A Mechanism for High-Frequency Electromagnetical Field-Induced Biological Damage?

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***Abstract*—It is shown that local electrical fields up to about 100 times larger than average fields can be induced around microscopic wedge-shaped boundaries between regions with different dielectric constants likely to be present in the human body. It is pointed out that this phenomenon might explain biological effects at low radiation power levels especially in the case of low duty-cycle pulsed radiation.**

I. Introduction

It is well known that electromagnetic fields are focused by mammalian bodies so that hot spots can be developed [1]. This is essentially due to the high dielectric constant of water ($\epsilon_r \approx 60$–80 in the frequency range 0–10 GHz) together with the varying water content of different tissues. These phenomena and their implications have been extensively studied, and a large amount of literature is available on the subject; reference [1] is a recent review.

It has been suggested often that pulsed radiation of low duty cycle may be more hazardous than continuous radiation of the same average intensity, i.e., that the peak power rather than the average power is significant for certain damage inducing mechanisms. There are also experimental results which seem to support this hypothesis [2]. It is difficult, however, to explain how field-induced damages can occur at practically involved peak intensities. Below we will show, however, that microscopic wedge shaped boundaries between regions with different dielectric constants likely to be present in the mammalian body may give rise to local fields, with extension on the order of 10^{-9} m, about 100 times larger than the macroscopic fields. This means that field-induced local damages could occur at 10^4 times lower incident radiation intensities.

II. Theoretical Results and Some Possible Consequences

Consider a two-dimensional dielectric wedge immersed in a static electric field. If the applied field is parallel to the symmetry plane of the wedge and normal to the edge, the potential distribution close to the edge has the form shown in Fig. 1 (see Appendix). The static field configuration is valid also for high-frequency fields as long as the corresponding wavelength is much larger than the dimensions involved. The expressions for the potential and field distribution are given in the Appendix, where it is shown that the electric field

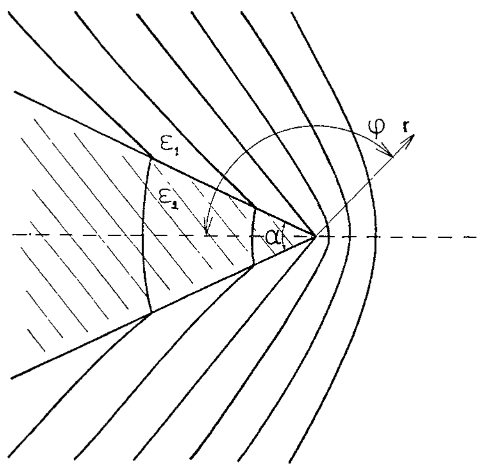

Fig. 1. A two-dimensional dielectric wedge in an electric field and the corresponding equipotential lines for the case $\epsilon_2/\epsilon_1 = 10$ and $\alpha \approx 50°$. If, instead, $\epsilon_1/\epsilon_2 = 10$, the lines in the figure are field lines corresponding to an applied field normal to the symmetry plane.

$$E \propto r^{t-1} \tag{1}$$

where t is shown as a function of the angle α with ϵ_2/ϵ_1 as the parameter in Fig. 2. The first important observation is that the electric field has a singularity at the tip ($r=0$), and that this singularity is stronger if ϵ_g/ϵ_1 is large.

The second observation is that such dielectric wedges may well occur in the mammalian body, e.g., in the form of water pockets of high dielectric constant ($\epsilon_r \approx 60$–80) in surrounding organic material with a much lower dielectric constant ($\epsilon_r \approx 3$–10). Even if such a water pocket cannot have any infinitely sharp edges, the radius of curvature of the edge may well be of molecular size, i.e., less than 10^{-9} m. If the wedge shape and the field pattern of Fig. 1 extends a few millimeters from the edge, one may put $E(r,\varphi) \approx E_a$ for $r = 3$ mm and $\varphi = \pi$, where E_a is the macroscopic field strength.

With (1) one then obtains

$$E_r(r,\pi) \approx E_a \cdot \left(\frac{3 \cdot 10^{-3}}{r} \right)^{1-t}. \tag{2}$$

For an edge with a finite radius of curvature r_0, a reasonable estimate for the maximum field should be obtained with $r = r_0$ in this expression, i.e.,

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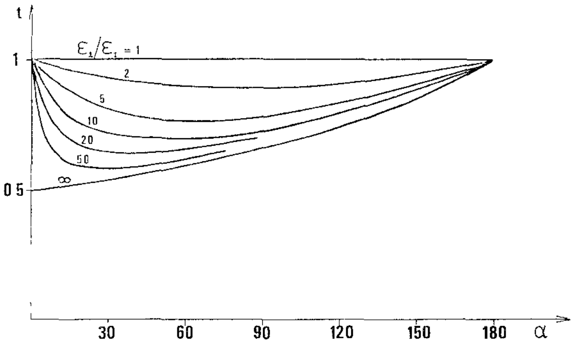

Fig. 2. Singularity parameter t as a function of wedge angle α with ϵ_2/ϵ_1 as the parameter.

$$E_{\max}\approx\left(\frac{3\cdot10^{-3}}{r_0}\right)^{1-t}E_a. \tag{3}$$

Taking the values $\epsilon_2/\epsilon_1=10$, $\alpha\simeq50°$, and $r_0=10^{-9}$ m, we get from Fig. 2 and (3)

$$E_{\max}/E_a\approx90 \tag{4}$$

which is an alarmingly high value. Even with r_0 as large as 10^{-6} m, the ratio will be higher than 10. Taking E_a to correspond to a low average incident power density of 10 W/m^2 at a duty cycle of 10^{-4}, i.e., a peak power density of 10^5 W/m^2, one obtains $E_{\max}\approx5$ kV/cm.

We have used the free-space impedance 377 Ω which overestimates the fields within the body, but this is more than compensated for by macroscopic focusing effects. We don't know if an electrical field of 5 kV/cm of such a small extension (10^{-9} m) can induce biological damages, but this possibility should be seriously considered.

It should be noted, furthermore, that the singularity is rather weak so that strong fields exist rather far from the edge. The potential difference measured from the edge in the present example is thus 4 mV at a distance of 10^{-8} m and 20 mV at 10^{-7} m from the edge. It has recently been pointed out [3] that such voltages across cell membranes of a thickness about 2.10^{-8} m may well give rise to nonthermal biological effects.

It is also of interest to estimate the possible effects of local heating. It is then necessary to compare the thermal time constant τ_{th} for the local region where the power is dissipated with the pulse duration τ_p. If the region where the power is dissipated has the spatial extension l, one has approximately

$$\tau_{th}\approx l^2\frac{C}{\kappa} \tag{5}$$

where C is the volume heat capacitivity in W·s/m^3·K and κ is the thermal conductivity in W/m·K. For water $C=4.2\ 10^6$ and $\kappa\approx0.6$. With $l=10^{-9}$ m one gets $\tau_{th}\simeq10^{-11}$ s which is much shorter than any possible pulse lengths. With $l=10^{-6}$ m, on the other hand, τ_{th} is about 10^{-5} s which is longer than typical radar pulses which often are 0.1–1 μs. In order to estimate the possible temperature rise ΔT within a region on the order of 10^{-6} m from the edge we may, therefore, calculate ΔT as the ratio between the energy dissipation per unit volume and the volume heat capacitivity C.

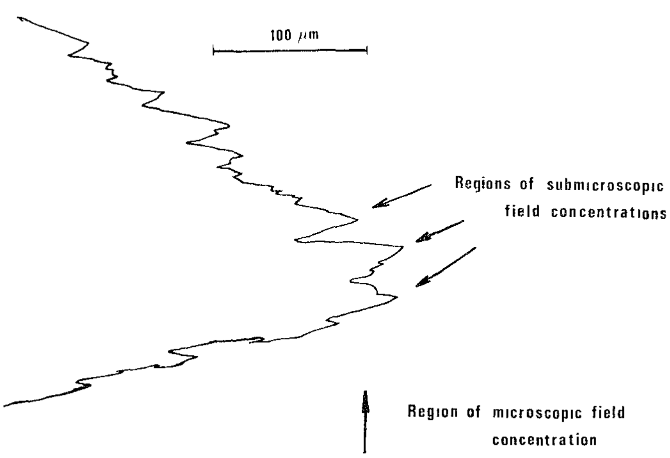

Fig. 3. Example of what a biological structure might look like.

Knowing that an incident power density of 1 W/m^2 typically may give a power dissipation in the body of 1–1000 W/m^3 (depending on many factors) one obtains for an incident peak pulse power P of 10^5 W/m^2, a ratio $E_{\max}/E_a\approx10$ and a pulse duration τ_p of $4\cdot10^{-6}$ s

$$\Delta T\approx(1-1000)\cdot P\cdot\left(\frac{E_{\max}}{E_a}\right)^2\cdot\tau_p\cdot\frac{1}{C}\approx10^{-5}-10^{-2}\ \mathrm{K}$$

which is probably too small to cause any biological effects even if the temperature gradients are large due to the small dimensions.

III. Concluding Remarks

Quantitatively we have only treated two-dimensional wedges. There is, however, no reason to believe that three-dimensional structures with sharp tips should be less dangerous. Looking at electron micrographs of different body tissues, one finds numerous structures with sharp wedges or tips. Generally, there is no information readily available about the dielectric properties of the different microstructures. It is known, however, that the relative dielectric constant of fat and bone are small, of order 3–10, depending on the frequency, e.g., [5], [6]. Wedges or tips formed by boundaries between these materials and water rich tissues, therefore, deserve special attention in this connection. (See Fig. 3.)

Appendix

In [4] the general time-dependent three-dimensional case is treated. If we restrict ourselves to the two-dimensional static case, we can simplify the problem but still get the correct behavior near the edge where we always will have a field equal to the static fields if, symbolically, $\partial/\partial r\gg2\pi/\lambda$. Thus in the two regions with $\epsilon=\epsilon_1$ and $\epsilon=\epsilon_2$, respectively, in Fig. 1, $\bar{E}=-\nabla V$ and $\nabla^2V=0$. The even solution around the symmetry plane is

$$V=\begin{cases}\Sigma a_t r^t\cos t\varphi, & |\varphi|<\alpha/2\\ \Sigma b_t r^t\cos t(\pi-\varphi), & |\varphi|>\alpha/2\end{cases}$$

$$\bar{E}=\begin{cases} -\Sigma a_t t r^{t-1}(\cos t\varphi \hat{r} - \sin t\varphi \hat{\varphi}), & |\varphi|<\alpha/2 \\ -\Sigma b_t t r^{t-1}(\cos t(\pi-\varphi)\hat{r} + \sin t(\pi-\varphi)\hat{\varphi}), & |\varphi|>\alpha/2. \end{cases}$$

Applying the boundary condition gives us equations for t and a_t/b_t

$$\epsilon_2 \tan t\alpha/2 = -\epsilon_1 \tan t(\pi-\alpha/2)$$

$$\frac{a_t}{b_t} = \frac{\cos t(\pi-\alpha/2)}{\cos t\alpha/2}.$$

The first equation gives us a number of t values. Of these we can only allow positive values since, otherwise, the stored energy will be infinite. We are also only interested in values of t less than 1 for which the fields are singular at the edge, that is

$$0<t<1.$$

This solution is shown in Figs. 1 and 2.

The solution which is odd around the symmetric plane gives an identical dispersion equation if we interchange ϵ_1 and ϵ_2. The equipotential lines in Figs. 1 are equal to the field lines in this case. Here,

$$\frac{a_t}{b_t} = -\frac{\sin t(\pi-\alpha/2)}{\sin t\alpha/2}.$$

The angle factors $\cos t\varphi$ and $\cos t(\pi-\varphi)$ divide the space in different regions with different signs of these factors. The lowest value of t gives two such regions (Fig. 1) while the second gives four regions, and so on. Thus if the field has a reasonably slow angle variation, we must conclude that a large part of it is represented by the lowest t value that is by the singular solution.

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Microwave Apexcardiography

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***Abstract*—A microwave technique for recording apexcardiograms is reported. The technique is based on detecting changes in the reflected microwaves caused by movement of the chest wall in response to left-ventricle activity. Results show that microwave technique is useful for delineating the fine structures in the precordial movement.**

I. Introduction

THE TECHNIQUE of recording the precordial movements is called apexcardiography, and the record is referred to as an apexcardiogram (ACG). The ACG represents the left-ventricular movement caused by low-frequency displacements of the precordium overlying the apex of the heart [1]–[3] and has been correlated with the hemodynamic events within the left ventricle [4], [5]. In all systems used to record ACG, either a displacement (linear) or velocity (gradient) microphone is used to convert the mechanical movement into electrical signals. It is necessary to strap or tape the microphone to the patient's chest. These systems have been found to be unreliable since a tremendous variation in sensitivity results from differing pressures applied to the skin through the microphone. The same problem is manifest even in recent designs using electrooptic sensors [6]. This paper reports the development of a low-power noncontact microwave technique for recording ACG which eliminates any change in sensitivity caused when the sensor is attached to the chest.

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II. Method and Measurement

The principle of operation of the microwave technique is based on detecting the changes in the reflected microwaves caused by the movement of the chest wall in