27. Microwave and Quantum Magnetics

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27.1 Microwave Hyperthermia

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Our understanding of both physics and physiology is challenged in trying to optimize techniques for heat production and for the thermometry associated with Hyperthermia modalities used in connection with cancer therapy. Fundamental considerations are based on designing proper microwave applicators which must be able to handle the microwave power required to raise the temperature of the tumor. They must also minimize the amounts of microwave power being delivered to the healthy tissue or being radiated into free space.

The Ph.D. thesis research of Carey Rappaport is progressing well. A paper entitled "Localized Hyperthermia with Electromagnetic Arrays and the Leaky Wave Troughguide Applicator," has been accepted for publication in a special issue of the *IEEE Transactions on Microwave Theory and Techniques*. The Abstract, Introduction, and edited versions of the Conclusions and References of that paper are reproduced below.

Abstract

Noninvasive Microwave Hyperthermia is an attractive cancer treatment modality. Understanding the advantages and limitations of focusing are vital for the practical implementations of electromagnetic heating of deep tumors. These, as well as the important issues of tissue coupling and proper choices of polarization and frequency are herein examined. An optimal theoretical source distribution and an applicator design which approximates distribution are discussed.

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Introduction

Many cancerous tumors embedded in healthy human tissue have well-defined boundaries and tend to be irreversibly damaged by hyperthermia. Tumor temperature elevation to 43–46°C for 90 to 120 minutes appears to be sufficient to kill many types of malignant growths.[1-3] Several methods of delivery of heat to these localized tumors have been proposed,[4-8] including capacitative and inductive RF source, single microwave source, focused ultrasound, invasive electromagnetic probe, and microwave array heating. Much of the current interest is with noninvasive sources, which are less traumatic to sick patients and minimize the risk of mixing abnormal cells into healthy tissue.

The optimal noninvasive applicator delivers maximum power to the tumor while minimally heating surrounding healthy tissue. Since waves attenuate as they penetrate lossy tissue, a focusing source arrangement is required. Constructive interference at the tumor is obtained by adjusting the phase and amplitude of each point of the source. Unlike in free space, nearfield focusing in a lossy medium is more involved than simply compensating for the path length variations from tumor to source. Also, since the attenuation rate varies directly (though nonlinearly) with frequency, while field resolution decreases with decreasing frequency, any attainable "focus" is relatively wide and of low intensity. The broadening and smearing of this focal maximum increases as the physical distance in the medium to the source increases, until the exponential decay overwhelms any geometrical focusing advantages. For heating a tumor in the center of a volume of tissue, the best range of frequencies is found by choosing those patterns of dissipated power (if any exist) which have the same power at the focus as at the tissue surface with lower power for all intervening tissue, including muscle/fat boundaries. Generally, the sharpest focus, or highest resolution will correspond to the highest possible frequency within this range of frequencies. Exceeding this range may produce higher resolution, but the actual penetration depth into the tissue will decrease.

More complicated than frequency selection is the determination of optimal source distribution. Unlike with the acoustic compression waves of ultrasound hyperthermia, electromagnetic waves incorporate polarization. For constructive interference at a focus, electric field at the tissue surface must be properly aligned and phased so that waves propagating along all paths in the entire tissue volume arrive in the same fashion. However, merely adjusting phase, polarization, and also amplitude for maximum focusing does not necessarily produce an acceptable power density distribution.

Consider Fig. 27-1 with a planar source on the left, with phase adjusted to focus on the point labeled F, 3 tissue wavlengths into the lossy medium. Although F is the only point of coherence in the tissue, having significant gain over a uniform phase distribution, as shown in Fig. 27-1b the power there is still much lower than at points closer to the source, Fig. 27-1c, which have a shorter exponential decay distance. These plots were calculated for muscle tissue at 915 MHz, with electrical parameters taken from Storm,[4] using 32-point Gauss-Legendre integration of the

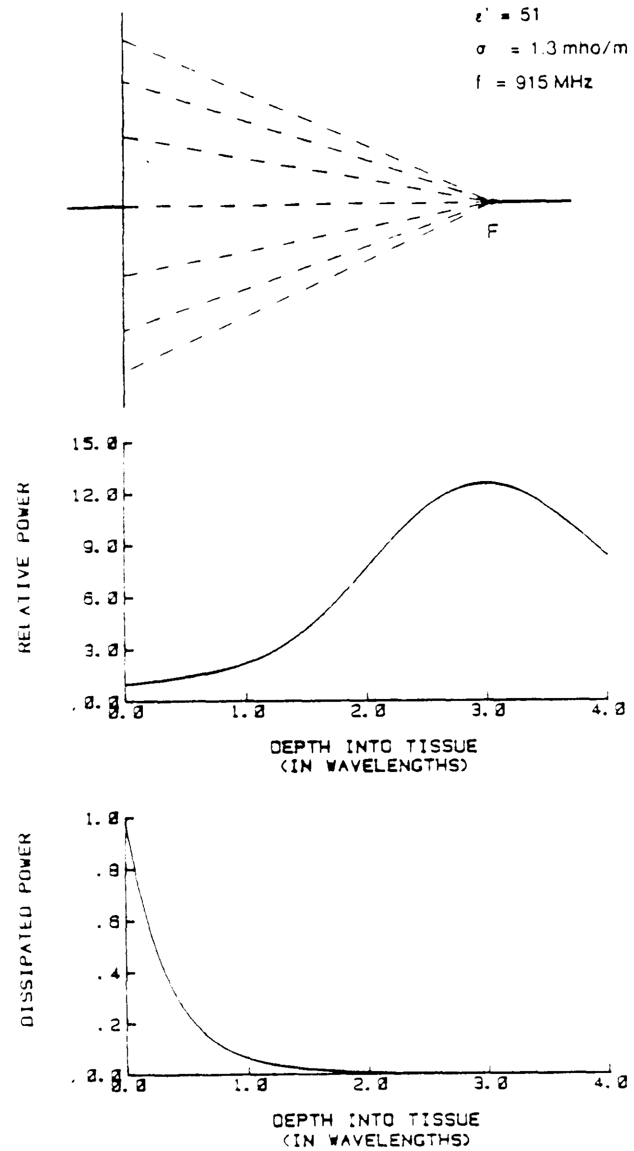

Figure 27-1: Focusing at Depth: Fallacy of Maximum Intensity at Focus in a Lossy Medium. a) Geometry, b) Power Gain Over Uniform Plane Wave, c) Relative Power Density

diffraction integral.

Several experimental means of determining source distribution have been proposed. These include passive methods, such as remote sensing;[9] and active methods, such as invasive implantation of a small source at the intended focus, subsequent phase measurement at the surface and inversion for source specification. Both methods overlook the difficulty of undesirable hot-spots or excessive surface heating, as shown in Fig. 27-1c. Correcting the source distributions to prevent this often eliminates any geometrical advantage at the focus.

One further requirement of applicators is a method of monitoring power deposited in the exposed tissue. Applied dosage information may be used as an approximate substitute for the difficult problem of direct non-invasive temperature measurement.

Although the effects of phase focusing a wave in tissue is not as great as in free space, advantage can be taken of a finite tissue volume by surrounding it with applicator sources. Two main simplified cases which yield good power patterns are examined in this study; planar arrays facing each other; and cylindrical arrays. Their geometrical simplicity allows a harmonic wave analysis which provides exact field solutions. The effects of phase focusing these source configurations is considered. Also, an applicator design which can be configured into these sources, with power monitoring capability is presented.

Conclusions

Electromagnetic hyperthermia offers a promising modality for treating cancer in humans. Important aspects including polarization, depth of heating, power profile resolution, secondary power maxima, and source distribution must be given careful consideration. Attempts have been made to synthesize power patterns and specify the maximum planar and cylindrical muscle dimension for practical heating. Using a modal scheme on simplified geometries, followed by phase correction improvement — rather than experimental inverse phase specification — leads to a pattern less likely to have hot-spots.

The optimal cylindrical source was shown to be polarized in the axial, z direction, have no phase variation φ and phase variation in z to compensate for the path length variations shown in Fig. 27–1a.

An applicator was suggested, based on an array of asymmetric trough-guide antennas, which produces a controllable transverse leaky wave. As a bound-mode structure, the radiation characteristics are weakly affected by lossy tissue loading. There exist adjustments to minimize reflections; and propagating, (and hence radiating) power be easily monitored. This applicator can be designed to closely simulate the theoretically optimal cylindrical configuration.

Experiments are progressing with the troughguide antenna, Fig. 27–2. This linear antenna element is tested at 915 MHz, with the appropriate phantom material simulating lossy muscle tissue. From this view into the top troughguide opening, six pairs of adjustable base blocks are visible, as are the E-field probes and H-field loops, as indicated schematically in Figs. 27–3 and 27–4.

In many ways, this antenna is an improvement over currently used applicators. It has most of the advantages of microwave horns, without the necessity of dielectric loading.

The troughguide is an electrically flexible linear array, and thus simplifies the power splitting and

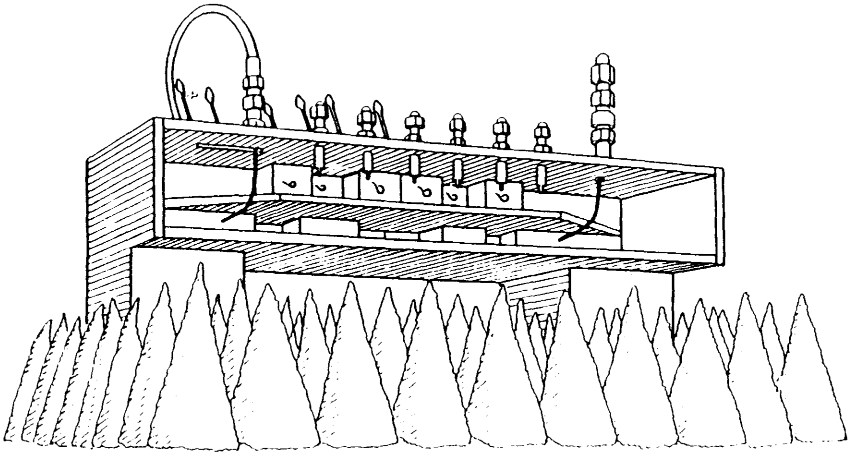

Figure 27-2: Experimental Linear Troughguide Set-Up

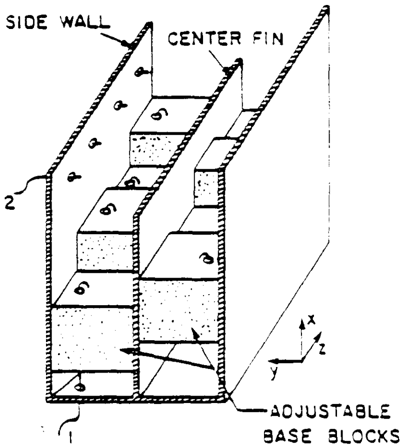

Figure 27-3: Asymmetric Troughguide with Alternating Base Block Asymmetries, H-Field Loops, 1, and E-Field Probes, 2.

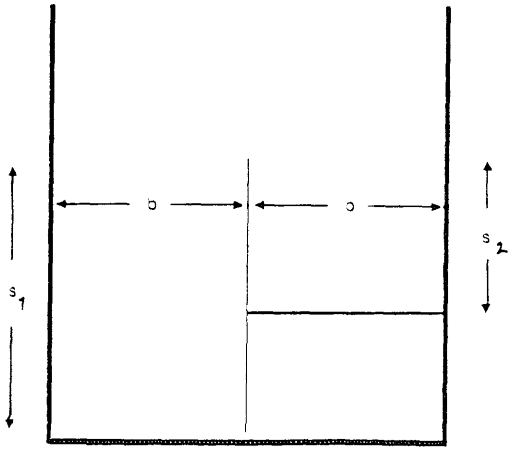

Figure 27-4: Asymmetric Troughguide: Typical Element Geometry.

phase shifting feed network. It also has a novel non-perturbing power monitoring capability. With all these advantages, the troughguide appears to be a good candidate for a microwave hyperthermia applicator.

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