

INTERACTION OF ELF ELECTROMAGNETIC FIELDS WITH BIOLOGICAL BODIES

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A numerical method has been developed to quantify the interaction of ELF EM fields with biological bodies of arbitrary shapes located on the ground. Consider a biological body, such as a human or an animal, standing on the ground being exposed to an ELF electric field of angular frequency ω . The contact between the body and the ground is represented by a grounding impedance Z . Due to the nature of ELF EM fields, the impressed electric field on the body can be assumed to be locally uniform, and the body is assumed to be equi-potential. The ground effect can be taken into account by the method of image. The analysis is simplified by using the quasi-static approximation.

The first quantity to be determined is the induced surface charge $\eta(r)$ on the body, which is expressed as the unknown in the following integral equation:

$$\frac{1}{4\pi\epsilon_0} \int_{S+S_i} \eta(r') \frac{ds'}{|\vec{r}-\vec{r}'|} + \phi_0(r) = \phi_b \tag{1}$$

where $\phi_0(r)$ is the potential maintained by the ELF EM source at \vec{r} on the body surface, ϕ_b is the unknown body potential, and S and S_i are the body and image surface areas, respectively. If the total current flowing between the body and the ground is I , $\phi_b = IZ$. The current I can be related to the total charge on the body surface as

$$I = j\omega Q = j\omega \int_S \eta(r) ds' = \phi_b / Z \tag{2}$$

Equations (1) and (2) can be combined and solved numerically. To do so, the body is divided into N subareas and the induced surface charge $\eta_n(r)$ on each subarea S_n is assumed to be an unknown constant. The impressed potential on the body at the location of ΔS_n is assumed to be ϕ_{0n} which is a given quantity. The unknown induced surface charge η_n and the unknown body potential ϕ_b can be determined from the following matrix equation:

$$\begin{bmatrix} M_{11} & M_{12} & \dots & M_{1N} & -1 \\ & & & & \\ & & & & \\ M_{N1} & M_{N2} & \dots & M_{NN} & -1 \\ \Delta S_1 & \Delta S_2 & \dots & \Delta S_N & j/\omega Z \end{bmatrix} \begin{bmatrix} \eta_1 \\ \vdots \\ \eta_N \\ \phi_b \end{bmatrix} = \begin{bmatrix} \phi_{01} \\ \vdots \\ \phi_{0N} \\ 0 \end{bmatrix} \tag{3}$$

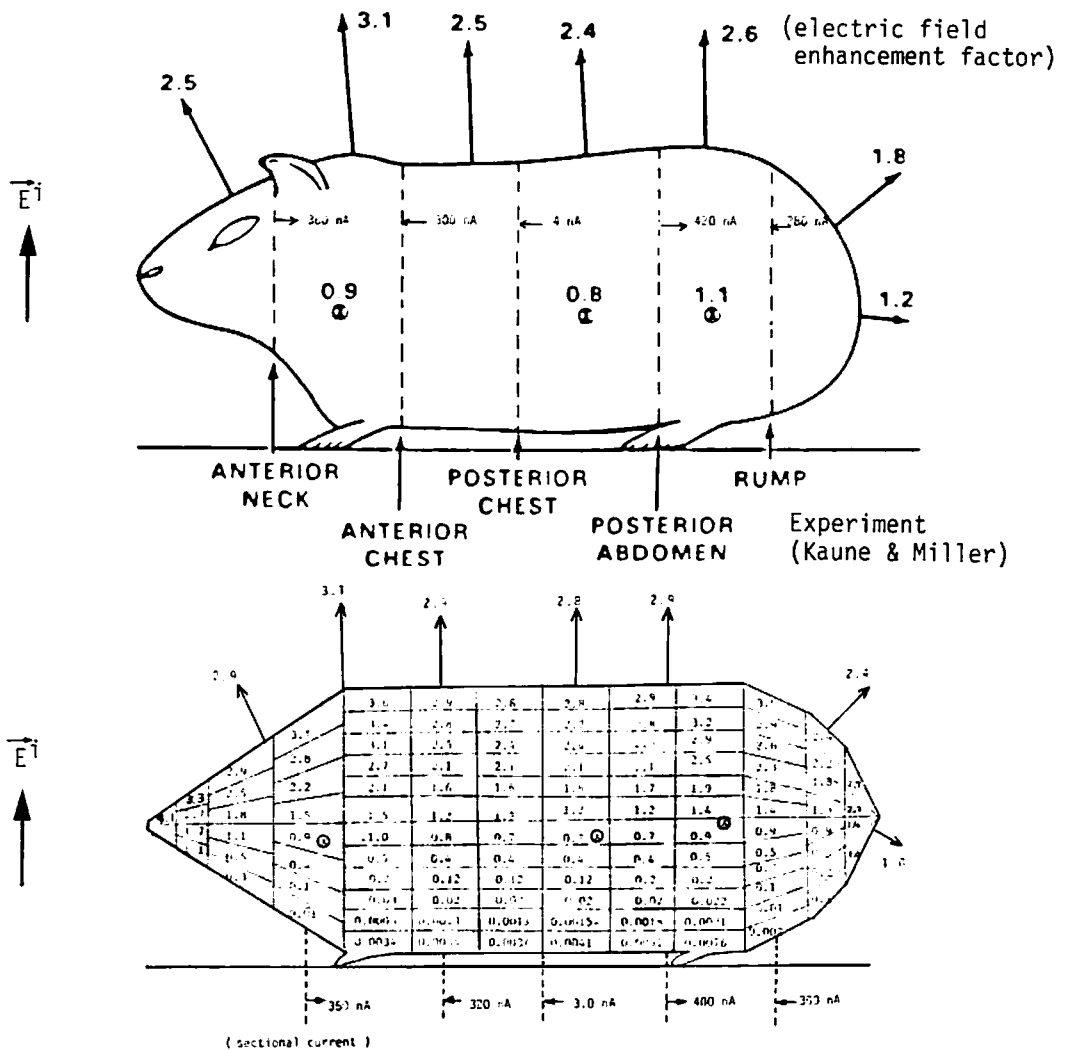
where the matrix element M_{nm} represents the potential at ΔS_n due to the induced surface charge η_m at ΔS_m .

After the induced surface charge is determined, the total normal component of current flowing through a cross-sectional plane at z is determined from

$$I_z = j\omega \int_{S_z} \eta(r) ds' \quad (4)$$

where S_z is the portion of the body surface area above the cross-sectional plane Z . For a slender body the current density at the cross-section can be approximated by $J = I_z/A_z$ where A_z is the cross-sectional area at z . The induced electric field E inside the body is found from J_z/σ where σ is the body conductivity.

The present method was used to quantify the interaction of the 60Hz electric field with a guinea pig, and the computed theoretical results are compared with the experimental results of Kaune and Miller [BEM, 5:361-364, 1984] as shown in Fig. 1. The agreement between theory and experiment is excellent. The quantities of interest include (1) the induced surface charge and electric field enhancement factor, (2) the short-circuit currents and sectional currents, and (3) induced current density and electric field inside the body. The present methods was also used to compute the induced electric field on the body surface and the induced current inside the body of a realistic model of man. Fig. 2 shows the electric field enhancement factor on the surface of such a model. Also included is the computed short-circuit current. These theoretical results agree very well with experimental and empirical results of Deno [IEEE, PAS-96:1517-1527, 1977] and Chiba et al. [IEEE, PAS-103:1895-1902, 1984]. Another interesting theoretical finding is the current flowing between the body and the ground as a function of grounding impedance which includes resistance, capacitance and inductance. It was found that when the grounding impedance is inductive, it may cause a resonance leading to a large induced body current. This may have adverse health implication.



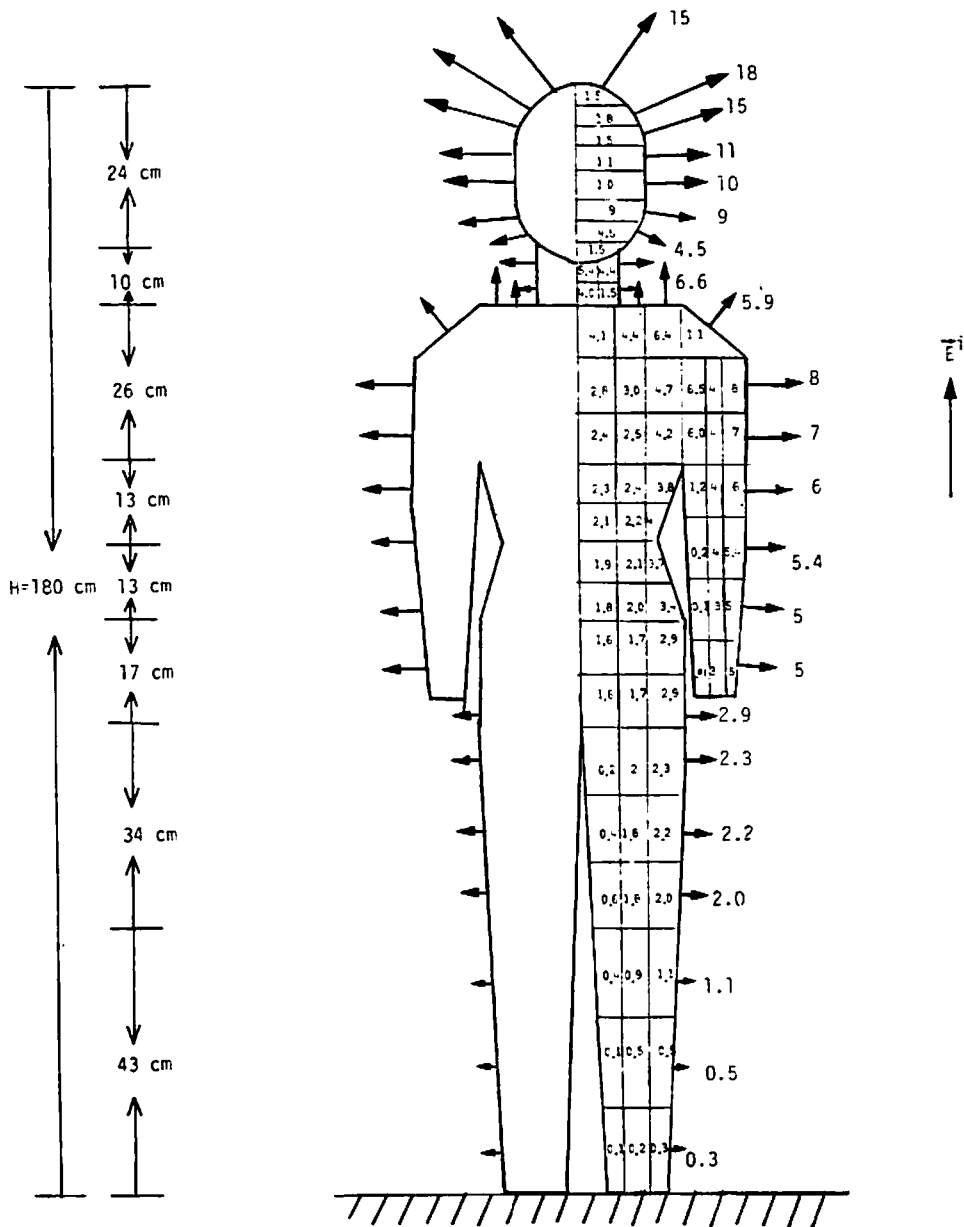
(electric field enhancement factor)

Experiment (Kaune & Miller)

Present Theory

	Surface area	I_{sc}
Experiment 1 (Kaune & Miller)	0.050 m ²	0.219 μ A/(kV/m)
Experiment 2 (Kaune & Miller)	0.053 m ²	0.225 μ A/(kV/m)
Present theory	0.048 m ²	0.212 μ A/(kV/m)

Fig. 1. Comparison of theoretical results by the present method with experimental results of Kaune and Miller on electric field enhancement factors, sectional currents and short-circuit currents for a grounded guinea pig exposed to 10 kV/m, 60 Hz electric field.



$I_{SC} = 17.5 \mu A$ (Present theory)

$I_{SC} = 18.0 \mu A$ (Based On $I_{SC} = 5.4 \cdot 10^{-9} \cdot H^2 \cdot E \cdot f / 60$
see Chiba et al.)

Fig. 2. Theoretical results on electric field enhancement factors and short-circuit current for a realistic model of man standing on the ground being exposed to 1 KV/m, 60 Hz electric field.