BE-23

AN IMPROVED IMPLANTABLE ELECTRIC FIELD PROBE FOR MICROWAVE DOSIMETRY

[redacted]

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^{o} 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.

I. INTRODUCTION

Several years ago, the Bureau of Radiological Health reported on an implantable electric field probe for microwave dosimetry applications (1). Now an improved miniature field probe has been developed and evaluated. This smaller, more accurate probe was designed for ease of implantation and use in living animals or models. The design included all of those features found necessary for an optimized implantable probe (1) specified in Table I. Improvements over the previously developed implantable probe were incorporated, including (a) shorter dipole length (L=1.5 mm) (b) low dielectric constant substrate (K=2.0) with a 1000 ohm/square high resistance line pair (each line 0.002" wide), (c) an optimized, low-barrier schottky diode (for improved performance at frequencies below 1000 MHz), (d) a continuous, 25 cm lead frame with a flexible rather than a rigid housings. (e) a small (1 mm by 2 mm) tip of epoxy fiberglass (dipole insulator) for reduced media dependance and improved biological compatibility.

Being a single axis probe, the dipole was oriented at a 54 degree angle with respect to the probe's long axis (Fig. 1). This would enable all three orthogonal components of an arbitrarily-polarized electric field vector, to be measured by rotating the probe in 120 increments around its long axis. By taking these three orthogonal (E^2) readings at any point in a dielectric object, the total field (squared) could be ascertained by summing the three measured values obtained at the fixed location in the dielectric object.

II. PROBE EVALUATION - FREE SPACE

Free-space probe sensitivity was found to be approximately 1 mV for 1 mw/cm^2 at 450, 915, and 2450 MHz. A good signal to noise ratio (10 to one) can be obtained when a stationary probe is exposed to 0.05 mw/cm^2 or more at 2450 MHz using a 1 Hz detector bandwidth. Moving the probe, while implanted in simulated muscle material, produced a much larger noise level due to the behavior of high resistance lines under flexure. This "Flexure" noise was minimized by rigidizing the probe body with a solid plastic tube, slid firmly around the probe body, but not around the flat tip. This reduced noise levels during movement to about 9 V/m equivalent response at 2450 MHz. Linearity was found to be excellent from 0 to over 6 mw/cm^2 and was proportional to E^2 (Figure 2). In muscle, at 2450 MHz, the maximum useable range of the probe would therefore be 80 V/m.

Antenna patterns were taken in free space at 450, 915, and 2450 MHz using a probe rotation device in a locally constant E field, in an anechoic chamber.

III. PROBE EVALUATION-SIMULATED TISSUE

Internal field scans were performed in muscle equivalent-spheres (housed in styrofoam) at 915 and 2450 MHz, using plane-wave exposures of the spheres in an anechoic chamber. A mechanical scanner (which did not perturb the microwave fields) drove the probe precisely along the axis of microwave propagation from the rear to the front of the sphere (front of the sphere facing the transmitting antenna). This probe support system enabled highly-repeatable data to be taken in muscle spheres, directly along the sphere's center axis.

Only one orientation of the probe was used, with the substrate plane containing the dipole being vertical, in a vertically-polarized E field. Free space and internal scans were taken under identical transmitted power levels. Since the central axis (parallel to the axis of propagation) contains no cross-polarized internal fields (2) three orientations of the probe (each rotated 120 about the probe body) were unnecessary, since internal and external field polarizations were both predominantly vertical (2).

A comparison of 2450 MHz data and theoretical predictions is shown in Figure 3 for plane-wave, 2 mw/cm^2 exposures of a 3.3 cm radius muscle-equivalant sphere. This test object was selected since it contains standing waves and internal peaks which are highly unique and predictable (1), if the dielectric properties of the sphere are well known. A comparison of 915 MHz data in the same test object is shown in Figure 4 for a 1.5 mw/cm^2 exposure situation.

At the frequencies of 915 and 2450 MHz, measured versus predicted fields were approximately 5.6 dB greater than those that would be obtained using an "ideal" probe, due to the media-dependence of an insulated dipole which is calibrated in air and then used in high dielectric constant media (k = 50). This phenomena (illustrated in Figure 5) and is not of serious consequence when using the probe in dielectric media with a relative dielectric constant greater than 10 (3,4). Additional tests in simulated brain material are in progress to fully evaluate the media dependency over the dielectric constant range of 35 to 50.

Preliminary in-vivo 2450 MHz measurements in mice have been made by Cairnie and Associates at the Defence Research Establishment, Ottawa, Canada.

I. CONCLUSIONS

An accurate, small, biologically-compatible implantable probe has been produced to BRH specifications by the Narda Corporation. For internal measurements in muscle equivalent spheres, good signal-to-noise ratios were obtained for free-space exposures of the spheres at 1 mw/cm^2. A dynamic range of 9 V/m to 80 V/m in muscle material at 2450 MHz is achievable (0.16 to 12.8 W/kg). The limitations are due to flexure noise and diode non-linearity respectively. When the dielectric properties of the biological media under test are not known, an error of approximately $\pm$ 1 dB should result for measurements in muscle, brain, eye media or tissue with high water content.

REFERENCES

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2. Neuder, S., Private communication on the analysis of depolarization of fields within homogeneous dielectric spheres, exposed to linearly-polarized plane waves.

3. S. Mousavinezhad, K. M. Chen, D.P. Nyquist, "Response of insulated electric field probes in finite heterogeneous biological bodies" IEEE Transactions on Microwave Theory and Techniques, pp. 599-607 (August 1978).

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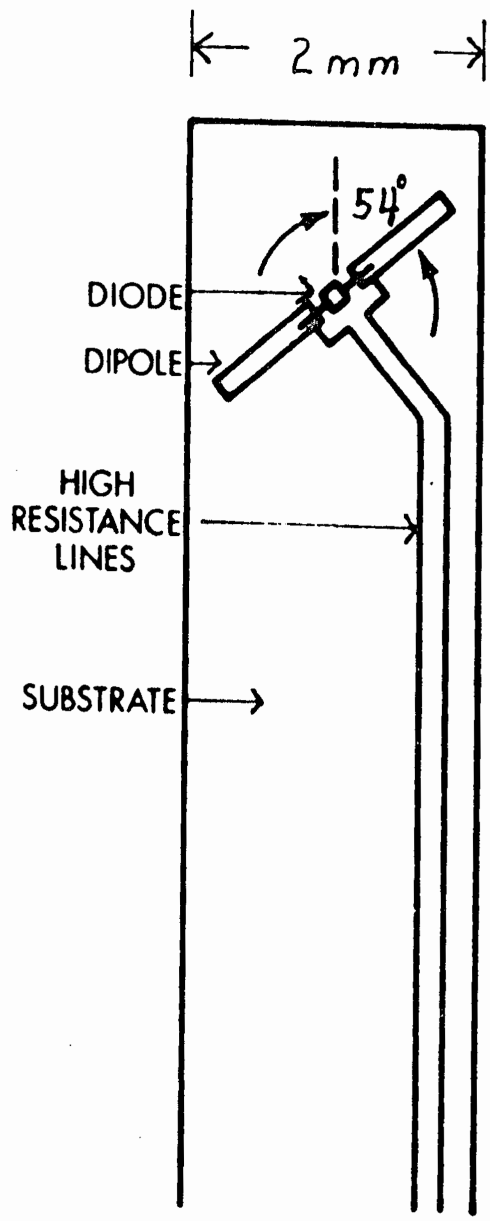
FIGURES

TABLES

TABLE 1
Microwave Probe Design Criteria

Criteria	Effect on Performance	Implementation
Electrically small dipole (in the medium)	Good spatial resolution, non-perturbing	Microminiaturization to produce total length < 3 mm
High detector impedance	Elimination of boundary effects	Subminiature diode chip. Total device capacitance < 0.1 pF. No inductive bonding wires. Low leakage current required.
Dipole insulation $>10 \times$ dipole width. Less than $1/4\lambda$ thick in medium	Absolute accuracy independent of dielectric constant	Insulator of low dielectric constant surrounding electrically small dipole
Non-perturbing probe	Good absolute accuracy near boundaries.	High resistance leads. Electrically small probe with respect to internal wavelength.



Implantable Probe Design

Fig. 1

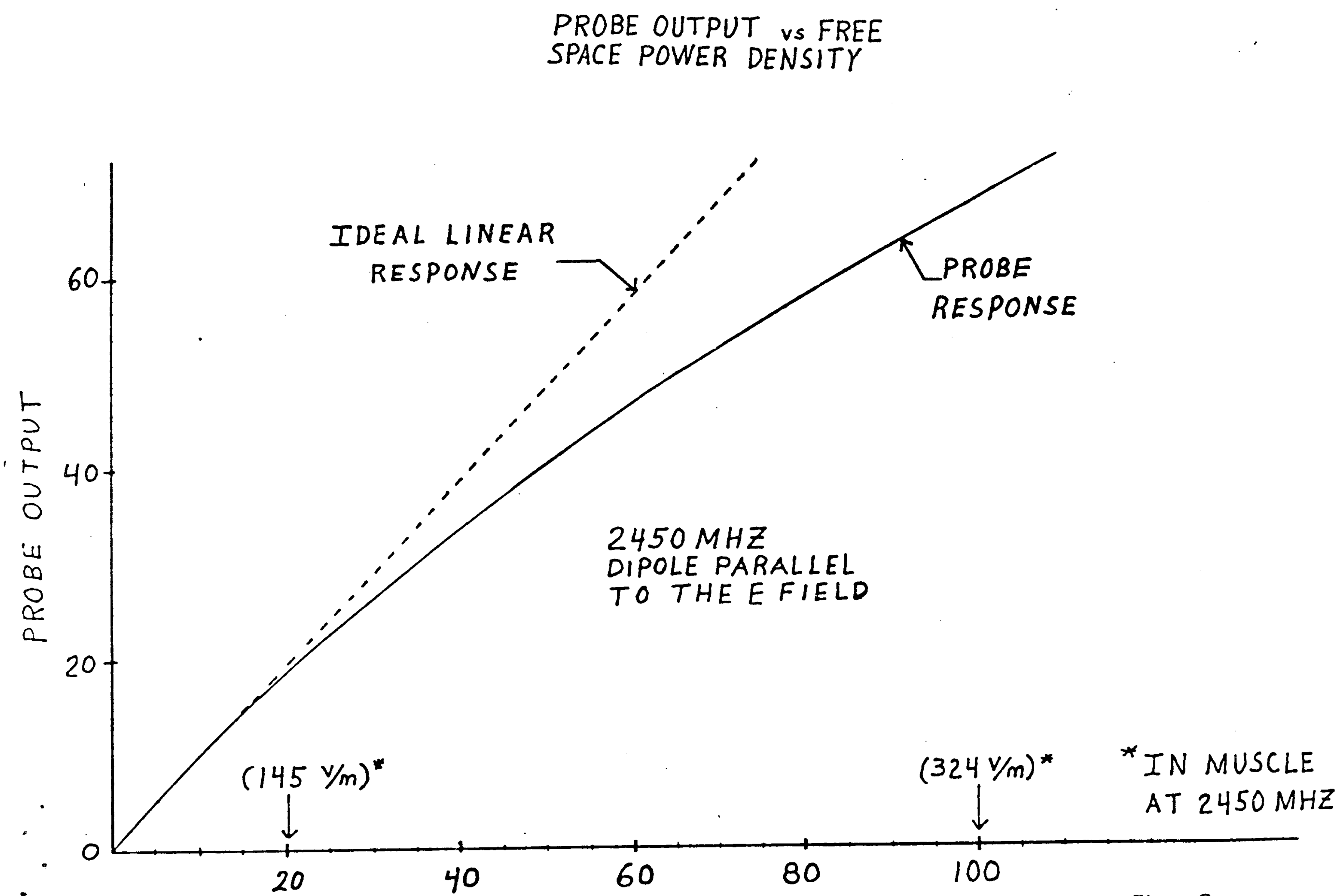
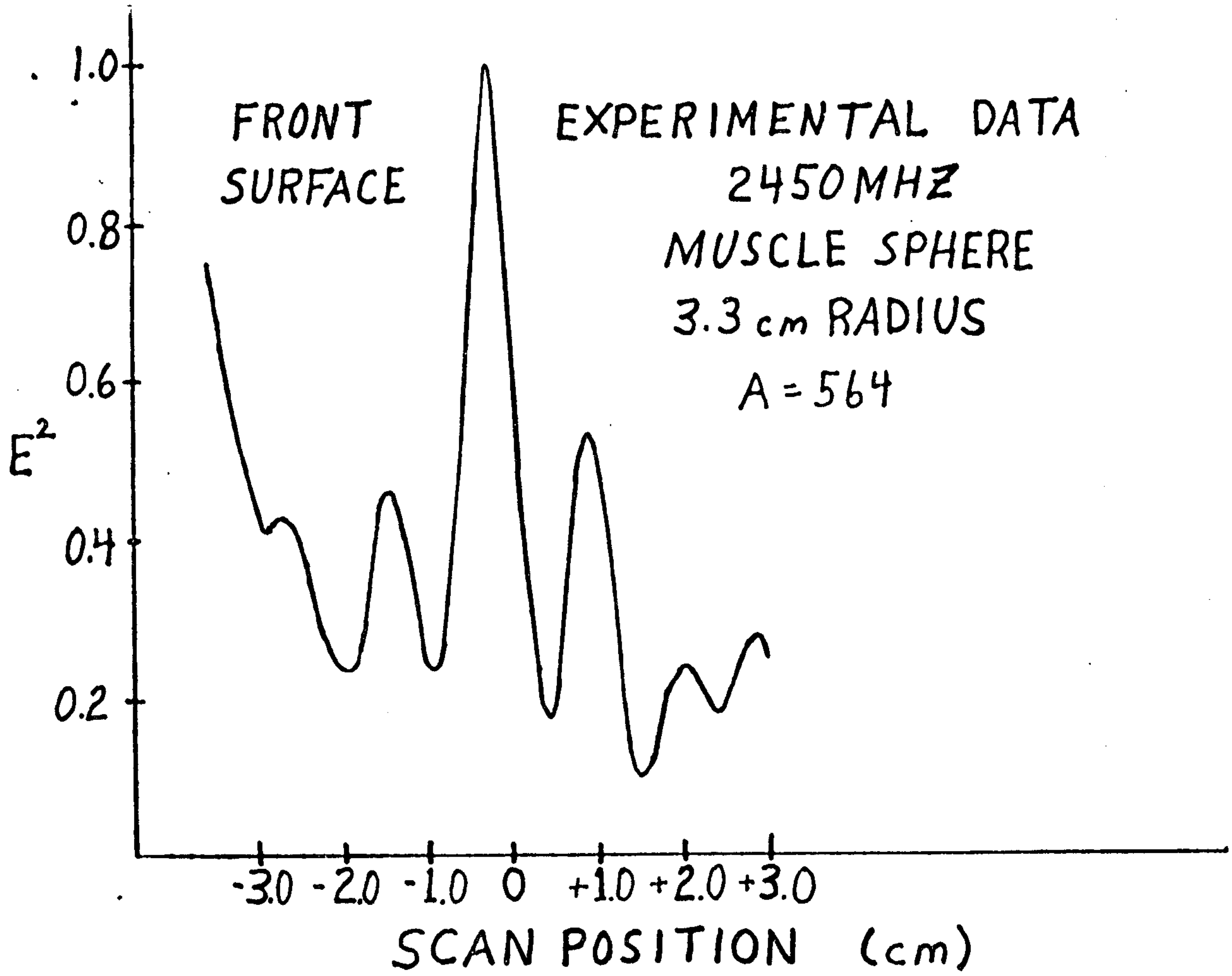
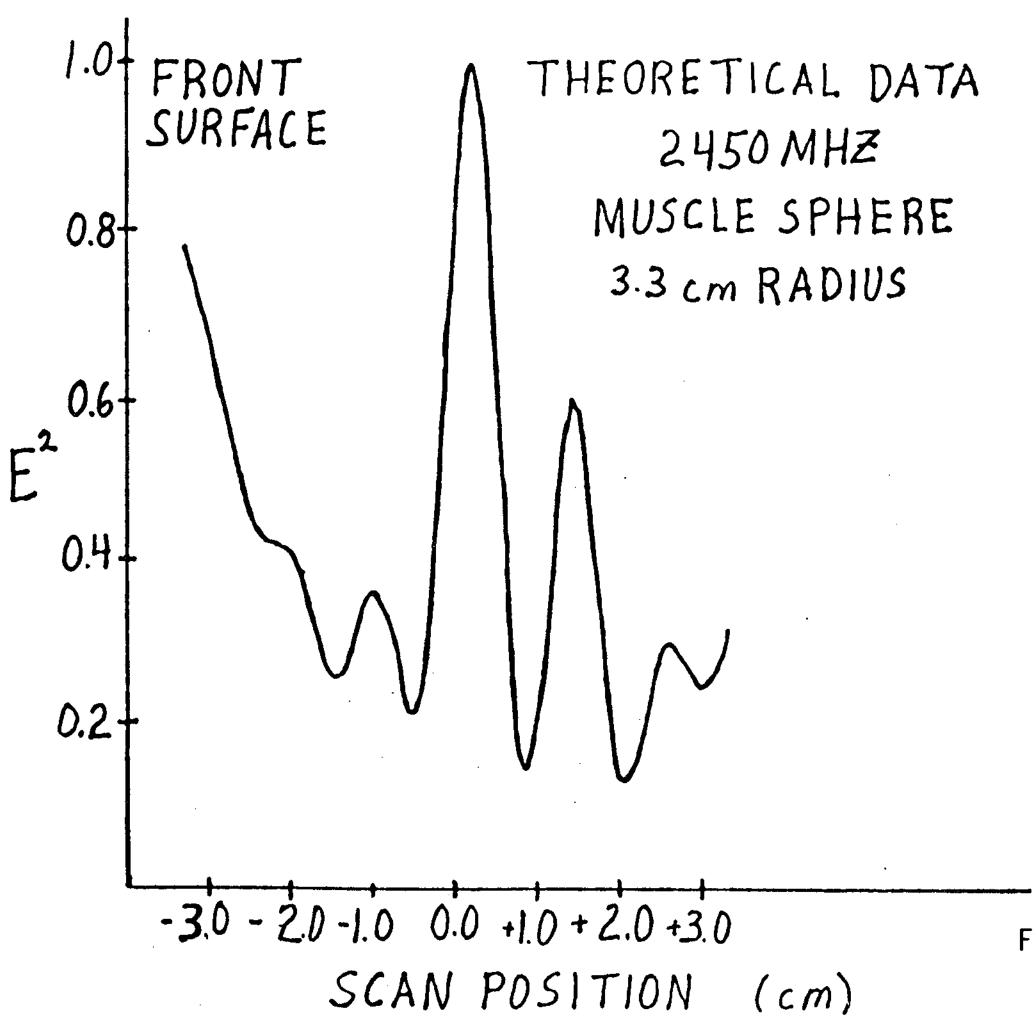

PROBE OUTPUT vs FREE SPACE POWER DENSITY
IDEAL LINEAR RESPONSE
PROBE RESPONSE
PROBE OUTPUT
2450 MHZ DIPOLE PARALLEL TO THE E FIELD
(145 V/m)*
(324 V/m)*
*IN MUSCLE AT 2450 MHZ
0
20
40
60
20
40
60
80
100

Fig. 2

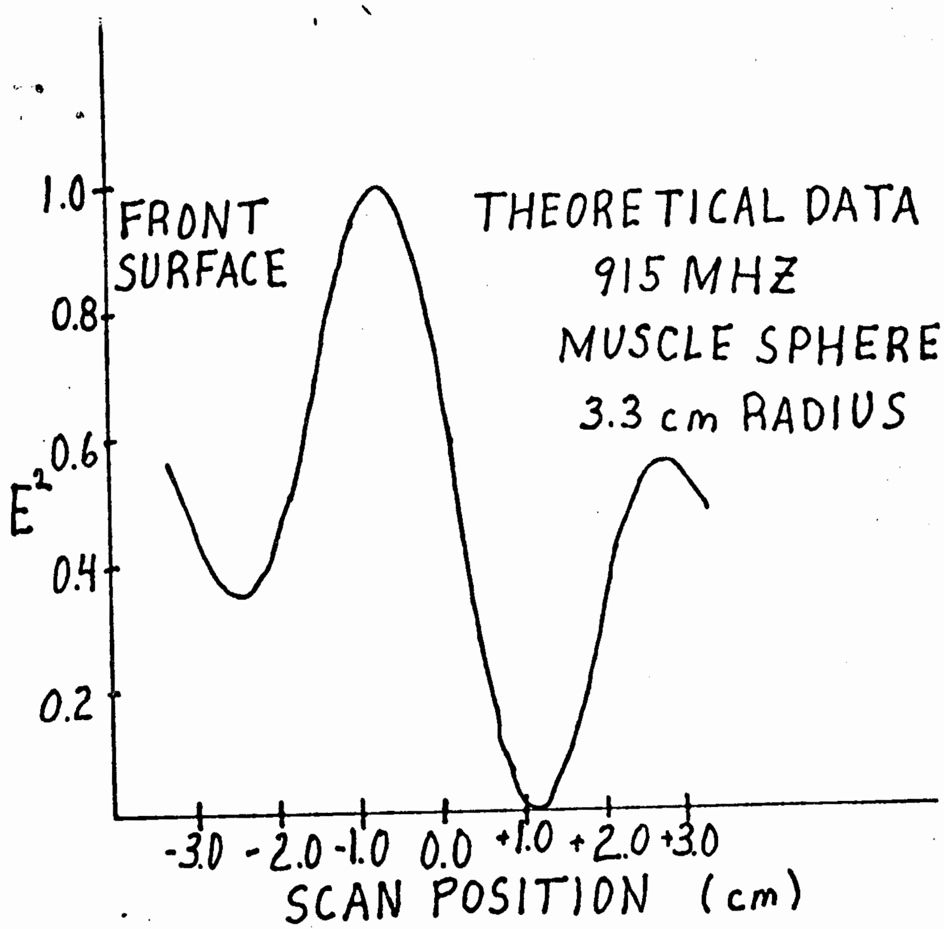


FRONT
SURFACE
EXPERIMENTAL DATA
2450 MHZ
MUSCLE SPHERE
3.3 cm RADIUS
A = 564
1.0
0.8
0.6
0.4
0.2
E^2
-3.0 -2.0 -1.0 0 +1.0 +2.0 +3.0
SCAN POSITION (cm)

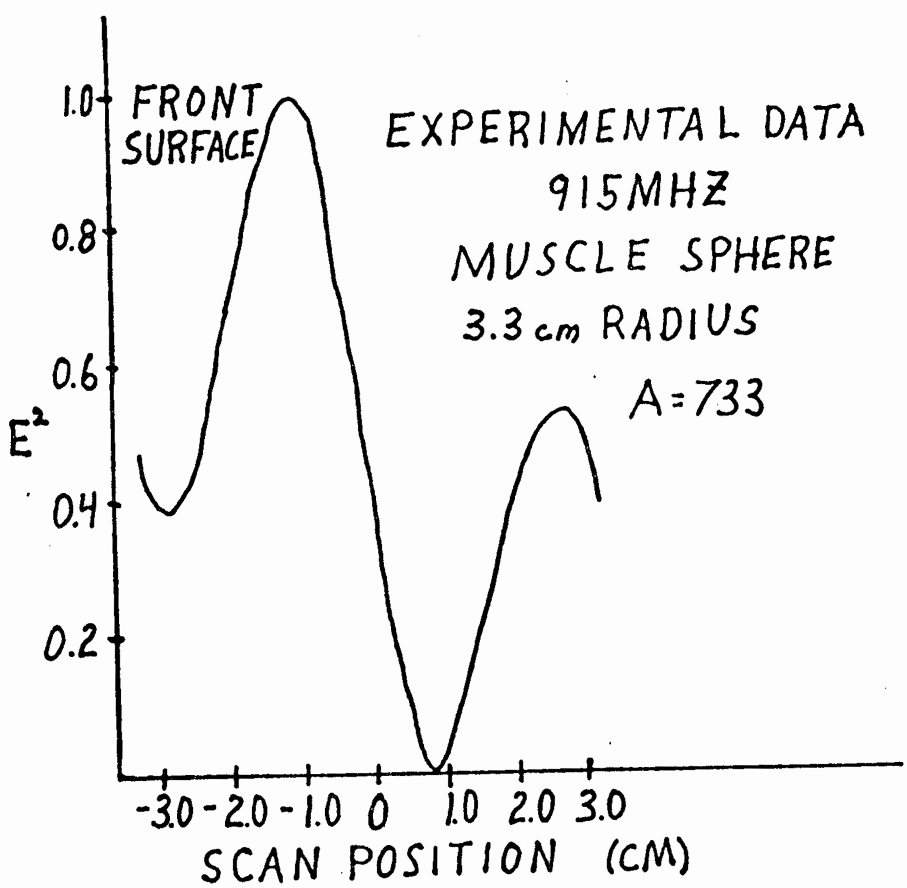


FRONT
SURFACE
THEORETICAL DATA
2450 MHZ
MUSCLE SPHERE
3.3 cm RADIUS
1.0
0.8
0.6
0.4
0.2
E^2
-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0
SCAN POSITION (cm)

Fig. 3



1.0
0.8
0.6
0.4
0.2
E²
FRONT SURFACE
THEORETICAL DATA
915 MHZ
MUSCLE SPHERE
3.3 cm RADIUS
-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0
SCAN POSITION (cm)



1.0
0.8
0.6
0.4
0.2
E²
FRONT SURFACE
EXPERIMENTAL DATA
915MHZ
MUSCLE SPHERE
3.3 cm RADIUS
A=733
-3.0 -2.0 -1.0 0 1.0 2.0 3.0
SCAN POSITION (CM)

Fig. 4