

Xwake 1.0: A New Tool for Wakefield and Impedance Calculations

T. G. Jurgens, G. W. Saewert, and F. A. Harfoush
Fermi National Accelerator Laboratory*
Batavia, Illinois 60510

Abstract

Xwake, a user friendly Finite Difference Time Domain (FDTD) code for wakefield and impedance calculations of rotationally symmetric structures is described. Contrary to the traditional stepped edge or half cell approach used in other codes, Xwake 1.0 incorporates the *contour* modeling approach allowing it to accurately represent curved boundaries. Other features include a mesh generator that allows for the handling of lossy materials, dielectrics, and ferrites, modeling of regions that are simply or multiply connected and automatic dynamic memory management. Xwake 1.0 is a fully integrated interactive code and is distributed free of charge. Xwake is written in ANSI-C for portability and has been demonstrated to run on several Unix platforms. A graphical user interface (GUI) allows easy access to all the processing modules in the code. The GUI uses the OSF/Motif1.1 widget set and the X11R4 window system. Simulation results emphasizing its capabilities, in particular for a very slowly tapered beam pipe, are presented.

1 INTRODUCTION

For a long time the Finite Difference Time Domain method [1] has suffered from stepped edge approximations to media interfaces which do not coincide with mesh lines. This limitation is due to the leap-frog marching in time of a finite difference mesh. However, recent advances in FDTD meshing have demonstrated it is possible to overcome this problem. Various techniques have and are still being explored for this purpose in an attempt to further enhance the meshing capabilities.

Among these methods is the conformal (or contour) modeling which uses Ampere's and Faraday's integral equations to deform the cells near the boundary of the geometry [2, 3]. This modeling permits a more accurate representation of a complex structure without the need to refine the mesh elsewhere. Since the cells are modified only near a material interface it follows that the computing costs associated with their meshing is asymptotically negligible.

Mesh refinement schemes have been investigated as another way of modeling small geometric features. If care is not taken artificial reflections can be introduced at boundaries of differently meshed regions. Other methods use a non-orthogonal, invariant coordinate system to better

adapt the grid lines to the geometry under consideration.

Section II describes the main features of Xwake 1.0, and Section III analyzes selected cases that highlight the advantages of the conformal modeling over the stepped or the half-cell approach as implemented in other codes such as TBCI (MAFIA) and ABCI. Section IV is summary and helpful information.

2 XWAKE 1.0 OVERVIEW

The initial development of Xwake began in mid-1993. That work accelerated later that year during a three months visit to CERN [4]. Version 1.0 is now complete and publically available.

There are two stages to using Xwake. One starts by describing the geometry and boundary conditions in a *problem description* file. This is done outside of running the program itself. The user is free to use any text editor to produce this ASCII, text file. The format of the description file has been inspired by some CAD like programs for their ease of use. Subsequently, one runs Xwake. Xwake's Motif interface allows the user to generate the computational mesh, calculate the wake potential and display the results in a intuitive, seamless manner.

Material boundaries are automatically meshed with a choice of two approximations, the traditional *stepped edge* modeling or the new *contour* modeling. Xwake 1.0 allows the user to select between the stepped edge and the contour approximations. Presently, contour modeling is implemented only for perfectly conducting structures. The stepped modeling permits structures to have arbitrary values of permittivity, permeability and conductivity. For either approximation, the mesh generator is capable of modeling structures that are multiply connected.

Ultimately, three solutions are computed: wake potential versus wake length, wake spectrum versus frequency, and wake impedance versus frequency. The user is provided with different options to display the results. This is all done interactively without ever leaving the program. Xwake includes many features for convenience.

Data computed by the mesh generator and the solver can be saved in a file. As a debugging aid for the problem description file, the problem geometry can be plotted with various options highlighting the lines where boundary conditions are applied. Any plot can be written to a file or printed directly to a PostScript printer. Effort was made to make Xwake intuitively easy to use and includes many error checking routines to make it robust. For example, only those push buttons which allow valid actions

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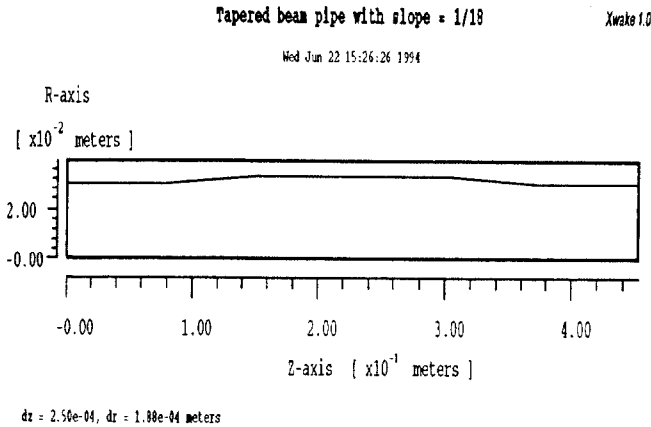


Figure 1: Slowly Tapered Beam Pipe Geometry

at any point in time are highlighted and enabled. It is not possible to do anything wrong or out of sequence. When necessary, informative messages are displayed.

3 RESULTS

Xwake 1.0 has been extensively validated against other existing codes (TBCI/ABCI). To demonstrate some of the main characteristics of Xwake, three cases were examined: a very slowly tapered beam pipe, a cavity loaded with ferrite and a very thin conducting shield pipe.

3.1 Very Slowly Tapered Beam Pipe

For many years impedance calculations of very slow and arbitrary tapered beam pipes have been a challenging problem in accelerator physics. Existing numerical models *at best* divide each unit cell in a FDTD grid along its diagonal creating two triangular cells. Some also allow for a limited variation in the mesh size in one direction only, although their numerical dispersion has not been quantified. In many cases these techniques are not sufficient for correctly modeling the geometry of a slowly tapered beam pipe. In the example illustrated in Figure 1, we look at a beam pipe of radius 0.03m with a taper angle of 0.0417 radians at each end of the pipe and separated by a distance equal to 0.15m. Convergence studies of the wake potential were conducted with ABCI (half-cell approximation) and Xwake using both the stepped and contour options.

Figure 2 plots the peak values of the wake potential versus mesh resolution. At the coarsest resolution modeled ($dr=0.003m$), Xwake with the contour option gives a value of 0.48 V/nC. ABCI needs a mesh resolution at least 8 times finer to match this result. This increased mesh density implies a 64-fold increase in the memory needed to store the electromagnetic field values and a 512-fold increase in solver run time. As the mesh gets finer the results converge in all cases to a value of approximately 0.31 V/nC. For simulations which are sensitive to geometrical

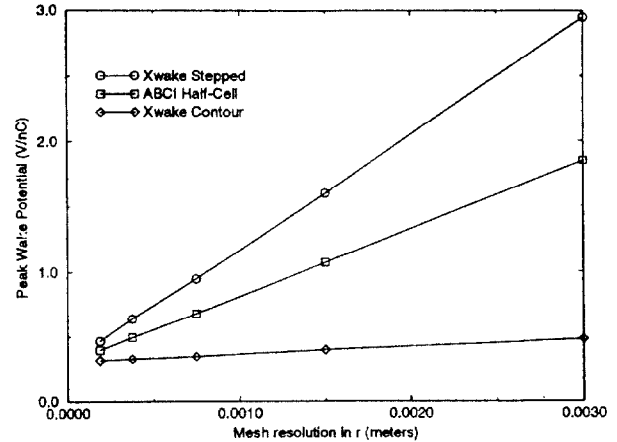


Figure 2: Convergence Study of a Slowly Tapered Beam Pipe

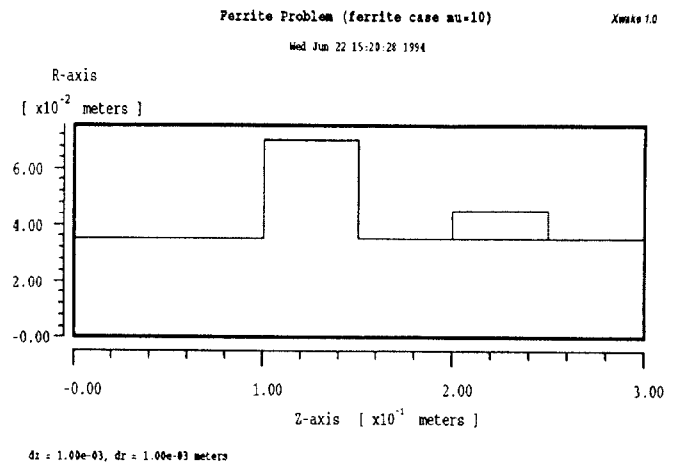


Figure 3: Ferrite Loaded Cavity Geometry

errors, contour modeling is clearly superior.

3.2 Ferrite loaded cavity

The mesh generator in Xwake 1.0 allows for the modeling of regions with different material characteristics by assigning values to the permeability, permittivity, and conductivity parameters in the problem description file. In this next example, shown in Figure 3, a ferrite material fills one of two cavities located in a section of a beam pipe. Figure 4 compares the wake potential of this geometry to this same geometry with the ferrite removed and the cavity left empty.

3.3 Thin Conducting Shield Pipe

Our final geometry, displayed in Figure 5, consists of a very thin conducting pipe, much less than the mesh discretization size, placed in a cavity. Xwake is capable of resolving

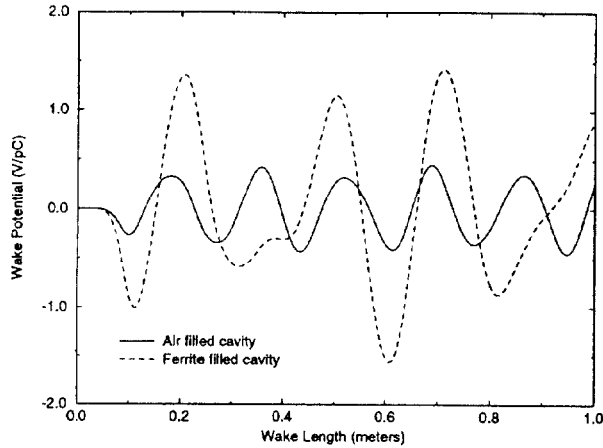


Figure 4: Ferrite Loaded Cavity Wake Potential

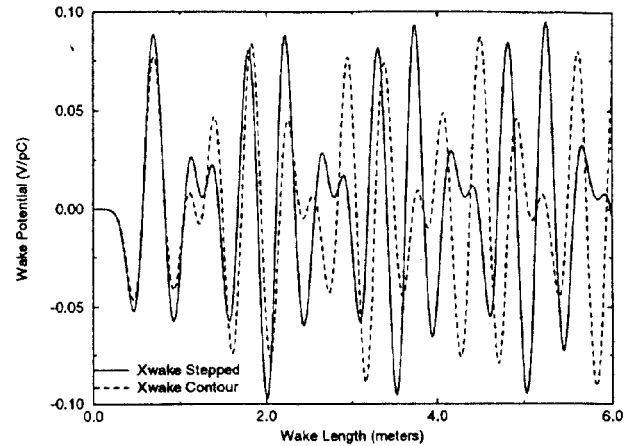


Figure 6: Thin Conducting Shield Pipe Wake Potential

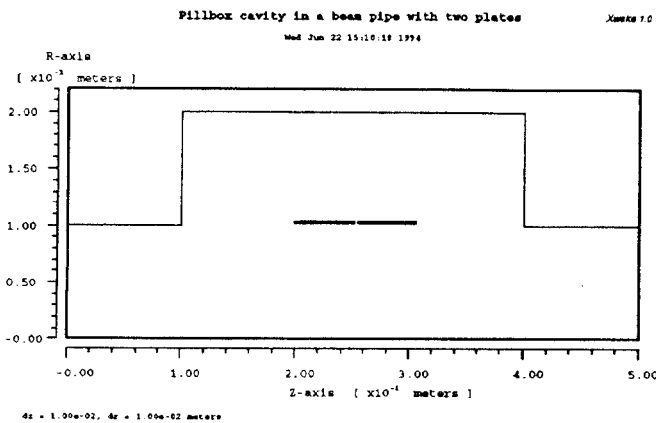


Figure 5: Thin Conducting Shield Pipe Geometry

plates a thin as 1/100th of a mesh cell. This geometry was modeled with Xwake using both the contour and stepped approximations, as well as with ABCI.

The stepped Xwake and ABCI results were identical – they both ignored the existence of the plates. Figure 6 compares the wake potential computed using Xwake with the contour option to the ABCI/stepped Xwake result.

4 SUMMARY

The main features of this first release of Xwake were quickly overviewed. The contour approximation for perfectly conducting structures, the change in material characteristics, the ability to model multiply connected regions and the user friendly interface, all make Xwake 1.0 an attractive analysis tool. Other improvements that incorporate the latest advancements in FDTD technology will be added, making Xwake an even more powerful tool for the calculations of wake potentials and impedances in acceler-

ator physics. To obtain a free copy of Xwake 1.0 for your Unix machine, an anonymous ftp area, *calvin.fnal.gov*, has been set up at Fermilab.

5 REFERENCES

- [1] A. Taflov, "Review of the formulation and applications of the finite-difference time-domain method for numerical modeling of electromagnetic wave interactions with arbitrary structures", *Wave Motion*, vol. 10, no. 6, pp. 547-582, 1988.
- [2] T. G. Jurgens and A. Taflov, "Three-Dimensional Contour FDTD Modeling of Scattering from Single and Multiple Bodies", *IEEE Trans. Antennas and Propagat.*, vol. 41, no. 12, pp. 1703-1708, 1993.
- [3] T. G. Jurgens and F. A. Harfoush, "Conformal FDTD Modeling of Wake Fields", in *IEEE PAC Conference Proceedings*, San Francisco, CA, pp. 321-323, May 1991.
- [4] F. A. Harfoush, SL/AP Note 94-07, CERN.