IV. Conclusions

We have presented an analysis and experimental results of a 180° hybrid. This hybrid has been realized on alumina substrate. It has a bandwidth of 3 GHz over the 4–8-GHz band with a loss of 0.5 dB, an isolation of >18 dB, and a phase unbalance of ±7°. The hybrid reported here is compatible to monolithic integration on GaAs substrates.

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An Empirical Relationship for Electromagnetic Energy Absorption in Man for Near-Field Exposure Conditions

I. CHATTERJEE, M. J. HAGMANN, AND O. P. GANDHI

***Abstract*—An empircal relationship is presented for the whole-body-average electromagnetic energy absorption in a 180-cell block model of man for near-field exposure conditions. Consideration is restricted to near fields with *P* polarization (no component of *E* directed arm-to-arm) in which the magnitude of the incident electric field is maximum immediately in front of the abdominal region. A highlight of this work is the considerably reduced whole-body average energy absorption for near-field partial-body exposures as compared to that obtained under plane-wave irradiation conditions.**

I. Introduction

The plane-wave spectrum approach [1] has previously been used [2] to calculate the mass-normalized electromagnetic energy absorption (specific absorption rate or SAR) and its distribution for prescribed near-field exposure conditions. This method is particularly suited for leakage-type near fields such as those from RF heat sealers and other electronic equipment where the coupling back to the source may be neglected. For the numerical calculations, a 180-cell block model of the 50th percentile man [3] has been used.

The procedure developed previously can be used for any incident fields with tangential components prescribed over a plane. We have restricted most of our calculations to fields prescribed over a vertical plane just in front of the feet of the block model. Since the fields emanating from many localized sources are likely to roll off monotonically to negligible values in the two dimensions of the plane, the calculations have been performed for prescribed electric fields having a half-cycle cosine variation along both the vertical and horizontal axes. For several test cases, it has been shown that such approximated fields give whole-body SAR's that are within 5–10 percent of the values that would have been obtained from exactly prescribed fields, [2]. For each set of prescribed fields, the remaining field components (body-normal $\boldsymbol{E}$ component and $\boldsymbol{H}$) may be obtained from Maxwell's equations.

The phase variation of the prescribed fields is important for exact calculations of SAR. It has, however, been shown [2] that the worst case (maximum whole-body SAR) is always obtained for constant phase in the prescribed fields. We have assumed no phase variation in the prescribed fields in order to avoid the need for phase measurements and thereby have obtained an upper bound for values of whole-body SAR. Since the whole-body SAR would also be a function of the height of the maximum of the prescribed E-field relative to the block model, various placements have been considered. Except at frequencies corresponding to strong part-body resonances, the condition for maximum whole-body SAR corresponds to the case where the peak of the prescribed field is located in front of the abdominal region. Consequently the empirical equation is applied for this placement for different values of physical extent of the assumed vertical electric fields, the accompanying $\boldsymbol{E}$ and $\boldsymbol{H}$ components being given by Maxwell's equations. We have considered only P polarization (no component of E directed arm-to-arm) for the prescribed fields since it produces greater absorption than N polarization ($\boldsymbol{E}$ arm-to-arm) at frequencies below 300 MHz [4]. Also, for currently encountered RF sealers identified as sources of significant leakage fields [5],[6], the vertical component of $\boldsymbol{E}$ (E_v) is much larger than the horizontal component (E_h). It is recognized that the SAR due to E_h may be comparable to that due to E_v for frequencies above 300 MHz. For these frequencies, the contribution of E_h to the SAR should also be included in the calculations for near-field electromagnetic energy absorption. Nevertheless, there are a number of applications where the vertical component E_v may indeed be much larger than the arm-to-arm directed field E_h. The empirical equation is useful for such cases even at frequencies above 300 MHz.

II. Effect of Placement of the Body Relative to Fields

As previously mentioned, whole-body SAR is a function of the height of the maximum of the prescribed E fields relative to the block model. Calculations of SAR were made for assumed half-cycle cosine variations with $\Delta_v = 0.2\ \lambda$ and $\Delta_h = 0.5\ \lambda$, where Δ_v and Δ_h are, respectively, the vertical and horizontal widths of the best fit half-cycle cosine functions to the prescribed leakage fields, and λ is the free-space wavelength. These results are given in Table I for various relative placements of the fields and the body for four different frequencies. The frequencies in Table I were selected to correspond to those used for RF heat sealers and to resonant frequencies for the whole body, the arm, and the head [7], [8]. The physical extents Δ_v and Δ_h of the fields were taken to be similar to those commonly encountered for RF sealers. From Table I one can see that the condition for maximum whole-body

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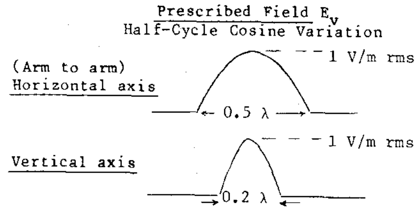
TABLE I

CALCULATED WHOLE-BODY-AVERAGE SAR AT VARIOUS FREQUENCIES AS A FUNCTION OF THE HEIGHT OF THE (SPATIAL) MAXIMUM OF THE PRESCRIBED E FIELDS RELATIVE TO THE BLOCK MODEL



Location of the Maximum E_v Above the Feet (meters)	SAR in W/kg x 10^{-6}			
	27.12 MHz (RF Sealers)	77 MHz (Whole-body Resonance)	150 MHz (Arm Resonance)	350 MHz (Head Resonance)
0.50 (knees)	1.32	3.66	0.82	0.08
0.83 (gonads)	1.52*	5.34	0.86	0.08
1.01 (abdomen)	1.42	5.44*	1.52	0.09
1.29 (shoulders)	1.06	3.60	2.00*	0.11
1.64 (eyes)	0.54	1.72	0.54	0.20*

* Condition for maximum whole-body absorption.

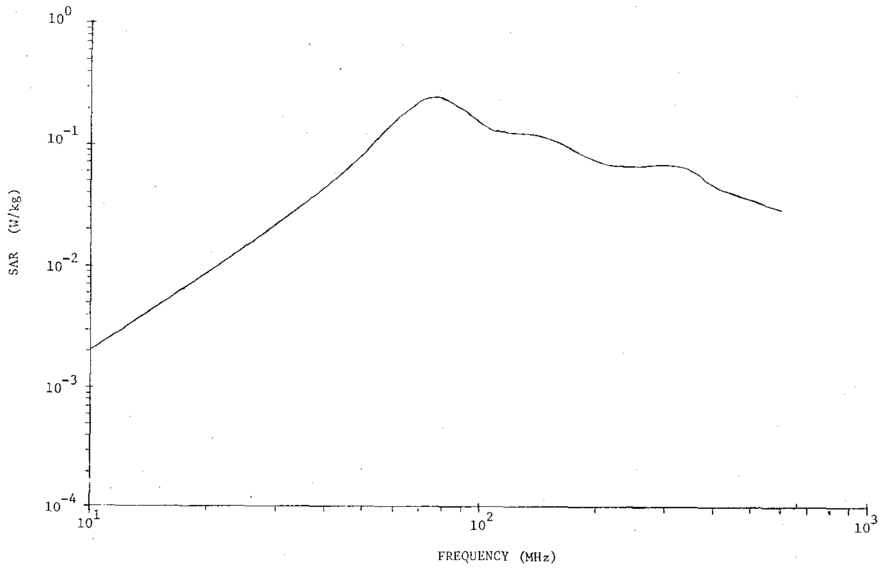


Fig. 1. Whole-body-average SAR (in W/kg for 1 mW/cm^2 incident energy density) for man in free space [3]. Multiply by 3770 for W/kg with 1 V/m rms incident field.

absorption at 27.12 MHz occurs when the maximum of the electric field corresponds to the center point of the 1.75-m tall block model (the gonadal area), with a close second when the peak is located in front of the abdominal area. As expected, the condition for maximum whole-body absorption at the arm and head-resonant frequencies is that the height of the maximum in the prescribed field is in front of the respective resonant regions of the body. We have restricted our calculations to the case where the maximum of E_v is located at the height of the abdominal region because this is the one commonly encountered in practice.

III. THE EMPIRICAL EQUATION

The procedure used for calculating the SAR in the 180-cell block model of man has been detailed in a previous paper [2]. There it was observed that for frequencies between 27.12 and 350 MHz, the dependence of whole-body-average SAR on the physical extents of the near field at a fixed frequency is approximately $(\Delta_v^2 \Delta_h^2 / \lambda^4)$ for small values of Δ_v and Δ_h. A general empirical relation for near-field whole-body-average SAR which has this behavior and reduces to known far-field values for wide field distributions is

$$\mathrm{SAR}|_{\text{near field}} = \frac{\mathrm{SAR}|_{\text{far field}}}{\left[1+\left(\dfrac{A_v}{\Delta_v}\right)^2\right]\left[1+\left(\dfrac{A_h}{\Delta_h}\right)^2\right]}. \quad (1)$$

In (1), the SAR for far fields ($\Delta_v, \Delta_h \rightarrow \infty$) is shown in Fig. 1 at various frequencies [3]. Empirical equations previously given for far-field exposure conditions [4], [9] may be used in lieu of Fig. 1.

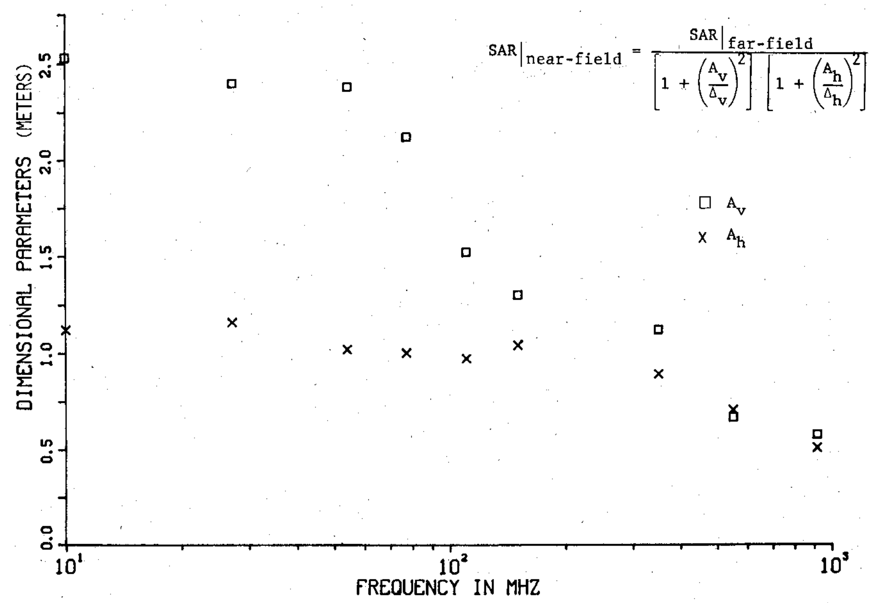


Fig. 2. Dimensional parameters for the near-field empirical relationship.

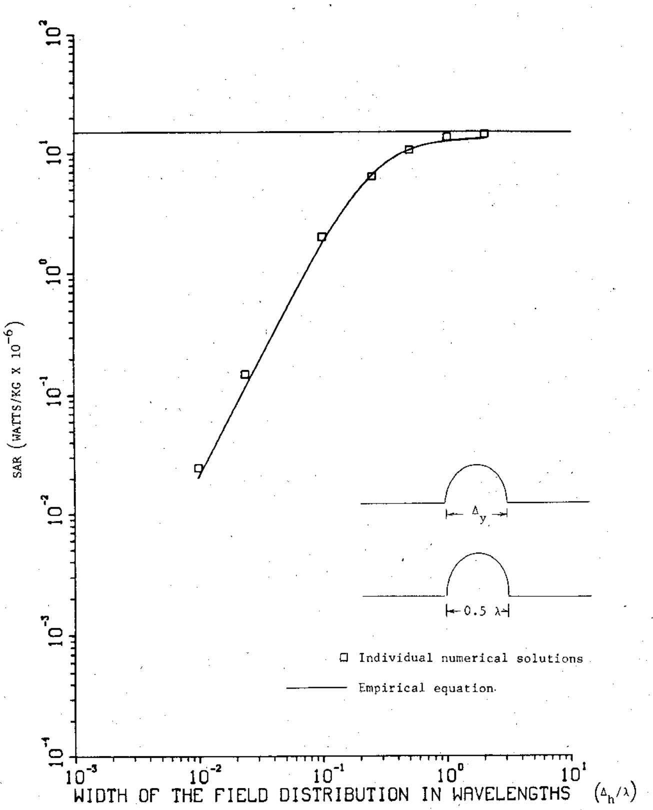


Fig. 3. Comparison of exact numerical solutions with those obtained from the empirical equation. Frequency = 77 MHz. Spatial maximum in vertical electric field = 1-V/m rms. $\Delta_v = 0.5\lambda$. The solid horizontal line indicates the value of SAR for $\Delta_y = \infty$.

The dimensional constants A_v and A_h have been obtained by matching to the asymptotic behavior of the numerical calculations of SAR for the block model at very low values of Δ_v and Δ_h. The values of the dimensional constants A_v and A_h so obtained are plotted in Fig. 2 for nine frequencies from 10 to 915 MHz.

The validity of (1) has been tested by comparing the SAR values so calculated with those obtained for several solutions with intermediate values of Δ_v and Δ_h at 27.12, 77, and 350 MHz. This is illustrated in Fig. 3 for the whole-body resonant frequency of 77 MHz. At this and the other chosen frequencies, good agreement was found, thus giving credence to the usefulness of the empircal equation.

From Fig. 2, it can be seen that the dimensional parameters A_v and A_h are relatively constant for frequencies below whole-body resonance. The values of A_v and A_h are approximately 2.5 and 1.1 m, corresponding to 1.4 times the height and 2.1 times the width of the man model, respectively. From (1) it is seen that for field distributions considerably broader than the physical dimensions of the target ($\Delta_v \gg 1.75$ m, $\Delta_h \gg 0.53$ m), the SAR corresponding to far-field values is obtained. For physical extents Δ_v and Δ_h of the near fields much less than A_v and A_h, the SAR for near-field irradiation conditions is considerably lower than that for whole-body plane-wave exposures.

A slight increase in the value of A_v at the head resonant frequency is ascribed to the shift of the maximally absorbing region to the head and the slight increase in A_h at the arm resonant frequency is ascribed to the shift of the maximally absorbing region to the arms. Somewhat larger values of Δ_v and Δ_h, respectively, are therefore needed to obtain a comparable SAR as a fraction of the far-field value.

IV. Example of the Use of the Empirical Equation

To illustrate the method of using the empirical equation, we consider the E_v measured in front of a 27.12-MHz RF sealer[1] (see Fig. 4). For a best fit half-cycle cosine function, the width Δ is twice the separation between points with fields that are given by 0.707 times the maximum value (the half-power points). The maximum value measured for E_v is 550 V/m. The half-power points, where the field magnitude is $0.707 \times 550 = 389$ V/m, are located 0.51 m apart (Fig. 4) so that $\Delta_v = 2 \times 0.51 = 1.02$ m. Since there were not enough data to specify the horizontal variation of E_v, Δ_h was assumed to be infinite, which would give an upper bound on the SAR. Using (1), the whole-body-average SAR is calculated to be 0.165 W/kg. This compares remarkably well with 0.164 W/kg calculated from exact numerical calculations using the plane-wave spectrum method [2].

[1]Robert Curtis, personal communition.

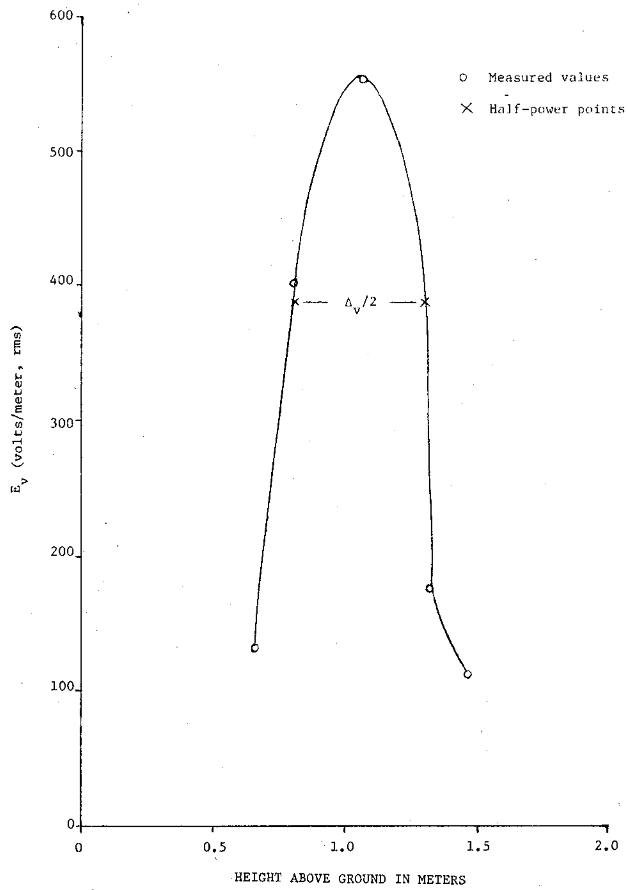


Fig. 4. Measured values of the vertical electric field component E_v from an RF sealer and application of the empirical equation.

V. Conclusions

An empirical relationship has been presented giving the whole-body-average SAR for a 180-cell block model of man exposed to near fields which roll off monotonically to negligible values in the vertical and horizontal direction over a plane tangent to the feet of the block model. The physical extents in the vertical and horizontal directions of the best fit half-cycle cosine functions to the vertical electric field component are required for use in the empirical relationship. These extents are equal to twice the distance between the half-power points on the two respective axes. Measurements of leakage fields from industrial RF heat sealers have shown that such fields are closely approximated by the best fit half-cycle cosine functions, as we have shown in an example. Numerical results have been presented to support the validity of the empirical relation. Experimental results supporting the results predicted by the empirical equation will be presented in a forthcoming paper. A highlight of this work is the considerably reduced whole-body-average SAR for near-field partial-body exposures as compared to the plane-wave irradiation conditions.

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An Easy Tunable Stepped Coupled Lines Filter

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***Abstract*—A stripline bandpass filter setup consisting of two stepped coupled lines is presented, with special emphasis being given to practical realization. The theoretical design of the filter is based on the known synthesis of directional couplers and is outlined briefly. Practical setup of the filter, together with a simple tuning mechanism, is described in detail. Measurements performed show good agreement with theoretical results.**

I. Introduction

On microwave filters consisting of parallel-coupled lines, a lot of literature has been written [1]. By contrast, a line filter as shown in Fig. 1 will be described in the following which is composed of two symmetrical stepped coupled TEM-mode transmission lines. Both lines have the same characteristic impedance Z_0 and are both short circuited at one end.

II. Synthesis

In accordance with [2], the design of such filters may be based on the synthesis of directional couplers [3]. According to [2], the two design methods just differ in one point, namely the odd polynomials $U_N(x)$ to be calculated which have different curves and extremes.

For the squared magnitude of the complex transmittance $\underline{S}_{12}$ of the filter according to Fig. 1 there applies [2]

$$|\underline{S}_{12}(x)|^2 = 4\frac{U_N^2(x)}{\left(1+U_N^2(x)\right)^2}, \qquad x = \sin 2\pi\frac{l}{N\lambda} \tag{1}$$

where $U_N(x)$ is an odd real polynomial of Nth degree

$$U_N(x) = c_1\cdot x + c_3\cdot x^3 + c_5\cdot x^5 + \cdots + c_N\cdot x^N \tag{2}$$

whose basic curve for obtaining of bandpass behavior is shown in Fig. 2.

Calculation of this polynomial according to the curve in Fig. 2 constitutes the focal problem of the synthesis and can only be

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