# IMPEDANCE OF A HALF-WAVE DIPOLE OVER A FINITE GROUND PLANE

P R Foster* and R A Burberry**

*Microwave and Antenna Systems, UK

** Consultant, UK

## ABSTRACT

A study has been carried out on the impedance of a half-wave dipole above a finite ground plane. The Method of Moment code, NEC-4, has been used and it has been found that for ground planes which are greater than 1.0 by 1.0 wavelengths, the changes from the effect with an infinite plane are negligible. With very small planes, the current distribution across the ground plane and the impedance are substantially different from those with larger ground planes.

## 1. INTRODUCTION

There is a dearth of information in the open literature on the effect of a finite ground plane on the impedance of a nearby halfwave dipole although several authors have considered the effect of finite sheets on radiation patterns. We examine the general problem of impedance as a function of sheet size and dipole position relative to the edges of the sheet. Dipole impedances have been calculated using the Method of Moments Code, NEC-4 [1], for various dipole positions over square sheets of side 0.5, 1.0, 2.0 and 2.5λ and are examined along with theoretical considerations.

## 2. COMPUTATIONS

The dipole was of diameter 0.002 λ (2mm) and was 0.5λ (500mm) long. Spacing from the ground plane was 0.221λ (221 mm). Throughout this paper, all dimensions are quoted in mm and in wavelengths at 300 MHz. The RF performance was examined over the frequency band 270-330 MHz.

Square sheets of size 0.5, 1.0, 2.0 and 2.5λ (500 to 2500 mm) were tested. The dipole position, initially in the centre of the sheet, was altered in steps of 0.25λ (250 mm) in either the x or y directions. The dipole lay along the x axis (Figure 1).

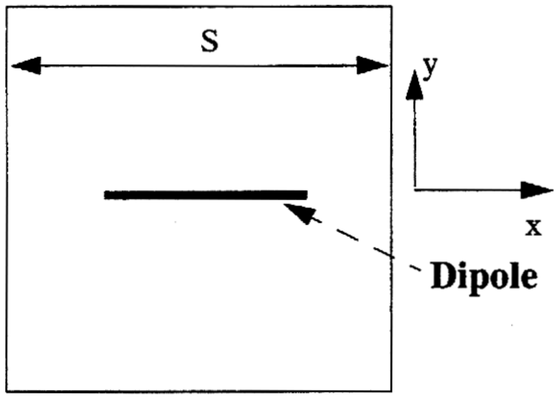


**Figure 1 Geometry of Dipole over a Finite Square Ground Plane. S was varied between 0.5 and 2.5 λ.**

The ground planes were modelled as a square mesh with segments which were 0.05λ long (50 mm) and had a radius of 008 λ (8.0 mm) giving a length to diameter ratio of 3.125 which is greater than the required lower limit of 2.0. This diameter is derived from the equal area rule but a convergence test was also applied (Section 7).

The dipole was modelled as 21 perfectly conducting linear segments in a length of 0.5 wavelengths (500 mm); each segment had a diameter of 0.002 λ (2 mm). The excitation was a voltage source of 1 volt applied to the centre segment. Trials were carried out with 51 segments for the dipole in free space but the results were very similar to those with 21 segments (Section 7).

Computations were carried out with both double and single precision versions of NEC-4 (Section 7).

## 3. FREE SPACE

An initial run was made with the dipole with no ground plane present. Table 1 gives the impedance values, the resonance frequency being just below 285 MHz where the length would have been 0.473λ.

1054-4887 © 2000 ACES

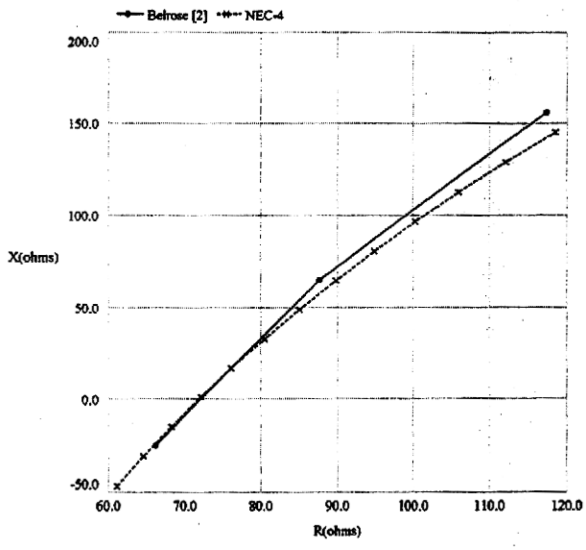


**Figure 2 Reactance against Resistance for a halfwave dipole in free space The NEC-4 values are indicated at 5.0 MHz steps between 270 and 330 MHz (Table 1).**

**Table 1 Impedance of dipole in free space (Dipole 0.002λ diameter, 0.5λ long at 300 MHz)**

| F MHz | NEC-4 | | Belrose [2] | |
|---|---|---|---|---|
| | R (ohms) | X (ohms) | R (ohms) | X (ohms) |
| 270 | 61.1 | -46.9 | 66.1 | -25.0 |
| 275 | 64.5 | -30.9 | | |
| 280 | 68.2 | -14.9 | | |
| 285 | 72.1 | 1.02 | | |
| 290 | 76.1 | 16.9 | | |
| 295 | 80.5 | 32.8 | | |
| 300 | 85.0 | 48.7 | 87.6 | 65.0 |
| 305 | 89.8 | 64.6 | | |
| 310 | 94.9 | 80.5 | | |
| 315 | 100.3 | 96.5 | | |
| 320 | 106.0 | 112.6 | | |
| 325 | 112.1 | 128.7 | | |
| 330 | 118.5 | 145.0 | 117.4 | 155.8 |

Figure 2 compares the computed impedances and those calculated from Equations 15.16 and 15.17 of Belrose, [2] which are for a monopole. These values were doubled to obtain the numbers for a dipole shown in Figure 2 and Table 1. The agreement is good. It implies that the antenna is about 3% longer electrically than its dimensions would suggest from Belrose. In their Figure 13.31, showing calculated values of resistance at resonance as a function of wavelength/diameter, Schelkunoff and Friis, [3], give a value of 64 ohms for a dipole of the dimensions used here whereas NEC-4 and Belrose both give 72 ohms.

## 4. GROUND PLANE

Figure 3 to Figure 5 show the impedance for the central and the two extreme positions. The values are indicated at 5.0 MHz steps between 270 and 330 MHz.

For sheets of side 1.0λ and larger, there is no significant change in impedance with sheet size when the dipole is centrally placed or when it is over a parallel edge. When the dipole is moved longitudinally so that its centre is on the edge, there is more variation with sheet size as Figure 5 demonstrates. Results for the λ/2 square sheet also show significantly lower resistance values. The impedance values for an infinite ground plane have been included in Figure 3 and show that, for plates of side greater than 1.0 λ, the results have converged. For the larger sheets, there does appear to be a very slight cyclical variation with dipole position. This is shown in Table 2 for 300 MHz on a 2.5λ square sheet.

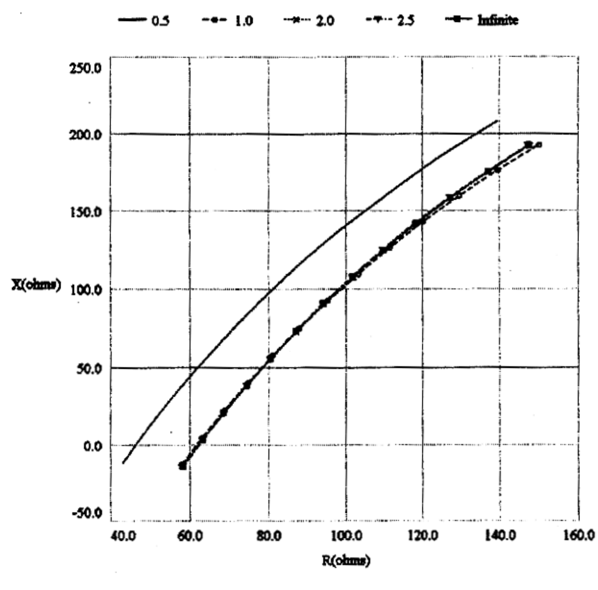


**Figure 3 Impedance of dipole (Central position) between 270 and 330 MHz**

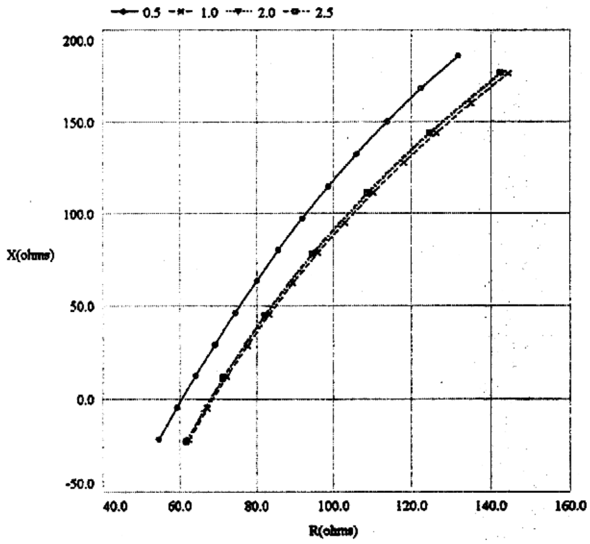


**Figure 4 Impedance of dipole (over parallel edge) between 270 and 330 MHz**

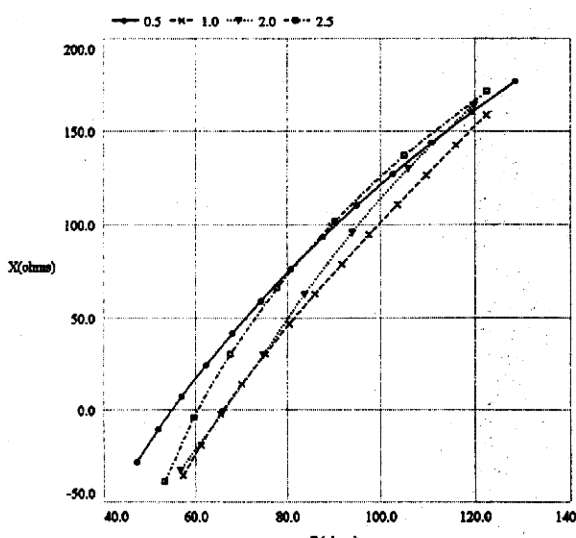


**Figure 5 Impedance of dipole (over perpendicular edge) between 270 and 330 MHz.**

**Table 2 Impedance of dipole above ground plane of side 2.5λ as a function of position off-centre. (Frequency 300 MHz)**

| y/λ | x/λ = 0 | x/λ | y/λ = 0 |
|---|---|---|---|
| 0 | 93.9 + j 90.2 | 0 | 93.9 + j 90.2 |
| 0.25 | 94.0 + j 90.2 | 0.25 | 94.1 + j 90.3 |
| 0.5 | 93.9 + j 90.1 | 0.5 | 93.8 + j 90.0 |
| 0.75 | 94.1 + j 90.1 | 0.75 | 94.7 + j 90.5 |
| 1.0 | 92.6 + j 90.6 | 1.0 | 87.7 + j 91.6 |
| 1.25 | 94.5 + j 77.8 | 1.25 | 77.8 + j 66.0 |

## 5. CURRENT FLOW

As noted above, the values of the impedance for the smallest ground plane (0.5 by 0.5 λ) were quite different from those of the larger ground plane.

The currents on the ground planes at intervals of 0.25 wavelengths have been plotted for a dipole centrally placed. The abscissa (current magnitude) has been multiplied by $10^4$ for convenience.

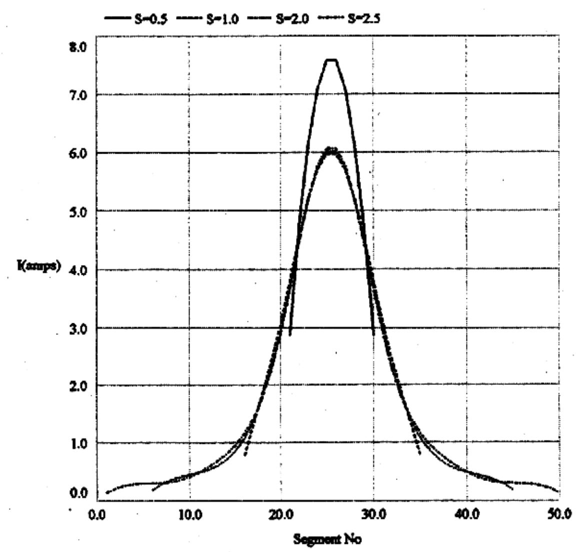


**Figure 6 Current Magnitude (x $10^4$) on a Ground Plane parallel to the dipole and immediately below the dipole**

Figure 6 shows the currents on the ground plane immediately below the dipole for several ground plane sizes while Figure 7 and Figure 8 show the currents 0.25 and

0.5 wavelength away from the centreline underneath the dipole. The most notable feature is that the current distribution is remarkably alike for ground planes with sides 1.0 to 2.5 wavelengths while the ground plane of side 0.5 wavelength is very different.

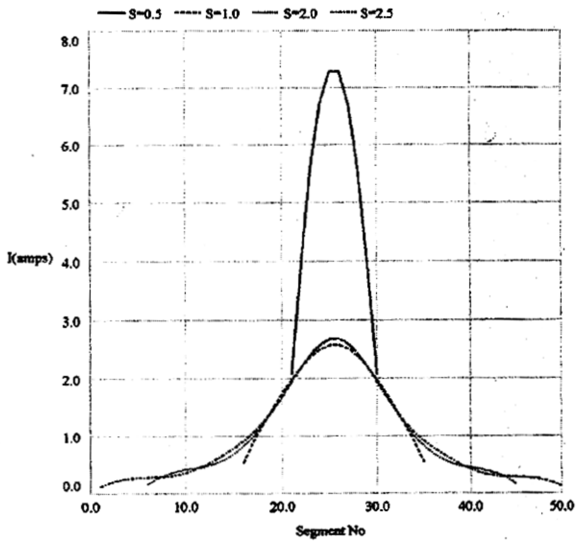


**Figure 7 Current Magnitude (x $10^4$) on a Ground Plane parallel to the dipole and offset by 0.25 wavelength from the dipole**

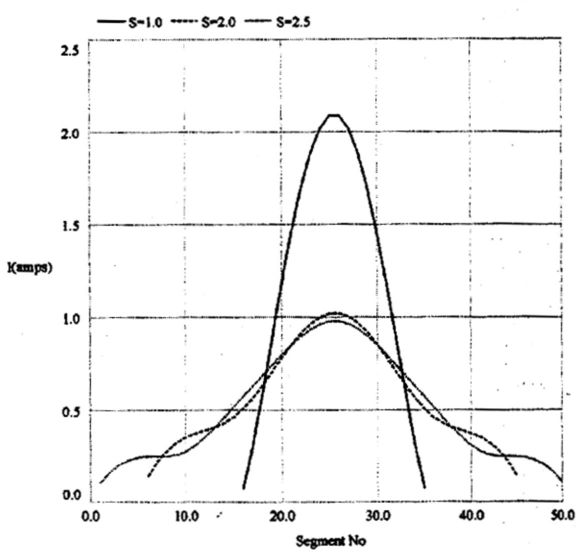


**Figure 8 Current Magnitude (x $10^4$) on a Ground Plane parallel to the dipole and offset by 0.5 wavelengths from the dipole**

## 6. CHECKS

It was possible to provide some corroboration for the predictions by computing the mutual impedance provided when a half-wave dipole is over an infinite ground plane. The mutual impedance is then the impedance of the dipole alone minus the mutual impedance of the dipole over an infinite ground plane. These are compared with results from Smith [5] and STC Data [4] in Table 3. These results are in better agreement with the STC data.

Since the image of the dipole in the ground plane is negative, the computed figures are in opposite senses to those from two parallel dipoles at the same spacing as the dipole and its image. The computed figures have been reversed in sign for comparison with other sets of data.

**Table 3 Mutual Impedance of a Dipole above an Infinite Ground Plane**

| ΔF MHz | NEC-4 | | STC data | | R A Smith | |
|---|---|---|---|---|---|---|
| | R | jX | R | jX | R | jX |
| -5.0 | 1.1 | -31.4 | 1.1 | -34.8 | 4.0 | -36.9 |
| -1.0 | -1.5 | -33.6 | -1.5 | -36.4 | 1.5 | -36.3 |
| +2.0 | -3.7 | -35.2 | -3.2 | -35.5 | -0.3 | -36.0 |
| +4.0 | -5.3 | -36.2 | -4.2 | -35.1 | -1.3 | -35.7 |
| +6.0 | -7.0 | -37.2 | -5.2 | -34.5 | -2.5 | -35.3 |
| +7.0 | -7.9 | -37.8 | -6.0 | -34.1 | -3.1 | -35.1 |
| RMS Error in NEC | | | 1.2 | 2.6 | 3.8 | 3.0 |

## 7. CONVERGENCE TESTS

Several convergence tests were carried out on the input data.

1) Single and double precision versions of NEC-4 were run on all the examples for a ground plane with a side of 0.5 λ. The changes in all values of impedance were less than 0.001%.

2) The radius of segments in the ground plane was varied between 20 and 2.5 mm with the segment length held constant at 50 mm (Figure 9). The value chosen, 8.0 mm, was based on the equal area rule and computed results agreed with other results to within 1 or 2 ohms.

3) The number of segments in the dipole was varied from 21 to 51. Differences of less than 1.0 degree

in phase and 1% in impedance magnitude were observed.

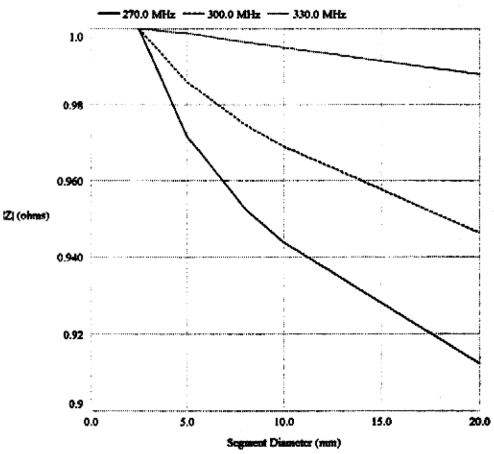


**Figure 9 Impedance for three frequencies for dipole in centre of 0.5λ ground plane with the segment radii of the ground plane varied. The impedance magnitude is shown normalised to the value at a segment radius of 2.5 mm**

## 8. CONCLUSIONS

1) The impedance of an isolated 0.5λ dipole obtained by NEC is closely modelled by the Belrose [2] formula for a dipole of the same dimensions. The difference of 3% in frequency may arise from small errors in Belrose's determination of electrical length which was empirical. Alternatively it may represent a genuine difference between the two models. It has been noted (Section 7) that small changes in the NEC-4 model resulted in changes in the impedance of up to 1% in magnitude.

2) When mounted above the centre of a finite ground plane, the dipole impedance does not alter significantly for sheets of 1λ side or larger. The resistance of a dipole above a sheet of side 0.5λ is significantly lower. The plots of current flow in Figure 6 to Figure 8 support the impedance results.

3) When the dipole is over the parallel edge of the sheet, the general picture is similar to that of the central position.

4) When the dipole centre is over the perpendicular edge, there is more variation with sheet size.

5) The impedance on larger sheets appears to be more sensitive to movement along the dipole axis than to movement in the perpendicular direction.

## 9. REFERENCES

1 BURKE, G. J., 'Numerical Electromagnetics Code -NEC-4', UCRL-MA-109338, Jan. 1992

2 BELROSE, J. S., 'VLF, LF & MF Antennas', IEE Handbook of Antenna Design, Vol. 2, 1983, p 561-563

3 SCHELKUNOFF, S. A. and FRIIS, H. T., 'Antennas, Theory and Practice', John Wiley & Sons Inc., New York, 1952

4 McPHERSON, W. L., 'Reference Data for Radio Engineers', STC, London, 1948

5 SMITH, R. A., 'Aerials for Metre and Decimetre Wavelengths', Cambridge University Press, 1949, p 10