ELECTROMAGNETIC ENERGY DEPOSITION IN AN INHOMOGENEOUS BLOCK MODEL OF MAN FOR NEAR-FIELD IRRADIATION CONDITIONS

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Summary

The plane wave spectrum approach is used to calculate the electromagnetic energy absorption and its distribution in a 180-cell, inhomogeneous model of man for a prescribed vector electric field generated by RF sealers and other electronic equipment. The whole-body-averaged absorption density increases approximately as $(\Delta/\lambda)^2$ to the asymptotic plane wave value where Δ/λ is the width in wavelengths of the best-fit half-cycle cosine function to prescribed $\vec{E}$-values.

Introduction

A great deal of progress has been made in the quantification of electromagnetic absorption by humans under plane wave irradiation conditions. However, to date, little work has been done with near-field exposure conditions which are of greater concern to workers involved in the operation of electromagnetic radiation equipment for communications, radar, and industrial and biomedical applications. Electromagnetic fields near several pieces of high-power industrial equipment have been measured and found to be fairly intense, with electric fields as high as 500-2000 V/m for 27.12 MHz RF sealers.

In many near-field problems, the sources are loosely coupled to the human operator, and it is this class of problems that we have solved in the first instance. Important examples of this are the leakage fields from RF sealers and microwave ovens.

Procedure

The 180-cell block model of man[1] illustrated in Fig. 1 has been used for all calculations. Anatomical drawings[2,3] were used to determine the contents of each cell and its volume-weighted complex permittivity was calculated using measured values for various tissue types.[4-6]

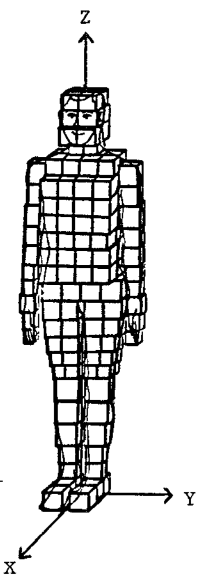


Fig. 1. Coordinate system and geometrical arrangement.

Input required for the computations is the calculated or measured leakage electric fields over a plane (Y-Z plane in Fig. 1) just in front of the intended location of the target. The prescribed incident electric fields (E_y and E_z) can then be used to calculate the remaining field components in the case of N-polarization (H_x, E_y, H_z nonzero) or P-polarization (E_x, H_y, E_z nonzero).

The plane wave spectrum approach of Booker and Clemmow[7,8] used earlier by us[9] with lossy semi-infinite slab models is used here with the block model. In order to use plane wave decomposition based on Fourier analysis, the prescribed fields are repeated with a spatial period that is considerably larger than the widths over which the fields are prescribed and also larger than 2-3 wavelengths to prevent interference from the fictitious sources. Implementation of the computationally-efficient fast Fourier transform and inverse fast Fourier transform has allowed usage of as many as 2^{12} or 4096 component plane waves. Many of these plane waves are evanescent (decaying with distance from the Y-Z plane). The incident electric field at each cell centroid is calculated by allowing for propagation of the plane waves from the Y-Z plane.

The method of moments[1,10] is used to calculate the electric fields in the various cells of the model from the incident electric fields. At each frequency, for both N- and P-polarizations, it is only necessary to perform one expensive L-U matrix factorization.[11] Thereafter the stored factors may be used to obtain inexpensive solutions for different incident fields.

Results of Numerical Calculations

A 1-D field variation is assumed and fields are taken to be invariant for the y-direction. This limitation will be avoided in future calculations.

Most of the calculations performed to date pertain to the case of P-polarization at 27.12 MHz. The fields measured* by BRH/OSHA personnel for an RF sealer have been used for a realistic example. The measured values of the magnitude of E_z are plotted in Fig. 2 along with a piecewise cubic spline fit to the data points. Figure 3 shows measured values of E_x as well as values generated from E_z in our computations. Zero phase difference was assumed between the various measured values of E_z in preparing Fig. 3. Figure 4 was obtained by assuming a phase difference in E_z (less than 37°) based on difference in retarded time for propagation from the center of the prescribed distribution. A closer agreement of calculated and measured values of E_x is evident in Fig. 4, suggesting that phase measurement is required (as well as a larger number of data points) in future field specifications. The calculated values of energy deposition for the fields with and without phase information are shown in Figs. 5 and 6, respectively. Also shown in these figures are the values calculated for a free-space plane wave field with a peak electric field of 826.8 V/m corresponding to the maximum electric field measured from this sealer. A whole-body-

* Robert Curtis, OSHA -- personal communication.

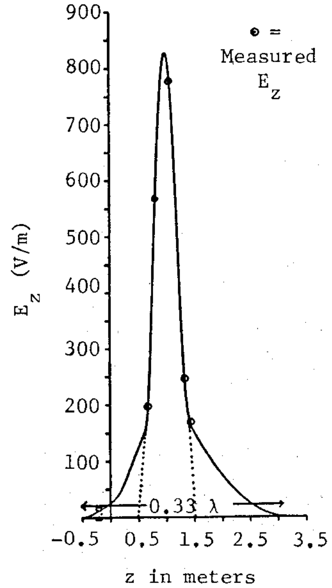


Fig. 2. Prescribed field E_z from a 27.12 MHz RF sealer.

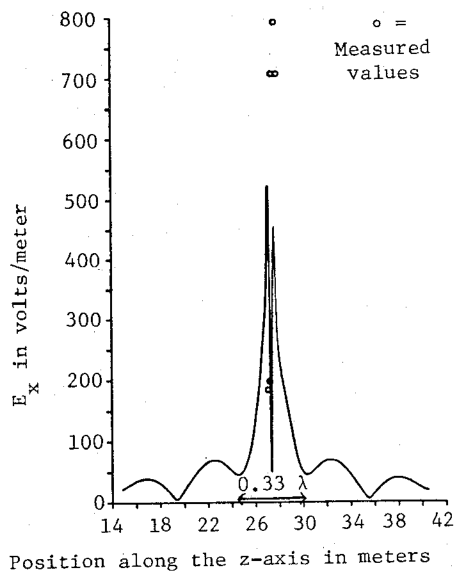


Fig. 3. Electric field E_x for a 27.12 MHz RF sealer calculated from E_z, assuming zero phase difference between the various values of E_z.

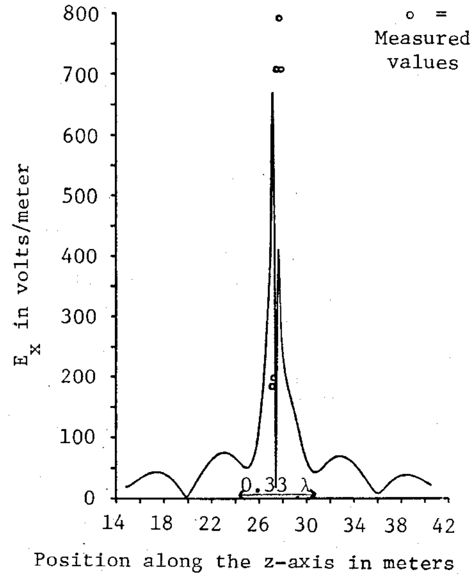
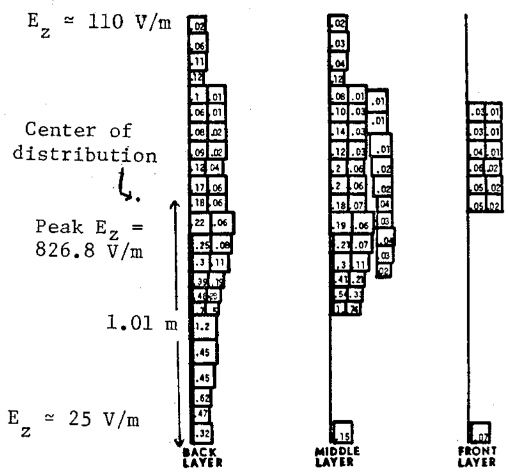


Fig. 4. Electric field E_x for a 27.12 MHz RF sealer calculated from E_z, assuming a relative phase difference $0 < \phi < 37°$ between the various values of E_z.



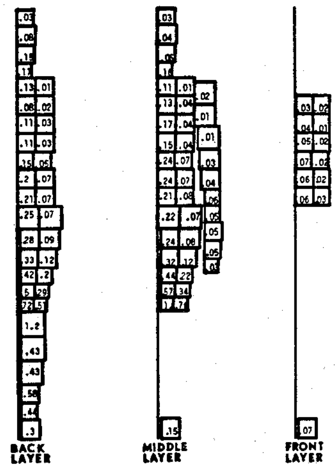
The numbers indicated are in watts/kg. The numbers in parentheses are for normal planewave irradiation.

Whole-body average:	0.16 (1.22)	Neck:	0.12 (1.9)
Torso:	0.08 (0.68)	Leg:	0.38 (2.5)
Head:	0.05 (0.79)	Arm:	0.02 (0.17)

Fig. 5. Distribution of energy deposition in the block model of man placed in the leakage field of a 27.12 MHz RF sealer, assuming a zero phase difference in the incident field E_z; peak E_z = 826.8 V/m.

average energy deposition on the order of 13-14 percent of the plane wave value is calculated for the prescribed fields. It is interesting to note that the inclusion of the relative phase causes very little difference (less than 7 percent) in the whole-body-averaged values of energy deposition. The relative unimportance of phase is attributed to the frequency being so low that the wavelength is considerably larger than the length of the target. It is felt, however, that the phase is likely to be important at higher frequencies and should be measured when prescribing the incident fields.

From Fig. 2 it is apparent that for many real-life near-field situations, it may be possible to approximate the fields by a single half-cycle cosine function. Such an approximate field variation is shown dotted in Fig. 2 and covers a width Δ of 1 meter. In order to allow an approximate calculation of electromagnetic absorption for real-life problems, the energy deposition for fields with half-cycle cosine variation, with $0.003 \leq \Delta/\lambda \leq 2$, has been calculated and is plotted in Figs. 7 and 8 for 27.12 and 77 MHz, respectively. The higher frequency of 77 MHz is used to correspond to the whole-body resonance frequency for this block model[1] of man. An important point to note in Figs. 7 and 8 is



The numbers indicated are in watts/kg. The numbers in parentheses are for normal planewave irradiation.

Whole-body average:	0.17 (1.22)	Neck:	0.16 (1.9)
Torso:	0.09 (0.68)	Leg:	0.38 (2.5)
Head:	0.07 (0.79)	Arm:	0.03 (0.17)

Fig. 6. Distribution of energy deposition in the block model of man placed in the leakage field of a 27.12 MHz RF sealer, assuming a relative phase difference $0 < \phi < 37°$ in the incident field E_z; peak $E_z = 826.8$ V/m.

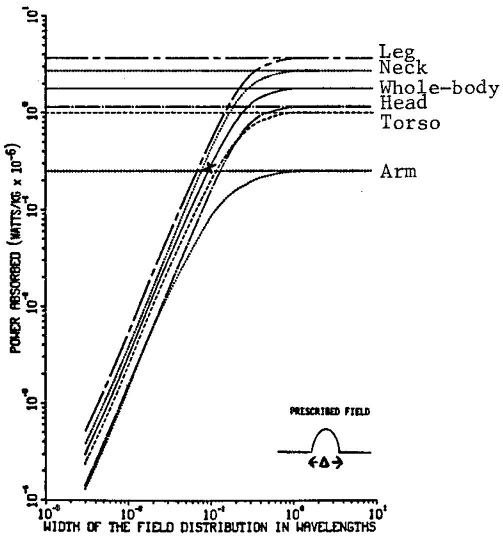


Fig. 7. Average whole- and part-body energy deposition in the block model of man placed in front of a half-cycle cosine field E_z with P-polarization; frequency = 27.12 MHz, $E_z|_{max} = 1$ V/m.

that the whole-body-averaged dose increases approximately as $(\Delta/\lambda)^2$ to the asymptotic plane wave value in each case. For each of the two frequencies used so far, the values of energy deposition for field distribution widths Δ on the order of 1.5-1.8 times the height of the target are given reasonably accurately by the plane wave values.

We have used a cross in Fig. 7 to show the whole-body-averaged dose corresponding to an approximate width Δ of one meter as indicated by dotted lines in Fig. 2. The one-meter width, corresponding to $\Delta/\lambda = 0.09$, corresponds to a dose of 0.18 W/kg calculated on the basis of a half-cycle cosine distribution, which

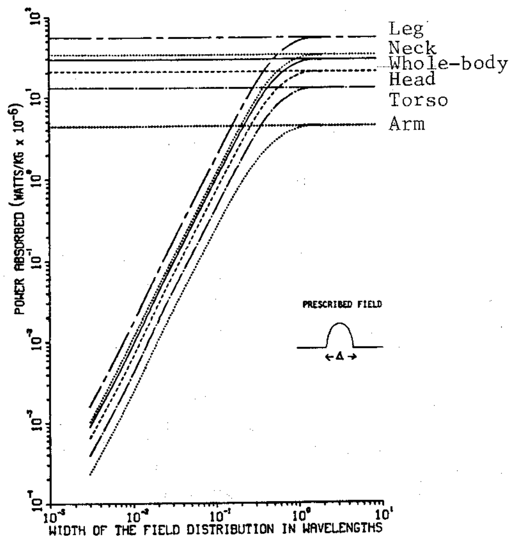


Fig. 8. Average whole- and part-body energy deposition in the block model of man placed in front of a half-cycle cosine field E_z with P-polarization; frequency = 77 MHz, $E_z|_{max}$ = 1 V/m.

compares reasonably well with the value of 0.16 W/kg (see Fig. 5) obtained from exact calculations. While exact calculations based on measured values may be necessary for some cases, it may be possible to use the half-cycle cosine approximation in many instances.

The computations will be extended to include N- as well as P-polarizations. Also, more detailed measurements of leakage fields around RF sealers will be obtained in cooperation with BRH and OSHA personnel, and results similar to those above will be presented. A computer program will be made available for the calculation of energy absorbed by the inhomogeneous block model of man in the near-field of an arbitrary leakage source. The only input required will be the prescribed distribution of $\vec{E}$.

Experiments are presently under way to confirm the highlights of the numerical results. The approach being taken is to use a frequency of 330 MHz (using a 50-W MCL model 15122 power generator) with a proportionately scaled 16" figurine placed in the leakage field of an open-ended parallel plate line. Before placing the figurine, the leakage field will be monitored using the BRH implantable field probe. The experimental results will be compared to those obtained numerically at 77 MHz.

Finally, we are considering the problem of man on a conducting ground plane, using the work done previously by Hagmann, et al.[12] Results of these calculations will also be presented.

Acknowledgment

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