COMPARISON OF THE INPUT IMPEDANCE OF MONOPOLE ANTENNAS OBTAINED BY NEC, MININEC, AND MEASUREMENTS

R. J. Bauerle and J. K. Breakall, Department of Electrical Engineering
The Pennsylvania State University, University Park, PA 16802

ABSTRACT - This paper compares the input impedance of monopole antennas numerically calculated by NEC and MININEC with experimental results. This comparison determines the limitation of these two computer codes used for modeling more complicated structures.

Two groups of monopoles are considered. The first group consists of eight electrically thin monopoles of length .28 meters (.235 wavelengths at 252 MHz) and radii of .4064, .7874, 1.168, 1.562, 2.390, 3.162, 6.350, and 7.920 millimeters (.341E-3, .661E-3, .981E-3, 1.31E-3, 2.01E-3, 2.66E-3, 5.33E-3, and 6.65E-3 wavelengths at 252 MHz). For this group, impedance calculations were compared to measurements over the band of 237-267 MHz. The second group consists of five electrically thick monopoles of length .2 wavelengths and radii of .0509, .0635, .0847, .1129, and .1270 wavelengths. For the second group impedance calculations were compared with measurements of tubular monopoles with flat ends.

The results of this paper show that the extended kernel option of NEC predicted measured monopole impedance measurements more accurately than MININEC.

1 INTRODUCTION

In recent years considerable effort has been spent developing general purpose computer codes capable of modeling wire antenna structures using the method of moments [1,2]. The power and flexibility of general purpose wire codes are largely due to the simplicity of wire problems, which in turn are simplified by the use of the thin-wire approximation. This approximation assumes that current flowing on the surface of a wire is azimuthally invariant and can be replaced by an infinitesimally thin filament of current flowing along the wire axis. However, when this approximation is used, certain questions arise in the formulation as to the upper limit of wire radius. Proper treatment must also be given to wire junctions of dissimilar radii. For a discussion on the modeling of stepped radius monopoles see [3,4,5].

The Numerical Electromagnetics Code (NEC) [6] and The Mini Numerical Electromagnetics Code (MININEC) [7] are two widely used antenna analysis programs which use the thin-wire approximation. However, it can be shown that antenna input impedance as calculated by NEC disagrees with that of MININEC for some wire radii [8]. A question exists as to which of these two codes is more accurately predicting input impedance.

To study the validation of NEC and MININEC simulations, the calculation of monopole input impedance is compared with measurements. A monopole antenna was chosen for the study due to its simple geometry and ease of experimental fabrication and calibration. This paper compares computer calculated impedance with measurements for monopoles of different radii. Comparisons are also made with previous measurements of King [9], who had the only applicable set of measurements of monopole impedance for use in this study.

This paper investigates two groups of monopole antennas which will be designated Group I and Group II. Group I consists of eight monopoles, each of .28 meters in length and different radii. The radii are .4064, .7874, 1.168, 1.562, 2.390 ,3.162 ,6.35, and 7.920 millimeters (.341E-3, .661E-3, .981E-3, 1.31E-3, 2.01E-3, 2.66E-3, 5.33E-3, and 6.65E-3 wavelengths at 252 MHz). For each monopole the input impedance was measured over the frequency range of 237 to 267 MHz. Each of the eight monopoles was modeled using NEC and MININEC to simulate the feed point impedance over the measured frequency band.

Group II consists of five electrically thick tubular monopoles with flat ends, each of .2 wavelengths in length and different radii. The radii are .0509, .0635, .0847, .1129, and .1270 wavelengths. For each monopole, impedance measurements were compared with NEC and MININEC models as in Group I.

2 COMPUTER SIMULATION OF MONOPOLE IMPEDANCE

NEC and MININEC are two computer programs for analysis of thin-wire antenna structures using the method of moments. MININEC is a personal computer based program which uses a Galerkin procedure applied to a mixed vector and scalar potential electric field integral equation to solve for the wire currents [2]. This formulation results in a short computer program making it simple to implement on a small computer system. For this reason MININEC is written in BASIC. NEC, the most advanced computer program available for analyzing thin-wire antennas, uses the Pocklington Electric Field Integral Equation (EFIE) for the currents. Although NEC can also be run on a PC, it is usually run on a main-frame computer system. NEC can model larger and more complicated wire structures than MININEC. All of the computer modeling done in this paper was run on an IBM compatible 486DX-33 MHz PC.

NEC has two thin-wire approximation options: the normal thin-wire kernel approximation option and the extended kernel option. In the normal thin-wire kernel option the current on the surface of a segment is approximated as a filament of current on the segment axis. In the extended thin-wire kernel, a current uniformly distributed around the segment surface is assumed. In either of these approximations, only currents in the axial direction on a segment are considered and there is no allowance for variation of the current around the wire circumference.

An antenna is modeled in MININEC by simply running the program on a PC and responding to all of the prompts of the program. To model an antenna using NEC one must create an input file first which dictates the antenna geometry (see reference [6] for information on how to create a NEC input file).

A program called ELNEC [10] was used instead of MININEC to do all of the MININEC calculations in this paper. The method of moments formulation used in ELNEC is identical to that used in MININEC, however ELNEC contains a user-friendly graphical interface not found in the original version of MININEC. Therefore, in this paper, ELNEC and MININEC will be considered synonymous.

Modeling a monopole antenna with NEC or ELNEC requires breaking the antenna up into segments or sections. Proper choice of the segments is the most critical step in obtaining accurate results. Geometrical as well as electrical dimensions must be considered. The segment length (Δ) and wire radius (a) relative to the wavelength (λ) should follow these five guidelines [6]:

(1) $\Delta < .1\lambda$

(2) $\Delta > 10^{-3}\lambda$

(3) $\frac{2\pi a}{\lambda} << 1$

(4) $\frac{\Delta}{a} > 2$ *(ELNEC and NEC normal thin wire approx.)*

(5) $\frac{\Delta}{a} > .5$ *(NEC extended kernal option)*

Also, NEC and ELNEC models should have adjacent segments approximately the same length. All models presented in this paper have adjacent segments of the same length.

Guidelines (1), (2), and (3) must be satisfied by NEC regardless of which option is in effect and guidelines (4) or (5) must be satisfied when using the normal thin-wire kernel or the extended kernel option respectively. ELNEC segmentation must satisfy guidelines (1)-(4).

It has been shown in [11] that guidelines (4) and (5) are the most critical as to the minimum segment length (maximum number of segments) when modeling electrically thick antennas. Therefore the NEC models used to calculate impedance for the Group I and Group II monopoles will have segmentation such that $\Delta = 2a$ is satisfied as nearly as possible when using the normal thin-wire approximation and $\Delta = .5a$ for the extended kernel option. Using such segmentation assures that all of the guidelines are satisfied for all of the monopoles of Group I. However the Group II monopoles cannot have all of the guidelines satisfied simultaneously due to the electrically large radii. Using the aforementioned segmentation for Group II assures that all guidelines will be satisfied with the exception of guidelines (1) and (3) which will be satisfied as nearly as possible. ELNEC models will be segmented as NEC models with the normal thin-wire approximation.

The NEC code models sources by allowing the user to specify a voltage over any segment of the specified geometry. An electric field is then forced at a single match point [6] with a strength equal to the specified voltage divided by the segment length. The ELNEC source model imposes a constant field over a pulse width [7], with magnitude and location chosen by the user. It has been shown in [12] that more complicated source models more accurately depicting the geometry of the feed point have little effect on calculated impedance.

3 MONOPOLE IMPEDANCE MEASUREMENT SYSTEMS

The impedance measurements of the Group I monopoles were taken using the HP-8510C network analyzer along with the HP-8340B Synthesized Sweeper. The HP-8510C was calibrated using the HP-85052 3.5 millimeter calibration kit and adjusted to measure and record impedance from 237 MHz to 267 MHz [13].

The antenna system consisted of a .28 meter long brass rod monopole and two .635 millimeters thick aluminum sheets for the ground plane. An infinite ground plane is approximated by two aluminum sheets that were electrically fastened by conductive copper tape. The size of the ground plane was 2.44 meters by 2.44 meters. With the monopoles placed in the center, at least one wavelength (1.2 meters) at 252 MHz of the ground plane exists between the base of the monopole and the ground plane edge. The monopole was connected to a four inch by four inch brass plate with an SMA barrel which was placed over a three inch diameter hole cut in the ground plane. A Type N-SMA adaptor joined the SMA barrel under the ground plane to a balun. The balun was connected to a 100 foot piece of half-inch diameter heliax coaxial cable leading to the HP-8510C network analyzer. The balun was created from a fifteen inch section of RG-142 coaxial cable surrounded by eleven ferrite beads. The purpose of the balun was to prevent any unwanted currents from flowing on the outside shield of the coaxial cable causing erroneous readings. The complete measuring system is shown in Figure 1.

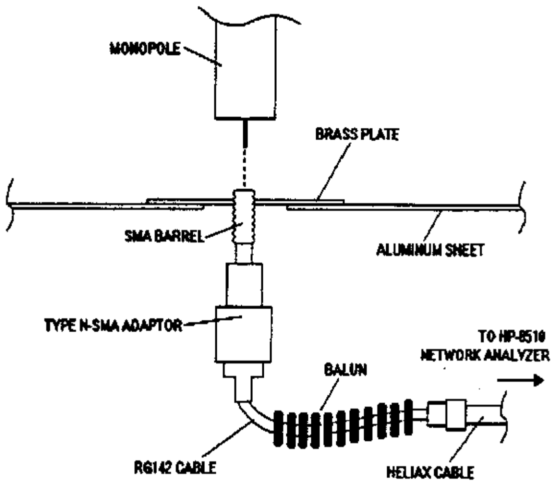

Figure 1. Feed Connection for Measuring System of Group 1 Monopoles

The impedance measurements of the Group II monopoles were made by Holly [14] and published by King [9]. Holly made measurements of tubular monopoles with both a flat circular end cap and without an end cap. The measurements without an end cap were chosen for this paper since the end cap effects have been shown by Li [8] to be negligible.

4 RESULTS

Figures 2-9 show results for the Group I monopoles. Real and imaginary impedance are plotted from 237 to 267 MHz for eight monopoles, each of length .28 meters with radii .4064, .7874, 1.168, 1.562, 2.390, 3.162, 6.350, and 7.920 millimeters. At the center frequency of 252 MHz the length is .235 wavelengths and the radii are .000483, .0009373, .001390, .001860, .002845, .003764, .007560, and .009429 wavelengths. Impedance as calculated by NEC with the normal thin-wire approximation option and the extended kernel option is shown as the solid line and the dashed line respectively. Segmentation is such that $\Delta = 2a$ is satisfied as nearly as possible when using the normal thin-wire approximation of NEC or ELNEC and $\Delta = .5a$ for the extended kernel option of NEC. For example the monopole of radius 7.92E-3 meters is modeled with the extended kernel option of NEC using 44 segments. Reference [11] contains the NEC input files used to calculate the NEC normal thin-wire approximation option and the NEC extended kernel option data of Figures 2-9. These NEC input files contain the number of segments used for each case.

At radii .4064, .7874, 1.168, 1.562, 2.390, and 3.162 millimeters (Figures 2-7), ELNEC agrees within one ohm with

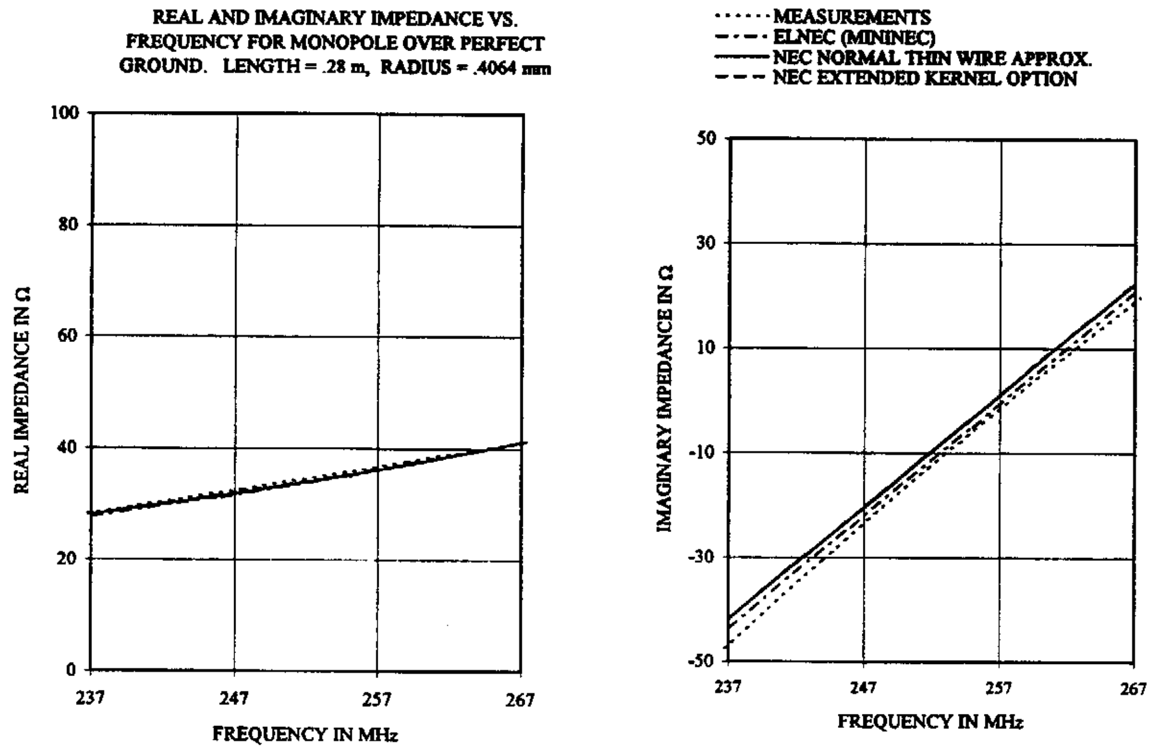

Figure 2. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = .4064 mm.

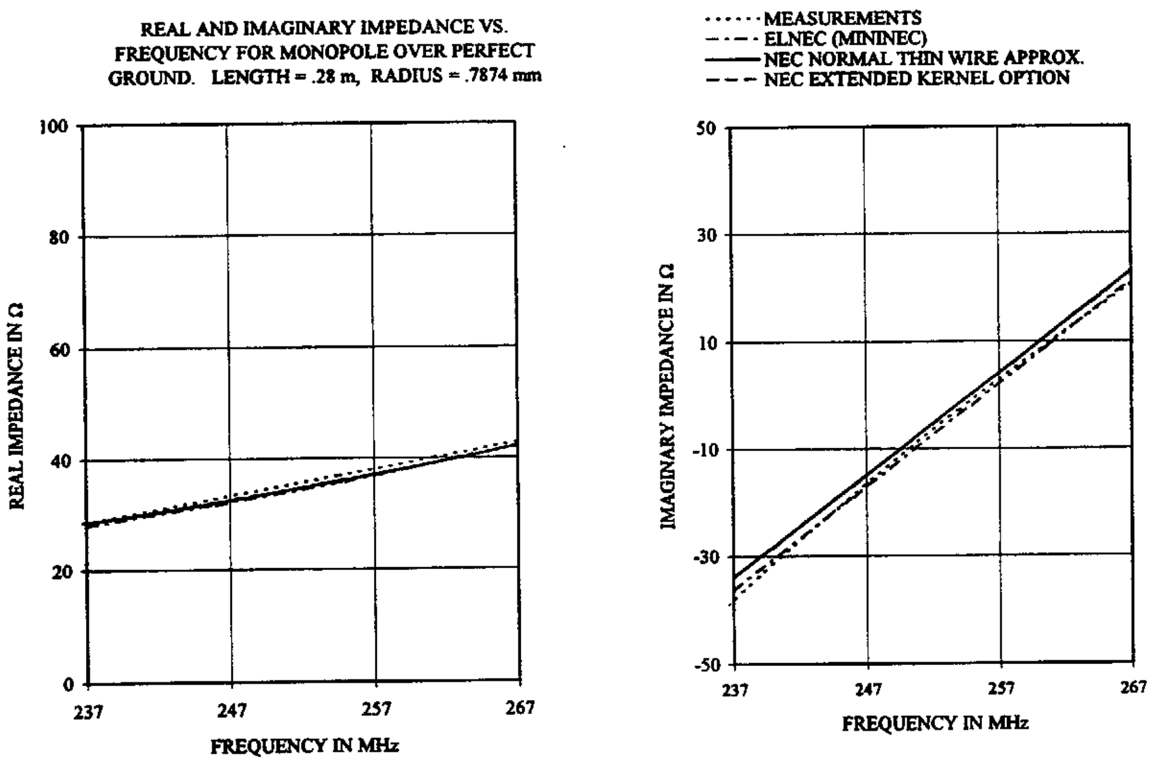

Figure 3. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = .7874 mm.

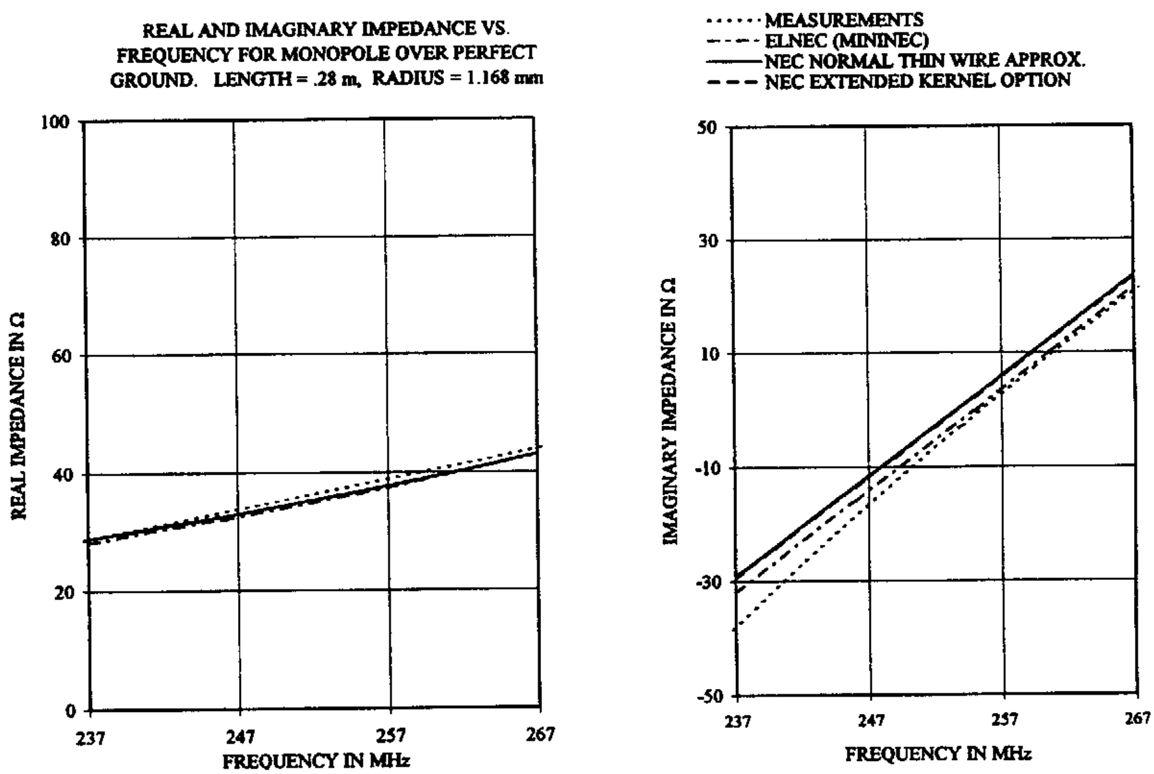

Figure 4. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 1.168 mm.

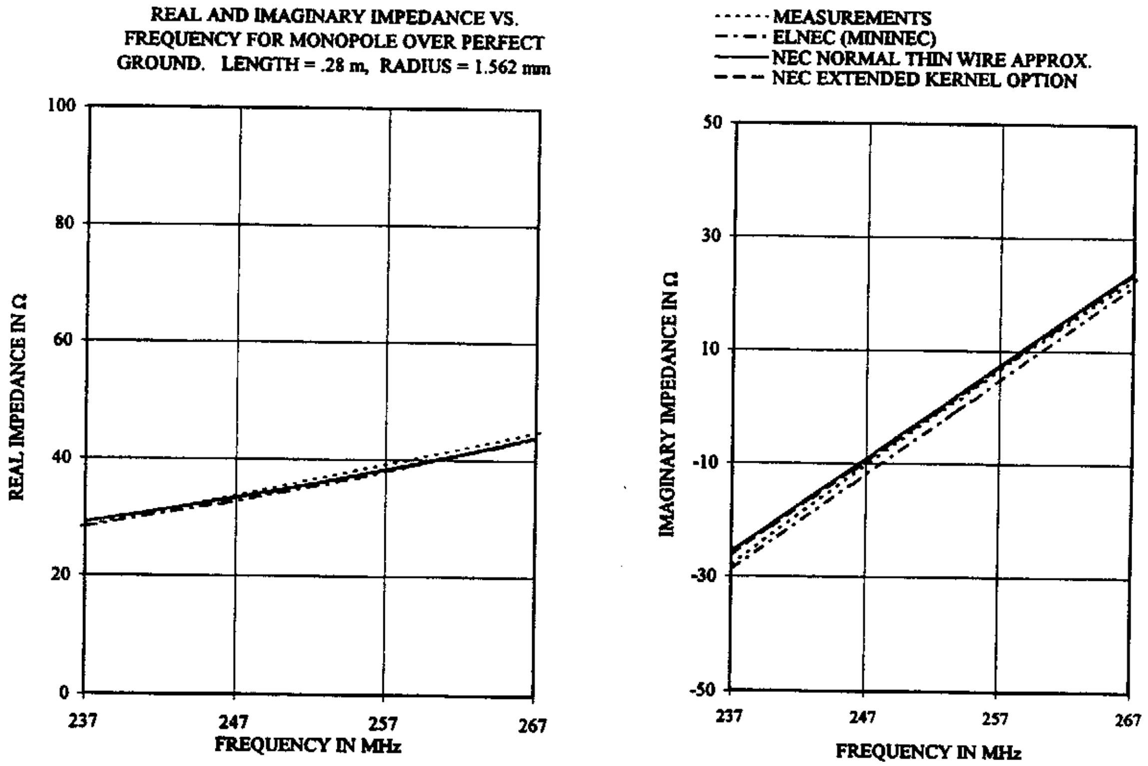

Figure 5. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 1.562 mm.

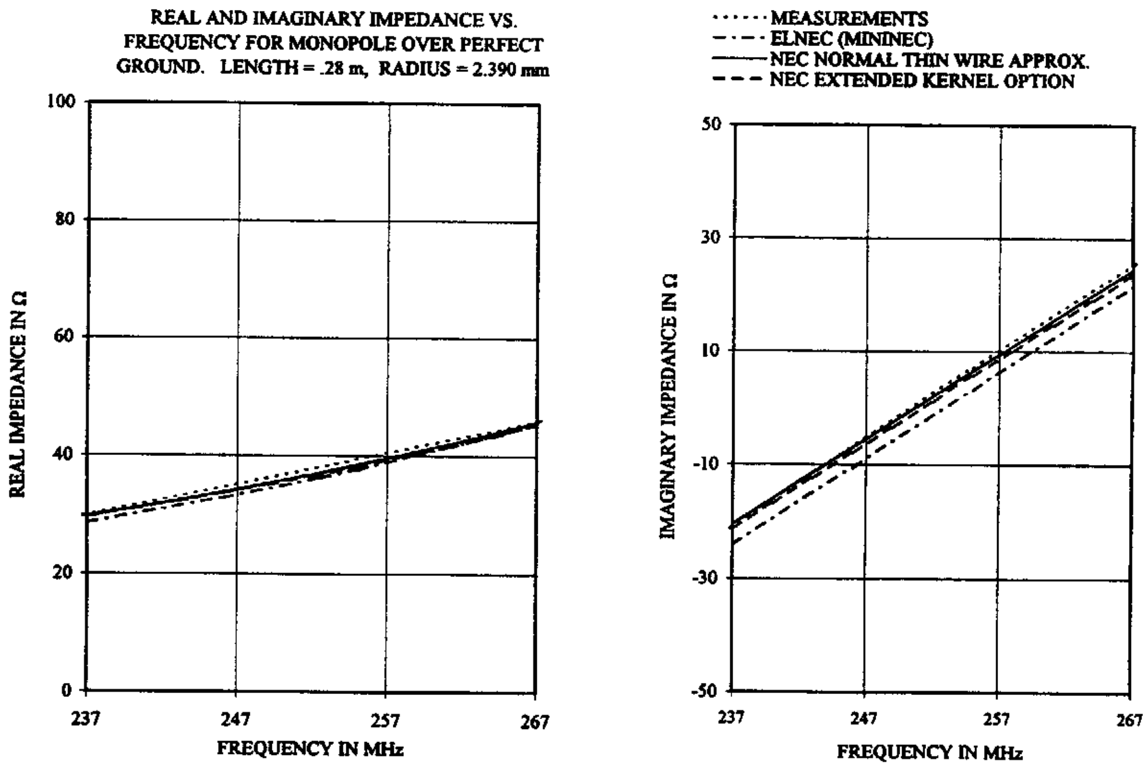

Figure 6. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 2.390 mm.

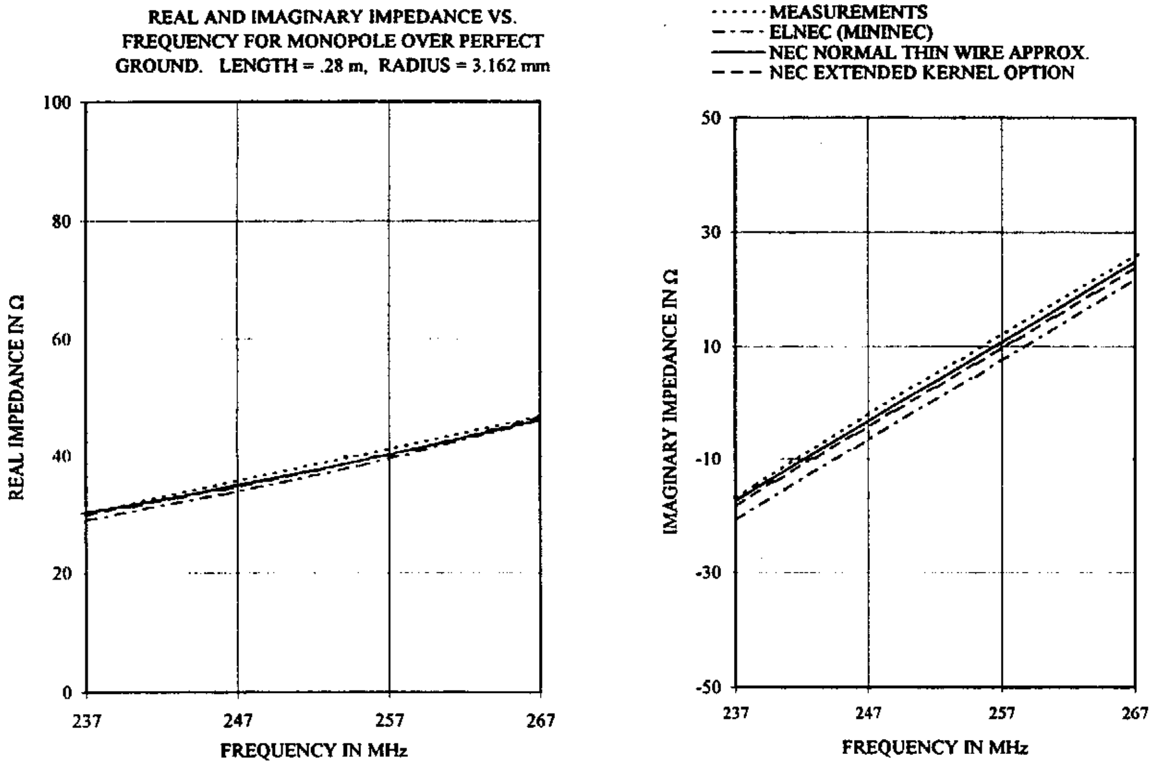

Figure 7. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 3.162 mm.

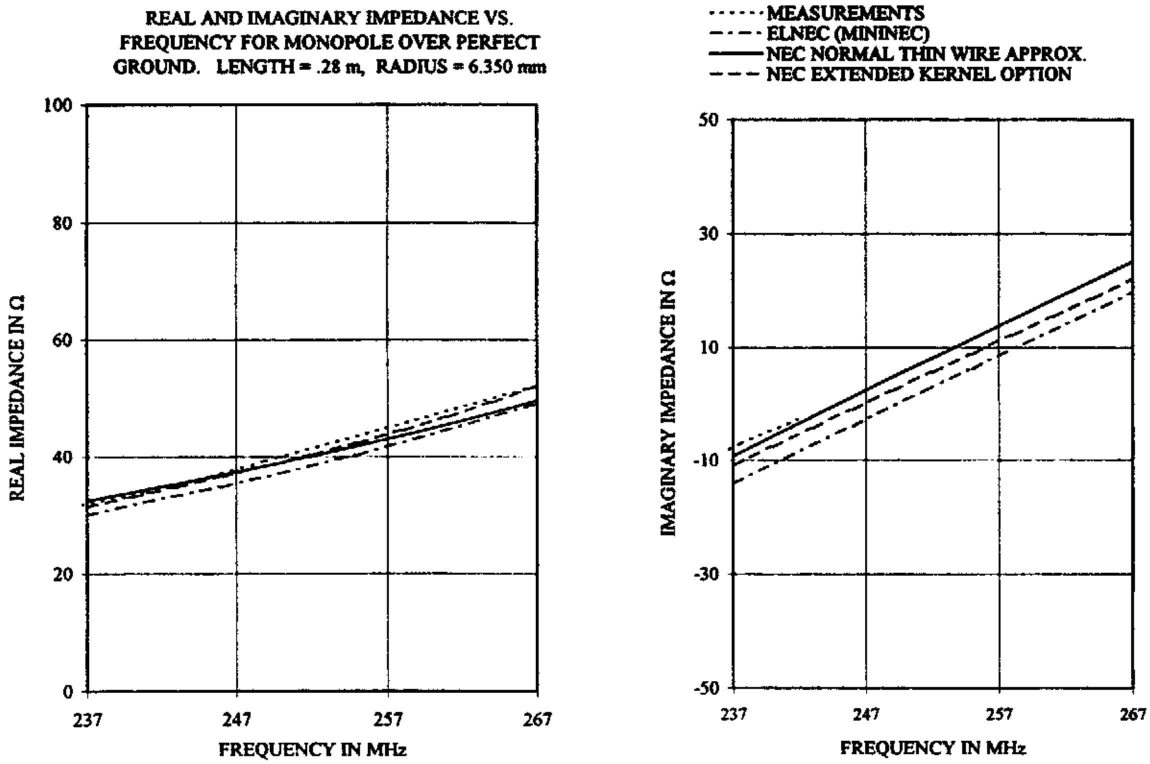

Figure 8. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 6.350 mm.

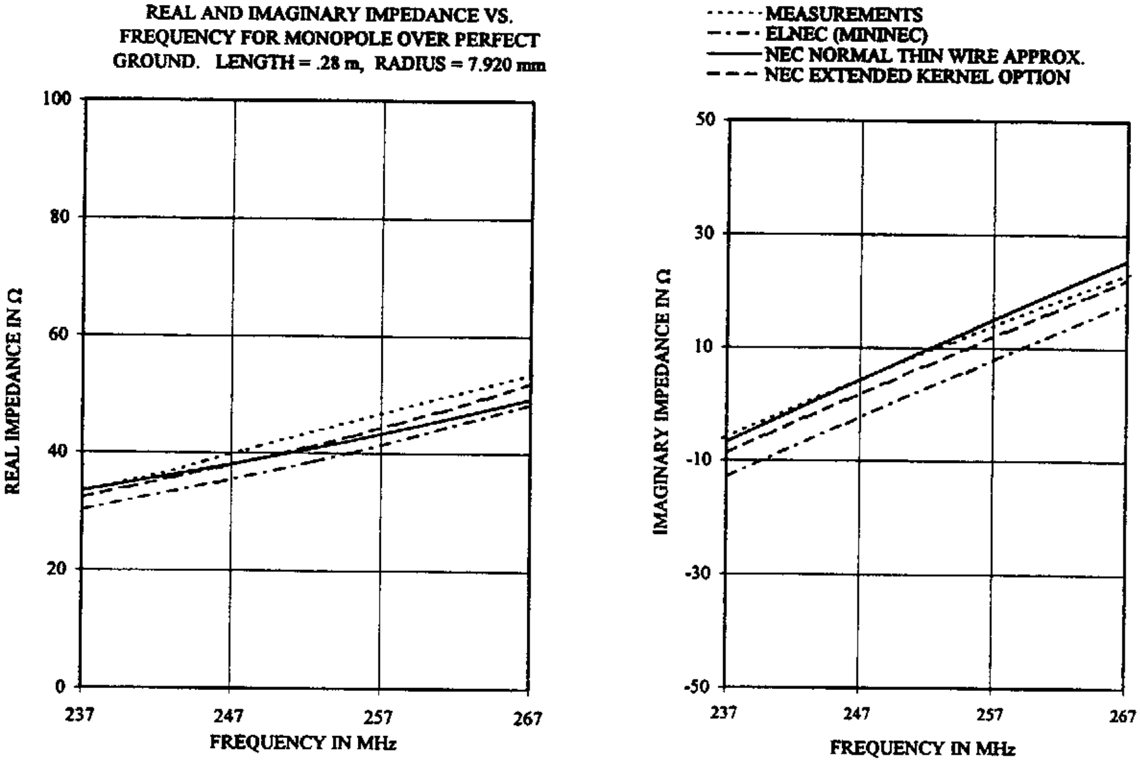

Figure 9. Impedance vs. Frequency for .28 m. Monopole over Perfect Ground. Radius = 7.920 mm.

both options of NEC for calculating real impedance. However, at a radius of 6.350 millimeters (Figure 8), ELNEC differs from NEC with the normal thin-wire approximation option by approximately two ohms and from NEC with the extended kernel option by approximately three ohms. Larger differences between both options of NEC and MININEC can be seen at a radius of 7.92 (Figure 9) millimeters. It is clear that Figures 2-9 show that as the radius of the monopole increases so does the difference between NEC and ELNEC calculated real impedance, with both options of NEC more closely following the measurements. It is also clear from these figures that the difference in calculated real impedance between NEC with the normal thin-wire approximation option and NEC with the extended kernel option increases as the radius increases. It is shown that the latter more closely follows the measurements. A similar trend can be seen for the calculated imaginary impedance. As the monopole radius increases, so does the difference between NEC and ELNEC calculated imaginary impedance. NEC with the extended kernel option agrees best with measurements for imaginary impedance as it does for the real impedance.

Figures 10 and 11 show results for impedance versus radius at 240 and 267 MHz respectively with data from that of Figures 2-9. These two figures further demonstrate the trends discussed above. Figure 10 shows that at 240 MHz, the extended kernel option of NEC more closely matches real impedance measurements than does ELNEC or NEC with the normal thin-wire approximation option. However, the normal thin-wire approximation of NEC more closely matches measurements of imaginary impedance. Figure 11 shows that at 267 MHz the extended kernel option of NEC more closely matches measurements of real and imaginary impedance than ELNEC or NEC with the normal thin-wire approximation option.

Figure 12 shows the results for the Group II monopoles. The real and imaginary impedance vs. radius is plotted for the five different radii of this group of monopoles. As with the Group I monopoles, the extended kernel option of NEC best matches measurements of real and imaginary impedance.

Figures 13-15 show percent error vs. radius. Percent error is calculated using the formula

$$\%error = 100 \times \left| \frac{measured - calculated}{measured} \right|$$

These figures further demonstrate the differences between NEC and ELNEC. Figures 13 and 14 show that the normal thin wire option of NEC has the least percent error for most radii. However figure 15 shows that the extended kernel option of NEC has the least percent error at all points considered.

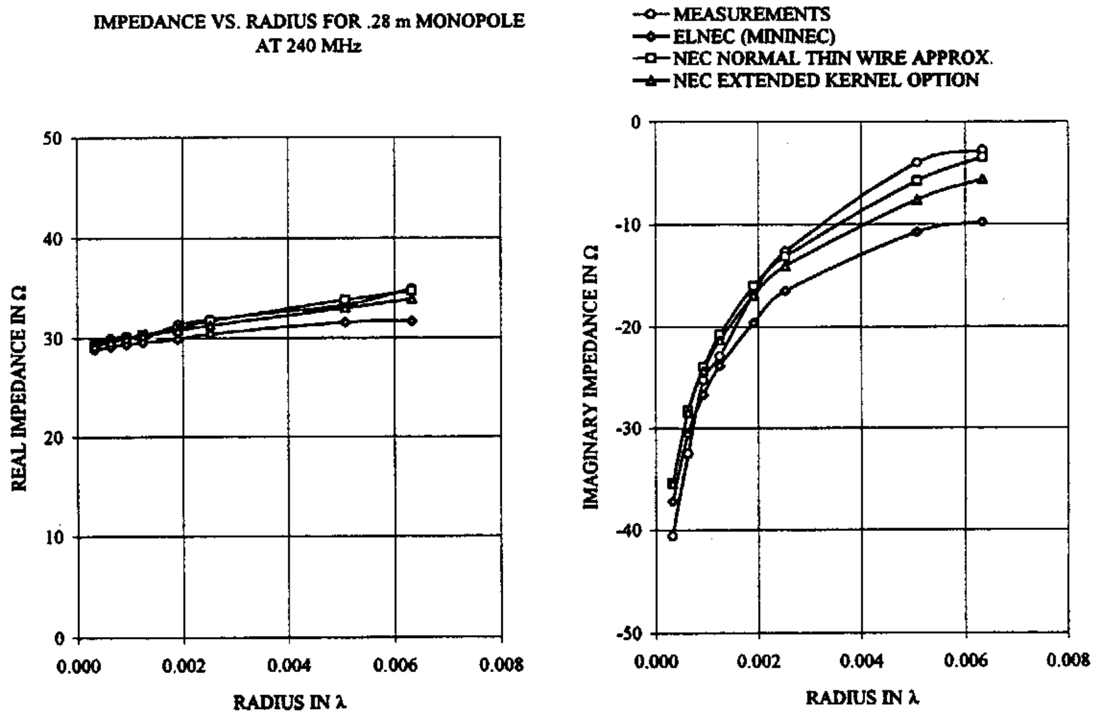

Figure 10. Impedance vs. Radius for .28 m Monopole at 240 MHz.

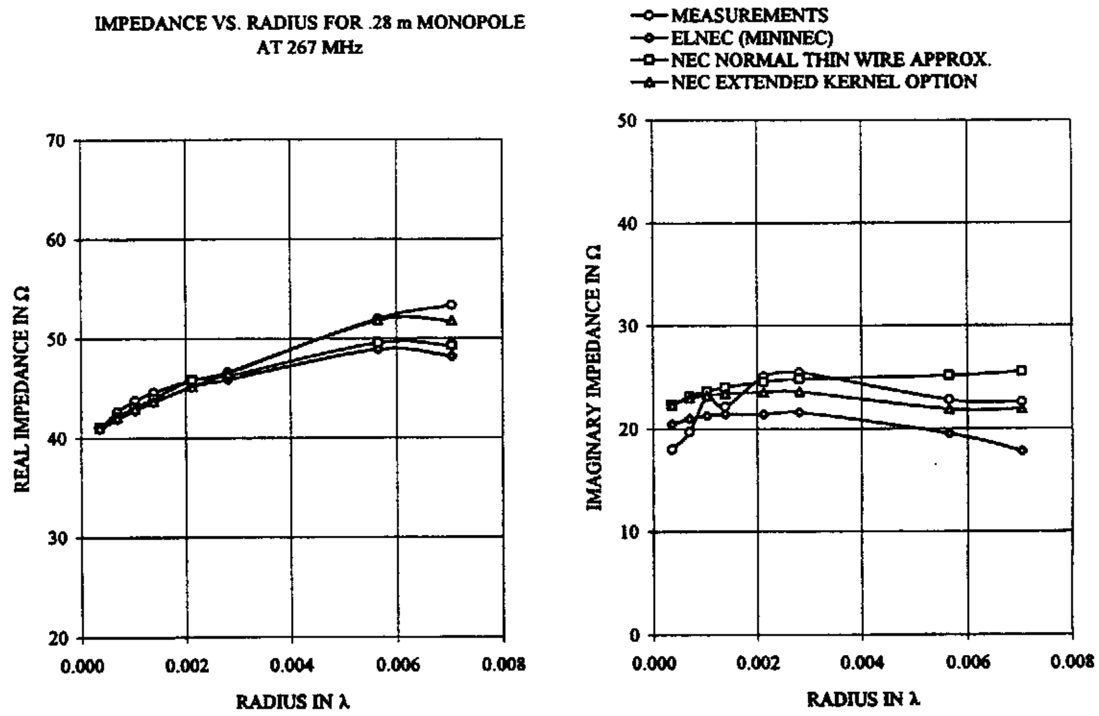

Figure 11. Impedance vs. Radius for .28 m Monopole at 267 MHz.

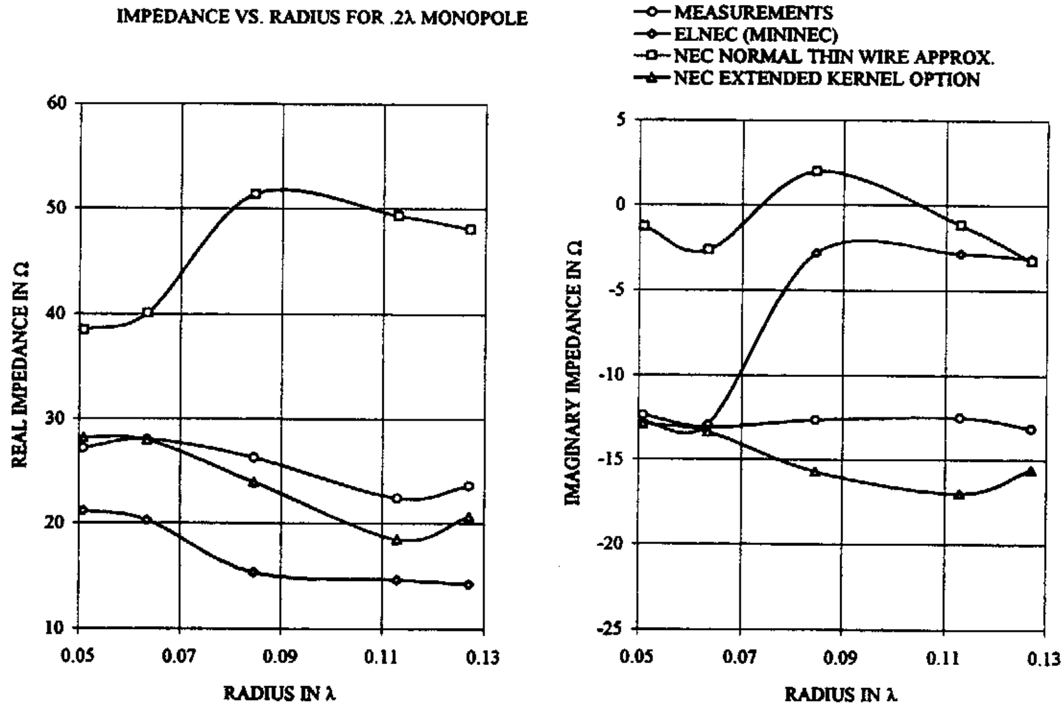

Figure 12. Impedance vs. Radius for .2λ Monopole.

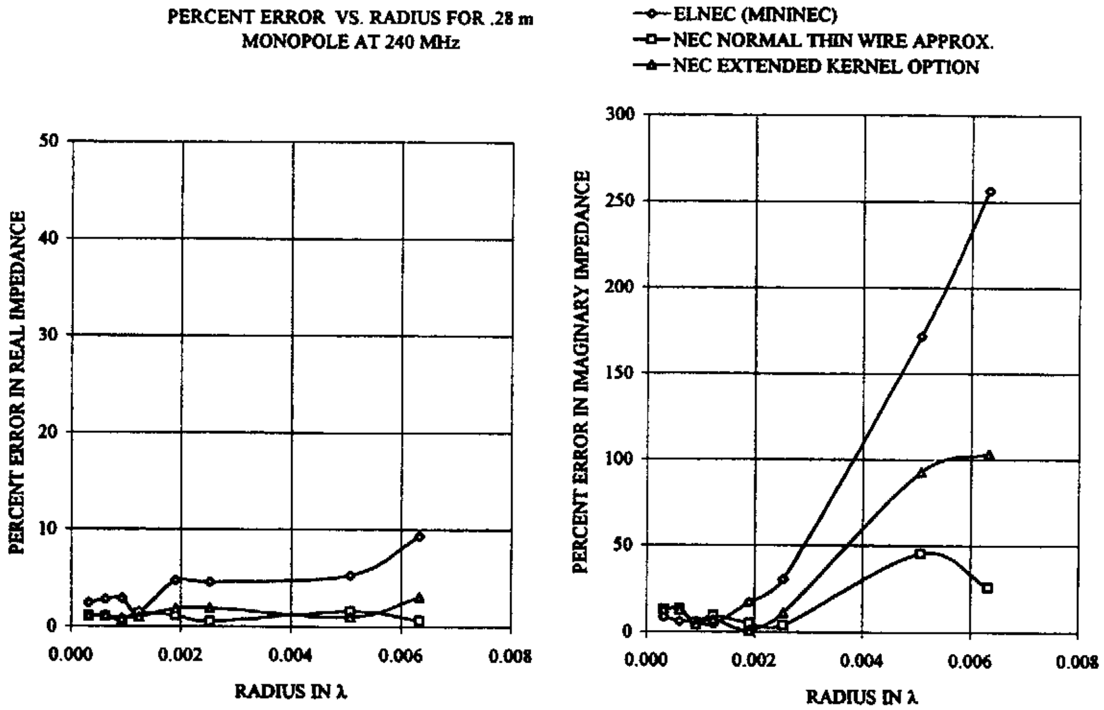

Figure 13. Percent Error vs. Radius for .28 m Monopole at 240 MHz.

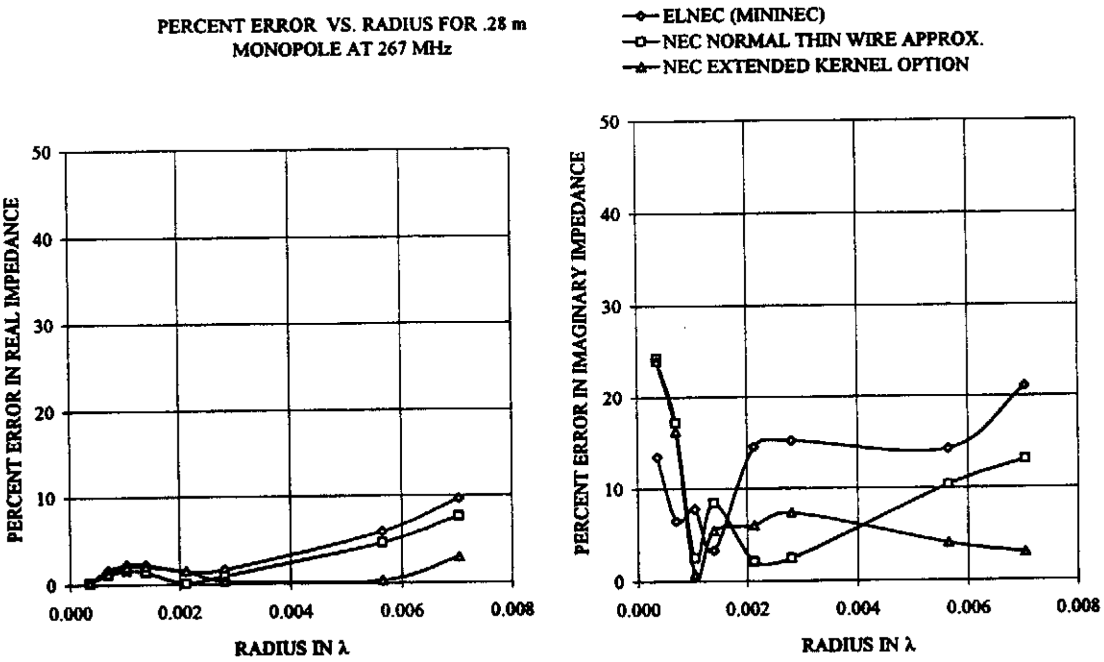

Figure 14. Percent Error vs. Radius for .28 m Monopole at 267 MHz.

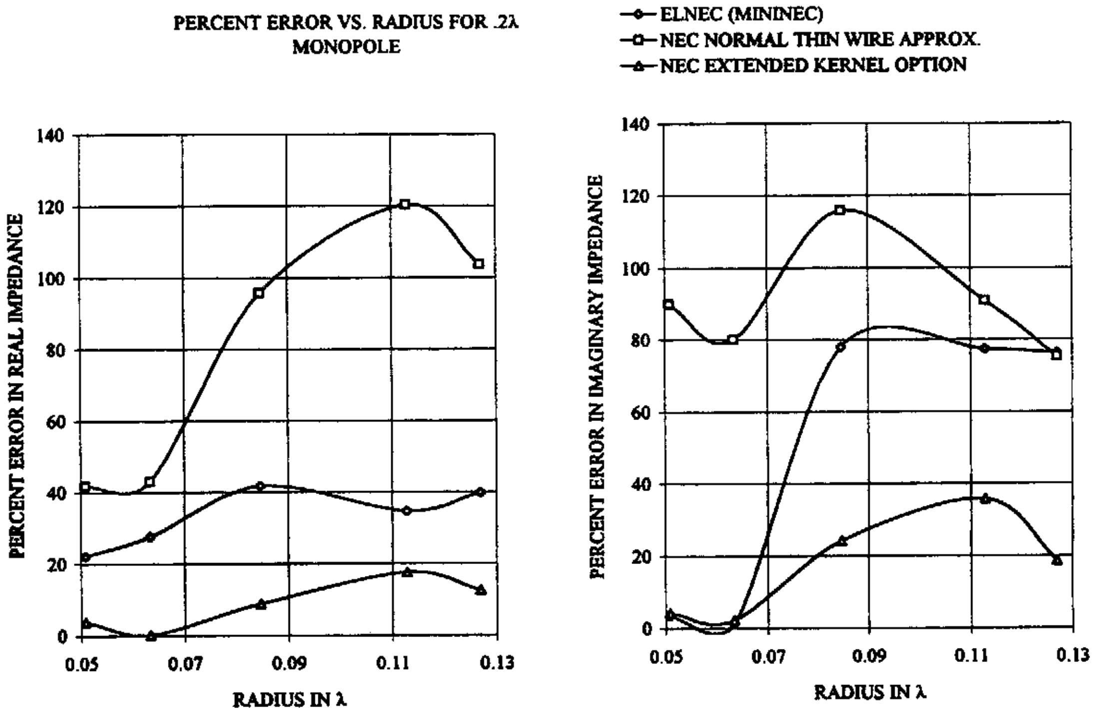

Figure 15. Percent Error vs. Radius for .2λ Monopole.

5 CONCLUSIONS

Both NEC and ELNEC impedance calculations agree reasonably well with measurements for monopoles with radii less than approximately .001 wavelengths. However, as the radius increases, a difference can be seen between NEC and ELNEC. The difference is largest for imaginary impedance calculations. The results in this paper show that the extended kernel option of NEC will predict monopole input impedance measurements more accurately than ELNEC for radii larger than approximately .05 wavelengths. For radii between .001 and .008 wavelengths the normal thin wire option and the extended kernel option of NEC both agree with measurements reasonably well. Therefore if it is desired to calculate input impedance of a wire antenna structure containing elements of the same radius, the extended kernel option of NEC should be chosen over ELNEC or MININEC if the radius exceeds .05 wavelengths.

Since the MININEC formulation does not predict monopole input impedance measurements as well as NEC, the formulation of MININEC needs to be analyzed further. The approximations that MININEC uses in calculating the EFIE could be causing inaccurate calculations for electrically large radii (see [15,16]).

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