A Thin Dipole Antenna Demonstration of the Antenna Modeling Capabilities of the Finite Difference Time Domain Technique

by

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August 1988

Revised April 1989

Abstract

The Finite Difference Time Domain (FDTD) technique has been successfully applied for modeling the electromagnetic scattering from and coupling into a variety of objects. In this communication we use FDTD to compute the input impedance of a thin dipole antenna. The short circuit current and open circuit voltage at the antenna terminals are computed over a wide bandwidth using pulsed plane wave excitation, then Fourier transformed to the frequency domain and divided to obtain the complex input impedance over a wide bandwidth using one FDTD computation. These results are compared with thin wire antenna results using the Method of Moments and good agreement is obtained except at very low frequencies, where the FDTD results obtained using this approach lose accuracy due to the imperfect outer absorbing boundary.

Introduction

While the Finite Difference Time Domain (FDTD) method has been applied to a variety of electromagnetic scattering and coupling problems, FDTD has not been applied to computing antenna performance parameters. In particular, application of FDTD to computing antenna impedance has not previously appeared in the literature. In this communication the complex input impedance of a thin (compared to a wavelength) center-fed dipole antenna is computed over a broad frequency band using FDTD with pulsed plane wave excitation. As the input impedance of a thin antenna is very sensitive to the antenna geometry, this is a severe test of the applicability of FDTD to antenna parameter calculations.

In order to validate the FDTD results, comparison is made with results obtained using a recognized Moment Method thin wire computer code (ESP version III) [1]. Using the usual thin wire approximation that the current distribution is circumferentially uniform, results using the Moment Method code are valid from very low frequencies up to frequencies where the wire radius is approximately 0.01 wavelength [1]. This determines the upper frequency limit of Moment Method application for scattering and impedance calculation if the thin wire approximation is used.

For the FDTD calculations the wire is modeled as being one cell in thickness. With the often-applied limitation that FDTD cells should be less than 0.1 wavelength in size, the upper frequency limit of the FDTD calculations is potentially an order of magnitude higher than the Moment Method using the thin wire approximation. However, FDTD antenna impedance calculations, especially the input resistance, apparently are not accurate at extremely low frequencies, with the low frequency limit dependent on the efficiency of the absorbing boundary and on the size of the problem space.

Another difference between these FDTD calculations and the Moment Method approach to thin wire impedance calculations in the modeling of the antenna terminals. The Moment Method used here models the terminals as an infinitesimally thin gap in the wire. Our FDTD results assume the dipole terminal gap to be one cell in length. The Moment Method thin gap is widely accepted while the terminal gap of an actual dipole antenna will be finite in length. Since the FDTD terminal gap is still only a small fraction of the dipole length (2% for our examples) it does resemble a real antenna but does not exactly duplicate the Moment Method feed model.

Despite the above differences, the comparisons contained in this communication indicate good agreement between the two methods over the frequency range where both are valid.

Approach

Consider a center fed dipole illuminated by an incident plane wave and the corresponding Thevenin equivalent circuit as shown in Figure 1. Z_{in} is the desired antenna impedance, and V_{oc} is the open circuit antenna voltage. Our approach to determining Z_{in} using FDTD is to perform two calculations with the same incident plane wave, one with the antenna terminal gap shorted, the second with the terminal gap open circuited. The current flowing through the shorted terminals is the short circuit current I_{sc}, while the voltage across the open circuited gap is Voc.

Referring to the Thevenin equivalent of Figure 1, we then transform our time domain results to the frequency domain and compute

$$Z_{in} = V_{oc}/I_{sc}$$

by a complex division at each frequency.

FDTD Model of the Thin Dipole

The FDTD code used for the calculations reported here is an extension of that described in [2]. It is based on the Yee [3] algorithm, but is a scattered field formulation. The code is three-dimensional and uses rectangular parallelepiped cells. In order to model a long, thin wire the cells were stretched in the direction along the wire, with each cell being 1 cm x 0.5 cm x 0.5 cm. It should be possible to model longer, thinner wire antennas even more efficiently using thin wire subcell models [4,5], but for the antenna geometry considered here this was not necessary.

Referring to Figure 2, the dipole model was 49 cm long, composed of 49

FDTD cells. In each cell the total electric field component along the wire was set equal to zero. For the short circuit computation the total current flowing in the center cell was computed by finding the line integral of the total magnetic field encircling that cell. For the open circuit computation the center cell of the dipole was specified as free space, and the total voltage across this cell due to the axial electric field component was computed. Both computations utilized a Gaussian-pulsed incident plane wave, with a peak amplitude of 1000 V/m, that reached 1/e amplitude in 16 time steps. The time steps were 11.11 picoseconds, and the resulting upper frequency limit is about 3 GHz at 10 cells per wavelength.

Results

Using the above approach the FDTD technique yielded the time domain results shown in Figures 3 and 4 for V_{oc} and I_{sc} in response to the Gaussian pulse illuminating both geometries broadside. These time domain responses were then Fourier transformed, with the frequency domain responses for V_{oc} and I_{sc} shown in Figures 5 and 6. The ratio of the frequency domain complex V_{oc} to the frequency domain complex I_{sc} produces Z_{in}.

The time domain results exhibit the typical damped ringing behavior of a dipole with the fundamental resonance dominating. The frequency domain results show the multiple resonant peaks at the expected frequencies on up to the 6th and 9th resonances respectively for V_{oc} and I_{sc}. There is a marked rolloff in the responses reflecting both the rolloff in the excitation waveform, down by 1/e at a frequency of 1.8 GHz, and the natural rolloff in the antenna's impulse response. When Z_{in} is formed the effect of the excitation waveform divides out, leaving the same result had the ratio been formed from impulse responses, except that the resulting Z_{in} is valid only to the upper frequency limit of V_{oc} and I_{sc} set by the dynamic range of the computed responses.

The input impedance Z_{in} is displayed as resistance and reactance in Figures 7 and 8. Small phase errors at low frequencies are enough to cross couple reactance (expected to be nonzero at zero frequency) into resistance (expected to be zero at zero frequency). This error sets a lower limit to the range of validity of the FDTD calculation. The results of Figures 3 to 8 were computed using a 16 x 64 x 16 cell problem space. Enlarging the problem space to 32 x 64 x 32 cells lowered this low frequency accuracy limit. We conclude that the outer radiating boundary condition is the source of this problem. With the outer boundary further removed it is more successful at "releasing" the radiated energy. The lower frequency limit can be reduced by using a larger space or, presumably, a better outer radiating boundary condition [6], since these computations used a first order absorbing boundary.

Comparison with Moment Method Results

By applying the Method of Moments to a thin wire geometry of the same length and approximate thickness at a number of frequencies we could compare the FDTD technique to MoM over the region where the MoM thin wire approximation holds. In order to avoid any appearance of "adjusting" the MoM wire thickness to fit the FDTD results, the cross-sectional area of the circular MoM dipole was set equal to that of the square FDTD dipole even though the capacitance of the different cross section shapes is quite different. Since the FDTD cells are 0.5 x 0.5 cm in cross-section, the MoM wire radius was set to 0.2821 cm. The comparison shown in Figures 9 and 10 covers the first peak in Z_{in}. Agreement between MoM and FDTD is reasonably good, considering the differences in fundamental approach between the two methods.

While we don't have direct validation of the capability of the code to predict thin wire antenna impedance at higher frequencies, we note that FDTD results presented here have the same signature in the short circuit current response as seen in thin wire measurements and NEC code predictions made by Breakall [7]. For this reason we are reasonably confident FDTD results are valid at higher frequencies, up to the limits set by dynamic range.

Conclusions

The capability of FDTD to compute broadband antenna input impedance has been demonstrated by computing the impedance of a wire dipole and comparing the results with a thin-wire Moment Method code. Despite differences in modeling the feed gap and the wire cross-section, reasonable agreement was obtained between the two methods. The FDTD results using the approach outlined here were valid over a broad band, but at frequencies below the first dipole resonance the input resistance was not accurate. This was due to the inability of the absorbing boundary condition to adequately absorb the outgoing radiation at the lower frequencies. Nevertheless, these results illustrate for the first time the capability of the FDTD method to compute the input impedance of a resonant antenna with reasonable accuracy. Extensions to dielectric and/or magnetically loaded antennas should be straightforward.

References

[1] E. H. Newman and R. L. Dilsavor, "A user's manual for the electromagnetic surface path code: ESP version III," Ohio State University ElectroScience Laboratory Technical Report No. 716148-19, May 1987.

[2] R. Holland, L. Simpson and K. Kunz, "Finite-difference analysis of EMP coupling to lossy dielectric structures," IEEE Trans. Electromagn. Compat., vol. EMC-22, pp. 203-209, August 1980.

[3] K. S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," IEEE Trans. Antennas Propagat., vol. AP-14, May 1966.

[4] R. Holland and L. Simpson, "Finite-difference analysis of EMP coupling to thin struts and wires," IEEE Trans. Electromagn. Compat., vol. EMC-23, May 1981.

[5] K. Umashankar, A. Taflove, and B. Beker, "Calculation and experimental validation of induced currents on coupled wires in an arbitrary shaped cavity," IEEE Trans. Antennas and Propagat., vol. AP-35, pp. 1248-1257, November 1987.

[6] T. G. Moore, J. G. Blaschak, A. Taflove, and G. A. Kriegsman, "Theory and Application of Radiation Boundary Operators," IEEE Trans. Antennas and Propagat., vol. AP-36, pp. 1797-1813, December 1988.

[7] J. K. Breakall, and H. G. Hudson, "The equivalent current measurement technique and its comparison with current probe methods," IEEE Trans. Antennas and Propagat., vol. AP-34, no. 1, pp. 119-121, January 1986.

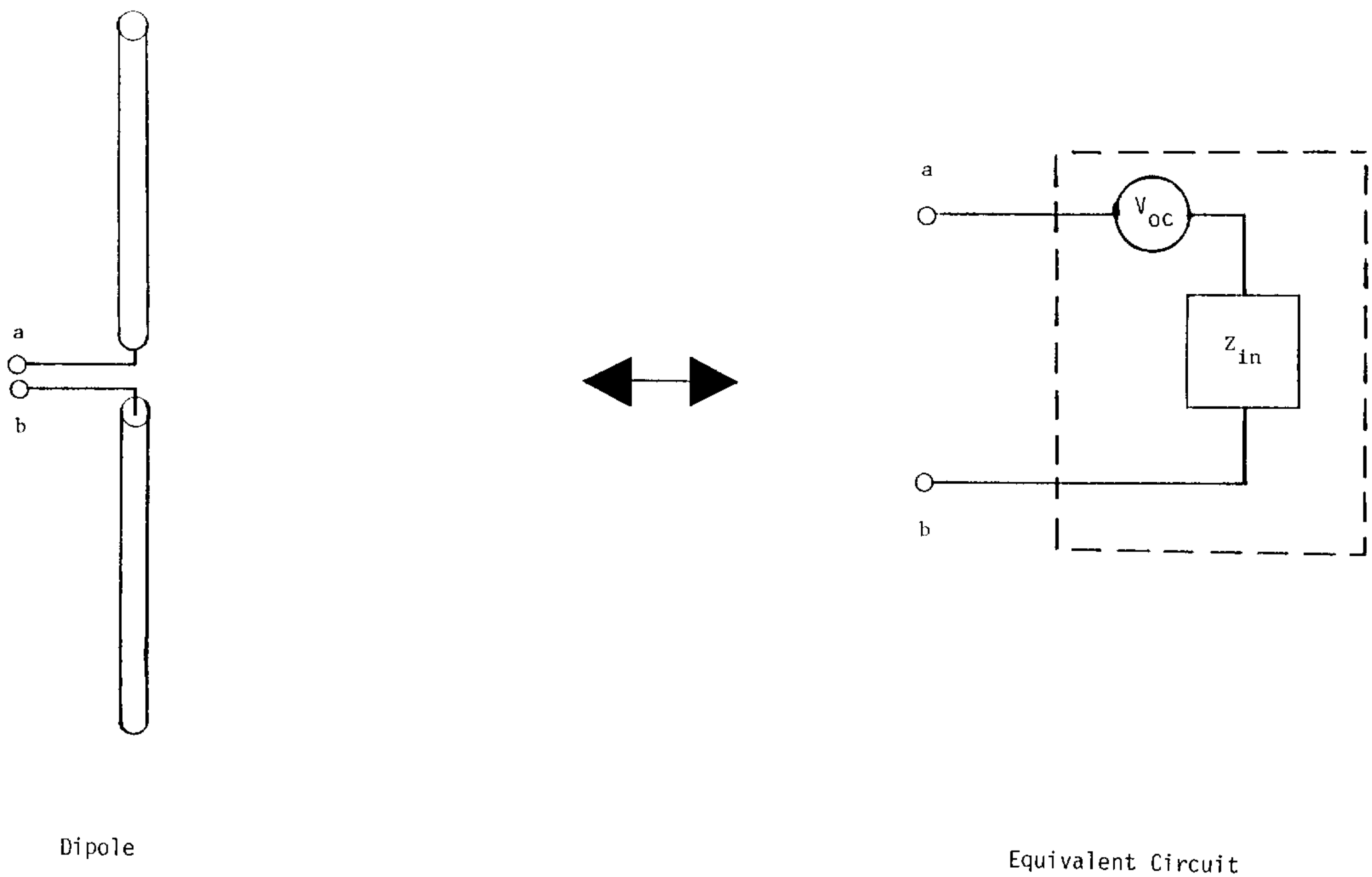

Figure 1. Thevenin equivalent circuit model of a thin dipole antenna.

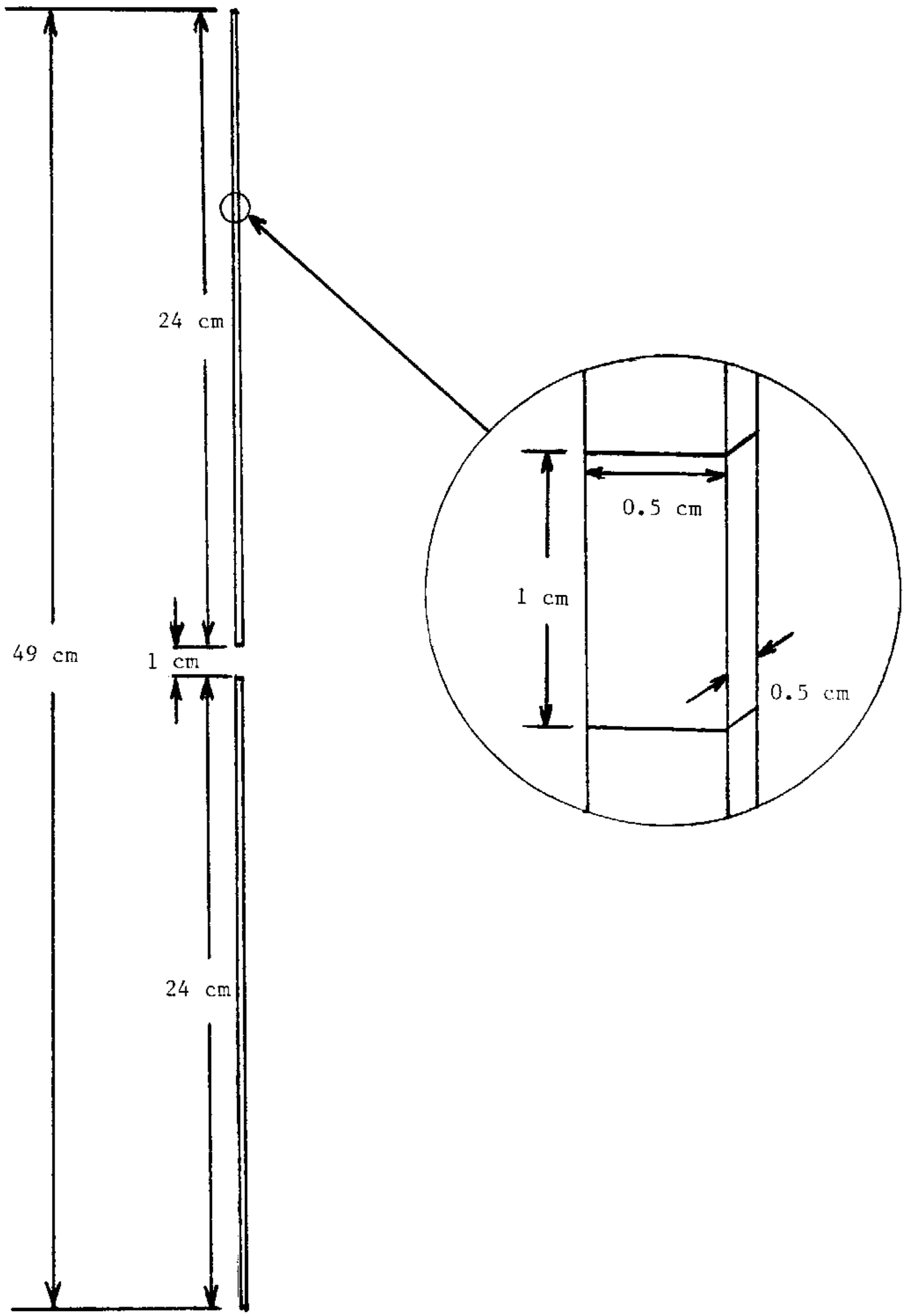

Figure 2. Geometry of a 49 cm long thin dipole antenna modeled with 49 collinear 1.0 cm x 0.5 cm x 0.5 cm conducting cells. The center cell is removed for open circuit calculations.

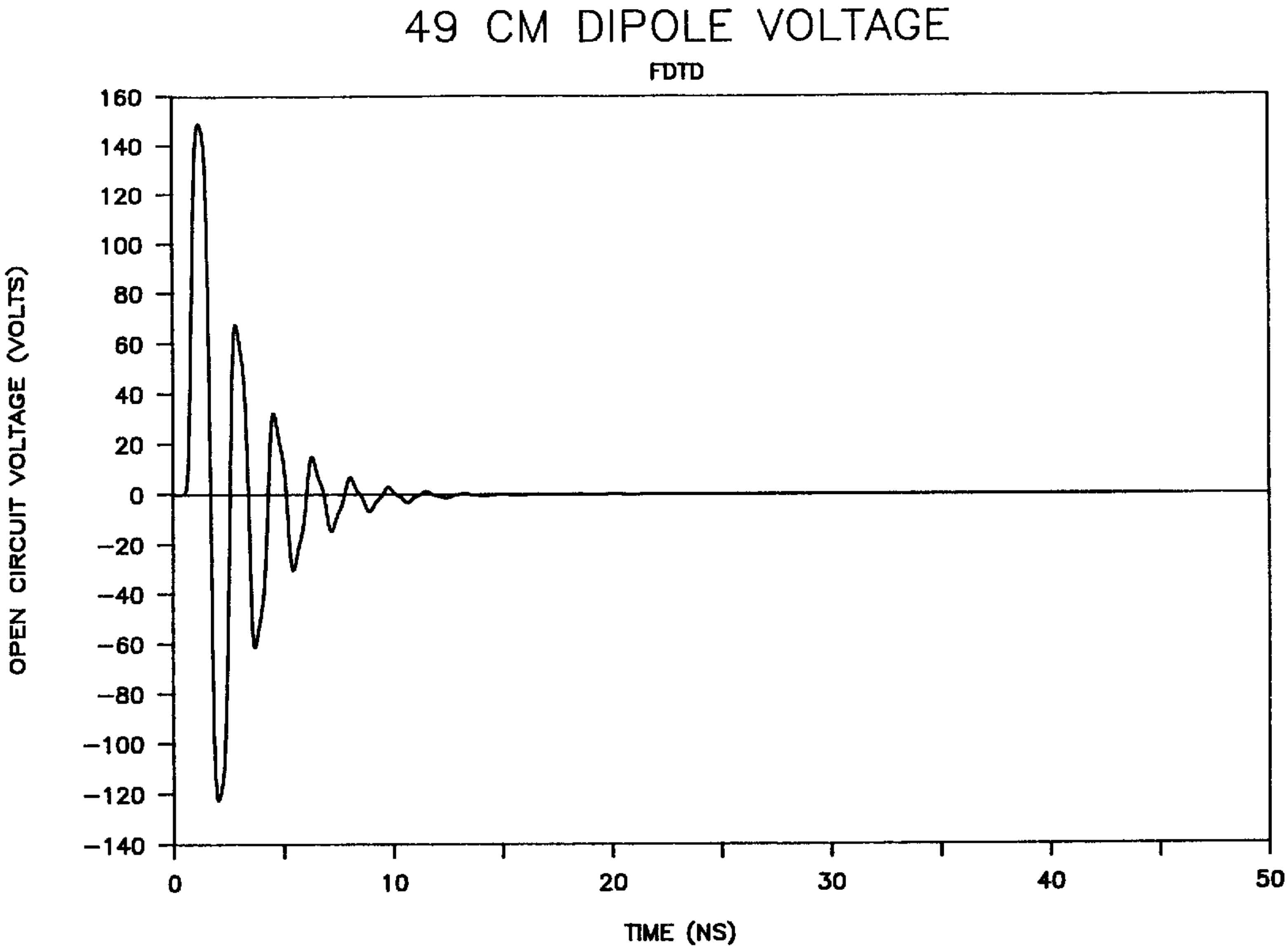

Figure 3. Time domain FDTD waveform of open-circuit voltage across the removed center cell.

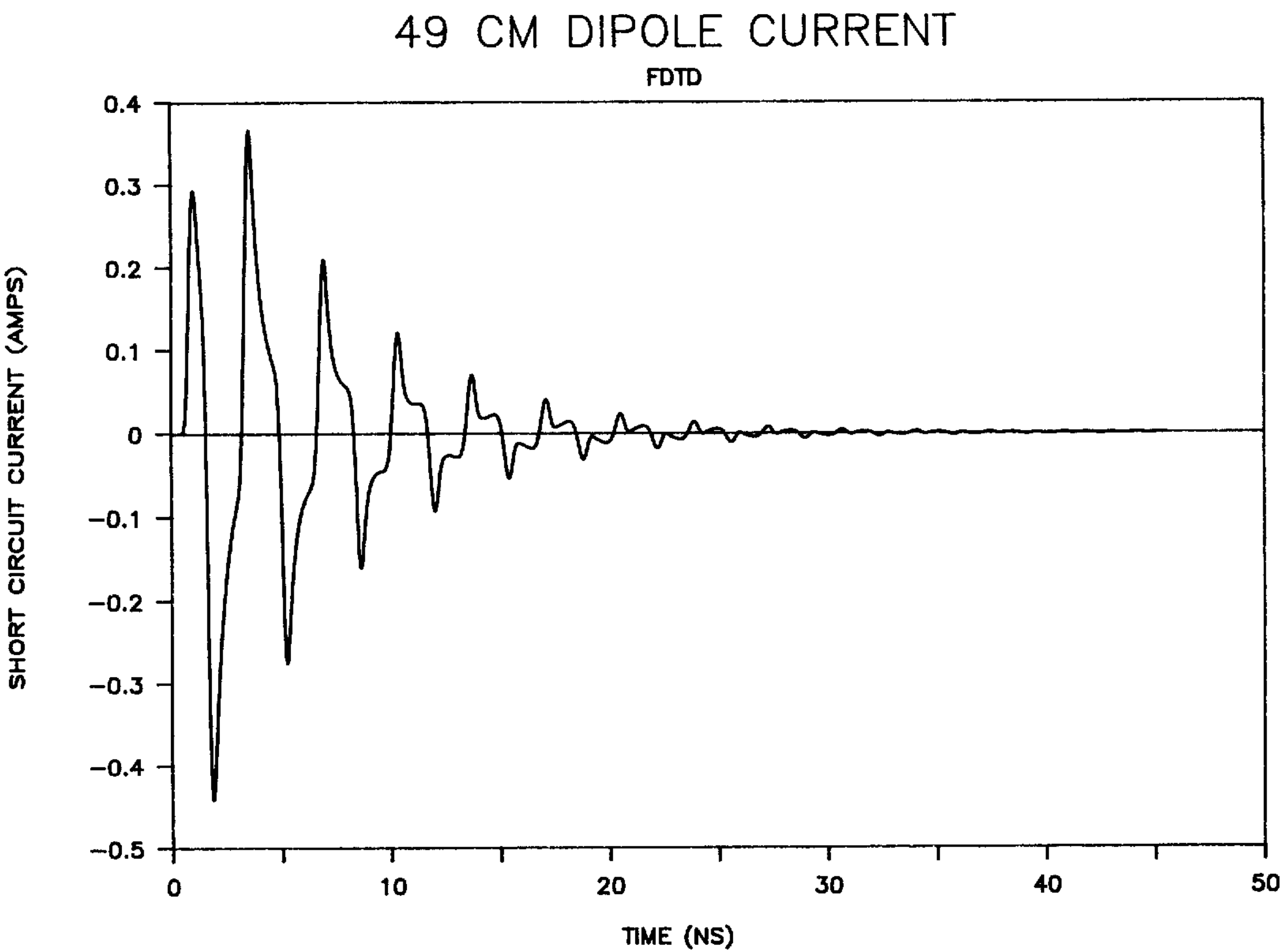

Figure 4. Time domain FDTD waveform of short-circuit current through the conducting center cell.

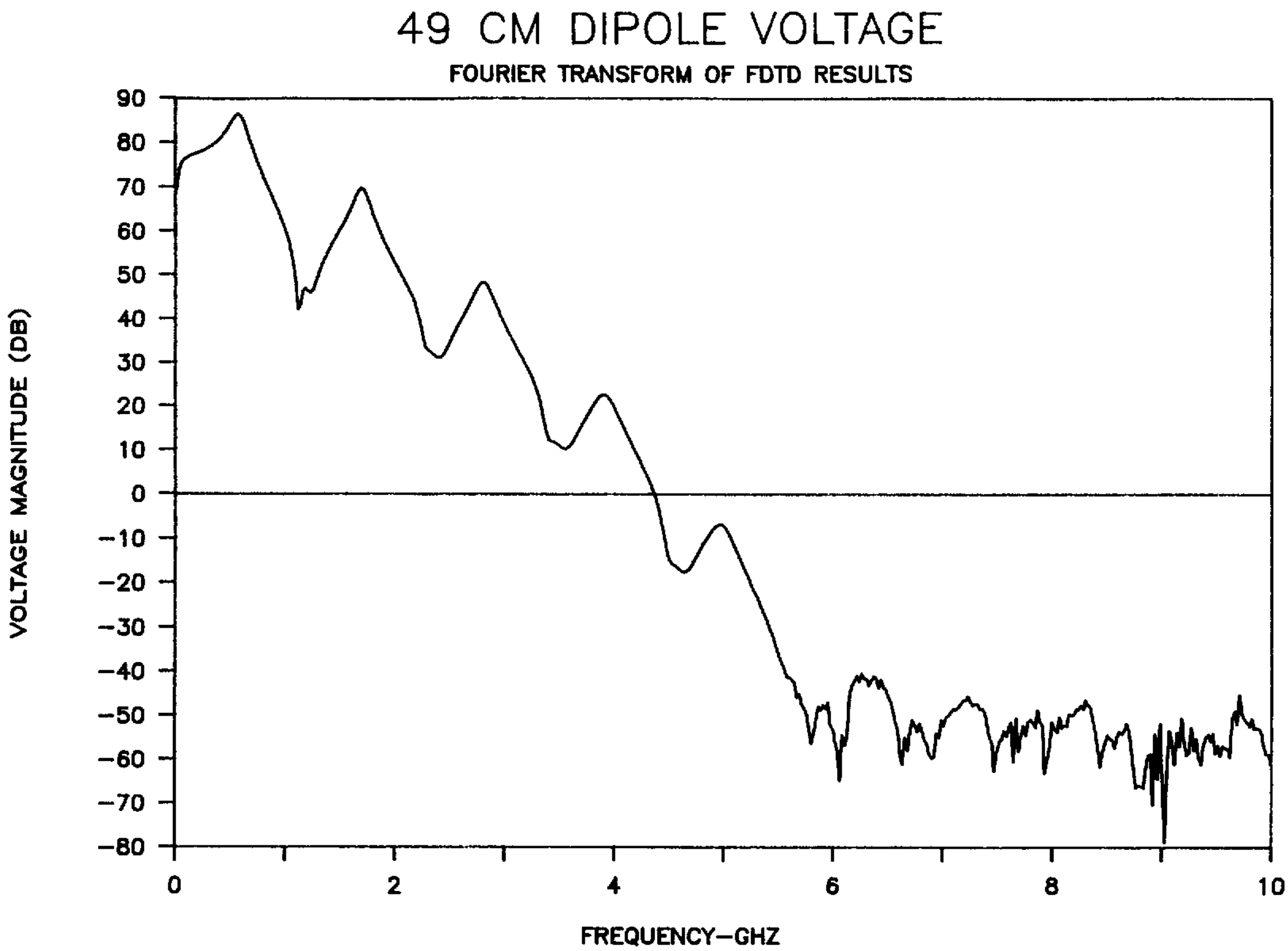

Figure 5. Fast Fourier Transform of the FDTD open circuit voltage of Figure 3.

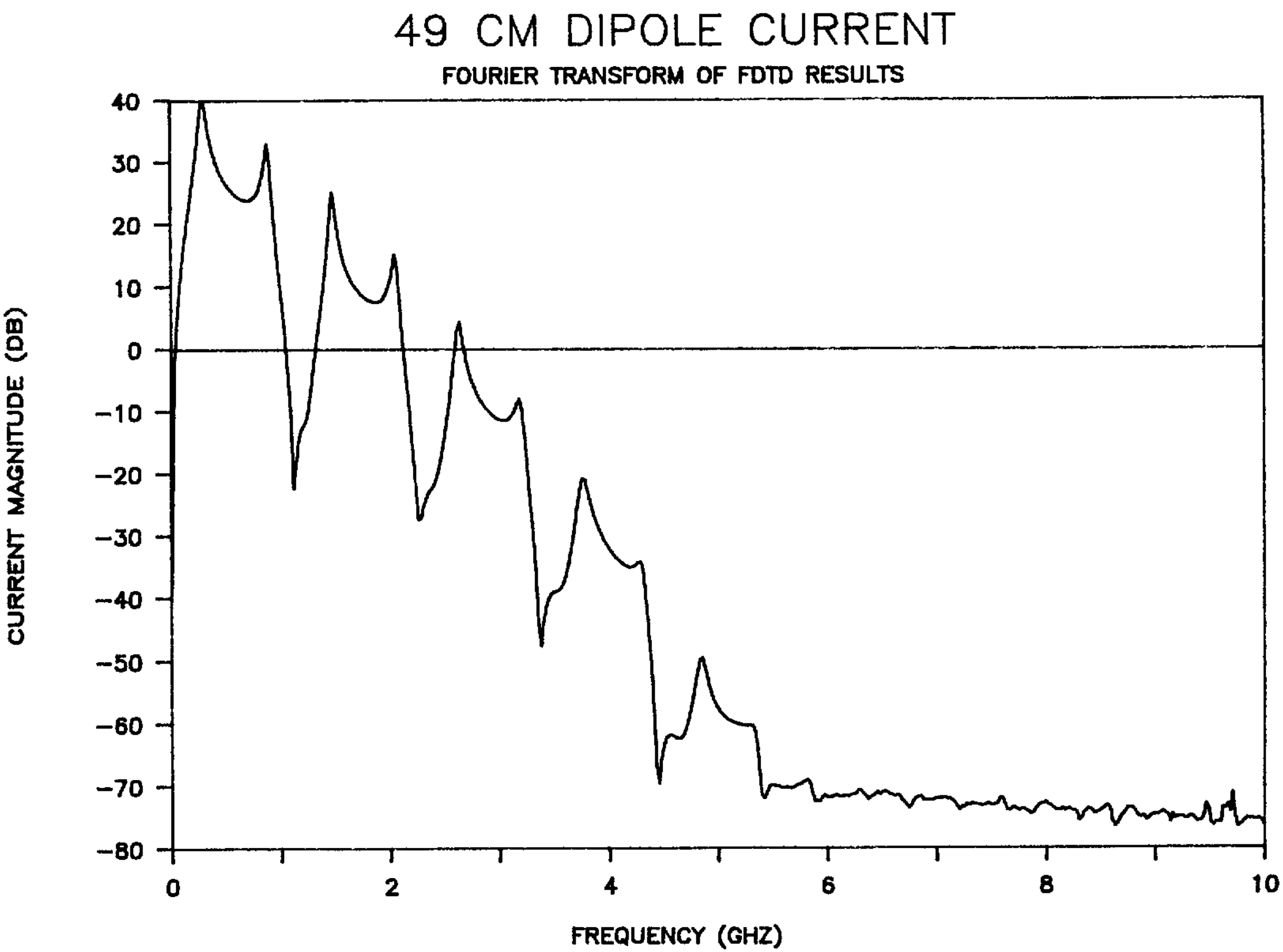

Figure 6. Fast Fourier Transform of the FDTD short circuit current of Figure 4.

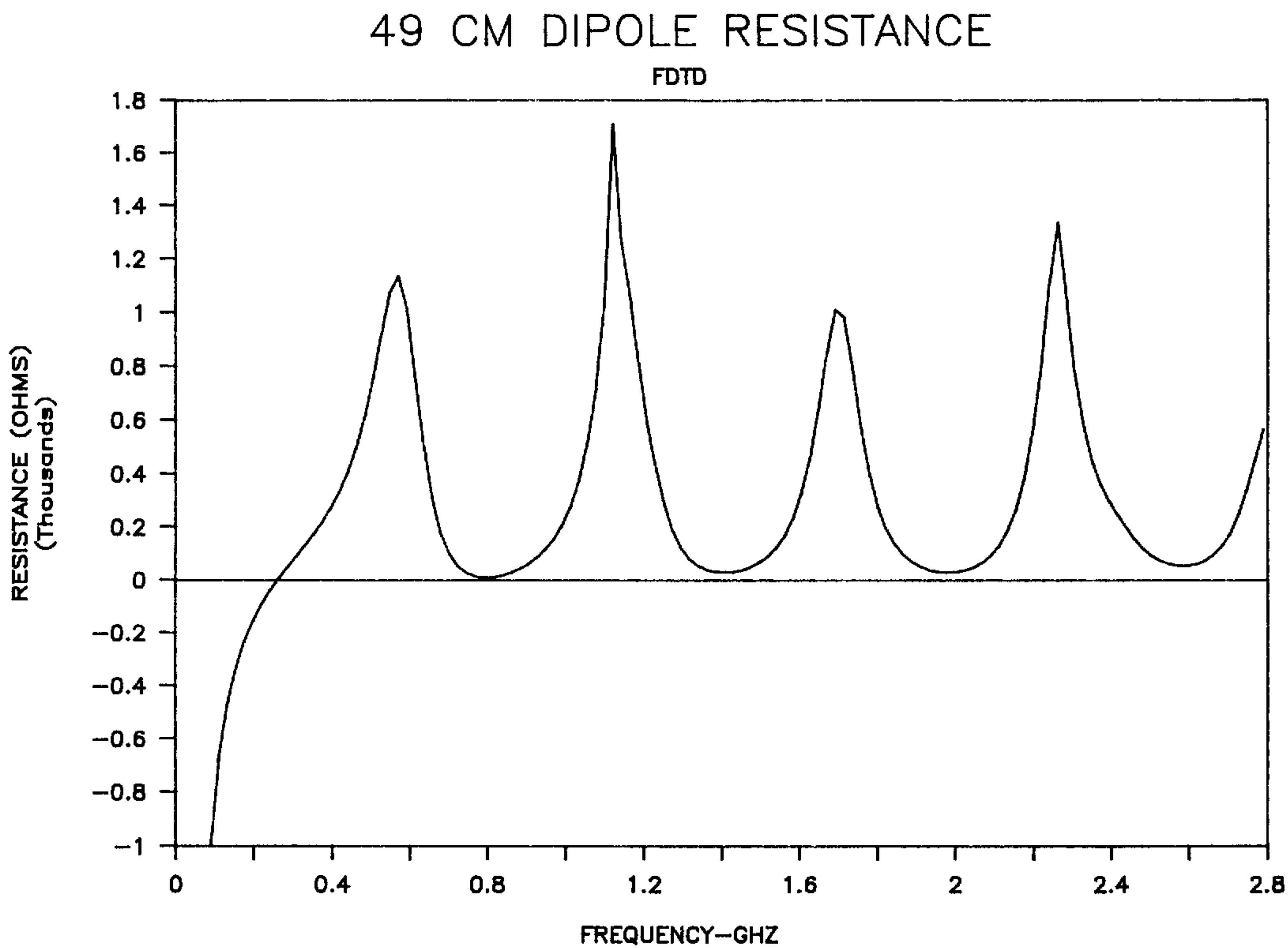

Figure 7. Resistance (real part of Z_{in}) of thin dipole antenna computed using FDTD.

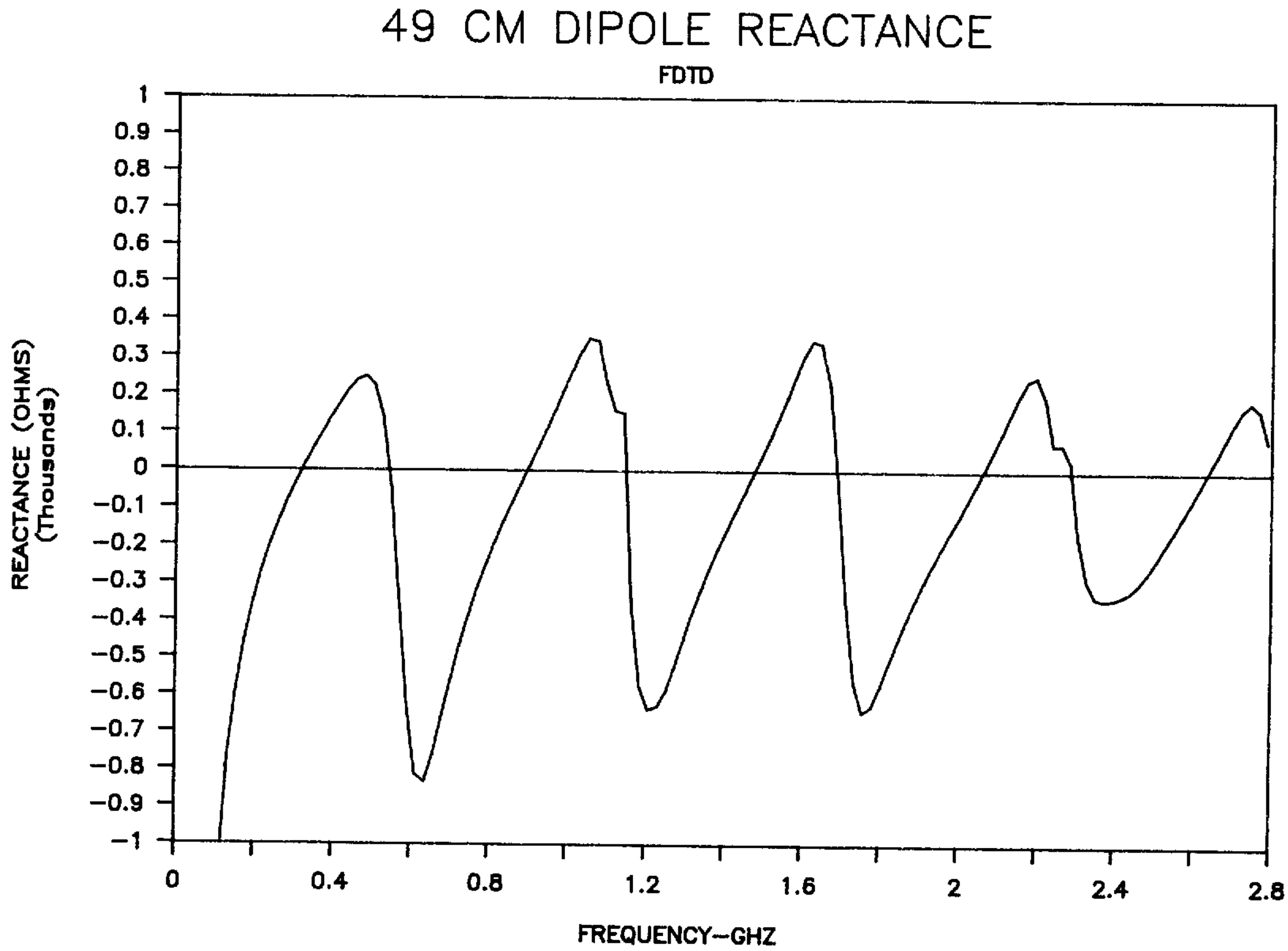

Figure 8. Reactance (imaginary part of Z_{in}) of thin dipole antenna computed using FDTD.

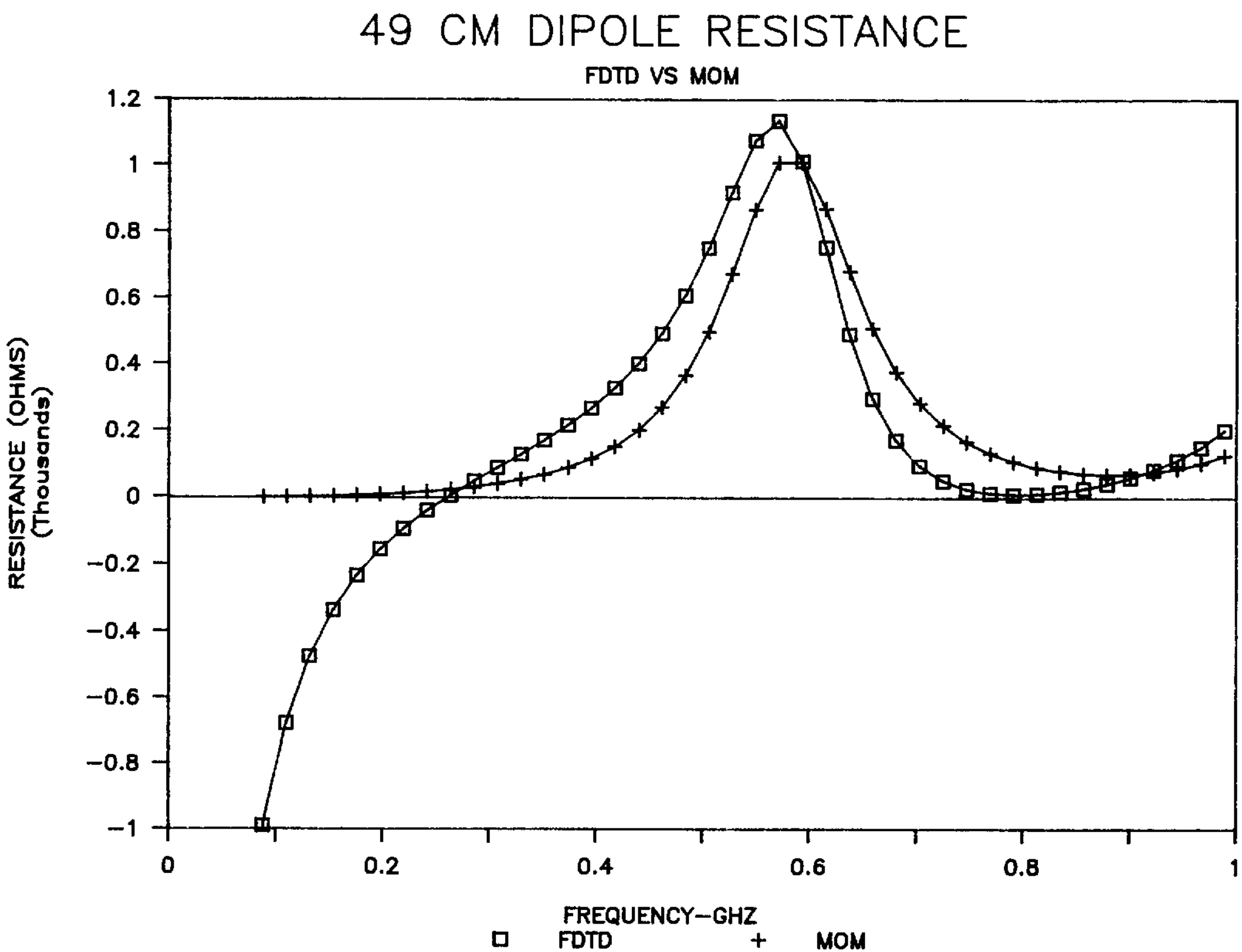

Figure 9. Resistance predicted by the Method of Moments and by FDTD. The Method of Moments assumes a circular cross section and a thin gap, while the FDTD results are for a square cross section and a 1 cm gap.

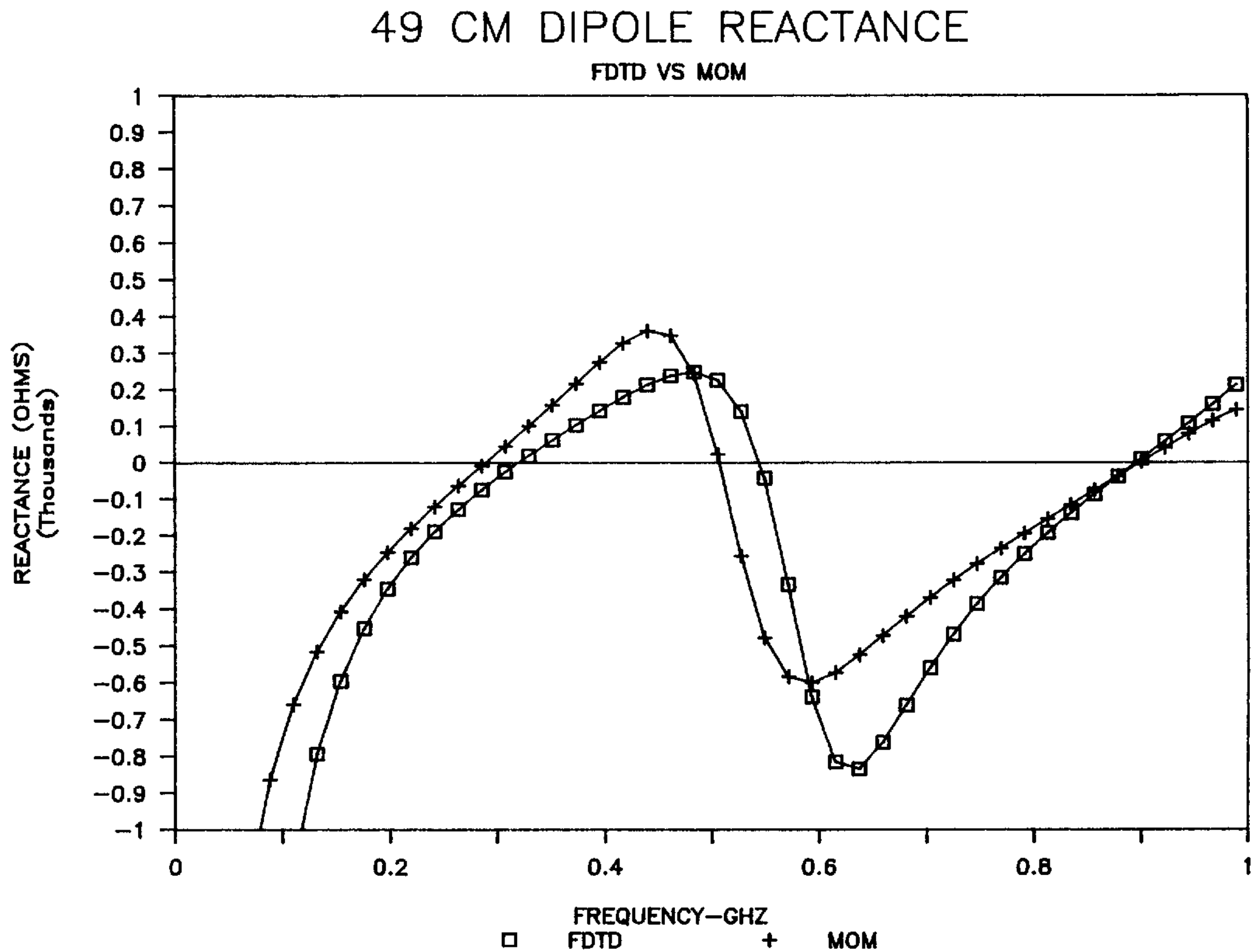

Figure 10. Resistance predicted by the Method of Moments and by FDTD. The Method of Moments assumes a circular cross section and a thin gap, while the FDTD results are for a square cross section and a 1 cm gap.