input resistance.

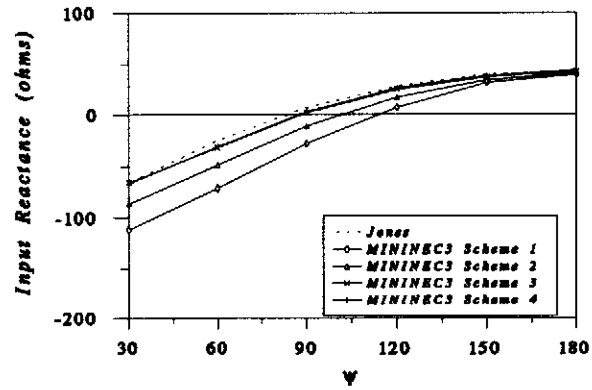


Figure 3. Comparison of analytical and MININEC3 predicted input reactance.

Figure 2 shows that the MININEC3 input resistances obtained with all of the segmentation schemes are virtually indistinguishable from those of Jones. For the input reactance, shown in figure 3, however it is noticeable that as Ψ is reduced the difference between MININEC3 and the analytical results is substantial for 12 and 20 segments. By contrast schemes 3 and 4 are in excellent agreement for all Ψ.

It is apparent from these results that MININEC3 is capable of accurately modelling wires with an acute angle provided that an appropriate segmentation scheme is employed. The results here suggest however that only in the local region around the junction between the wires is it necessary to use this relatively dense segmentation scheme. Thus for Ψ<90°, schemes 3 and 4 show good agreement compared to the poor agreement of schemes 1 and 2. The advantage of scheme 4 compared to scheme 3 is the reduction in computation time. Tapering the segments in the vicinity of the feed has also been shown by Lewallen (1991) to improve the accuracy significantly.

5 Comparison with NEC

The NEC program is the one of the most widely used and highly regarded moment method codes for the analysis of complex antenna systems. Comparing its results to those of MININEC3 is therefore a useful validation exercise. A wide range of continuous surfaces represented by wire grid models were therefore modelled using both codes. This section compares both the predicted far-field patterns and input impedances of two specific geometrical configurations. The first is a 0.4λ x 0.6λ flat plate with a monopole mounted in the centre as shown in figure 4. The second is a more complex box structure containing a aperture and two vertical monopoles as shown in figure 5. Wire grid models of these structures were developed using the mesh generator of Najm (1991). The grid spacing is 0.1λ and the so-called equal-area rule was applied to determine the wire radius. Figures 6 and 7 show the resulting wire meshes.

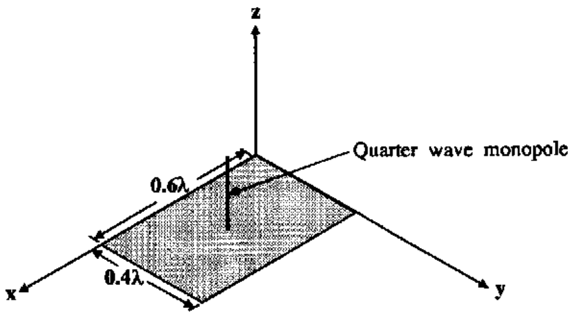


Figure 4. Flat conducting plate with centre mounted monopole.

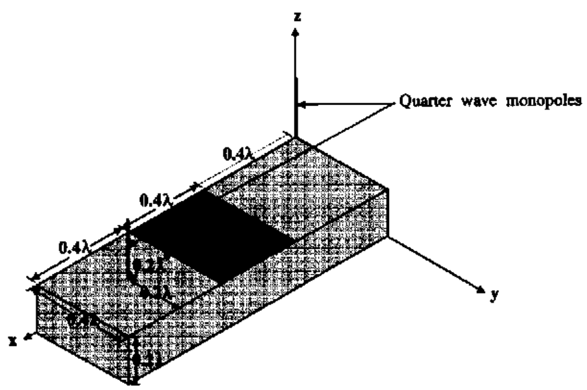


Figure 5. Conducting box with aperture and two monopoles.

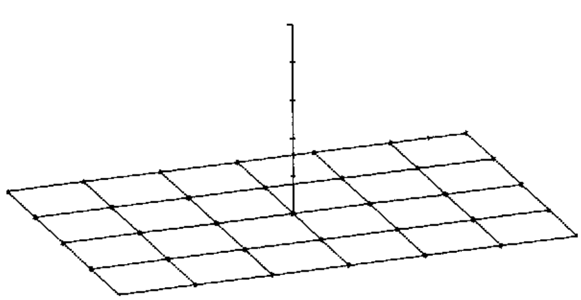


Figure 6. Wire grid model of the geometrical configuration shown in figure 4.

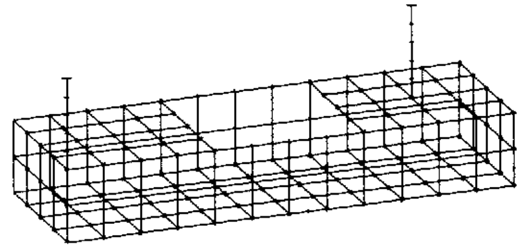
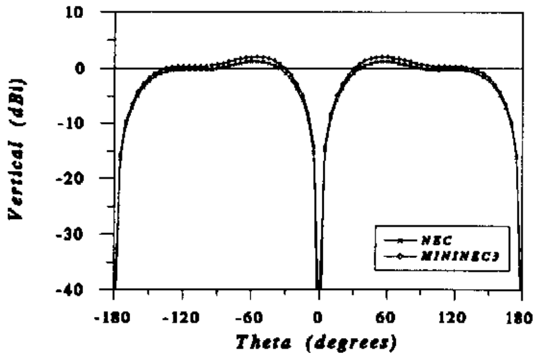


Figure 7. Wire grid model of the geometrical configuration shown in figure 5.

For the first model the monopole was excited with a single voltage source situated at its base. The two monopoles of the second configuration however allowed them to be base fed with voltage sources of different magnitude and phase. This is clearly useful in a validation exercise as numerous dissimilar far-fields are obtainable, as well as complex current flow on the whole structure.

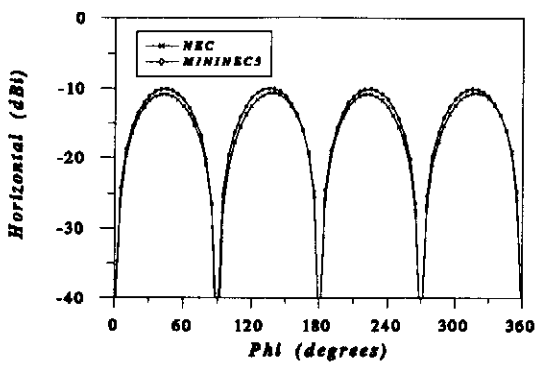
Considering firstly the predicted radiation patterns in free space of the simpler plate configuration, figure 8 shows the variation in elevation of the vertical *E*-field component, while figure 9 shows the azimuthal variation of the horizontal *E*-field component. Excellent agreement is achieved in each case with a maximum difference of less than 1dB at any point. Next considering the more complex box structure figures 10 and 11 show the azimuthal variation of the vertical *E*-field component with the monopoles fed firstly in-phase and secondly in anti-phase. Figures 12 and 13 show the variation in elevation of the horizontal *E*-field component for the same feed configurations. Overall the agreement shown for this configuration is reasonably good with the patterns, in general, exhibiting the same shape with nearly identically positioned peaks and nulls. The most noticeable difference in the pattern plots is in the depth of the nulls which in the worst case is up to 5dB. Overall though both codes are predicting substantially similar spatial distributions of power.

Next we consider the input impedance where table II shows the values predicted by both codes. It is noticeable that the largest difference between the two sets of results is in the reactive component. MININEC3 consistently predicts an input reactance that is substantially more capacitive than that of NEC. Miller (1989b) identified a similar effect where different computer models occasionally produce similar results but with a noticeable frequency shift from one another. The overall dimensions of the structures considered here are around the first natural resonance where generally the reactive component of the input impedance is changing rapidly.



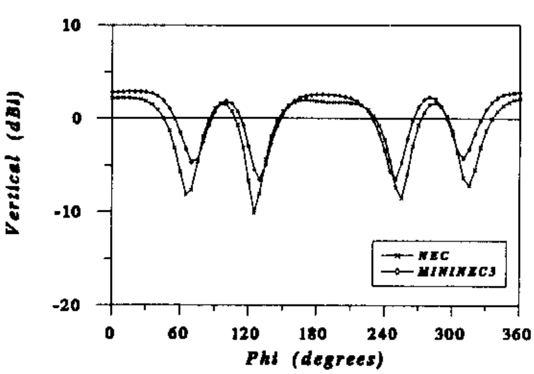
(ϕ=0°)

Figure 8. Variation in elevation of the MININEC3- and NEC-predicted vertical *E*-field component for the flat plate.



(θ=90°)

Figure 9. Azimuthal variation of the MININEC3- and NEC-predicted horizontal *E*-field component for the flat plate.



(θ=90°)

Figure 10. Azimuthal variation of the MININEC3- and NEC-predicted vertical *E*-field component for the box with aperture with the monopoles fed in phase.

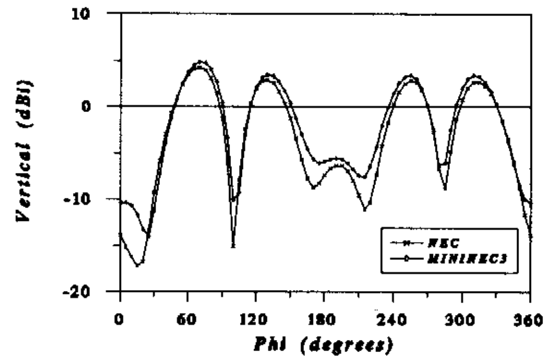


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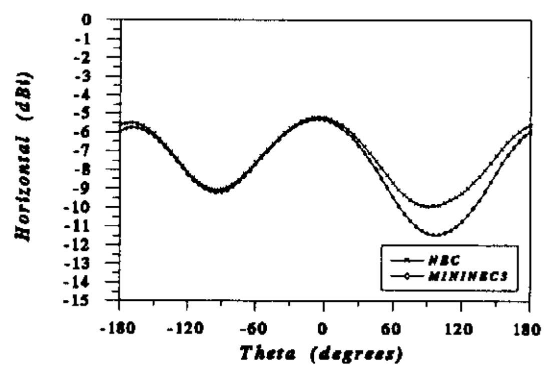
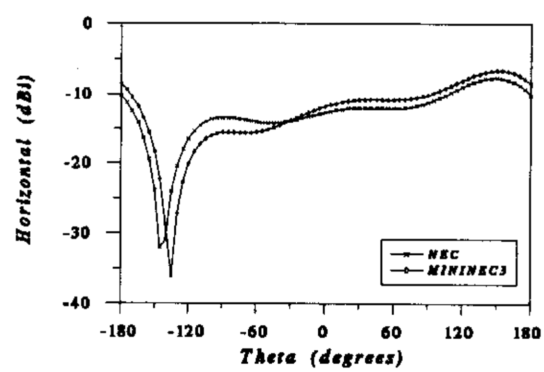
Figure 11. Azimuthal variation of the MININEC3- and NEC-predicted vertical *E*-field component for the box with aperture with the monopoles fed in anti-phase.



(ϕ=90°)

Figure 12. Variation in elevation of the MININEC3- and NEC-predicted horizontal *E*-field component for the box with aperture with the monopoles fed in phase.



(ϕ=90°)

Figure 13. Variation in elevation of the MININEC3- and NEC-predicted horizontal *E*-field component for the box with aperture with the monopoles fed in anti-phase.

Table II. NEC and MININEC3 predicted input impedances.

Geometrical Configuration	NEC	MININEC3
Flat plate	43.34+j42.43	37.66+j18.08
Box with cavity (fed in-phase)		
Monopole 1	151.64+j25.55	148.88+j7.14
Monopole 2	57.10+j22.26	39.80-j1.73
Box with cavity (fed in anti-phase)		
Monopole 1	66.46+j21.87	54.64+j1.28
Monopole 2	36.59+j15.21	27.45-j4.98

Table III. NEC and MININEC3 predicted input impedances with an empirically determined frequency shift in the NEC results.

Geometrical Configuration	NEC Frequency = $0.95f_0$	MININEC3 Frequency = f_0
Flat plate	34.46+j23.21	37.66+j18.08
Box with cavity (fed in-phase)		
Monopole 1	150.70+j9.21	148.88+j7.14
Monopole 2	52.15+j7.26	39.80-j1.73
Box with cavity (fed in anti-phase)		
Monopole 1	64.39-j1.42	54.64+j1.28
Monopole 2	35.12-j1.34	27.45-j4.98

Hence reducing the frequency of the NEC models by an empirically determined value of 5% gives the input impedances shown in table III. The original MININEC results are also shown for comparison.

The frequency shift of 5% clearly reduces the difference between the two sets of impedance results. Whereas the resistive component of the NEC results generally changes negligibly, the NEC-predicted input reactance of each feed-point is reduced considerably. Good agreement is now achieved between the two sets of results. The shift was first thought to be possibly due to the sparseness of the mesh used in the models. It was however, consistently present using mesh densities of up to $\lambda/60$.

The closeness of the NEC and MININEC3 far-field and impedance results shown here suggests that MININEC3 is capable of the comparable emulation of the current distribution on complex structures when compared to NEC. The codes use dissimilar expansion and testing functions to model the current distribution and minor differences in results would therefore be expected. The level of agreement obtained though, especially with the far-fields, proves the validity of using MININEC3 to model complex structures represented as wire grid models.

6 Comparison with Experimental Data

As a final test of the ability of MININEC3 to model complex antenna structures accurately we used an appropriate set of experimental data as a reference. Bhattacharya *et al* (1987) measured the input impedance of a monopole antenna mounted on a conducting metal box. The structure was a five sided 10cm cube attached centrally to a 105cm square conducting ground plane. A base-fed 6cm vertical monopole was mounted at various positions on the upper face of the cube. The radiation patterns of the same configuration were later measured by Chu *et al* (1990) in the same frequency range as Bhattacharya, 1-2GHz.

To model this configuration with MININEC3 a wire grid model was again set up. Each surface of the box was divided into a 6x6 mesh and the equal-area criterion was enforced to calculate the wire radius. The resulting wire grid model is shown in figure 14 with the monopole mounted in the centre. Two simplifications were also made with the MININEC3 model. Firstly the wires of the grid were assumed to be perfectly conducting and secondly the finite conducting ground plane was assumed large enough, in term of wavelengths, to be replaced by a infinite, perfectly conducting ground plane.

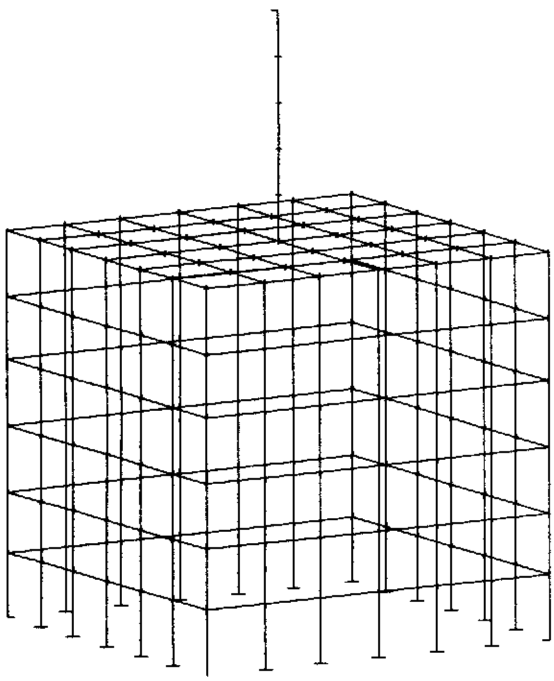


Figure 14. Wire grid representation of the conducting box with centre-mounted vertical monopole.

Figures 15 and 16 compare the MININEC3 predicted input conductance and susceptance with the experimental results of Bhattacharya *et al.* It is noticeable that both the computed and experimental results have a similar trend with a clear, well defined resonance. For both G and B however the peak values differ somewhat and there is a noticeable difference between predicted and measured resonant frequency.

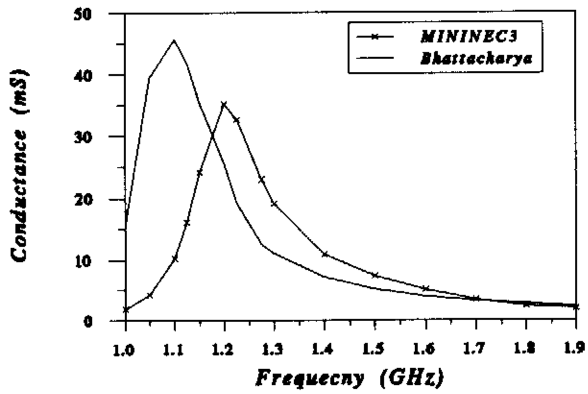


Figure 15. Comparison of experimental and MININEC3-predicted input conductance.

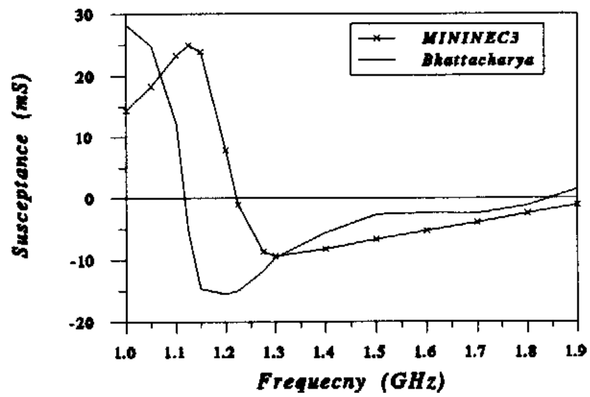


Figure 16. Comparison of experimental and MININEC3-predicted input susceptance.

To test if this difference was due to the inability of the chosen wire grid to represent the continuous surface accurately two further models were developed. Firstly the mesh density was doubled, using a 12x12 grid to model each surface of the cube. Secondly the twice surface area rule was enforced and this yielded a larger wire grid radius. Both of these more refined models however only marginally improved the agreement of the MININEC3 results. These results therefore proved that the MININEC3 model had converged in terms of the necessary grid density and area factor. The discrepancies are therefore probably due to two further factors. Firstly, the assumption made regarding the replacement of the finite ground plane with an infinite, perfectly conducting one may not be valid. Secondly external, unspecified factors due to the measurement system are another probable cause. Cox (1991) compared the measured and NEC-predicted input impedances of a number of HF antennas on aircraft. He attributed differences which existed between predicted and experimental input impedance to dissimilarities in the modelled and actual feed-points. He also showed how slight differences in the position of the actual point of measurement introduced a predominantly reactive differential between results. Considering the MININEC3 model of the centre-mounted monopole the difference between the predicted and experimental reactance at each frequency corresponded, within $\pm 5\%$, to an inductive offset of $L = 2.938$nH. Introducing this inductance in series with the MININEC3 predicted results produced the G and B plots shown in figures 17 and 18. Clearly this empirically determined reactive shift reduces the frequency offset of the resonance significantly. Also the difference in the magnitude of G is reduced substantially.

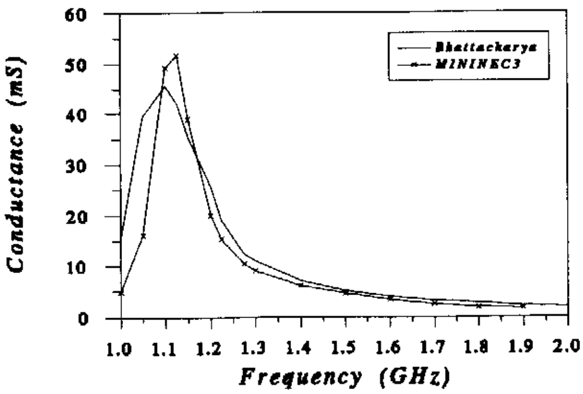


Figure 17. Comparison of experimental and MININEC3-predicted input conductance with an empirically determined inductive offset in the predicted results.

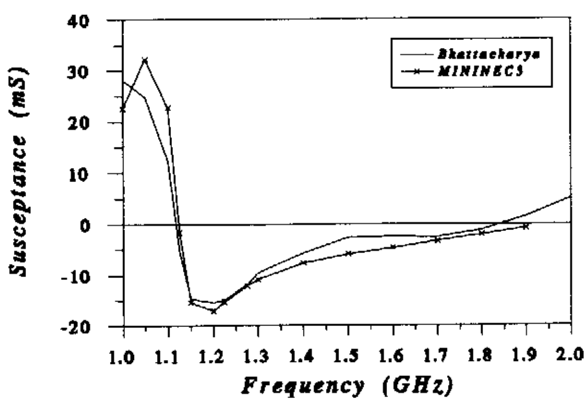


Figure 18. Comparison of experimental and MININEC3-predicted input susceptance with an empirically determined inductive offset in the predicted results.

7 Conclusions

This paper has addressed the validation of an expanded MININEC3 method of moments computer code. The antenna structures used in the validation were particulary appropriate for assessing the code's ability to model complex radiating systems accurately. Until its recent conversion from BASIC to FORTRAN it was impossible to use this code for such applications because of the computer CPU time and compiler constraints. The three techniques used in this validation exercise show that MININEC3 may be used with confidence to model electrically large structures. Firstly, excellent agreement was obtained with analytical results for the input impedance of a V-dipole antenna. This was achieved even at the most acute angle considered of 30°, provided adequate segmentation was employed at the junction of the wires. Secondly, good agreement was obtained with the NEC-predicted results for the radiation patterns and input impedances of two wire grid models of typical vehicular type structures. An important finding however was the noticeable frequency shift between the two codes. Although this was most noticeable because of the near-resonant structures that were used in the simulation it must clearly be considered when employing the code. Finally the good agreement with the experimental data for the input impedance of a monopole antenna on a conducting box again demonstrated the usefulness of this modified MININEC3 code.

8 Acknowledgement

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