Heating of Biological Tissue in the Induction Field of VHF Portable Radio Transmitters

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Abstract—The results of a research project on the heating of simulated human tissue in the induction field of portable radios at VHF are summarized. The investigation was initiated because measurements made with commercially available field probes indicated that, in some cases, apparent power levels higher than 10 mW/cm^2 are incident on the operator. Two phantom models have been built for RF heating tests. The first is a parallelepiped of simulated muscle material 26 in long, 9 in wide, and 6.5 in high, topped by a 0.5 in layer of fat and bone composition. The other phantom is a human-size head and shoulders. This "dummy" is a 1/3-in thick shell of bone composition containing simulated brain material. The measurements of temperature increment due to radiation were performed with a digital thermometer having a sensitivity of 0.01°C. Temperature measurements on the parallelepipedal phantom have shown that the penetrating power densities in the simulated tissue are substantially lower than what could be expected from an incident plane wave with the same *E*-field intensity. The physical reason for this apparent discrepancy is that the strong fields of static nature emanating from a VHF helical antenna (commonly used with portable radios) are normally rather than tangentially directed to the surface of the phantom. These fields practically collapse at the air-body interface because of the high complex dielectric constant of human flesh. The results of the measurements performed on the head phantom have shown that a 6-W portable radio with a helical antenna held at 0.2 in from the operator's mouth causes very little heating of the simulated biological tissue (less than 0.1°C is highest temperature increase for one minute exposure). The maximum power density penetrating the dummy is less than 1 mW/cm^2 in the middle forehead. No detectable temperature increase is present in the immediate eye area. This is because in normal use, the eyes of the operator are exposed to the relatively low fields at the base of the antenna. A health hazard is present if the user places the tip of the antenna in the immediate vicinity of the eye (less than a 0.2-in distance) and then operates the transmitter. In this case, the possibility of damage is greatly reduced by a thick insulating cap at the tip of the antenna.

INTRODUCTION

THE HEATING OF biological tissue due to exposure to RF fields has been the topic of a large number of papers [1]-[6]. The research effort, so far, has been directed mainly to the investigation, theoretical and experimental, of the heating patterns induced by incident plane waves. The work performed by Guy [7], [8], [11] in the analysis of diathermy applicators addresses the problem of the heating patterns due to RF fields in the vicinity of the source. These RF fields, however, are transverse electric (TE) in nature and analogous to a plane wave at skewed incidence except for edge effects at the boundary of the applicator. To date, no literature has treated the problem on RF heating of tissue by the induction fields of VHF radio antennas.

A research project has been conducted in this somewhat unexplored area to gain knowledge of the heating of simulated human tissue in the induction field of a portable radio antenna at VHF. The investigation was initiated because of the growing use of portable transmitters of higher powers. Recent measurements made with field strength probes calibrated in terms of plane waves indicated that apparent power densities could in some cases exceed the 10 mW/cm^2 level, which is part of current safety standards. Previous work led to the conclusion that the actual energy transfer had to be significantly lower than indicated by such a meter due to the low total energy and very high field impedances involved. However, no substantiating measurements were available, and so this project was begun to provide both analytic and experimental data.

EXPERIMENTAL METHOD

The phantom models of human tissue have been built with the materials suggested by Guy [9]. To simulate muscle and fat at VHF (≅150 MHz), the following compositions were used (percentages are in weight):

Muscle		Fat and Bone	
H_2O	77.24 percent	Laminac 4110	85.20 percent
NaCl	.82 percent	Aluminum Powder	14.51 percent
Polyethylene Powder	13.3 percent	Acetylene Black	0.28 percent
Super Stuff[1]	8.65 percent	MEK Peroxide	7cc/2Kg

The flat surface phantom, shown in Fig. 1, is a parallelepiped of muscle material 26 in long, 9 in wide and 6.5 in high. The muscle material is topped by a layer of fat and bone composition 0.5 in thick. A simulated human head and torso, shown in Fig. 2, has been built to imitate the geometry of the human body in the immediate vicinity of the radiator. The "dummy" head has a 1/3 in thick shell of fat and bone material, which contains the simulated brain material, whose composition is similar to the muscle compound.

The measurement of temperature increment due to radiation was performed by using a digital thermometer with two thermoelectric probes (Bailey Instruments, BAT-8), as shown in Fig. 2. The instrument has a sensitivity of 0.01°C for differen-

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[1] A jelling agent, product of Whamo Manufacturing Co.

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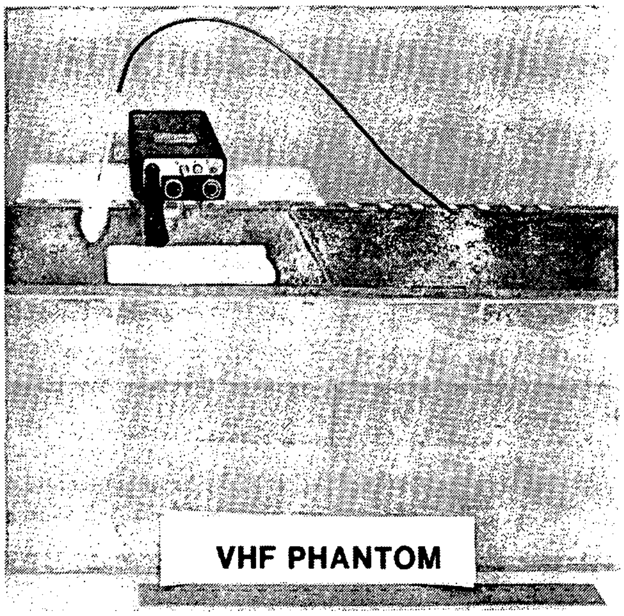


Fig. 1. Flat surface phantom.

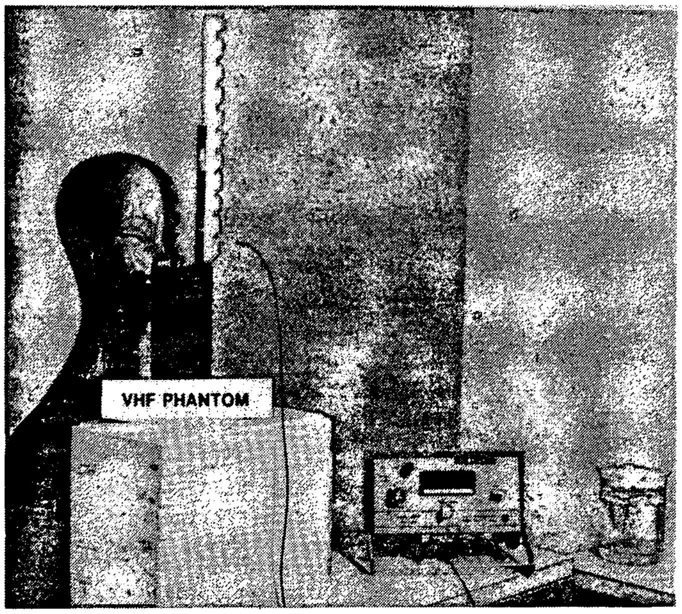


Fig. 2. Head phantom.

tial temperature measurements, and is provided with chart recorder. Small holes (1.5-mm diameter) were drilled on the phantom fat and bone layer to insert the thermoelectric probes before and after irradiation. The holes were filled with rendered animal fat to eliminate unwanted temperature transients due to the insertion of the probe. The animal fat, in addition, secured good thermal contact between the probe and the simulated human bone tissue.

The experiments consisted first of recording the temperature of the "dummy" before irradiation. Then, the simulated human tissue was exposed to the RF source (a portable radio) for an interval of time between fifteen and sixty seconds depending on the power source. At the end of exposure, the thermal probe was immediately reinserted in the dummy and the temperature increase was recorded. Typical temperature charts are shown in Figs. 3 and 4. The repeatability of the

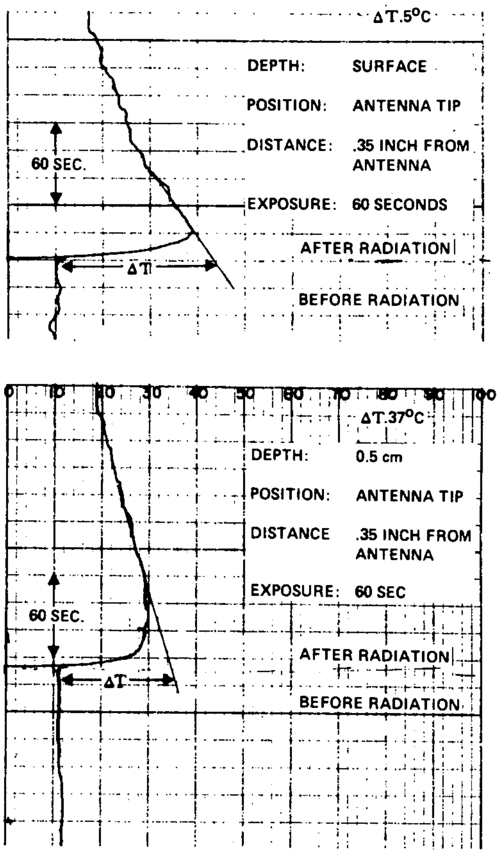


Fig. 3. Experimental data.

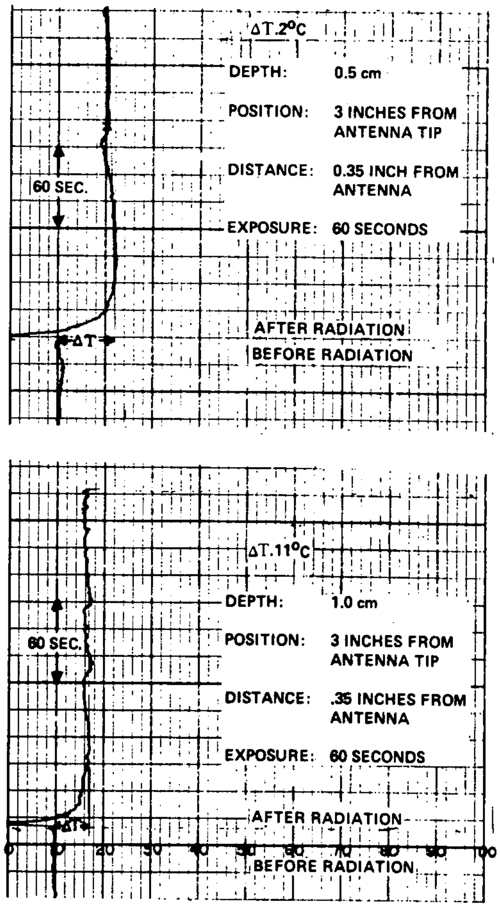


Fig. 4. Experimental data.

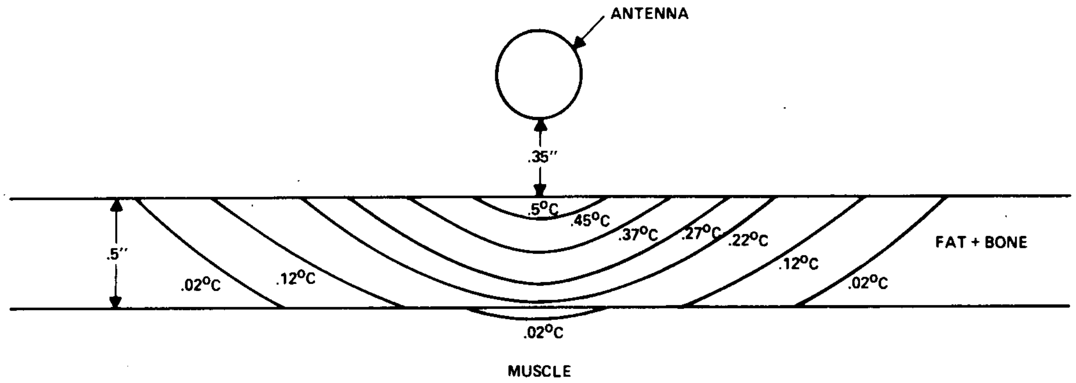


Fig. 5. Temperature profile.

measurements was excellent. Data dispersion was within ±5 percent, mainly due to ambient temperature variations.

In Figs. 3 and 4, the inserts indicate the depth of the measurement point below the flat phantom surface, the position of the point relative to the antenna tip, and the minimum distance between the antenna and the phantom. All data shown in Figs. 3 and 4 were taken along the axis of the antenna.

EXPERIMENTAL RESULTS

A great quantity of experimental data were collected during the program. Only a representative sample of typical results will be shown here. All the radios used in the experiments had 6.4 W transmitter power and helical antennas (see Fig. 2), which have near fields much stronger than quarter-wave whips.

The temperature profiles in the flat phantom give a very good measure of the penetration of the induction fields in human tissue. Fig. 5 shows the measured isotherms in the phantom in a plane orthogonal to the antenna axis and near its tip. The distance between the simulated body and the antenna is 0.35 in, producing in the phantom the strongest fields in the plane of Fig. 5. Note the large temperature gradient at the fat-muscle interface. This temperature variation shows that there is little penetration of fields in the muscle material. The highest field intensity just below the fat surface, as calculated by the temperature rise, is 6.3 V/cm, which attenuates to 4.4 V/cm just above the fat-muscle interface. The field in the muscle is 0.34 V/cm. The highest E-field in the air above the fat surface is approximately 44 V/cm, as determined by the knowledge of the relative dielectric constant of fat ($\epsilon_r = 7$). The ratio between air and muscle E-field is 130, the modulus of the complex relative dielectric constant of muscle. The electric field has been attenuated about 43 dB in passing from the air to the muscle material.

The situation is completely different for a plane incident wave. The E-field reflection coefficient is about 0.85 ($\phi \cong 180^\circ$) [10], thus giving an attenuation of 16 dB. So, the static field is attenuated 27 dB over the plane wave field. This substantially different behavior of the fields suggests that plane wave-based safety criteria would be over-restrictive for induction fields. A plane wave incident with a field intensity of 44 V/cm would have caused, for a minute exposure, a temperature rise of 7.3°C [7] in the muscle phantom, instead of the 0.02°C shown in Fig. 5.

An ideal electric field radiation meter (an instrument similar to the commercially available Narda Model 8300, but with probes small enough to be placed without distrubing the fields under measurement) would read an incident power density of 5.1 W/cm^2 at the spot of highest field, as can be computed using the formula $W = |E|^2/377$ with $E = 44$ V/cm. The power density penetrating the phantom along the axis of the antenna is shown in Fig. 6, obtained by integrating the measured power dissipation (in mW/cm^3) in the cross section of the simulated human tissue. At no point is the power flow density higher than 10 mW/cm^2.

In the measurements shown in Figs. 5 and 6, the antenna is very close to the simulated body. If the spacing is increased to 2 in, the power penetration detected experimentally is shown in Fig. 7. The maximum power density in the body is less than 2.6 mW/cm^2 with a maximum field just below the fat surface of approximately 3.6 V/cm. A radiation meter in these conditions would read an incident power of 1.68 W/cm^2, about 30 dB above the effective power density in the simulated body. Again, the use of an ideal far-field instrument would produce readings which are orders of magnitude above the power penetrating the body, a situation substantially different from the plane wave case where the same instrument would read about 5 dB above the effective power penetrating the tissue.

The results of the measurement performed using the head phantom are shown in Fig. 8. The power densities penetrating the body are very small (<1 mW/cm^2). It is worth noticing that no detectable temperature increase was observed in the immediate eye area. This is due to the fact that in normal use, the eyes of the operator are exposed only to the rather low electric fields at the base of the antenna.

To confirm that no additional "hot spots" are present on the phantoms other than the ones detected, thermograms of the models were taken using an IR scanner (AGA-Thermovision Model 680). Fig. 9 shows IR pictures of the flat surface phantom before and after irradiation. The experiment was performed in the same conditions as Figs. 5 and 6. The only "hot spot" present is the one near the antenna tip as detected using the thermoelectric instrument. Fig. 10 presents the thermograms of the head phantom. No "hot spots" are detectable at the

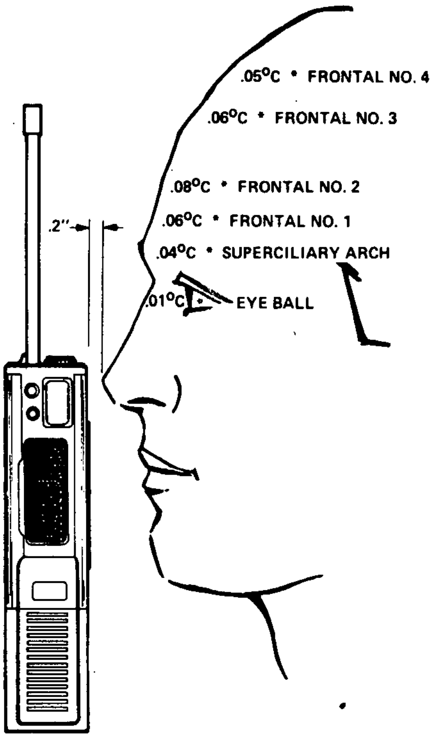
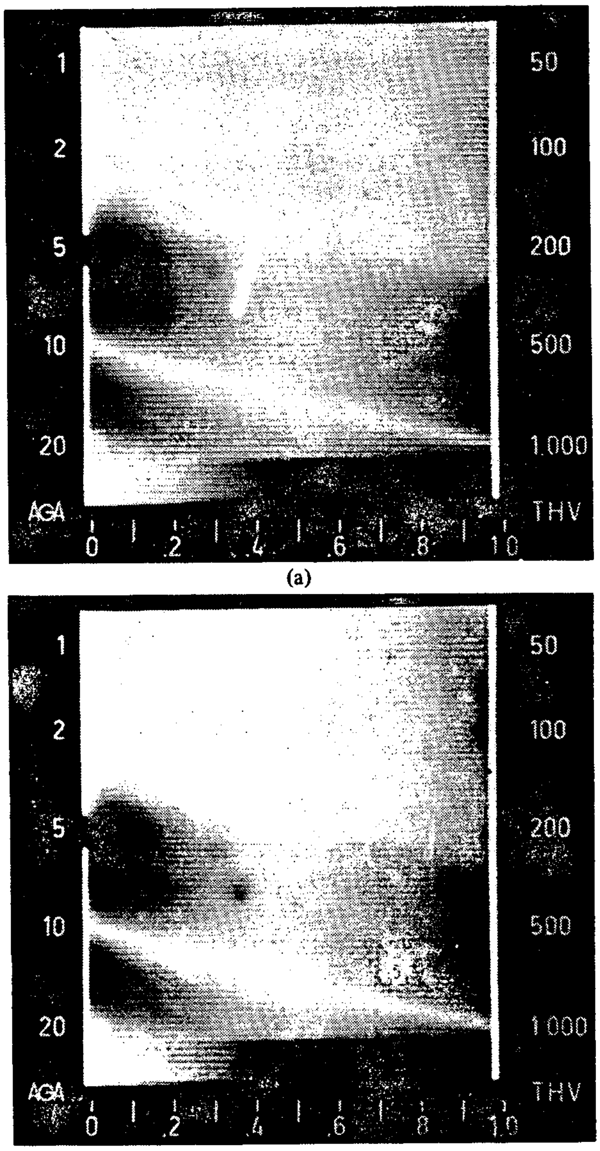


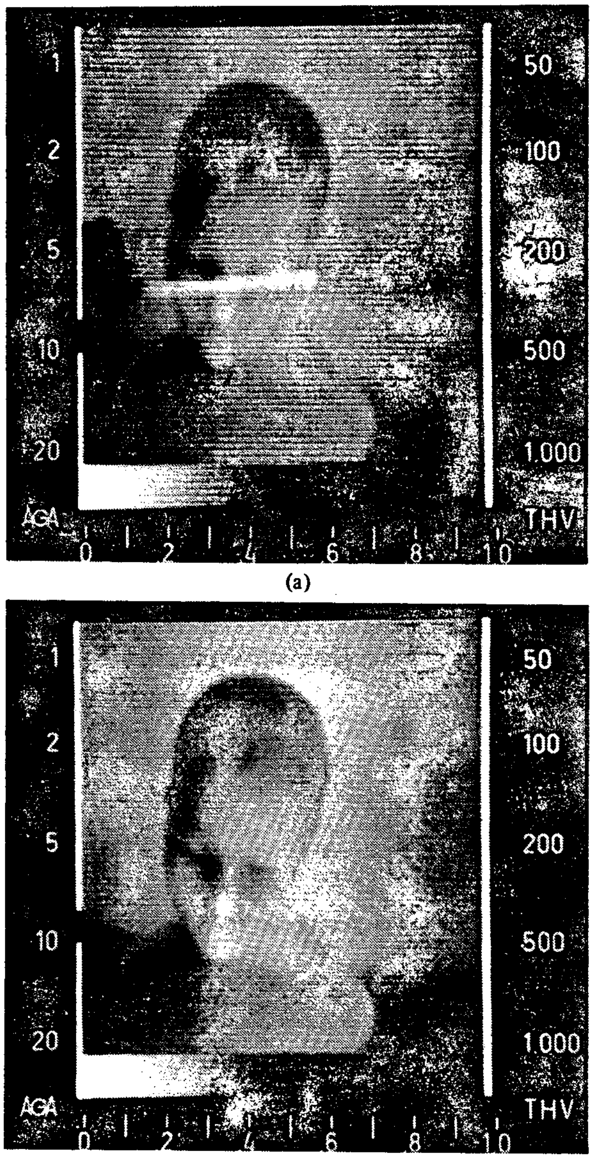
Fig. 8. Temperature profile.



(a)

(b)

Fig. 9. Flat surface phantom thermograms. (a) Before radiation. (b) After radiation (60 s exposure).



(a)

(b)

Fig. 10. Head phantom thermograms. (a) Before radiation. (b) After radiation (60 s exposure).

surface of the model for a phantom-antenna distance of 2 inches, in accordance with the results of Fig. 8.

CONCLUSION

This paper has attempted to give some insight into the attenuation of the induction fields of antennas due to the high complex dielectric constant of the human body at VHF. It has been shown that very high static fields outside the simulated human tissue practically collapse at the air-fat and fat-muscle interface. The readings of commonly used radiation meters can overstate the real power penetrating the tissue. If these instruments could correctly measure the *E*-field, the penetrating power would be magnified by at least two orders of magnitude. Safety standards based on such readings would seriously restrict the power available in portable radios without preventing any health or radiation hazard. Existing standards are based on measurements of the effects of essentially transverse electric incident fields, whose propagation in human tissue is completely different from the induction fields investigated in this paper.

VHF portable radios of the type shown in Fig. 2 and for the power levels currently available seem to be perfectly safe,

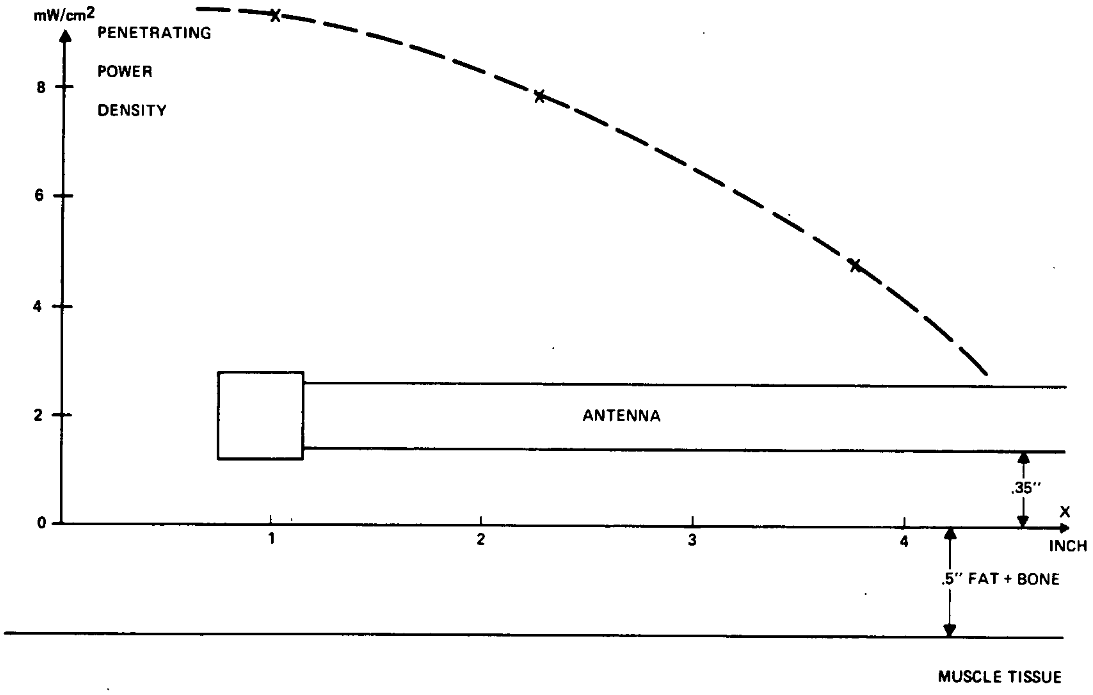


Fig. 6. Power density.

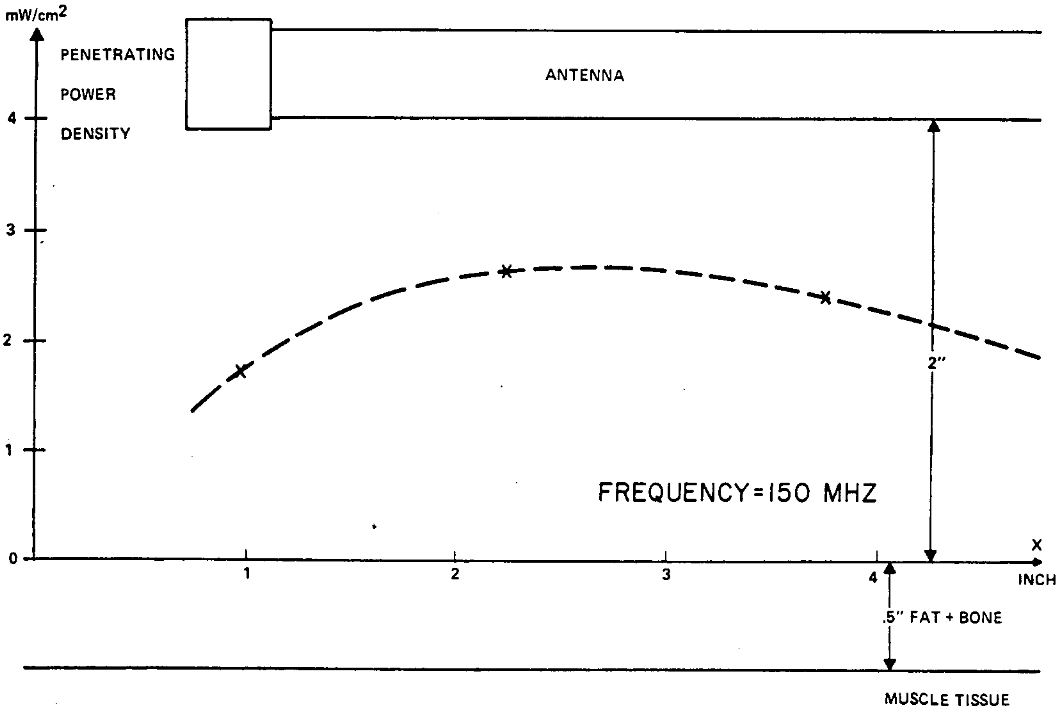


Fig. 7. Power density.

if properly operated. The maximum power density absorbed by the body of the operator (see Fig. 8) is slightly less than 1 mW/cm^2. The same absorption could be obtained from an incident plane wave of 3 mW/cm^2 power density, which is well below the 10 mW/cm^2 of the current safety standards for occasional exposure. Additional safety margin accrues in normal use from the fact that portable radios are employed only intermittently with relatively low-duty factor. A health hazard is present in the event that the user places the tip of the antenna in the immediate vicinity of the eye (distance <0.2 in) and then operates the transmitter. Chances of this happening are somewhat remote because normally anyone would not keep a strange object that close to the eyes. Even in this case, the probability of damage is greatly reduced by having an insulating cap on the tip of the antenna.

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