Reports

Computer-Generated Motion Pictures

Abstract. *A motion picture of the electromagnetic field pattern of a prolate spheroid antenna was completely produced by an IBM 7094 computer and an SC 4020 microfilm plotter. The technique of illustrating complex mathematical subjects by means of computer pictures should lead to better understanding in electrical engineering.*

I am reporting on a computer-generated movie that I produced using an IBM 7094 and an SC 4020 CRT plotter at the Ohio State University department of electrical engineering. My purpose was to determine if computer-generated movies would be of value in the understanding of electrical engineering phenomena.

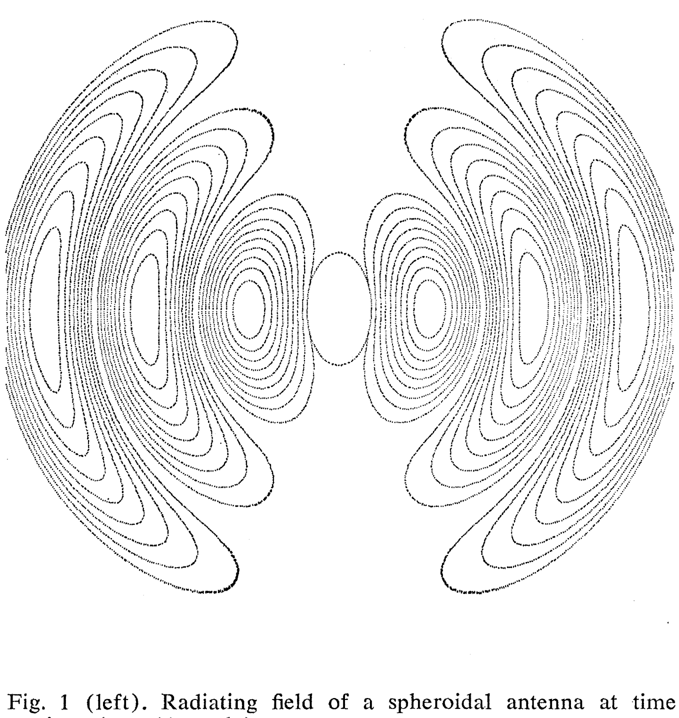
A number of topics have been reported based on the use of computer pictures (*1*). Electromagnetics are an ideal subject for this technique because the mathematical abstractions obscure the real events taking place. This is particularly true with time-varying fields where even a still picture cannot give a true representation of the motion taking place.

The subject selected was "the resonant spheroidal radiator." The distribution of current on the spheroid was chosen to be rotationally symmetric so that the radiated field could be pictured with a two-dimensional representation of a plane section containing the interfocal axis. Figures 1 and 2 show scenes from the movie. The field in the second picture is approximately 90 degrees out of phase with the first. The lines represent streamlines of constant potential, which are actually a plane sectional view of toroidal-shaped tubes. The stream surfaces in the three-dimensional case represent surfaces over which no displacement current flows. The mathematical basis for these surfaces can be derived from Ampere's law. If **H** is independent of ϕ and the path of integration is a circle normal to the interfocal axis, then

$$\int \mathbf{H} \cdot d\mathbf{l} = 2\pi\rho\, H_\phi = I_c + I_D$$

where **H** is the magnetic field vector; $d\mathbf{l}$ is the vector differential along the path of integration; H_ϕ is the single component of a rotationally symmetric magnetic field; I_C are the conduction currents enclosed by path of integration; I_D are the displacement currents enclosed by path of integration; and ρ is the radius from z-axis in x-y plane. If the currents are set equal to a constant, a surface of revolution is generated.

Since $2\pi\rho\, H_\phi$ is equal to a constant, the integral around a closed path in one of these surfaces must be equal to zero. Therefore, if the only conduction currents are on the spheroid, the flow of displacement current across any surface must be zero. The movement of the field can be pictured as follows: each group of lines represents a nest of toroids. A constant displacement current flows between each surface, with each set reversing in direction as the current on the antenna



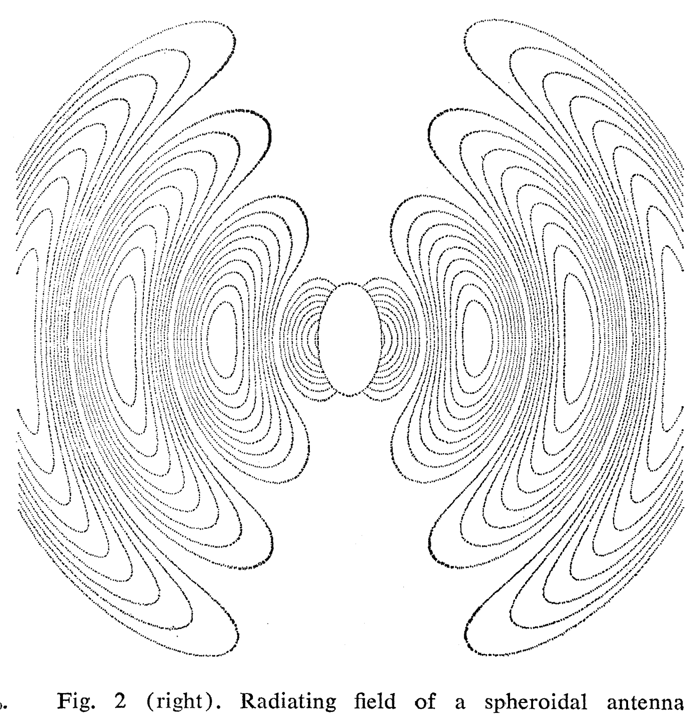


Fig. 1 (left). Radiating field of a spheroidal antenna at time t_0. Fig. 2 (right). Radiating field of a spheroidal antenna at time ($t_0 + 1/4$ cycle).

changes. The density of this current is greatest closest to the x-axis, and this is shown by the greater density of lines there.

An equation for $\rho H \phi$ was obtained from Ryder (*2*):

$$\rho H_{\phi} = K_1 \sin \frac{\pi}{2} p \, (1 - \zeta) \cdot e^{i} \left(\frac{\pi}{2} p\eta - \omega t - \frac{\pi}{2} p \right)$$

where η and ζ are the radial and angular coordinates, respectively, ω is the angular velocity, and p is an integer for each harmonic. The real part of this equation was used with p set equal to 1:

$$R_e \, (\rho \, H_{\phi}) = K_1 \cos \left(\frac{\pi}{2} \zeta \right) \sin \left(\frac{\pi}{2} \eta - \omega t \right)$$

This equation was made equal to a constant, and a different value was used for each streamline in a nest.

$$K_2 = \cos \left(\frac{\pi}{2} \zeta \right) \sin \left(\frac{\pi}{2} \eta - \omega t \right)$$
$$K_2 = .05, .15, \cdots\cdot .95$$

where the outermost streamline of each half cycle is determined by the smallest constant. The spheroid coordinates ζ and η are related to the 2-*D* cartesian coordinates ρ and χ by

$$\rho = f \, [(1 - \zeta^2)(\eta^2 - 1)]^{1/2}$$
$$x = f \cdot \zeta \cdot \eta$$

These equations hold for a resonant spheroidal antenna whose interfocal distance ($2f$) is $\lambda/2$. The points along a streamline are computed at approximately equal spacing through an iterative process. First, ζ is incremented, then η is computed, followed by ρ, χ, and the distance from the preceding point. If the distance between points is within set limits, the new point is stored; otherwise, the increment in ζ is changed by the ratio of the desired distance to the calculated distance, and the above procedure is repeated. When all the points for one streamline have been calculated, they are transformed into SC 4020 control words and placed on magnetic tape.

Both the time increment between each frame and the distance for each half-cycle can be calculated by adding the proper value to η before transforming to the ρ,χ coordinate system used by the plotter.

My investigation shows that, for many curves, it may be better to plot curved lines by means of touching dots rather than by line segments. The pictures have a smoother appearance, and the machine time for calculating these does not seem to be excessive. In the examples shown, the dots are two raster counts apart. About 20 seconds on the 7094 computer was used to produce the tape for each picture.

The IBM 7094 computed this pattern at 96 different positions in the cycle. The tape represented one cycle over 4 seconds of movie at 24 frames per second. This tape was processed eight times by the SC 4020 to create 30 seconds of 16-mm film.

The movie started with the title, credits, and one scene of text. This was followed by displaying the focal points, drawing an ellipse, and rotating it to show that three dimensions were present. A generator symbol in the center and the dark fringe on the surface, proportional to charge, were added. This was followed by three main scenes. First, the radiated field was shown (Figs. 1 and 2). Then the field was frozen, and two rulers were used to show that the distance between the focal points of the ellipse was equal to one-half wavelength. Finally, segments were added to the streamlines. These segments moved around the streamlines to indicate the direction of motion of the displacement field. This was followed by "the end" in block letters. All scenes including the lettering were generated by the computer. The method of using streamlines to show the magnetic field and moving segments to show the displacement current could be applied to a number of field configurations in electromagnetics.

One of the main purposes behind the film was to explain a rather complex subject to the viewer regardless of his mathematical background. For example, the increased phase velocity of the near field can be seen very clearly. In conclusion, the technique should serve as an accessory in promoting understanding in both classrooms and laboratories.

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References and Notes

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2. These equations are explained in detail by R. M. Ryder, *J. Appl. Phys.* **13**, 327 (1942).
3. I thank Prof. J. D. Cowan, Jr., Prof. E. Kennaugh, and D. Shupe of the electrical engineering department of Ohio State University, the Numerical Computation Laboratory of Ohio State University, the National Committee for Electrical Engineering Films, and Educational Services, Inc., for help in this work.

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Ratio of Blue to Red Light: A Brief Increase Following Sunset

Abstract. *Visible spectra of solar radiation were recorded during sunset. With the development of twilight, there was an expected decrease in the blue-to-red ratio; but directly upon setting of the sun there was a sharp rise in this ratio (due to the predominance of skylight) which attenuated rapidly to follow the pattern that it had previously taken.*

Microclimatology has made tremendous strides in elucidating the physical parameters of the environment to which the plant is exposed, but, of all the factors comprising the above-ground environment, light (and its measurement) has posed the most elusive problems (*1*). This relates not only to physical factors, such as simultaneous variation in intensity and spectral composition (*2*), but also to the lack of instruments capable of recording significant data. The thermopile or photoelectric cell can produce a simple integration of the variables of light, but such readings have limited relevance to photobiological responses which are largely

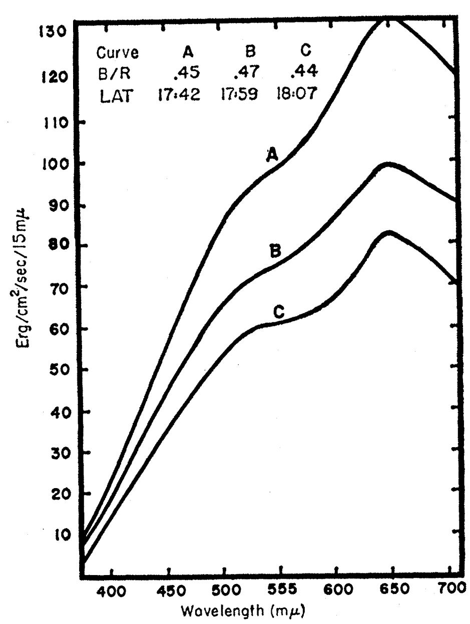

Fig. 1. These data were recorded 23 miles (37 km) west of Washington, Kansas, at an elevation of about 1300 feet. Sunset was apparent (sun barely above horizon). Time was recorded in local apparent time (*LAT*). The integrating sphere was directly facing the sun. Note that after sunset had occurred the visible spectrum assumed the same general shape as before sunset. Compare with curves D and E, Fig. 2. Numbers on the ordinate must be multiplied by 10^2.