focus on finite element techniques for solving electromagnetic field problems. Prior to joining the faculty of Carnegie Mellon in 1982, he served as an Associate Professor of Electrical Engineering at McGill University, and as an Adjunct Associate Professor of Electrical Engineering at Union College, Schenectady, New York. His previous experience includes eight years with the General Electric Company, first in the Large Steam-Turbine Generator Department and then in the Corporate Research and Development Center. Dr. Cendes is also founder of Ansoft Corporation, a leading supplier of easy to use electromagnetics design software. He provides the principle vision behind the company’s product planning and development and is responsible for managing the technical research underlying Ansoft products including the Maxwell® 3D Field Simulator and the High-Frequency Structure Simulator developed by Ansoft Corporation and marketed by the Hewlett-Packard Corporation. He is an active member of the IEEE and initiated the now Biennial IEEE Conference on Electromagnetic Field Computation (CEFC). He is a member of the International Steering Committee of the Compumag Conference and is a member of the Advisory Board of the CEFC

Interactive Display of Vector Fields Inside Waveguides

Atif Z. Elsherbeni, Senior Member, IEEE, Darko Kajfez, Senior Member, IEEE, and John A. Hawkes

Abstract—The educational software package WGVMAP has been developed to enable students to plot interactively the electric and magnetic field lines of TE and TM propagating modes in cylindrical waveguides. The considered waveguide cross-sections are rectangular, circular, sectoral, and circular with a conducting baffle. The vector field display and generation of the field lines can be performed on a very modest configuration of an IBM-PC or compatible computer, and plotted on an x - y plotter. Examples are presented to demonstrate the interactive procedure for generating the field lines.

I. INTRODUCTION

The modes in rectangular and circular waveguides are an important topic in any electromagnetics field course. The comprehension of the waveguide behavior requires associating the analytical expressions of the field components with the graphical display of the modal patterns. It is relatively easy to find elementary problems that help students to practice the analytical aspect of the field in waveguides. However, any attempt to make a realistic plot of the modal pattern requires an extensive computation of the field components as functions of position. This would require that students perform a considerable amount of busy work before they can plot the first field line. In the name of learning economy, students are never assigned to make an accurate graphical display of fields. Consequently, some students remain incapable of making even the most elementary sketches of electromagnetic fields.

The abundance of personal computers and plotting equipment, such as plotters and laser printers, opened a possibility of making accurate graphical displays in a relatively short time. By eliminating the drudgery, the software should enable the student to concentrate on the important aspects. This paper will describe the software WGVMAP [1]–[2], which we have developed with such an educational use in mind.

WGVMAP is an interactive software for computing and plotting the electric and the magnetic field lines of various TE and TM modes in rectangular and circular waveguides, including the circular sectoral ones [3]. The user can observe the effect of changing any of the physical or electrical parameters on the resulting electric and magnetic field distribution in a plane perpendicular to the propagation direction. The program can be executed on very modest personal computers available in engineering schools and even possessed by many students.

There are two major parts of the field plotting procedure; first, the program computes the vector field components at a grid of equidistant points, and second, it constructs the field lines in small increments by interpolating between the computed data points. The field components are computed from the known analytical expressions based on the solution of Helmholtz wave equation inside hollow waveguides [3]–[6].

For each of the selected waveguide modes, the field lines are plotted in the transverse plane of the waveguide as a two dimensional map of a three-dimensional situation following the procedure described in [8].

II. INTERACTIVE PROCEDURE

The waveguide cross sections that can be selected from the main menu of the program are shown in Fig. 1. These are as follows: rectangular, circular, sectoral (of any angle between 0 and 360°), and circular with a baffle; Suppose we wish to plot the TM21 mode in the waveguide with a square cross section. After specifying that the number of the data points along the side of the waveguide cross section is 25, and that we wish to generate the magnetic field lines, the interactive screen appears such as shown in Fig. 2. We can see that the data contain 25 points horizontally and 25 points vertically. Each point is represented by a small vector. The magnitude of the vector indicates the field intensity, but the vectors of very weak fields are not allowed to be shorter than 1/3 of the grid size, so that their orientation would

Manuscript received February 1993.
The authors are with the Department of Electrical Engineering, University of Mississippi, University, MS 38677.
IEEE Log Number 92088900.

0018-9359/93$0.00 © 1993 IEEE
The following waveguide geometries may be analyzed:

- **RECTANGULAR**
  - Press → R

- **CIRCULAR**
  - Press → C

- **SECTORIAL**
  - Press → S

- **CIRCULAR WITH PERFECTLY CONDUCTING BEVEL**
  - Press → B

Select one of the above types or F10 to exit or return to main menu.

---

**Fig. 1.** Menu of waveguide cross sections.

---

**Fig. 2.** Interactive screen, initial view.

---

**Fig. 3.** Interactive screen with one horizontal intercept line and ten magnetic field lines.

---

**Fig. 4.** Interactive screen for the electric field, minimum magnitude set to $-60 \text{ dB}$.

---

remain visible. Since this is a transverse-magnetic type of field, and since we are observing the magnetic field data, the individual vectors obviously circulate around two closed loops. One signal intercept line can capture the entire flux of the magnetic field, if we place it horizontally, reaching from the center of the left loop to the center of the right loop. The end points of the intercept line are positioned with the use of cursor keys. After requesting to graph 10 field lines, we can observe the creation of individual field lines, each of them starting from the intercept line. When all the lines are completed, the interactive screen looks such as shown in **Fig. 3**. The program can accommodate up to 20 intercept lines in one screen, and there is no limit to the number of field lines emanating from each of the intercept lines, other than the patience of the user.

The interactive screen for the electric field of the same TM$_{21}$ mode is shown in **Fig. 4**. We see two points at which all the vectors converge; we call them vertexes. They are points of confusion for the Runge-Kutta procedure. When the field line progresses toward a vertex and passes the center, the direction of the field is suddenly reversed, and the plotting of the field line begins to run back. After the first step backward, the local field vector points again toward the vertex. Very often, the progress of the field line appears to be frozen, because the actual movement reduces to an endless back and forth jumping across the vertex. To avoid this problem, we raise the magnitude level, below which the plotting of field lines is discontinued. The default level for plotting **Fig. 4** was $-60 \text{ dB}$ below the maximum field magnitude. This value can be changed from the interactive screen by pressing the key (M) (for magnitude), and specifying the new minimum level (here, we choose $-10 \text{ dB}$). The data points with magnitudes below the new minimum are erased, as seen in **Fig. 5**. The construction of the particular field line will be terminated when it reaches the region of minimum magnitude. Thus, the problem with the vertexes will not be relevant any more.

After the user feels satisfied with the appearance of the field
III. CONCLUSIONS

An educational software has been developed which makes use of the personal computer for generating graphical displays of the various modes in hollow waveguides. The process of creating the field plot is interactive, leaving the user freedom to make many decisions on how the final plot will look like. The user can choose the number of grid points, the step size, and decide whether to change the minimum field magnitude below which the field lines are not plotted. He/she must place one or more intercept lines across the field display, and specify how many field lines will emanate from the first intercept line. If the initial intercept lines fail to cover the field area satisfactorily, he/she may place additional intercept lines in the blank areas. Finally, he/she may use a plotter to create a high quality copy of the modal field pattern, possibly both electric and magnetic field lines on the same figure. Thus, he/she is not a passive observer of the show, but runs the show.

REFERENCES


Atef Z. Elsherbeni (S’84–M’86–SM’91) received the honor B.Sc. degree in electronics and communications, the honor B.Sc. degree in applied physics, and the M. Eng. degree in electrical engineering, all from Cairo University, Cairo, Egypt, in 1976, 1979, and 1982, respectively, and the Ph.D. degree in electrical engineering from Manitoba University, Winnipeg, Manitoba, Canada, in 1987.

He was a Research Assistant with the Faculty of Engineering at Cairo University from 1976 to 1982, a Research Assistant at the Department of Electrical Engineering, Manitoba University from 1983 to 1986, and from January to August 1987 as a Post Doctoral Fellow in the same department. He joined the faculty at the University of Mississippi in August 1987 where he is currently an Associate Professor of Electrical Engineering. His professional interests include scattering and diffraction of electromagnetic waves, numerical techniques, antennas and computer aided design.

Dr. Elsherbeni has authored and/or co-authored over 80 technical papers and reports on applied electromagnetics, antenna design, and microwave subjects. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE) and belongs to the Antennas and Propagation and to the Microwave Theory and Techniques Societies. His honorary memberships include the Electromagnetics Academy and the Scientific Sigma Xi Society.
Darko Kajfez (SM'67) received the electrical engineer's degree (Dipl. Ing.) from the University of Ljubljana, Slovenia, in 1953 and the Ph.D. degree from the University of California, Berkeley, in 1967. He is currently a Professor of electrical engineering at the University of Mississippi. His teaching and research interests are in numerical solutions of electromagnetic problems in microwave circuits and antennas.

Dr. Kajfez co-edited the book *Dielectric Resonators* and authored three volumes of the graduate textbook *Notes on Microwave Circuits*.

John A. Hawes was born on May 4, 1963, in San Leandro, CA. His parents, Dr. James L. Hawes and Suzanne R. Hawes moved to New Orleans, LA, where he lived through his childhood. He graduated from Benjamin Franklin Senior High School in 1981 and attended Louisiana State University for two years before enlisting in the United States Air Force. He completed six years of active duty service as a ground radar technician and operator, and was awarded the USAF Good Conduct and Commendation Medals. After separation from the service, he returned to college at the University of Mississippi where he is now a senior in Engineering. He is currently an AFROTC Cadet and will seek a Master's degree after graduation in May of 1993. After completion of his Master's, John will reenter the Air Force as a commissioned officer.