Simple Techniques For The Desk-Top Production Of Computer Movies Which Illustrate Fundamental Concepts In Electromagnetics

by

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Abstract

Using Macintosh® computers and a selection of readily available commercial software, computer animations that effectively illustrate fundamental concepts in electromagnetics can be quickly and easily produced. The methodology, typical movie preparation, and the software and hardware requirements are discussed.

Introduction

Electromagnetic phenomena tend to be four-dimensional, represented by vectors that depend on the spatial coordinates and time. To facilitate their mathematical description, they are generally expressed as complex phasor vector fields, masking their time-varying nature. This complexity can make it difficult for the beginning student to visualize correctly the wide range of fundamental abstractions and principles which come into play in time-varying electromagnetism.

It is generally agreed that the use of computer movies can greatly enhance classroom presentation of these phenomena, and programs such as *TLS: Transmission Line Simulator*, developed by Charles H. Roth [1], have been well received by the electrical engineering undergraduate students at our university. However, movies to address the full range of fundamental concepts that must be dealt with in typical electromagnetics courses are not widely available to individual instructors.

Previously reported efforts to generate such movies have often required rather specialized hardware and a considerable investment in time by the instructor for the preparation of each movie, and have provided virtually no practical guidance to aid an instructor in generating such movies to augment his or her own lecture presentations [2,3,4]. Lately, very sophisticated mathematical analysis software, which incorporates animation features, notably *Mathematica* [5], has become popular. However, because of their complexity, such programs are very difficult to master quickly, and are often limited in their presentation capabilities.

This paper presents a very simple — yet flexible — approach to the preparation of computer movies. Using Apple Macintosh® computers equipped with typical office productivity and desk-top presentation software, an individual instructor can personally author a sophisticated movie and tailor it to his or her needs. A typical movie can be planned and prepared at the instructor's desk in a matter of a few hours at most, and classroom presentation will be seen to be as simple as using an overhead projector. The basic methodology for preparation and presentation of a movie, and the software and hardware requirements will be discussed.

Preparation of a movie

The phenomena that are to be displayed in a movie are time-varying, though not necessarily time-harmonic. The period of time over which the phenomena are to be observed is divided into equally spaced time intervals. The objective is to choose a sufficient number of intervals so that the phenomena change only marginally from frame to frame, but not so many as to incur unnecessary labor in the preparation of additional frames. For time-harmonic phenomena, 24 frames per cycle are generally satisfactory, while the number of frames can vary widely for non-harmonic cases. One image of a phenomenon is produced for the beginning of each time interval. These images, or frames, are then recorded and played back sequentially as a movie.

For time-harmonic phenomena it is convenient to loop the sequence into an endless display. The speed at which the movie runs may be varied for optimal effect, or the movie can be advanced a single frame at a time. Such film strips, with explanations supplied by the instructor during presentations, are generally adequate. However, several filmstrips can easily be assembled to form a completely self-explanatory composite movie with titles and equations. All the steps that are necessary to produce a movie are implemented in "off the shelf" software packages so that no intricate programming is required. Even novice computer users who have a basic familiarity with the Macintosh environment can quickly become proficient at creating their own movies.

In all cases an equation or several equations have to be established that describe the curve or surface which is characteristic of the phenomena that are to be graphically displayed, such as a distribution of field amplitude or the location of lines of force. These equations contain one or more spatial variables and time. The equations must first be evaluated at the beginning of each time interval for the coordinate locations that define the space in which the phenomenon is to be viewed. There are a number of software programs available for the Macintosh computer that can display curves and surfaces with as little effort as typing in the equation or equations. Such programs as *Matlab* [6], *Systat* [7], *Theorist* [8], and *Mathview Professional* [9] present the data in a variety of graphical formats. The images so created can be stored in the *Scrapbook*, a standard feature of the Macintosh operating system.

Alternately, spread sheet programs, such as *Microsoft Excel* [10], or user programs written in Fortran or other languages, can be used to evaluate the equations and to write tables of coordinates as text files. Raw numerical data produced in this way can be easily imported into a suitable graphing program, such as *Excel's* Chart window, *Cricket Graph* [11], or indeed into one of the programs previously mentioned, such as *Matlab* or *Systat*, where the images can be rendered and stored as before.

The approach selected is largely a matter of choosing the desired level of sophistication of the graphical output. Programs such as *Cricket Graph* provide elaborate 2-D graphics with control of axes, labelling, line width, font and so on, but cannot be used in the numerical evaluation of the equations. On the other hand, programs such as *Matlab* provide basic 2-D and 3-D images, but with little editing control of the images.

The final assembly of images into film strips can be achieved with any one of a number of animation programs. The authors have found *Video Works II* [12] entirely satisfactory. It is extremely easy to use and incorporates a basic drawing capability that permits the editing and enhancement of graphical images, as well as the addition of text. The makers of *Video Works II* have now replaced this program with a more powerful program called *Director 3.1* [13]. Assembly of images is quite similar in these two programs (*Video Works II* is upward compatible). Instructors interested in producing filmstrips may also wish to investigate the capabilities of *Mathematica*, *Maple* [14], *Apple Quick Time* [15], and *Delta Graph* [16], which have a variety of capabilities for producing graphic images and/or filmstrips. However, the authors have found that the greatest versatility and control for producing film strips, and in particular for linking them together and producing complete movies, resides in *Video Works II* and *Director 3.1*.

The general approach outlined above will now be illustrated with two examples. Variations on the particular steps involved will be apparent to those familiar with the Macintosh environment.

Sample Movie #1

The authors have developed a number of companion filmstrips to support classroom discussion of the reflection and transmission of plane waves at the interface between two dielectric half-spaces. Some of these strips are organized to depict simultaneously the instantaneous amplitudes of the individual component signals, i.e. the incident, reflected and transmitted signals in the two regions. Others illustrate the variation of the total instantaneous fields within the static envelope curve that defines the phasor field magnitude, and which is superimposed on each frame. In each case the simple steps outlined below, which pertain to the creation of the instantaneous field amplitudes, were followed in creating and assembling the 24 individual frames comprising the filmstrip. A typical frame from a filmstrip is shown in Figure 1.

1. *Formulate*

The electric fields are expressed in the two regions by the standard expressions

$$e_1 = E_o e^{-\alpha_1 z}\cos(\omega t - \beta_1 z) + E_o|\Gamma|e^{+\alpha_1 z}\cos(\omega t + \beta_1 z + \phi)$$

$$e_2 = E_o|\mathrm{T}|e^{-\alpha_2 z}\cos(\omega t - \beta_2 z + \theta)$$

where $\Gamma = |\Gamma|\angle\phi$ is the reflection coefficient

and $\mathrm{T} = |\mathrm{T}|\angle\theta$ is the transmission coefficient.

The objective is to present this *e*-field information in a conventional 2-D graphical format with the horizontal axis coinciding with z, the direction of propagation, and with the vertical axis representing the instantaneous field amplitude.

2. *Calculate*

A convenient way to evaluate these expressions is with a spreadsheet program. The authors used *Excel* by *Mircosoft*, which is one of the most popular and versatile such programs for the *Macintosh* computer. *Excel* provides a matrix of cells defined by rows and columns. Into each cell can be placed a number, or an equation that will be automatically evaluated in terms of numbers stored in other cells. There is no unique way to organize these cells to evaluate the above equations, however, the following suggestion works well for the present example. The description is brief and is not intended as a lesson on the use of a spreadsheet. Rather, it is included to indicate the remarkable ease with which the necessary equations can be calculated the several thousand times necessary to provide values for the field at each of 100 to 200 axial locations for 24 separate instances of time. The mechanics of the construction of the spreadsheet will be obvious to anyone familiar with this type of program and are, in any case, well described in the *Excel* documentation.

As shown in Figure 2, cell $R1C1$ (row 1 - column 1) is left empty and in $R1C2$ to $R1C25$ are stored the 24 individual times, $t1$ to $t24$, at which the signals are to be determined. This storage is accomplished by entering only the first time and then inserting a formula that will cumulatively and automatically increment each adjacent cell by a time interval equal to the period, T, divided by 24. For reasons that will become obvious, this procedure is then repeated for $R1C26$ through to $R1C49$. Then, in column 1 are stored the individual, equally spaced, axial locations at which the fields will be evaluated. For example, if there are 101 axial locations, cells $R2C1$ to $R52C1$ would be filled with $z1$ to $z51$, and cells $R53C1$ to $R103C1$ would be filled with $z51$ to

$z101$ ($z51$ designates the location of the interface at which the reflection takes place). Again, this is accomplished automatically by storing a first axial location and using an appropriate incrementing formula. Next, the correct incident wave formula is inserted into each of the matrix of cells defined, for this example, by the space $R2C2$ to $R52C25$, in such a way that the field value at an axial location z_i and time t_j will be automatically calculated and stored in cell $R_{i+1}C_{j+1}$. Again, it is not necessary to manually insert thousands of individual equations. The program automatically inserts an appropriately modified version of one representative equation, stored in an arbitrary location, for instance the upper left cell R2C2, as shown in Figure 2, into a predefined block of cells by means of "relative addressing." This procedure is repeated for the transmitted wave over the space defined by $R53C2$ to $R103C25$, and for the reflected wave over the space defined by $R2C26$ to $R52C49$. The complete construction of this spread sheet, which will contain the data for the entire filmstrip, can be accomplished in well under an hour. *Excel* permits storage of the results in text format, allowing other programs, such as *Cricket Graph*, to read the data directly.

3. *Graph*

The next step is to prepare the 24 individual graphical images that will comprise the filmstrip. The popular and easy to use application *Cricket Graph* was used for this purpose. *Cricket Graph* can directly open and read the data stored in step 2, and organize it into a row and column format identical to that of *Excel*. The first row of data containing the time intervals is then deleted. The remaining columns of data can now be manipulated and plotted in an almost limitless number of ways. In the present example, a 2D-plot is desired with Column 1 (the axial locations) as the horizontal axis, and some combination of the other columns (the field values at various times) representing the vertical axis. For example, selecting a plot of column 1 versus columns 2 and 26 produces a graph showing the individual values of the incident, reflected and transmitted fields at time $t1$ over the range of z values defined in step 2 . On the other hand, the instantaneous total fields in both dielectric half-spaces can be displayed at time $t1$ by adding columns 2 and 26, storing the result in say column 50, and by then plotting column 1 versus column 50. Such manipulations of the data are easily accomplished in *Cricket Graph*. Also, once the desired graphical image has been generated the axes may be labelled with any desired font, the image may be resized, and additional text, legends, arrows, and so on, may be added. Using this method, all of the 24 individual frames are created. They are then stored by copying them to the *Clipboard* and then into the *Scrapbook* (standard features of the *Macintosh* operating system.)

4. *Assemble*

The 24 frames are now assembled to form a filmstrip that will run as a continuous loop depicting the instantaneous field variations in the vicinity of the dielectric interface by using the program *Video Works II* (or its successor *Director 3.1*). This software program is well documented and supports a wide variety of editing options. (For example, the shading of the dielectric region in Figure 1 was added in *Video Works II*.) The process is as simple as copying the stored images to a "cast window", shown in Figure 1. From the cast window, cast members are moved onto the "stage" in the order in which they are to be shown, simultaneously creating a movie "score." Assembly of a movie, once the graphical images have been created and stored (steps 2 and 3), rarely takes more than a few minutes.

Sample Movie #2

The preparation of this movie demonstrates the use of the software application *Matlab* to evaluate the equations that define the phenomenon to be studied and to simultaneously graph the results. The filmstrip selected for this example is one of a number of strips that have been produced by the authors to aid the student in picturing dipole radiation. It depicts the variation with time of the distribution of the instantaneous amplitude of the total radiation magnetic field in the horizontal plane of two vertical dipoles separated horizontally by 0.75 wavelengths (λ), and excited 90° out of phase. A 3-D surface plot is generated by plotting the magnetic field amplitude on the vertical axis over a square grid $6\lambda \times 6\lambda$ centered at the origin. Figure 3 illustrates a typical frame from the completed film strip, which was created in the following manner.

1. *Formulate*

In this case the total radiation magnetic field in the horizontal plane can be written simply as

$$h = \frac{\cos(\omega t - \beta R_1 - 90°)}{R_1} + \frac{\cos(\omega t - \beta R_2)}{R_2}$$

where $R_1 = \sqrt{(x-d)^2 + y^2}$

$R_2 = \sqrt{(x+d)^2 + y^2}$

when the two dipoles are located on opposite sides of the origin at $(\pm d, 0, 0)$.

2. *Calculate and Graph*

Matlab is a versatile matrix oriented mathematical calculation and graphing program with its own high level, formula-like command language. Its use is easy to learn and well documented. In order to evaluate and graph the above field expression, a simple program (called a script) is written. It is included here to illustrate the simplicity of the procedure. (It has been assumed that the wavelength is one meter.)

```
wt = 0;
```
(this value is changed for each frame)

```
[x,y] = meshdom (-3.0:0.1:3.0,-3.0:0.1:3.0);
h=cos(wt-pi./2-2.*pi.*sqrt((x-d).^2+y.^2))./sqrt((x-d).^2+y.^2)+...
cos(wt-2.*pi.*sqrt((x+d).^2+y.^2))./sqrt((x+d).^2+y.^2);
mesh (h)
```

This short program automatically evaluates `h` over a grid of 3721 points and produces a 3-D surface plot similar to the one shown in Figure 3. The program is executed once for each time interval with an appropriate value for `wt`, and the resulting graphical image is copied to the *Clipboard* and stored in the *Scrapbook.* Several additional lines of coding are required to limit the vertical scale of the plot to the same maximum and minimum values for each frame.

3. *Assemble*

The graphical images are assembled into a filmstrip using *Video Works II* as previously described.

These two simple examples illustrate that the actual preparation of a movie is quite straightforward. The major task is the initial creative effort needed to decide what one wishes to demonstrate. The authors have produced, and incorporated into their classroom presentations, many such filmstrips designed to illustrate specific conceptual points on such topics as

- wave reflection and transmission (normal and oblique incidence)
- total internal reflection and Brewster angle
- quarter wave window
- wave polarizations
- phase and group velocities
- distribution and propagation of fields in waveguides
- eddy currents in metal strips
- skin depth
- current and charge distributions on wire antennas
- electric lines of force in dipole radiation

- phased arrays

Projection

While small classes may view the movie on the computer monitor itself, some means of projecting the image will generally be required. One could for instance, prior to class time, photograph the computer screen as the movie runs with a conventional movie camera for later projection. One could also record the movie on videotape. There are several commercially available systems for large screen projection of such video images. Such "canned" presentations, however lose some effectiveness because the instructor can no longer easily replay, stop-start, step forward one frame at a time, and so on, as is often desirable in stressing specific points related to the movie.

A much simpler and more flexible approach (and used exclusively by the authors) is to use the *Kodak Datashow HR/M Projection Pad* (now handled by *Sayett Technology*, Rochester, N.Y.). This device is a transparent liquid crystal screen about the size of a large book. It operates on the video output of the *Macintosh*, taken through a video adapter that is included with the projection pad and which must be installed in the computer. The screen image is projected by simply placing the device onto an ordinary overhead projector as one would with any other overhead transparency. Figure 4 illustrates the simplicity of the basic setup. This projection pad, and other similar ones, such as the *3M 4100 Projection Panel*, do, however, have a rather long refresh time. This may limit the number of frames/second that can be clearly displayed. An alternative is to use a more costly projection pad, such as the *3M 5800 Active Matrix LCD Panel*, which has a very much smaller refresh time.

System Requirements

Most of the software mentioned above for the preparation of a filmstrip can be used on any currently available Macintosh computer. However, the professional versions of *Systat* and *Matlab* require a math coprocessor. Moreover, systems without coprocessors are limited to rather low frame speeds when running *Video Works II*. A hard disk is necessary. The authors have been using a Mac SE/30 system with 8 MB RAM and an internal 80 MB hard disc.

Conclusions

The classroom use of instructor-generated movies has been found to be very effective as an aid for teaching fundamental concepts in electromagnetics. These movies are easy to prepare, can be easily structured to reflect an instructors preferred style of teaching, and can be integrated into a lecture as easily as any other overhead illustration. Indeed, the projected film strip is an overhead "come alive" that provides a learning experience against which no amount of conventional blackboard illustration can compete. The movies produced by the authors have been well received in the classroom. They have helped students to clarify important concepts, have stimulated student thought, and have heightened student interest in the study of electromagnetics.

Use of computer movies is now an integral part of two introductory courses on electromagnetics and a course on antennas taught by the authors at the University of Alberta. Further movies on additional topics in electromagnetics are in preparation. As well as using movies in the classroom, a bank of computer movies is being created to which students will have independent access to review important fundamental concepts that were introduced as lecture material.

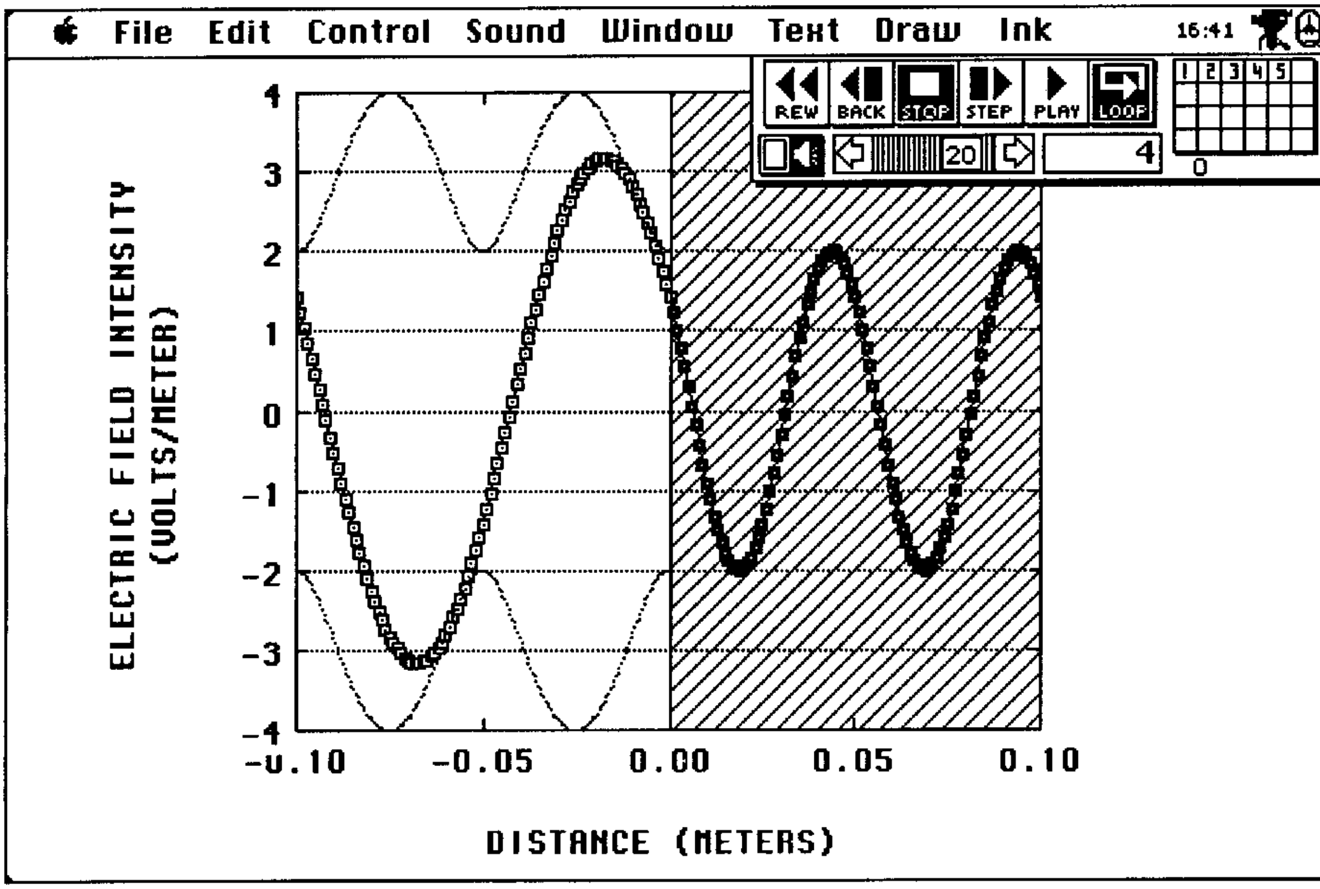
References

1. *TLS: Transmission Line Simulator* is available from Kinko's Academic Courseware Exchange, 4140 State St., Santa Barbara, CA 93110.
2. R.W. Cole, E.K. Miller, S. Chakrabarti and S. Gogineni, "Learning About Fields and Waves Using Visual Electromagnetics," *IEEE Trans. Educ.*,Vol.33, pp.81-94, 1990.
3. E.K. Miller, R.D. Merrill and R.W. Cole, "Computer Movies for Education," *IEEE Trans. Educ.*, Vol.31, pp.58-68, 1988.
4. M.F. Iskander, "CAEME: An Exciting Opportunity to Make a Difference in Electromagnetics Education," *IEEE Ant. and Prop. Soc. Newsletter,* Vol.31, No.5, pp.41-43, 1989.
5. *Mathematica:* Wolfram Research, Inc.,100 Trade Center Drive, Champaign, IL 61820-7237.
6. *Matlab:* The Math Works, Inc., Cochituate Place, 24 Prime Park Way, Natick, MA 01760.
7. *Systat:* Systat Inc., 2902 Central St., Evanston, IL 60201.
8. *Theorist:* Prescience, 814 Castro St., San Francisco, CA 94114.
9. *Math View Professional:* Brain Power Inc., 24009 Ventura Blvd., Suite 250, Calabasas, CA 91302.
10. *Excel:* Microsoft Corporation, 16011 NE 36th Way, Box 97017, Redmond, WA 98073-9717.
11. *Cricket Graph:* Cricket Software, 40 Valley Stream Parkway, Malvern, PA 19355.
12. *VideoWorksII:* MacroMind Inc., 1028 W. Wolfram, Chicago, IL 60657. (MacroMind Inc. has now become Macromedia, Inc.)
13. *Director 3.1:* Macromedia, Inc., 600 Townsend, San Francisco, CA 94103.

14. *Maple:* Waterloo Maple Software, 160 Columbia Street W, Waterloo, Ontario, N2L 3L3.

15. *Quick Time:* Apple Computer, Inc.

16. *Delta Graph:* DeltaPoint, Inc., 2 Harris Court, Suite B-1, Monterey, CA 93940.



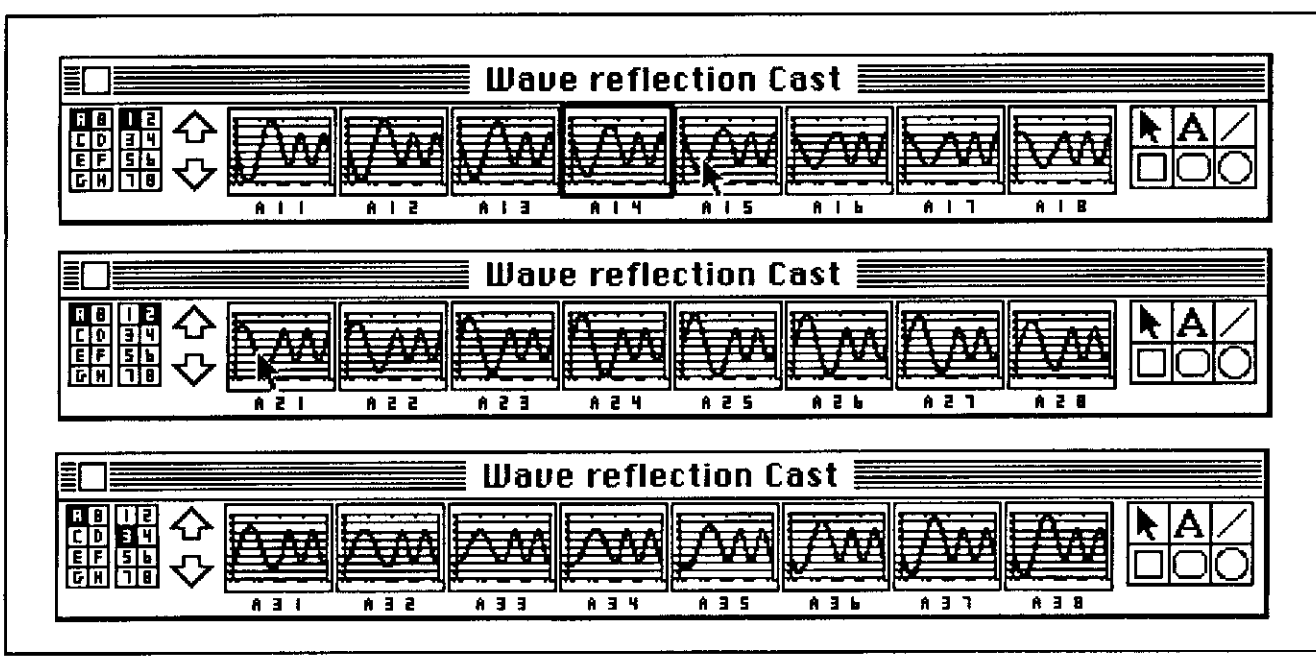


Fig. 1. Instantaneous electric field amplitude of a wave in free space, normally incident on a dielectric half-space of relative dielectric constant 4. The standing wave pattern is designated by lightly dotted lines. Also shown is the cast of 24 frames, which, when assembled, form a film strip.

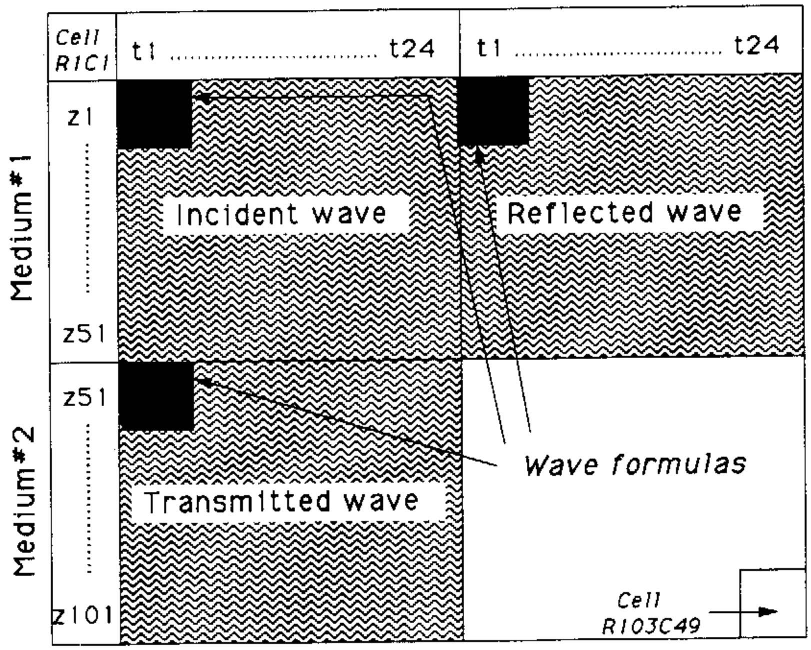


Fig. 2. The construction of the *Excel* spreadsheet, showing the cells allocated for the successive frame times and the axial positions for the incident, reflected, and transmitted waves.

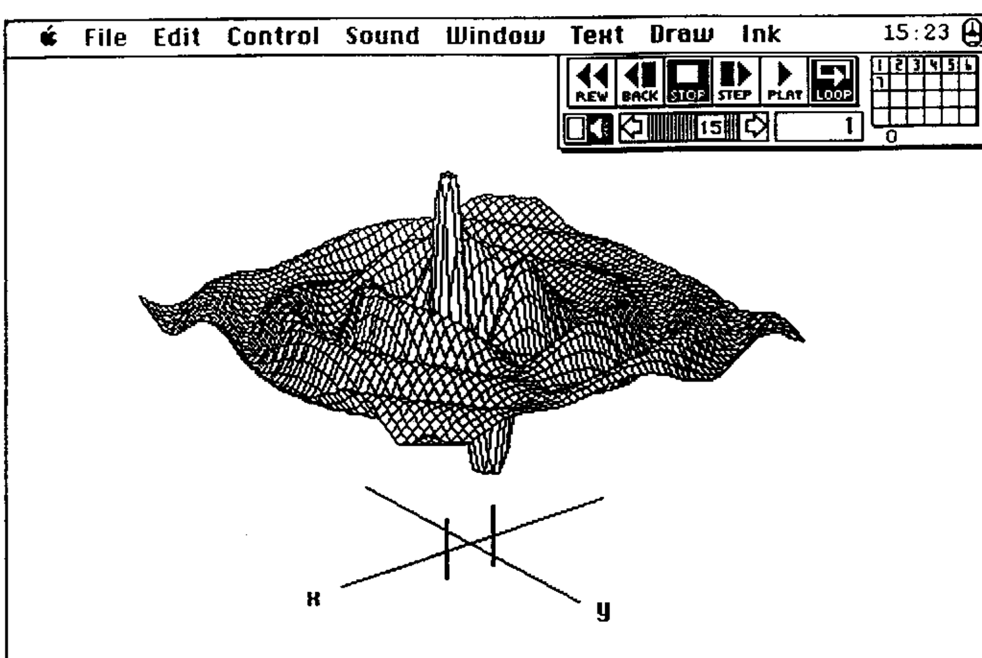


Fig. 3. Instantaneous amplitude of the radiation magnetic field in the principal H-plane of two vertical dipoles, for the case where the dipoles are separated by 3/4 wavelengths and excited in time quadrature.

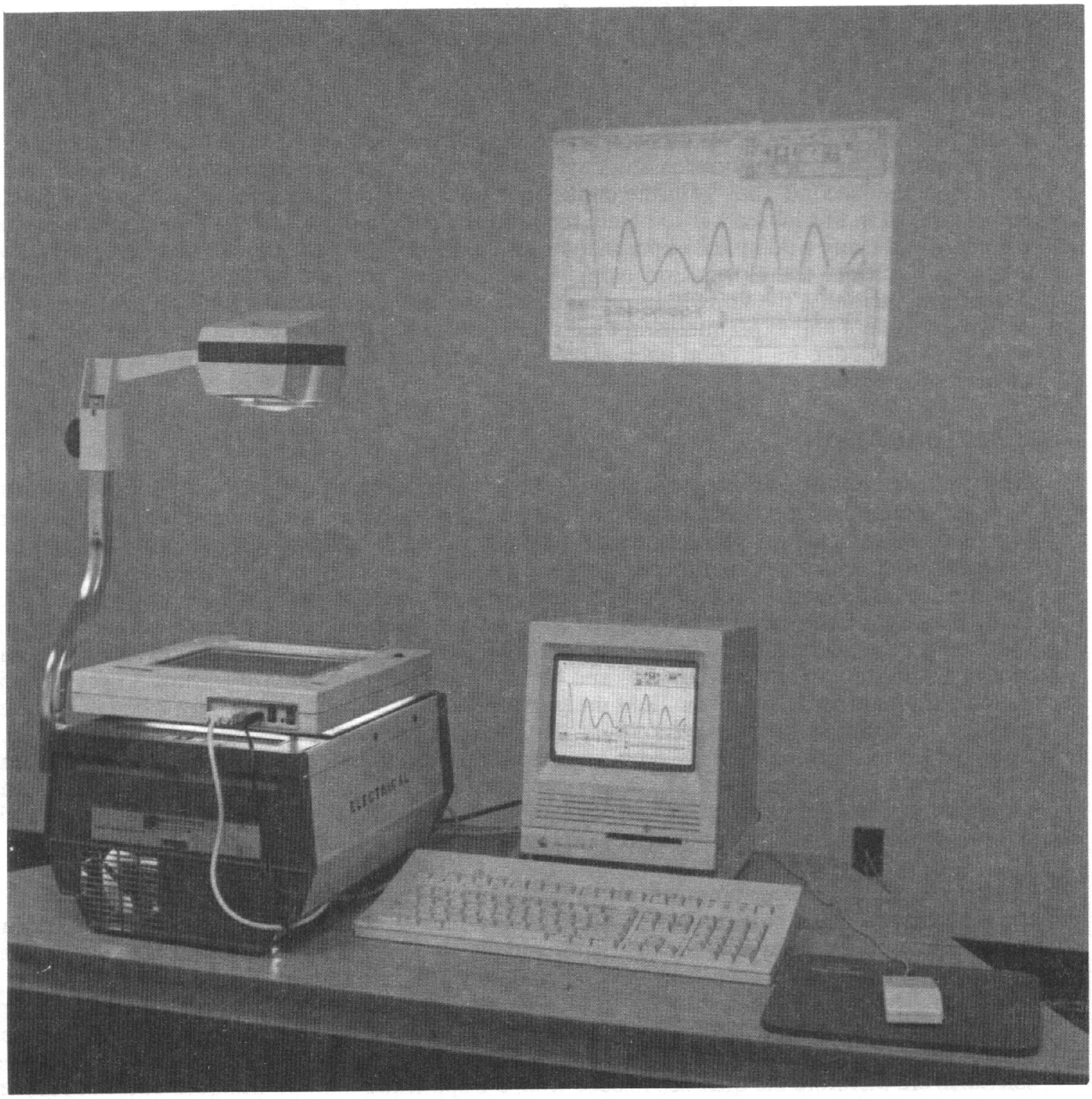


Fig. 4. The simple hardware required for movie projection consists of a *Macintosh* computer, an ordinary overhead projector, and the *Kodak Datashow HR/M Projection Pad* or similar device.