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MEASURED INTERNAL ELECTRIC FIELD IN PHANTOM HUMAN HEADS EXPOSED TO LEAKAGE RADIATION FROM MICROWAVE OVENS

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Information on energy absorption induced in human bodies exposed to actual microwave sources are needed to assess health hazards through a comparison with animal biological effects data using the common denominator of local absorbed energy. The existing absorption data based on whole body exposure to plane waves cannot be readily applied to the case of exposure in the near field of sources such as microwave ovens.

In the present investigation, the internal electric field distributions of phantom human heads were measured, and the data were converted to equivalent dose rate. The sources of exposure were leaking 2450 MHz and 915 MHz microwave ovens. The phantom human heads were made of actual skulls of an adult and a child and were filled with dielectric materials equivalent in electrical properties to that of muscle or brain. A miniature 3-D probe was used to detect the internal electric field in the phantom tissues. The amplitude-modulated envelope of the detected waveform was processed by a low-pass filter so that only the time-averaged value of the electric field was recorded. The ovens were made to emit 2 to 20 mW/cm^2 leakage radiation measured 5 cm from the oven surface by the use of teflon strips inserted between the door seals. The phantom heads were located as close to the oven door as possible with the maximum leakage field near the left eye. The surface of eye was 3 cm from the oven door. The 3-D probe was motor-driven by a scanner along a straight path normal to the oven door surface, from the back of the phantom head to the surface of the left eye.

The results indicated that for a leakage of 5 mW/cm^2 as measured 5 cm from the surface of the 2450 MHz microwave oven, the maximum equivalent dose rate was 9.6 W/kg in the adult phantom head and 14.6 W/kg in the child phantom head. The positions of the maximum dose rates were 0.5 cm interior to the eye for the child phantom head, and at the surface of the eye for the adult phantom head. Some penetration of the microwave energy into the cavity filled with brain equivalent material in the child phantom head was evident. The peak value in the brain equivalent material was approximately 20% of the maximum absorption in the eye. For a leakage radiation of 5 mW/cm^2 from the 915 MHz oven, the maximum equivalent dose rate was 3.0 W/kg in the adult phantom head and 5.3 W/kg in the child phantom head. The positions for these maxima were both 3 cm from the surface of the eye. Penetration of the radiation into the phantom brain region was found for both phantom heads. The peak absorption in the phantom brain region was approximately 50% of the maximum eye absorption in both phantom heads.

SEATTLE, JUNE 1979

TASK 252

MEASURED MODULATION WAVEFORM OF LEAKAGE RADIATION FROM MICROWAVE OVENS

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Recent reports of biological effects indicate amplitude modulation of microwave radiation as a parameter of interest. The leakage radiation from microwave ovens is known to be low-frequency amplitude-modulated because of the effect of the mode-stirrer built into the ovens.

In the present investigation, amplitude-modulated waveforms of leakage radiation from a 2450 MHz and a 915 MHz microwave oven was measured by the use of a miniature 3-D probe which utilized microwave-diode detector chips. The frequency spectra of the resultant detected modulation envelopes were also analyzed.

The results indicated that the amplitude-modulated envelopes of both the 2450 MHz and the 915 MHz radiation had large fluctations. These leakage radiation waveforms were essentially 100% modulated. The frequency spectrum of the detected amplitude-modulation envelope of the 915 MHz oven leakage radiation contained components which were primarily within the range of 0 to 100 Hz. The frequency components with relatively high amplitudes were concentrated within the 0 to 10 Hz range, with 1 and 3 Hz components having the highest amplitude. The detected amplitude-modulation envelope of the 2450 MHz oven leakage radiation had a frequency spectrum that contained components between 0 and 500 Hz. The frequency components of 60 Hz (and its higher harmonics) and 4 Hz (and its higher harmonics) dominated this spectrum. These two modulation spectra contained frequencies that are within the range where biological effects of modulated RF radiation have been reported (3 to 30 Hz).

Seattle, June 1979

TASK 252

THE EFFECT OF PRENATAL MICROWAVE EXPOSURE ON THE DEVELOPMENT OF BEHAVIOR RESPONSES IN THE MOUSE

John C. Monahan and W. W. Henton

ABSTRACT

Prenatal exposure to high level microwave radiation has been shown to cause fetal abnormalities including gross morphological changes of the central nervous system. Unfortunately, the effects of low-level microwave exposure to a fetus are less clearly defined. The approach taken in the present investigation focused on functional behavioral changes in the newborn as a consequence of prenatal exposure.

Pregnant ICR mice were exposed to 2450 MHz CW radiation in an anechoic chamber from day 7 through day 17 of gestation for 3 hours daily at an ambient temperature of 24°C. The subjects could move freely within a plexiglas holder during irradiation. Average exposure levels were 10 mW/cm^2 and the estimated specific absorption rate (SAR) ranged from 5.5 to 9.5 mW/g. A battery of standard behavioral tests to determine both reflexive and neurological development were employed in this study. These included tests such as righting reflex, grasp reflex, crossed extensor reflex, eye opening, walking, etc. Pups from both irradiated and sham irradiated mothers were tested from day 1 through day 21 post partum and all tests were done blind.

The results indicate a difference between the two groups in a number of the measured parameters, with exposed pups showing a "retardation" in the initiation of specific behavioral indices. Some delay in the time necessary for 100 percent of the exposed pups to develop a given response was also evident. It should be emphasized, however, that all exposed pups did eventually display the same neurological development and reflexive behaviors as the sham pups.

SEATTLE, JUNE 79

TASK 252

MILLIMETER-WAVE RADIATION FAILS TO INDUCE LAMBDA PHAGE EXPRESSION

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There has been considerable current interest in the possibility that millimeter-waves can induce lysogenic or colicinogenic bacteria to express phage or synthesize colicin. Smolyanskaya and Vilenskaya reported that low levels (less than 1 mW/cm^2) of continuous-wave radiation in the frequency range 45.7 to 46.1 GHz cause the frequency-dependent induction of colicin synthesis (A. Z. Smolyanskaya and R. L. Vilenskaya, Sov. Phys.-Usp., 16, 571, 1974). We have previously reported our attempts to verify this result (Swicord, et al., Workshop on Millimeter-Wave Effects, URSI Symposium, Helsinki, 1978). Preliminary data had seemed to show excess induction in exposed cells, but repeated replications of the experiments failed to show this effect.

The purpose of the present research was to determine the level of induction, if any, of lambda phage in *E. coli* strain BR-475 when irradiated by millimeter-waves in the frequency range 45.6 to 46.1 GHz. Since the same biochemical pathways which lead to colicin synthesis are also believed to be responsible for the induction of phage expression, this approach can serve to clarify the results with the colicin system.

The prophage of the lysogenic strain BR-475 (lac^-) has an extra gene, the normal *E. coli* lac gene which has been inserted (R. Elespuru and M. Yarmolinsky, P. N. A. S., 1979, in press) so that when the phage genome is transcribed, the lac gene is transcribed also. A standard colorometric assay for β-galactosidase, a lac gene product, may be used to determine the levels of lambda induction, allowing improved quantification over the traditional plaque assays.

BR-475 cells were exposed in liquid media in a closed waveguide system. A slotted line was used to measure the degree of mismatch into the sample, and the mismatch was removed with a tuner. The cells were maintained in two identical sample holders, one for exposure and the other for sham-exposure, at 4° C during the 90-minute exposure period. Several levels of millimeter-wave radiation in the range 100 $\mu W/cm^2$ to 10 mW/cm^2 were used. No differences in induction levels were observed between the exposed and sham-exposed cultures.

SEATTLE, JUNE 1979

TASK 252/452

TASK 450

MICROWAVE HAZARD INSTRUMENTS: AN EVALUATION OF THE NARDA 8100 HOLADAY HI-1500, AND SIMPSON 380

W.A. Herman

D.M. Witters, Jr.

ABSTRACT

A set was devised of 13 parameters which are likely to have significant impact on the accuracy of microwave oven survey meters. Measurement systems and protocols were developed and evaluated. The resulting techniques were used to evaluate widely used survey meters produced by three manufacturers. The results of these evaluations are presented, along with additional analyses of problems generic to such survey instruments.

I. INTRODUCTION

The Federal Performance Standard for Microwave Ovens (CFR 1030.10) sets allowable limits on radiation leakage from such ovens. It also imposes certain technical requirements on instruments which may be used to determine whether this leakage exceeds the allowable limits.

TASK 450

INEXPENSIVE MICROWAVE SURVEY INSTRUMENTS: AN EVALUATION

by

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INTRODUCTION

In accordance with the Radiation Control for Health and Safety Act of 1968, the Bureau of Radiological health is responsible for the development and assessment of methods for measuring radiation from electronic products. Evaluations of the sophisticated regulatory instrumentation used for precise measurement of microwave oven emissions have been published previously (1). The recent commercial availability of several simpler, less expensive, and less precise instruments has generated considerable interest from repair shops and consumers. While the possibility of reliable readings from such devices is clearly a potential benefit, the possibility of unreliable readings presents several potential problems. If the readings are erroneously low, the instruments might fail to identify a hazard; if the readings are erroneously high, the consumer may incur the expense of an unnecessary house call by repair personnel. In this paper we describe the results of our laboratory evaluations of these instruments.

COMMERCIAL MICROWAVE HAZARD METERS: A LABORATORY EVALUATION

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Based on experience in the laboratory, and in field surveys, a test protocol has been devised to evaluate the performance of commercially available microwave hazard meters. The protocol was designed to yield a comprehensive analysis of instrument errors associated with the most significant environmental ~~valuables~~ variables and source characteristics, as well as with the instrument design and production tolerances. The use of such instruments in biological research has necessitated a meaningful assessment of measurement uncertainty. The protocol was designed to yield information of practical value to such researches, and to enable a straightforward evaluation of the meaning of hazard-meter measurements in real-life situations. Among the parameters included were calibration accuracy, response linearity, frequency response, polarization ellipticity, temperature response, near-field characteristics, RFI susceptibility, response to amplitude-modulated fields, probe receiving pattern, drift, response time, and sensitivity to battery supply voltage.

Five different absorber-lined laboratory test systems were designed and built for the implamentation of the test protocol. The systems were tested, and the uncertainty associated with each evaluation was quantified. Particular attention has been paid to the meter-to-meter variation in key parameters such as calibration and polarization ellipticity. A computer-based system was designed to collect and reduce laboratory data and to perform relevant statistical analyses.

The procedures of the test protocol have been employed in the evaluation of commercial hazard meters in current use. Error values for each parameter have been computed for each instrument, and a worst-case composite uncertainty is calculated for each model. Special tests were devised and implemented for each model to complement the general protocol. These included an evaluation of the parasitic interaction of E-field probes with the H-field, and the impedance loading of meters. Results are compiled and presented in such a way as to allow individual experimenters to compute the appropriate uncertainty levels in specific measurement environments.

SEATTLE, JUNE 79
TASK 450

ENERGY ABSORPTION FROM SMALL RADIATING PROBES IN LOSSY MEDIA

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Theoretical calculations of energy deposition around small antenna probes in lossy media have been made and are reported here. Such small probes have been used or proposed for use in dielectric constant measurements, hyperthermia threatment of small tumors, and microwave spectroscopic investigations of liquids. The results of this investigation are instructive in all of the above cases, but are particularly helpful for those interested in hyperthermia.

The design of probes has varied depending upon the desired use. Basically, these probes are open-ended coaxial lines with the center conductor extending beyond the outer conductor by an amount which is always a small fraction of a wavelength in the medium. The authors' interest in these evaluations stems from the use of this type of probe for coupling microwave energy into dielectric media and the subsequent observation of absorption as a function of frequency with an optical heterodyne technique (Davis and Swicord, companion paper, this conference).

Two theoretical models were used and compared, a short dipole antenna and an open-ended coaxial cable replaced with its equivalent magnetic current. The dipole model yields exact results for the fields. The calculated fields, however, become infinite as one approaches the origin, yielding an infinite value for the total power absorbed in a small sphere or radius R. This method can be used for calculating isopower contours in the far field.

The second theoretical approach follows the far field, free space calculation made by Jordan and Balmain in which the surface separating the inner and outer conductor of the coaxial cable is replaced by an equivalent magnetic sheet. The results must be integrated numerically. An examination of the results by either method indicates that extraction of exact values of the absorption coefficient in the near field of this particular antenna design is at best very difficult if not impossible due to the complexity of the equations. Any attempt to use the results in the far field is also difficult because of the poor microwave induced heating of the liquid in this region. Thus an alternative method is suggested. The fields calculated from the open coax method remain finite in value as one approaches the origin allowing for the calculation of the relative total power absorbed in a sphere of radius R. Such calculations and their implications for hyperthermia will be presented. Isocontour plots of absorbed power for various values of frequency, dielectric constant, loss tangent and antenna dimensions will also be presented.

SEATTLE, JUNE 1979

TASK 452

STUDIES OF MICROWAVE ABSORPTION IN LIQUIDS BY PHASE FLUCTUATION OPTICAL HETERODYNE SPECTROSCOPY

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The operating principles of a newly developed, very sensitive, technique for studying the local absorption of microwaves by liquids will be described. In this technique, which we call phase fluctuation optical heterodyne (PFLOH) spectroscopy, the liquid under study is irradiated with pulsed microwaves in an optical cell placed in one arm of a Mach-Zender interferometer. This interferometer is illuminated with a single-frequency helium-neon laser. The half of the beam from this laser which passes through the irradiated sample suffers a phase fluctuation because of the microwave-induced local thermal expansion of the sample. This phase fluctuation is coherently detected with very high sensitivity by heterodyning with the reference beam which has passed through the other arm of the interferometer. The resultant heterodyne signal is a measure of the average temperature rise of the sample along the laser beam path which results from the absorption of microwave energy. The quantitative evaluation of data obtained in this way will be discussed in terms of its dependence on the absorption coefficient of the sample and the field distribution of the irradiating antenna immersed in the liquid. Data obtained in this way for water, ethanediol and other liquids of biological significance will be evaluated for the case of an open-ended coaxial stub antenna and a more sophisticated irradiation system using a minature dielectric-loaded X-band waveguide immersed in the sample. This latter arrangement produces a more predictable electric field distribution in the liquid and simplifies quantitative measurements.

The very high sensitivity of the optical heterodyne method for detecting small temperature rises in a transparent sample allows us to make a search for possible microwave absorption resonances in biological systems, such as aqueous solutions of DNA. Our current theoretical sensitivity can be stated in terms of a hypothetical sinusoidal induced temperature fluctuation as

$$\Delta T_{min, H_2O} = 3.9 \times 10^{-7}\ {}^{o}K\ (\Delta f)^{1/2} (Hz)^{-1/2}$$

where Δf is the bandwidth of the signal processing electronics. One of the greatest advantages of PFLOH spectroscopy in this application is that there can be no doubt about the existence, or not, of microwave absorption in the sample. If the sample does not absorb microwaves its temperature does not rise and no heterodyne signal results. Such certain conclusions cannot usually be drawn when absorption by a sample is inferred from measurements of power incident on, reflected from, and transmitted through a sample.

SEATTLE, JUNE 1979

TAS
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AN IMPROVED IMPLANTABLE ELECTRIC FIELD PROBE
FOR MICROWAVE DOSIMETRY

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A miniaturized probe has been developed for microwave dosimetric measurements in phantom models and experimental animals. Its primary features are a small tip size (1 mm by 2 mm, including insulation) and optimized sensitivity, achieved through the use of a specially-selected Schottky diode whose parameters match those of the 1.5 mm-long dipole antenna. Extensive testing in free space and in muscle equivalent spheres yielded data which were compared with theoretically predicted responses. Because of the small tip size, excellent agreement with theoretically-predicted fields was achieved in a highly repeatable manner at 915 and 2450 MHz. Three readings must be taken with this single axis device, at a point within a dielectric object or biological specimen, to obtain the total internal field strength at that site. These readings are obtained by rotating the probe in 120° increments around the axis of the handle. Rapid, continuous line scans can be made by driving the probe through phantoms, since the response time of the probe is less than 1 millisecond.

The probe's high sensitivity allows the measurement of internal field strengths of 9 to 80 V/m (SAR = 0.16 to 12.8 W/Kg) in muscle. Both CW and amplitude modulated fields can be measured. Probe sensitivity is limited by flexure noise in the high resistance lines at the low end of its range and diode non-linearity at the high end of its range (both of which could be compensated for, through additional steps). In free space, the probe's useful range is from approximately 10 microwatts per square centimeter to 5 milliwatts per square centimeter.

Present tests indicate that good accuracy should be achievable in muscle, brain, eye, and other high-water-content tissues. Preliminary in-vivo 2450 MHz measurements in mice testes were performed by Cairnie and associates of the Radiation Biology Section, Defence Research Establishment of Canada. Additional biological compatibility tests with various animals will be performed in the near future, by several groups.

Task 452

1/79 Submitted to BEMS

6-78

An Optically Linked Telemetry System for Use with Electromagnetic-Field Measurement Probes

HOWARD I. BASSEN, MEMBER, IEEE, AND ROBERT J. HOSS

Abstract—A battery-powered optical telemetry transmitter, 2.5 × 2.5 × 3 cm, has been developed for use with various electromagnetic-field hazard probes. The electrical outputs from one of these probes, containing three orthogonal sensors, are electrooptically converted to three separate optical pulse trains so that a dc to 2-kHz information bandwidth is established in the transmitter using frequency-modulation techniques. The three optical pulse trains are transmitted over a 4.6-m fiber-optics bundle to one of two types of receivers. These units reconvert the information to either an analog replica of the transmitter input waveform, or to a three-digit, scaled numerical display of the time-averaged value of the input signal. Practical applications involving field-strength measurements in the 1-MHz to 12-GHz region are presented. Advantages over hardwire data links are discussed, and significate reductions in RF interference and cable backscatter during field-strength measurements are described.

Key Words: EM-field probes, telemetry system, optically linked.

I. INTRODUCTION

AN OPTICALLY LINKED telemetry system has been designed for use with microwave and RF hazard probes. The telemetry transmitter is designed for use where high-level electromagnetic fields are present and a hardwired output link would perturb the field under investigation. The use of a fiber-optic link and a miniature telemetry transmitter reduces interaction with the ambient electromagnetic fields and therefore improves the detector's overall accuracy. Conventional hazard probes with metallic output wires scatter and reflect the electromagnetic field in the vicinity of the probe, obscuring the true field distribution [1]. Experimental data will be presented to illustrate these effects. Other field measuring systems utilizing high-resistance output cables to reduce such interaction introduce increased background noise [2]. Fiber-optics data links have been used with medical [3] and electromagnetic-field instrumentation [4] systems, but not in the micropower, microminiature form required for isotropic hazard probes.

The optically linked telemetry system accepts low-level analog input signals (dc to 2 kHz, 0-50-mV peak) via a high-input-impedance micropower differential amplifier. The conditioned analog signal is fed into a CMOS voltage-controlled oscillator (VCO) which produces a square wave output pulsetrain whose frequency (15-30 kHz) is linearly proportional to the analog input signal. The VCO output drives an infrared light-emitting diode (LED) with an average LED current of

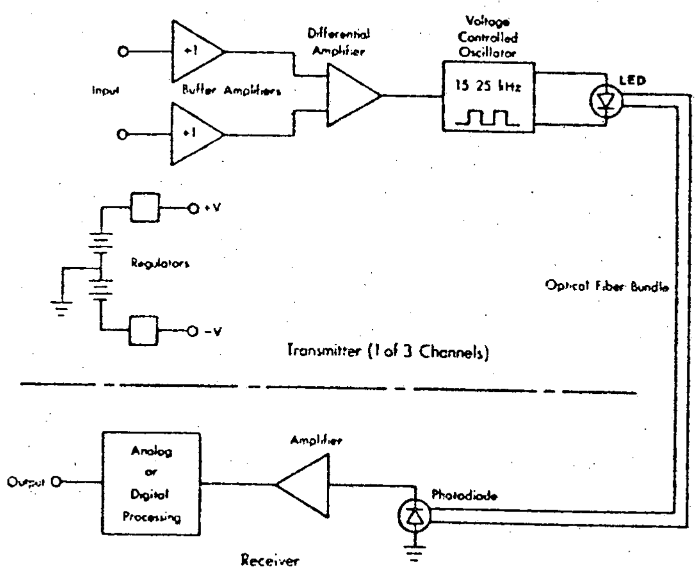

Fig. 1. Block diagram of optical telemetry system.

200 μA. Power-supply regulation is incorporated in the transmitter to maintain accuracy during battery voltage decay.

A fiber-optic link, 4.6 m in length, optically couples the telemetry transmitter's output to three photodiode detectors in a receiving system which can be located out of the high-field-strength zone. The cable consists of three multifiber glass bundles with a total cable diameter of 1 cm. No attempt to analyze or minimize scatter from the glass-fiber bundle was attempted. An analog receiver has been developed which reconverts the frequency-modulated pulsetrain to an analog replica of the signal present at the input of the telemetry transmitter. A digital receiver has also been developed. It utilizes counting and scaling to provide a three-digit display of the time-averaged transmitter input signal. Fig. 1 illustrates the telemetry system in block-diagram form.

The above transmitter was designed throughout with minimal power consumption in mind. All transmitter circuitry (inlcuding the LED's) in the three-channel system requires a total of 1.25 mA from +6- and −4.5-V battery supplies. The transmitting system has been developed using hybrid integrated circuitry. It is contained in a metallic case whose size, including batteries, is 2.5 × 2.5 × 3 cm. The three channels allow simultaneous monitoring of three orthogonal antenna detectors, thus providing complete measurement capability for all components of an electric or magnetic field. Fifty hours of continuous use are provided from a set of miniature mercury batteries.

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Task 452

TASK 452

A LIMITED EVALUATION OF CICOIL "PERSONAL EM RADIATION HAZARD DETECTOR"

by Howard Bassen

REVISED

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1. INTRODUCTION

The Cicoil Corporation's "Micro-Gard" "personal RF Radiation Hazard Detector" is described by the manufacturer as a device, to be worn on the body, which sounds an audio alarm when the power density incident upon it exceeds a factory preset level (0.5 to 10 mW/cm2) over the frequency range of 0.5 to 13 GHz. The response to amplitude modulation imposed upon the incident EM radiation is not discussed in the manufacturer's literature. The scope of this limited evaluation included tests of alarm threshold accuracy versus the frequency and the modulation of incident EM fields. Both vertical and horizontal polarizations were utilized, with the unit under test having its front surface oriented orthogonally to the direction of propagation (Fig. 1). Tests were performed on three units purchased by a government agency and by its contractor.

A physical examination of the unit revealed a microwave antenna array consisting of two orthogonal dipoles, each approximately 1.5 cm in length (Fig. 2). These dipoles were etched on a printed circuit board, and a detector diode was soldered across the center gap of each antenna. From a knowledge of the dynamic range limitations of diode detectors, it was suspected that problems would occur when short pulses of microwave energy (such as those emitted by a radar system) were detected by these nonlinear devices. Shielding of the associated electronic detection circuitry was found to be minimal. The shielding consisted solely of a copper-clad printed circuit board in front of the electronic detection circuitry. No metallic enclosure or "feed-thru" filters for battery wires, etc., were incorporated in the unit. Therefore, RF interference problems were anticipated in the form of anomalous behavior for certain orientations of the unit.

An EM Radiation Safety Controller

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ABSTRACT

A safety control system has been developed for use in high power RF/microwave radiation exposure facilities. The system features Fail-Safe RF detectors, visible "RF ON" indicators, door-status sensors and digital logic to maintain safe opera conditions in spite of human errors or unsafe equipment malfunctions.

INTRODUCTION

The need for a personnel safety-monitoring/interlock-controlling device exists due to the increasing use of high-power microwave/RF generating equipment used in EM radiation testing, calibration, and biological effects facilities. In these facilities this equipment can cause acute injuries to operating personnel due to accidental exposure to intense electromagnetic fields. Many presently-manufactured high-power RF/microwave generators possess inadequate "power on" indicators, interlock circuits, and other safety features which are fail-safe. This can create unsafe situations in which operating personnel can be exposed to high field strengths after supposedly "turning off" the equipment or tripping an interlock, while in reality, no power shutdown has occurred due to faulty relays, switches, etc. Another common cause for accidental exposure is human error in which a person enters an EM radiation area, forgetting to turn off a high-power source. Because inadequate visible indicators or exposure area personnel sensor circuits are in the system, the forgetful person would be exposed unnecessarily to electromagnetic radiation. Similarly, one person could shut down an RF microwave source and enter the "exposure zone" while a second person could reactivate the source and expose the second person not knowing that someone was in the exposure zone. The exposed person would not be warned of the situation due to a lack of visible and audible indicators in the high-field-strength zone, and might only realize he was being exposed by sensing warmth due to RF heating effects. All of the above incidents have occurred in operational situations.

A safety controller has been developed to provide fail-safe protection for operators and users of high-power microwave and RF generators. The system uses multiple fail-safe RF detectors to monitor the presence of transmitted or radiated power, together with "door status" sensors which monitor access points to the hazardous exposure area. Digital logic is then used to determine potentially hazardous situations in which a person could be in a location where high field strengths exist. Once such a situation is detected, the controller activates visible and audible alarms, and the high-power source is turned off, via redundant relays.

CONTROLLER SYSTEM DESCRIPTION

A block diagram of the controller integrated into a typical microwave exposure facility is shown in Figure 1. One set of controller inputs consists of two contact closures which can be activated by exposure-area "door status sensors" such as mechanical switches, light-beam/photocell sensors, or a pressure-sensitive mat on the floor of the exposure area passageway. The sensors are fed into latching circuits, so that once tripped, they remain so until reset with a push button on the safety controller panel. The second set of inputs are two RF sensors consisting of commercial diode detectors in coaxial mounts. These detectors may be used to sense transmitted power when connected to the generator's waveguide or coaxial output port via a suitable directional coupler or signal-sampler. They may also be connected to a small antenna, placed in the exposure zone, to monitor radiated fields. The detectors are operated in a biased mode, and are part of a "balanced bridge" circuit which continually monitors the diode detector to ensure that it is both connected to the controller system, and is neither open nor short-circuited due to RF overloading or static electricity damage. This bridge uses a second identical diode detector mount, not connected to the RF source, as the reference element of the bridge circuit (Figure 2). An unbalanced condition of the bridge exists if the RF detector receives RF or microwave energy, or if it is open or short-circuited. Thus, a failure of the detector is a safefailure, causing the safety controller to receive a false "RF-on" signal. With a 1N23 diode in a standard coaxial mount, approximately 0.1 mW is sufficient to turn the detection circuitry to the "ON" state. At microwave frequencies, a half-wave dipole connected to the above crystal detector will activate the detection circuitry when irradiated by fields below one mW/cm^2.

The controller utilizes digital CMOS logic circuitry for increased noise immunity. Basically, the controller uses a key operated "master switch" which the user places in the "on" or "off" position. This switch activates the appropriate logic and relays which can activate a high-power RF generator. The key is removable only in the RF off state, so that the user may enter the exposure zone and automatically prevent another person from

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Task 452

AUTOMATED DIELECTRIC MEASUREMENTS WITH A SMALL MONOPOLE IMPEDANCE PROBE

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Interest is increasing in the use of a small monopole antenna as a probe of the dielectric properties of materials, including in vivo and simulated biological tissues. This approach allows a relatively simple measurement system at the point of contact with the material, eliminating the need for precision sample holders and sample preparation. The probe is simply inserted into, or placed against, the material under study. It has broadband capabilities covering HF through X-band.

There is also considerable current interest in automating the measurement of microwave network parameters. Very expensive systems have been available in the past for this purpose, but low-cost desktop computers and minicomputers which can communicate with instruments over the IEEE-488 Interface Bus have brought this approach into widespread usage. We have developed such a system from existing components which is controlled by a minicomputer.

The use of semi-automated microwave network measurements with the monopole dielectric probe potentially provides an extremely simple and versatile tool for making dielectric measurements. Uncertainties in the measured dielectric properties may be significantly reduced. However, there are unique problems associated with the calibration of a network analyzer when using the impedance probe.

The network analyzer system is normally calibrated at a reference plane where standard connectors are available. However, upon attachment of the monopole probe, the system is no longer completely calibrated because of the added connector and short transmission line. We have developed a solution to this problem utilizing a specially-designed probe which can mate directly to similarly designed impedance standards. This allows calibration of the system at the plane of the monopole.

A detailed description of the probe and network analyzer system is given and an analysis of the residual errors is included. Results obtained on standard materials with the system fall well within the range of values reported in the literature.

SEATTLE, JUNE 1979
TASK 452

FIELD DEPOLARIZATION IN A SPHERICAL LOSSY MEDIUM

S. M. NEUDER

SUMMARY

When a spherical lossy dielectric is irradiated by a plane electromagnetic wave, electric and magnetic fields are induced in the enterior. If the original field is linearly polarized, then the direction of polarization is generally not maintained internally. The internal field is depolarized, exhibiting three components at each point whose magnitudes vary spatially from point to point.

An experimental determination of the electric field intensity, E^2, at an arbitrary internal point would require the measurement of three field components at that point. Using a miniature implantable probe with single dipole would necessitate three angular orientations about a fixed axis in order to determine the electric field intensity (1).

For the spherical dielectric, theory products that certain field components are absent along various symmetry planes and axes. This has implications for minimizing the heating of metallic leads of implantable thermistors or field probes and for reducing the required number of probe orientations during interior E - field measurements.

A computer program (2) has been used to predict the internally induced fields in a spherical lossy medium. The calibration of an E-field probe in this medium can be achieved by scanning internally along the direction of field propagation and comparing the measured E^2 with theoretically predicted E^2. Only one probe orientation, rather than three, is necessary during probe scanning (3), since no depolarization is predicted along the scan path.

The computer program has also been used to investigate depolarization gradients in small regions transverse to the scanning direction. These results have implication to the possible errors in probe calibration in spherical media and to preferential directions for metallic lead implantations.

Seattle, June 1979
TASK 452

URSI/BIOELECTROMAGNETICS SYMPOSIUM, JUNE 1979
TO BE SUBMITTED TO IEEE MTT JOURNAL

DOSIMETRIC USE OF SCHOTTKY DIODES

by William A. Herman
Bureau of Radiological Health, FDA

In current biological research, there is considerable use of electric and magnetic field probes to complement thermographic and thermometric measurement techniques. Such probes are often used to quantify both external and internal fields. Because of its small size, ruggedness, and high impedance, the microwave diode has been the overwhelming detector of choice in these applications. Yet the performance characteristics of such diodes and their limitations and strengths have been little anlyzed for this application.

The basic operational model of the diode is examined in this paper from the dosimetric standpoint. Its physical operation is used to generate an equivalent circuit. This, in turn is used to generate analytic expressions describing the behavior of the diode probe. The resulting expressions are used to reveal the presence of linear, square-law, and other operating regions. Because of its common use, the Schottky barrier or hot-carrier diode is especially discussed. Quantitative limitations on probe performance are shown to be specific functions of load impedance (including high resistance leads), bias current and temperature, as well as reverse saturation current.

The analysis thus developed is actually applied in an example which shows computations for a diode probe which was designed and employed for dosimetric use. The performance of the probe type is explained in terms of the model, and a comparison of actual and predicted values is presented.

A more general discussion of dosimetric diode probes is employed to suggest ways to use diode characteristics to maximize probe performance, and to predict limitations in this measurement approach.

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TASK 452

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A MICROWAVE DIATHERMY APPLICATOR

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ABSTRACT

The existence of some indication that microwave induced hyperthermia may be successful in the treatment of certain types of cancer, and the forthcoming introduction of the government regulations on microwave diathermy devices in Canada and the draft proposed microwave diathermy standard in the U. S. have stimulated an increased interest and progress in the development of new improved applicators. The main objective is to minimize leakage radiation and optimize energy deposition.

This paper provides a design method and experimental results for a direct contact circular aperture applicator. The applicator is equipped with a corrugated flange which purpose is twofold, to improve the uniformity of the heating pattern and to limit the leakage. The performance of the applicator operating at 2.45 GHz, has been tested using a short monopole probe and a thermographic camera, and the results obtained by the two methods have been compared.

TASK
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COMPARATIVE STUDY OF 2450 MHz and 915 MHz DIATHERMY APPLICATORS WITH PHANTOMS

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In support of the BRH diathermy programs, techniques to evaluate the relative effectiveness and safety of applicators were developed. According to the proposed microwave diathermy standard, a leakage of not more than 10 mW/cm^2 at 5 cm from the phantom-applicator boundary is required. The leakage is determined under conditions in which a Specific Absorption Rate (SAR) of 235 W/kg is delivered to simulated muscle tissue of a phantom beneath its 1 cm or 2 cm fat layer. Three recently developed BRH applicators with chokes, one for 2450 MHz and two for 915 MHz use, meet the requirements of the proposed standard (the smaller 915 MHz applicator has a thin sheet of absorbing material around the exterior choke surface). Analysis of their performance revealed that it is much easier to control leakage at 2450 MHz than at 915 MHz. The 2450 MHz applicator has less than 5 mW/cm^2 leakage for both direct contact and 1 cm spacing between aperture and planar phantom. Both the large and small 915 MHz applicators have less than 5 mW/cm^2 leakage for direct contact. However, for a 1cm spacing between aperture and planar phantom, the leakage exceeds 10 mW/cm^2 for the large 915 MHz applicator and is about 100 mW/cm^2 for the small 915 MHz applicator.

Four microwave hyperthermia applicators of various cancer therapy groups, including RTOG, were evaluated. None of these applicators had special design features to control leakage radiation. They include a 2450 MHz design with three concentric circular tubes and three 915 MHz designs with dielectrically loaded waveguides. A comparison of the heating patterns of all the tested applicators shows that the depth of penetration normal to the fat-muscle interface (defined at a point where half the maximum SAR in muscle tissue exists) is nearly identical for 2450 MHz and 915 MHz. The depth is about 2 cm beneath the fat-muscle interface for both of these ISM frequencies.

To summarize, 915 MHz applicators require much more net power than 2450 MHz applicators to deliver the same SAR to muscle tissue, when not in direct contact. For even a small spacing between aperture and phantom (cm), excessive leakage results. In addition, since depth of penetration is about the same, 2450 MHz applicators seem to be considerably more effective and safe.

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455

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Leakage in the Proximity of Microwave Diathermy Applicators Used on Humans or Phantom Models by H. Bassen, G. Kantor, P. S. Ruggera, D. M. Witters

ABSTRACT

In early 1978, members of the Bureau of Radiological Health performed a brief, collaborative study with the Physical Therapy Department, U.S. Public Health Service Outpatient Clinic, Washington, DC. The study's objective was to obtain sets of data on the leakage fields existing in the immediate vicinity of a specially designed diathermy applicator (developed for BRH by Transco Products, Inc., Venice, CA) operated at 2450 MHz in conjunction with simulated human arm, thigh, and trunk (back) models or phantoms, and with two human volunteers. The data were analyzed to obtain the relationship between leakage emission levels when using standard test phantoms and when simulating diathermy treatment on humans. The volunteers were minimally exposed, over 1-minute intervals, to low-power (1 to 1.5 watts of net power) simulated treatments, while leakage fields were mapped over the entire applicator/body interface surface. A commercially available isotropic radiation survey instrument was used, as well as a BRH-developed miniature E field probe. The mapping was performed manually, at a 5-cm distance from the applicator/subject interface.

Identical leakage measurements were performed on three types of human models (phantoms). A proposed BRH microwave diathermy performance standard calls for specific tests only using phantoms, and purposely omits any performance tests that would involve human subjects. Yet, the correlation between leakage levels existing in the proximity of the humans undergoing treatments is needed to evaluate the usefulness of phantoms as models. Agreement was found, to be good for all three phantoms (within a factor of 2), when compared to the corresponding actual human treatment data on the portion of the anatomy so long as leakage was higher than background instrument noise levels. The data were analyzed by extrapolation to effective treatment conditions (235 W/kg delivered to the phantom muscle material). Based on the low-power test data for the trunk phantom and lower back of the human patient (lumbar region-excluding the spinal area), leakage levels of less than 0.2 mW/cm^2 and 0.5 mW/cm^2 were calculated for full-power treatments, respectively. For the thigh phantom, a leakage level of less than 2.3 mW/cm^2 was calculated, while for the human thigh a leakage of less than 2.9 mW/cm^2 was calculated from experimental data. Tests conducted with the arm phantom revealed that less than 9.6 mW/cm^2 would exist under full power treatments, while for the upper arm (biceps region) and lower arm of actual patients the values were less than 11.9 and 8.3 mW/cm^2, respectively. Since this applicator was not designed for arm treatments, the leakage levels were higher than those for the thigh and back. Limited tests with the conventional, non-contact applicators most frequently used (Burdick types B and E) in conjunction with only a planar phantom revealed that low-energy deposition (less than 102 W/kg) resulted when the manufacturer's recommended power levels were used. Conversely, when input power to the applicators was increased so that 235 W/kg were deposited in the phantom muscle material, high-leakage levels (greater than 35 mW/cm^2) existed, 5 cm from the applicator/phantom interface. General conclusions that resulted from this study are that phantom models of appropriate parts of the human body can be used to predict leakage levels existing under clinical situations with actual human subjects with accuracy sufficient for purposes of hazard evaluation.

TASK 455

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Free-Space Electric Field Mapping of Microwave Diathermy Applicators

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ABSTRACT

In 1975 the Bureau of Radiological Health proposed a microwave diathermy performance standard. This paper describes an electric field mapping study which was designed and executed to study the performance characteristics of various prototype and clinically used microwave diathermy applicators. It details the experimental system, the methodology, and the results. Safety and thermal effectiveness of systems using these applicators also are investigated.

TASK USS

(2) B

Evaluation of Microwave Diathermy Applicators for Hyperthermia

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New BRH-developed direct contact applicators for microwave diathermy operating in the ISM (Industrial, Scientific and Medical) frequency bands of 2450 MHz and 915 MHz were evaluated by investigating thermographic heating patterns in phantoms, and measuring their associated leakage with a commercially available electromagnetic field probe.

One of the new designs operates at 2450 MHz and is a circularly polarized horn with a microwave choke around a 15 cm diameter aperture. The other two, which operate at 915 MHz, are designed with four ridges inside a circular waveguide to provide circular polarization. The larger of the 915 MHz applicators has a 25 cm diameter aperture with three concentric annular chokes, while the smaller has a 15 cm diameter aperture with one annular choke and a thin sheet of absorbing material around its exterior surface.

The heating patterns induced in the muscle tissue of a planar phantom beneath its 1 cm thick fat layer were obtained and analyzed for the spatial distribution of the temperature rise. Values with the induced temperature rise 50 per cent of the maximum (peak) value were used to define the area and depth of the temperature distributions. The heating patterns are relatively uniform in a square area of 56 cm^2 for the 2450 MHz applicator and in a rectangular area of 28 cm^2 and 42 cm^2 for the small and large 915 MHz applicators. The depths of penetration at this temperature are 2.2 cm at 2450 MHz and, on the average, 2.3 cm for the quasi-symmetrical heating patterns at 915 MHz. For the 2450 MHz applicator the net power needed to deliver an effective rate of energy deposition of 235 W/kg to a planar muscle phantom with the 1 cm layer of simulated fat is 19.3 W and the maximum leakage at this power level is 0.2 mW/cm^2. For the large 915 MHz applicator the corresponding heating and leakage values are 36.4 W and 0.15 mW/cm^2, while for the smaller model they are 33 W and 2.5 mW/cm^2.

These new applicators meet the safety and heating effectiveness performance requirements of the draft proposed standard for microwave diathermy equipment. Recently, their designs were dedicated to FDA for public use.

Proceedings of 3rd R.T.O.G. Hyperthermia Group Meeting, Nov. 26-27, 1978, Chicago, Illinois

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