Arthur W. Guy (S'54–M'57–SM'74–F'77) was born in Helena, MT, on December 10, 1928. He received the B.S. degree in 1955, the M.S. degree in 1957, and the Ph.D. degree in 1966, all in electrical engineering from the University of Washington, Seattle.

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Short Papers

Focused Electromagnetic Heating of Muscle Tissue

POVL RASKMARK AND J. BACH ANDERSEN

Abstract—**A cylinder of muscle tissue may be heated at depth by applying an electric field to a circumferential gap in a metallic cylinder surrounding the tissue. Experiments at 150 MHz on a 10-cm-diameter cylinder verify the theoretical calculations and show a well-defined focus on the axis.**

I. INTRODUCTION

In cancer treatment, the use of elevated temperatures in tumors (hyperthermia) has now been established as a very promising supplement to other therapies. For the proper selective treatment of the tumor cells, it is important that the healthy tissue not be overheated, so technical means for creating a hot spot or focus in the tissue are of interest. There is especially a need for heating deep-seated tumors, since superficial ones may be treated by a variety of techniques. In muscle tissue or other "wet" tissues, focusing at depth is made difficult by the fact that the attenuation in the medium is large; penetration depths and wavelengths are comparable. Focused heating has been considered at microwave frequencies [1], [2], but here the concern is with lower frequencies, around 100 MHz, in order to explore the potentialities of deep penetration. Previously [3], it has been shown theoretically in a two-dimensional case that a symmetric distribution of sources around the axis of cylinder may create a maximum of power at the center. This short paper reports on experimental and theoretical results for an especially simple applicator around a cylindrical structure.

II. A COAXIAL APPLICATOR

The applicator shown in Fig. 1 is applied to a cylindrical shape of tissue, or tissue supplemented with water to form the shape of a cylinder. The lossy medium is surrounded by a shell of low-loss dielectric of thickness $d = (b - a)$, and this again is surrounded by a metal cylinder with a circumferential gap of width w. Thus, a gap-excited coax transmission line with the tissue as the center conductor is provided. This configuration has been analyzed numerically by assuming a field distribution in the gap between the two metal edges and the following conclusion may be drawn from the simulation: power distribution is sensitive to the frequency, gap width w, and insulator spacing d.

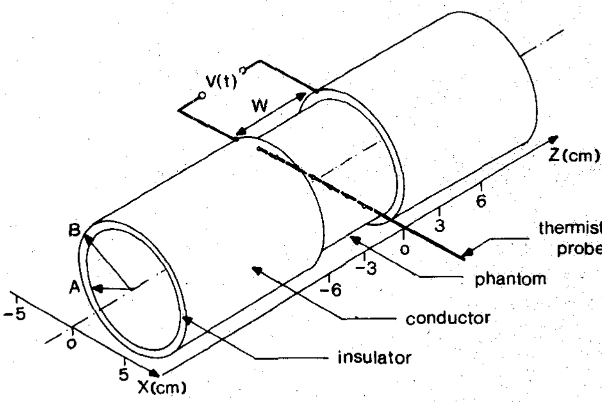

Fig. 1. Cylindrical applicator and phantom. The RF voltage is distributed around the gap. The thermistor probe is shown in the gap center ($z = 0$). Difference in radius A and B correspond to insulator thickness.

First, the frequency is chosen such that the radius of the lossy medium approximately equals the focal spot size in a lossy medium [6], ρ_M, where

$$(k_0\rho_M)^2 = \frac{8\epsilon^1}{3(\epsilon^1)^2 + (\epsilon^{11})^2}.$$

This choice of frequency may lead to a local maximum of power on the axis of the cylinder if reactive nearfields are sufficiently small. In simple words, the frequency is chosen so low that the exponential decay into the tissue is avoided, and so high that

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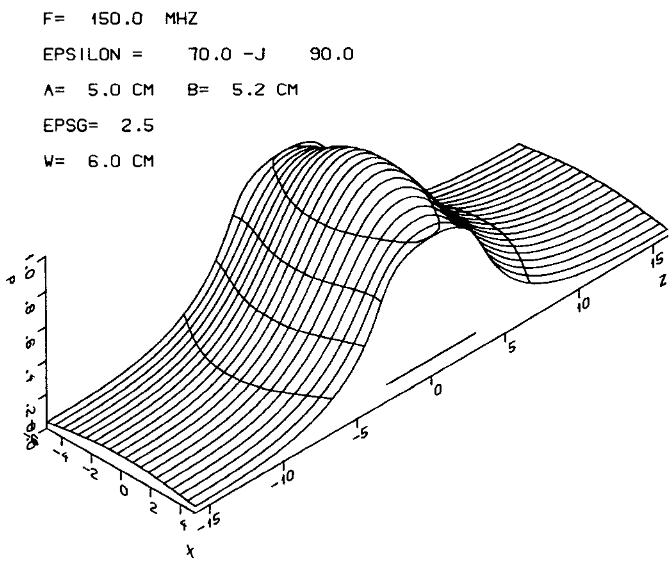

Fig. 2. Plot of relative power distribution in muscle cylinder excited by quasistatic field distribution in gap in metallic cylinder. A layer of lossless dielectric separates the tissue from the metal. The contour lines correspond to $P = 0.8, 0.6, 0.4$, and 0.2.

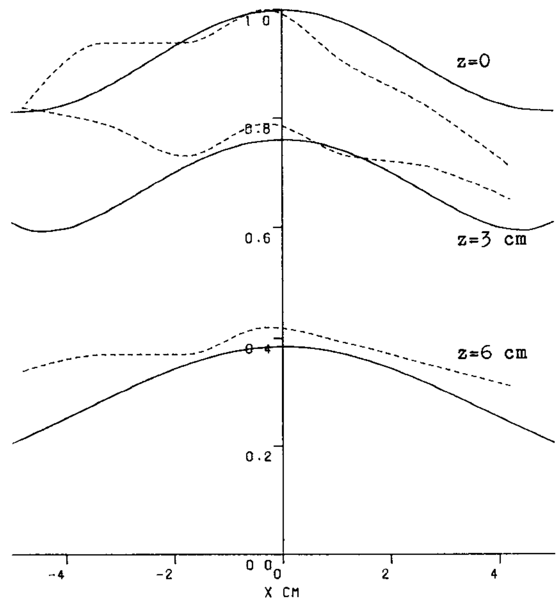

Fig. 3. Relative power distribution as in Fig. 2 for different z-values. $z = 3$ cm corresponds to the position of the edge ——theoretical results (as in Fig 2), ----- experimental results.

constructive interference between the waves creates a local maximum.

Near the metallic edges the fields are singular, $(E \sim (1-(2z/w)^2)^{-1/2})$ so if $b = a$ $(d = 0)$, excessive heating takes place near the edges. As d is increased, this effect disappears, and the power distribution becomes insensitive to the precise aperture fields. If d becomes very large, the usual coax-line mode becomes dominant with low attenuation in the axial direction, and the axial confinement of the hot spot is lost. Thus, there is an optimum value for d, which in the 100-MHz range is of the order a few millimeters. The edge fields are avoided, and the shielding of the tissue outside the volume of interest is effective.

The width of the gap is important in the sense that too narrow a gap leads to excessive amounts of nearfields destroying the focus obtained with the other parameters. Numerical simulations show that w should be larger than approximately a quarter of a wavelength in the lossy medium.

Fig. 2 shows the theoretical result for a muscle cylinder of 10-cm-diameter and a complex permittivity of $\epsilon = 70 - j90$. The lossless dielectric has a thickness of only 2 mm, which seems to be sufficient for suppression of the singular edge fields. The aperture has a width of 6 cm, and there is a clearly developed focus which is in marked contrast to the standard coil excitation of a cylinder with a zero on the axis.

III. Experimental Results

Experiments were performed in phantom material simulating muscle tissue. The diameter was 10 cm and the length about 40 cm. The lossy material was surrounded by a thin shell (2 mm) of low-loss dielectric, $\epsilon \sim 2.5$, which had a close fit to the metallic shield. The gap may be excited in many ways, but for this experiment a balanced RF voltage was applied between the two sleeves four points around the circumference. Lagendijk [4] has used an additional outer conductor for axially symmetric excitation of the gap. The power distribution was determined by measuring the temperature gradients in time after the application of power. A probe of eight thermistors was placed in a radial direction at three different axial positions (see Fig. 1). For a discussion of the temperature measurement problems, the reader is referred to [5]. Results of the measurements are shown in Fig. 3, together with theoretical results. Although there are some discrepancies, a well-defined focus is clearly seen. The results obtained cannot be directly scaled to other dimensions and other frequencies since the material constants of tissue are frequency dependent, but the general philosophy of a gap-excited cylinder is valid.

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On The Nonthermal Microwave Response of Drosophila Melanogaster

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Abstract—**The fertility of microwave-irradiated fruit flies was investigated in an experiment conducted at 40 GHz and at a low power level to**

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