Foreword

HYPERTHERMIA cancer therapy is a treatment procedure in which tumor temperatures are elevated to the range of 43–50°C. Experiments performed on cell cultures, tumor-bearing animals, and human patients have clearly shown that hyperthermia affords preferential killing of malignant cells. It is noteworthy that while tumor cells exhibit inherent hyperthermic sensitivity, the response may also depend on such conditions as nutritional deprivation, low pH, and chronic hypoxia that often characterize the interior of many tumors. Moreover, it has been shown that the cytotoxic effects of many anticancer drugs are enhanced and the cell-killing ability of ionizing irradiation is potentiated by hyperthermia.

At present, however, hyperthermia shows its greatest promise when combined with radiotherapy. A recent assessment has indicated that the average complete response with hyperthermia and X-irradiation is about 70 percent, compared to only 30 percent with irradiation alone. These results pertain to matched comparable and/or randomized superficial tumors. When partial response is included, a summary of recent clinical reports showed an overall response rate of 90 percent for combined modality and 55 percent with radiotherapy alone. It appears that hyperthermia inhibits DNA repair at more modest doses of irradiation. The possible mechanisms of inhibition of DNA repair by hyperthermia and radiation include the loss of DNA polymerase beta activity and structural alteration of chromatin.

Despite its increasing use in the clinic, hyperthermia is still in a relatively early stage of development. An important aspect of this development is the production of adequate thermal field distribution in superficial, accessible, and deep-seated tumors. A large number of antennas and applicators have been designed to produce therapeutic heating of tumors of different volumes in a variety of anatomic sites. For superficial tumors, single-contact applicators operating at 915 and 2450 MHz have been used. Because of the limited depth of energy penetration, these antennas have been applied to the heating of well-localized tumors extending to depths of up to 3 cm. In addition, tumors in such hollow viscera or cavities as esophagus, cervix, and prostate are amenable to treatment with intracavitary hyperthermia techniques.

For accessible tumors of large volume, interstitial techniques have been employed to generate the desired hyperthermic field. Electrodes operating in the frequency range of 0.5 to 1 MHz and antennas operating between 300 and 2450 MHz have been employed for this purpose. The advantages of interstitial techniques include safe and effective as well as uniform heating of large well-defined tumors. Recently, several techniques have been devised to provide noninvasive heating of deep-seated tumors. These include capacitive plates, helical coils, and multiapplicator arrays. The capacitive plates operate at low frequencies so that the wavelengths are long compared to typical body dimensions. With appropriate design, this simple applicator can provide fairly uniform heating of tissue between the two plates. The helical coil applicator gives rise to a power deposition pattern or pattern of specific absorption rate (SAR) that varies slowly with radial distance and gives good penetration. The multiapplicator array concept is rapidly gaining utility in the clinic. The Food and Drug Administration (FDA) approved a commercially available annular phased-array system manufactured by BSD Medical Corporation that operates at 60–90 MHz and is designed to heat large anatomical regions such as the thorax, abdomen, and pelvic area. The most promising region for this system appears to be the pelvis, since heating of the upper body is frequently limited by systemic hyperthermia and hemodynamic compensation, and by excessive heating of adjacent normal tissue structures. A major advantage of multiapplicator array systems is the ability to steer the hot spot electronically by varying the phase of each element, thereby allowing phased arrays operating at microwave and radio frequencies (RF) to be used to effect selective heating of deep-seated tumors in a variety of anatomic sites.

In this Special Issue we have attempted to sample the spectrum of present activities in phased-array systems and, to the extent possible, to provide examples of what the directions for this research appear to be. The papers are organized in six categories: noninvasive planar, circumferential, ultrasonic array systems, invasive interstitial arrays, thermal field mapping and control, and emerging applicators.

In the planar array area, the two papers by Hand *et al.* and by Loane *et al.* describe results of theoretical calculation and experimental measurement, respectively. They present parameters and techniques important to the design and operation of planar phased-array systems for improved penetration and differential power deposition.

The section on noninvasive circumferential arrays begins with three papers directed at upper and lower limbs or the neck. The paper by Jouvie *et al.* provides a numerical comparison of the power deposition patterns obtained by aperture phased arrays and by more conventional modalities. Guy *et al.*, through theory and measurement, give some results and insight into the wide range of power deposition patterns rendered by a simple system of four square applicators. The paper by Turner explores the use of an array of dipole radiators. This is followed by a paper contributed by Sathiaseelan *et al.*, which discusses amplitude and phase control of SAR patterns under clinically relevant conditions for an annular phased-array system. The next three papers give an early view of what the future may hold in phased arrays for the body trunk. Sato *et al.*

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present preliminary results demonstrating focusing and steering of power deposition patterns in a cylindrical phantom and suggest designs for narrow-beam RF radiators. The paper by Cudd *et al.* discusses the problems caused by tissue layers and gives guidelines for determining the number of array elements required for selective heating of lung tissues within the thorax. The increased degree of freedom for manipulating power deposition afforded by phased-array systems is predicated on the ability to prescribe the amplitude and phase of each array element. The paper by Morita *et al.* presents a scheme for determining the optimal excitation for each amplitude and phase. It also suggests that only a small number of elements is needed to effectively control power deposition. The final paper of this section, by Wait, gives a criterion for neglecting the leakage radiation in the regions between apertures in a phased-array system.

It is appropriate to sample the area of noninvasive ultrasonic phased-array systems in this Special Issue because of the close affinity of ultrasound to microwave propagation. Moreover, ultrasound possesses several features which make it suitable for selective heating of a well-defined volume at depth in tissue. Thus, the paper by Cain and Umemura presents new approaches to scanning array design and provides results of numerical simulation to illustrate power deposition and heat-producing capabilities. The second paper, contributed by Hynynen *et al.*, discusses the relation between scanning speed and equivalent thermal exposure of animal tissue in a focused ultrasonic array system.

The interstitital array topical area begins with a paper contributed by Wong *et al.*, which shows via theory and experiment a coherent system in which the electric fields add constructively and give rise to an SAR maximum at the center in the junction plane of a square array of four antennas. The next paper, by Trembly *et al.*, discusses a rapid phase-shifting scheme for driving the antennas in a square interstitial array system to improve uniformity of power deposition. The paper by Turner presents a numerical model and suggests applicator design for an interstitial array system with improved tip power deposition. There is a need for designs with preferential power deposition at the tip, and this paper may be illustrative of the future.

In the thermal field mapping and temperature control area, the first two papers provide calculations pertinent to microwave radiometric detection of subcutaneous temperature variations. Bardati *et al.* give some results and insight into the potential of the Kalman filter algorithm for retrieval of tissue temperature. The paper by Alanen *et al.* presents a methodology and suggests an antenna aperture for improved spatial resolution. the next three papers explore specific optimization techniques which may be illustrative of the future. De Wagter *et al.* describe a numerical procedure for optimizing two-dimensional temperature distribution and offer a tool for patient treatment planning. Knudsen and Hartmann present a strategy for controlling temperature distribution in cylindrical homogeneous muscle phantoms. Babbs *et al.* discuss an approach to minimize the standard deviation of one-dimensional intratumor temperature.

The dynamism that attends this area of research is exemplified by the multitudinous innovations in the design of multi-element applicators. Thus, Franconi *et al.* describe magnetic structures that use induced current for controlled volume heating. Nussbaum *et al.* discussed the manipulation of heating patterns with a three-electrode capacitive device. The two papers by Nikawa *et al.* present results on controlled local hyperthermia using converging lens and integrated waveguide-array applicators, respectively. This is followed by a paper on the feasibility of an asymmetric leaky wave troughguide structure for localized hyperthermia, contributed by Rapaport *et al.* The last paper, by Mizushina *et al.*, proposes the use of large rectangular waveguide for deep regional hyperthermia and provides SAR calculations on a tomographic cross section of the abdomen. The constructive interference afforded by multiple waveguides and the technique of polarization diversity which has been found to help smooth power deposition may prove useful in the production of hyperthermia with this type of applicator.

Finally, my experience as Guest Editor has been a rewarding one, and was made more so by the fine support of Tatsuo Itoh, Editor, and William Hagen, Associate Editor for these TRANSACTIONS. The authors and reviewers deserve special praise for the high quality represented on these pages. A list of reviewers is given below. I wish to express my appreciation to them for their magnanimous effort.

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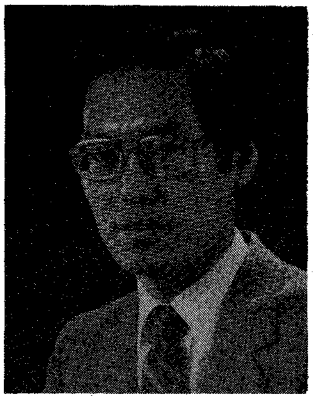
JAMES C. LIN
Guest Editor



James C. Lin (S'67–M'71–SM'77–F'86) received the B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Washington in Seattle.

Presently, he is Head of the Department of Bioengineering at the University of Illinois at Chicago, where he also serves as a Professor of Bioengineering and of Electrical Engineering and as Director of the College of Engineering Robotics and Automation Laboratory. He has published over 100 papers and two books. One paper received an IEEE TRANSACTIONS Prize Paper Award.

Professor Lin has been a scientific consultant to numerous private, state and federal agencies. He has served on four editorial boards, and as Program Chairman for the 1985 EMBS Annual Conference. He presently serves the IEEE as a member of the Committee on Man and Radiation (COMAR), Robotics and Automation Council, and Engineering in Medicine and Biology Society (EMBS) Administrative Committees. He serves also as Chairman of both the EMBS Committee on Biomedical Robotics and the MTT Committee on Biological Effects and Medical Applications of Microwaves. Dr. Lin has been a member of the National Research Council-IEEE Task Force on Research Needs in Bioengineering Systems, ANSI Subcommittee C95.4 (chaired its Dosimetry Working Group), and URSI/U.S. National Committee of the National Academy of Science. He has served on the NIH Diagnostic Radiology Study Section and special study sections on SBIR. He has been a Board member of the International Microwave Power Institute and of the Bioelectromagnetics Society. He has served on the Governor's Task Force to Review Project Seafarer (Michigan), the NSF Panel for the Presidential Young Investigators Award, and on committees for the Governor's Commission on Science and Technology (Illinois). He is also a member of Phi Tau Phi and Sigma Xi.