Electric and Magnetic Fields Near a Circular Loop at 27 MHz

Introduction

In a discussion of the biophysics of electromagnetic irradiation effects, the electric and magnetic field strengths and their distribution as well as the energy distribution are of interest. Differences between pulsed radiation and continuous radiation of the same average energy level could depend on whether or not it produces a critical threshold of the electric or magnetic field in the tissue.

The field of a circular coil which is approximated by commercial units [1] was investigated. To our surprise we found that none of the standard classic textbooks such as Smythe [2] and others had an explicit solution to the electric field problem near a circular current loop. Because this electric field at 27 MHz (the FCC-permitted frequency used for this application) is also very difficult to measure, the need for an analytical solution is doubled. Solutions to the magnetic field are available and in that case the results can easily be checked by measurements.

We wish to give the results of our calculations, both the equations we derived and the calculated field distribution. Experimental confirmation for the magnetic field showing the applicability of the calculated results for an actual coil are also shown.

Field Calculation

The field of a circular current loop of radius a and current I is evaluated in a region having dimensions which are smaller than or equal to the size of the loop and much smaller than that of the wavelength, in air, of an electromagnetic plane wave at the frequency considered.

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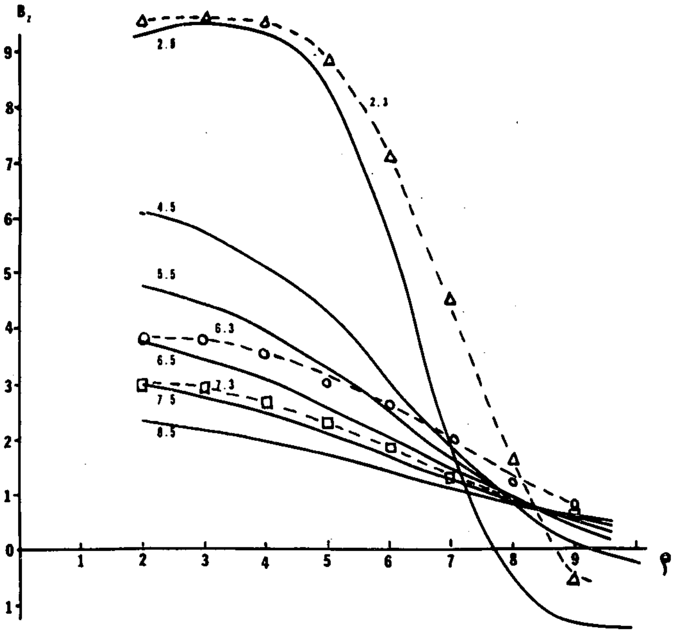

Fig. 1. Spatial variation of the peak axial component B_z of the magnetic field of a current loop, for $I=120$ amperes, peak; $R=6.5$ cm; $\omega=1.7\times10^8$. The distances in centimeters from the current loop are noted for each curve. The dashed curves are experimentally determined ones.

The zeroth-order approximation of the vector potential and the coulomb gauge $\nabla A=0$ was used in the derivation. The resulting expressions for B_ρ and B_z are

$$B_\rho(z,\rho)=\frac{2I}{c}\frac{z}{\rho}\left[(a+\rho)^2+z^2\right]^{-1/2}\left[-K(m)+\frac{a^2+\rho^2+z^2}{(a-\rho)^2+z^2}E(m)\right]$$

$$B_z(z,\rho)=\frac{2I}{c}\left[(a+\rho)^2+z^2\right]^{-1/2}\left[K(m)+\frac{a^2-\rho^2-z^2}{(a-\rho)^2+z^2}E(m)\right]$$

as given in the literature. That for E_ϕ is

$$\left|E_\phi(z,\rho)\right|=\frac{\omega}{c}\frac{2I}{c}\frac{1}{\rho}\left[(a+\rho)^2+z^2\right]^{1/2}\cdot\left[\frac{a^2+\rho^2+z^2}{(a+\rho)^2+z^2}K(m)-E(m)\right].$$

where K and E are the complete eliptical integrals and the coordinates are shown in Fig. 5. All other components of E and B are zero.

Figs. 1, 2, and 3 show plots of these equations for a peak current $I=120$ amperes and a coil radius $R=6.5$ cm, and $\omega=1.7\times10^8$ ($f=27$ MHz). The values of I and R were chosen by fitting the results of measurements of the magnetic field on a unit [1] using a single-turn 1-cm² search coil and a Tektronix oscilloscope (Type 549 with Type 1A2 plug-in unit).

Energy Absorption

In addition to the electric and magnetic field strength the power absorbed by tissue is of interest. This has been discussed for various treatment-head configurations by Schwan [3] and Pätzold [4]. In our case, for a total time-averaged radiated power of approximately 40 watts, as measured by absorbing it in a matched single-turn load connected to a calibrated RF meter, the power absorbed by successively more distant parallel flat cylinders of physiological saline solution was measured. The results are given in Fig. 4 and indicate the rapid decrease in power absorption with distance from the treatment head. From this one can estimate that the maximum power absorbed by a patient, with the treatment head placed on the abdomen, is of the order of 20 watts or 3000 calories for a ten-minute treatment at a setting 600-6 corresponding to a nominal total power level of approximately 40 watts.

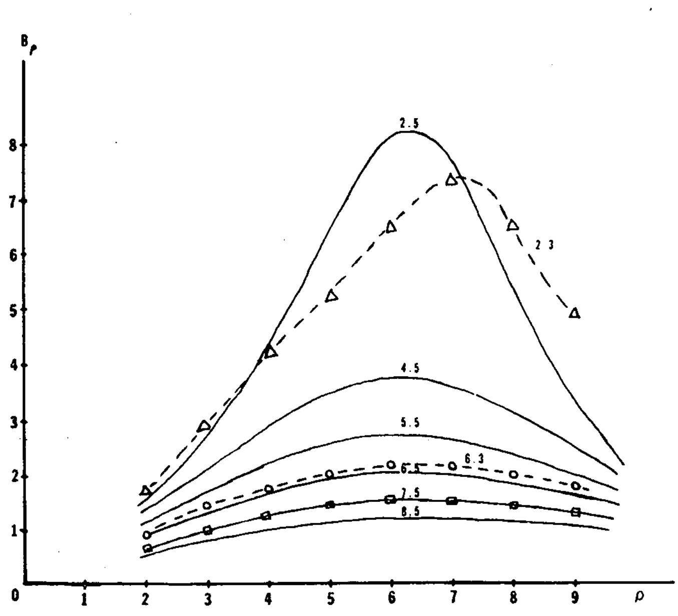

Fig. 2. Spatial variation of the radial component B_ρ of the magnetic field. Details are identical to Fig. 1.

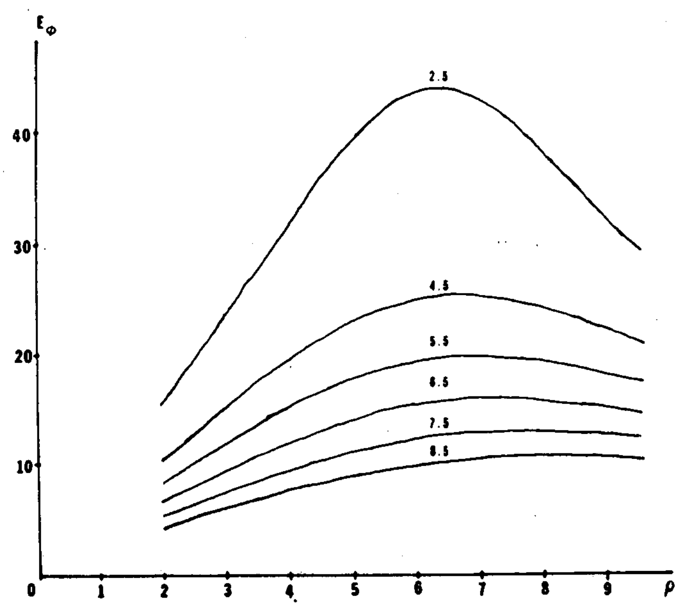

Fig. 3. Spatial variation of the azimuthal component E_ϕ of the electric field ($E_z=E_\rho=0$). Details are identical to Fig. 1.

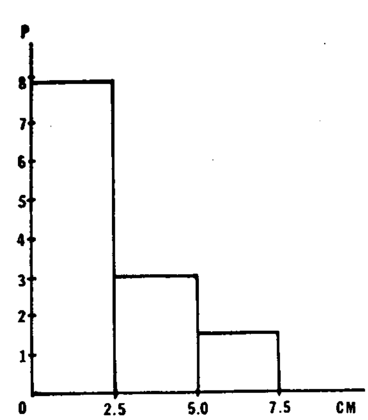

Fig. 4. Power P in watts, absorbed by physiological saline cylinders of 17.5-cm diameter, 2.5-cm thickness at different distances from the treatment head.

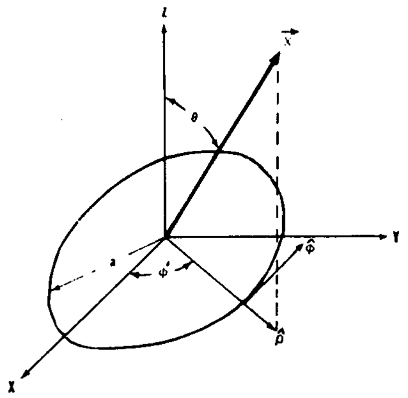

Fig. 5. Coordinate axes as used in the derivation.

Conclusions

The results describe the field and energy values for a pulsed power unit. The magnetic field reaches a maximum of about 10 oersteds peak, the electric field one of about 45 volts per cm peak during the 70 μs of the "on" period of the pulses, which at their maximum repetition rate recurs every 1600 μs. It is estimated that about half of the resulting time-averaged power output of 40 watts of the unit can be absorbed in a treated patient because of the electrical conductivity of the tissue exposed to the high electric field near the treatment head. This is true even though a 27-MHz plane wave would be transmitted through a person with only minor attenuation.

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References

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[4] J. Pätzold, "Physikalische gesetzmabigkeiten der energieverteilung bei den verschiedenen, in der warmetherapie angewandten hochfrequenzmethoden," *Ultraschall in Medizin und Grenzgebieten*, vol. 9–II pp. 43–52, 1956.