Comment on "Experimental and Theoretical Studies on Electromagnetic Fields Induced Inside Finite Biological Bodies"

H. I. BASSEN AND A. CHEUNG

The above paper[1] states unequivocally: "When a probe is immersed in a finite biological body to measure the induced electric field, the output of the probe becomes location dependent, especially at the edge of the body." This statement is only true for an electrically large dipole antenna with a relatively low impedance detector as a load. We have developed a set of probe design criteria for implantable electric field probes. These criteria have been applied to produce a miniature isotropic probe [1], [2] which is neither location dependent nor calibration dependent with respect to the dielectric properties of the surrounding media. This calibration independence is analyzed as a function of dipole insulation thickness by Smith [3].

The fabrication of our probe uses thin-film microminiaturized circuitry to produce an electrically small dipole (2.5 mm tip-to-tip) with integral beam-lead diode chip detector. No bonding wires are present to resonate with the very low reverse bias capacitance of the diode (0.1 pF). A layer of low-dielectric-constant encapsulation, which is less than one-quarter wavelength in the media, surrounds the dipole. In contrast, the device described by Guru and Chen is electrically large in the media (the diode package alone is 5 mm long) and is insulated only with a film of plastic spray. At 2450 MHz, the internal wavelength in a saline solution is approximately 1.5 cm. The diode package contains internal bonding wires and parasitic capacitances. Thus this large antenna readily interacts with dielectric boundaries causing a large antenna terminal impedance change. These changes affect system response significantly since the diode presents a low-impedance load.

The performance of our miniature probe has been recently evaluated by performing continuous scans within muscle-equivalent spheres ($\varepsilon_r \approx 50$) irradiated by a plane wave at a frequency of 2450 MHz. Good agreement of the spatial distribution of fields exists between experimental data and the theoretically predicted values computed by the methods described by Neuder *et al.* [4]. Fig. 1 compares a typical set of curves for a scan taken through the sphere, parallel to the external axis of propagation. The good agreement at the boundary region of the sphere, surrounded by foam plastic and air, should be noted. The magnitude of the theoretical versus measured field strengths agrees within several decibels after the probe is calibrated in free space at 2450 MHz. It is possible to improve this agreement by increasing the insulation thickness around the dipole, but this leads to boundary area inaccuracies in the experimental plots. These inaccuracies are due to the alteration of fields in this critical region caused by the presence of the electrically large insulation with its low dielectric constant. By decreasing the dipole size, we plan to increase the insulator-to-dipole-width ratio, thus enhancing calibration independence, while eliminating field perturbation within high dielectric constant media.

In summary, a practical probe is available which overcomes the drawbacks described by Guru and Chen. The location dependence has been eliminated, and readings may be taken in arbitrary geometries and media, with a minimum of uncertainty.

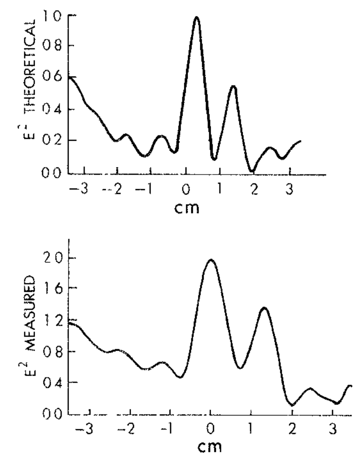

Fig. 1. Theoretical (top) and experimental (bottom) field scans in a 3.3-cm-radius sphere of muscle-equivalent material (2.45-GHz plane wave exposure).

References

[1] H. Bassen, M. Swicord, and J. Abita, "A miniature broad-band electric field probe," *Biological Effects of Nonionizing Radiation*, edited by P. Tyler, pp. 481–493. Annals of the New York Academy of Sciences, vol. 247, 1975.

[2] A. Cheung, H. Bassen, M. Swicord, and D. Witters, "Experimental calibration of a miniature electric field probe within simulated muscular tissues," *Proc. October 1975 URSI Bioeffects Symposium*, to be published.

[3] G. Smith, "A comparison of electrically short bare and insulated probes for measuring the local radio frequency electric field in biological systems," *IEEE Trans. Biomed. Eng.*, vol. 22, pp. 477–583, Nov. 1975.

[4] S. Neuder, R. Kellogg, and D. Hill, "Microwave power density absorption in spherical, multilayered models of the head," *Proc. October 1975 URSI Bioeffects Symposium*, to be published.

Reply[2] by K. M. Chen[3]

The comment made by Bassen and Cheung on the EM field probe used in our study [1] needs a clarification.

In our paper we stated that "when a probe is immersed in a finite biological body to measure the induced electric field, the output of the probe becomes location dependent, especially at the edge of the body." This statement is still valid for any linear EM field probe in a finite biological medium. The only modification we like to add to this statement is that "a field probe with a *thick* insulation (dielectric coating) can be designed to minimize this location dependence." This modification is based on the findings in our recent study on "Implantable EM Field Probe in Finite Biological Bodies" [2]. In this study it was found that when the thickness of the dielectric coating is the same as the radius of a spherical probe, the location dependence can be reduced to be about 10 percent as the probe is moved from the center of the body to the body edge. This location dependence can be reduced even more if the coating thickness is further increased. An extensive theoretical and experimental study on this subject will be published in the near future.

Bassen and his coworkers were successful in making an EM field probe which was nearly location independent because their probe was essentially a thickly coated probe [3]. The probe used

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[1] B. Guru and K. M. Chen, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 433–440, July 1976.

[2] Manuscript received October 26, 1976.
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in our previous study [1] was coated only by a very thin layer of plastic spray. With such a thinly coated probe, a strong location dependence on the probe characteristics is always observed near the edge of the body.

Bassen and Cheung commented that the location dependence of a probe characteristic can occur only for an electrically large probe. This statement is erroneous. An electrically larger probe has a smaller input impedance compared with an electrically small probe which has a large input impedance (mainly capacitive reactance). It is this input impedance of the probe which varies with the location in a finite biological body. Thus, with a fixed load impedance, the variation of the input impedance of a small probe will cause a larger percentage variation in the total impedance of the equivalent circuit of the probe as compared to the case of a larger probe and, consequently, a smaller probe will exhibit a stronger location dependence.

It is now clear that the key factor which determines the location dependence of an EM field probe is the thickness of the insulation layer. The size of the probe only plays a secondary role. Of course, it is the common goal for researchers in this area to construct an EM field probe with a minimum dimension and, at the same time, possessing location-independent characteristics. To achieve this goal, the probe size and the thickness of the insulation layer must be properly compromised and selected. The important fact is that it is impossible to construct a linear EM field probe which is completely location independent in a finite biological body. One can only minimize the location dependence by a proper design.

It is perhaps worthwhile to mention that Smith [4] studied the probe in an infinite biological medium. The geometrical discontinuity of a finite biological body was not considered in his paper.

References

[1] B. S. Guru and Kun-Mu Chen, "Experimental and theoretical studies on electromagnetic fields induced inside finite biological bodies," *IEEE Trans. Microwave Theory Tech.*, vol. 24, pp. 433–440, July 1976.
[2] H. Mousavinezhad, K. M. Chen, and D. P. Nyquist, "Implantable EM field probes in finite biological bodies," *Digest of 1976 IEEE Int. Symp. Antennas and Propagation*, pp. 409–412, Oct. 1976.
[3] A. Cheung, H. Bassen, M. Swicord, and D. Witters, "Experimental calibration of a miniature electric field probe within simulated muscular tissues," *Proc. October 1975 URSI Bioeffects Symposium*, to be published.
[4] G. Smith, "A comparison of electrically short bare and insulated probes for measuring the local radio frequency electric field in biological systems," *IEEE Trans. Biomed. Eng.*, vol. 22, pp. 477–583, Nov. 1975.

Further Comment by H. I. Bassen[4]

In our original comment on the paper of Guru and Chen, we made the statement that a location dependence exists for an electrically large dipole antenna *with a relatively low-impedance detector as a load.* We also pointed out that a thin insulation layer was used by Guru and Chen, and concluded that this combination of factors caused the undesirable location dependence observed by them. We then pointed out the necessity for proper design parameters of high-impedance load (low-reverse-bias capacitance diode, without bonding wire inductances), sufficient insulation thickness, and small dipole size. Using these design parameters, an accurate location-independent probe can be produced. We did not make the statement that location dependence of a probe can occur for an electrically large probe, regardless of load impedance.

[4] Manuscript received October 26, 1976.
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Dr. Chen then states (in his reply to our comments) that the size of a probe plays only a secondary role. We feel that proper size is critical in the design of an accurate internal field probe. In a biological body whose relative dielectric constant is high, the internal wavelength is foreshortened. In addition, finite bodies contain steep spatial gradients and standing waves when irradiated. In the case of bodies with curved surfaces, internal focusing occurs. These complex field distributions can only be accurately measured with a probe whose size is small compared to the internal wavelength because only this type of probe can provide adequate spatial resolution. An electrically large probe will measure only the spatial average of the complex fields within a finite body, and produce erroneous data. Secondly, an electrically large probe will produce significant internal field perturbations, due to its higher induced current flow on the dipole elements. For practical purposes, however, one cannot make a probe antenna excessively small, since its impedance then would greatly exceed the equivalent load impedance of even a microminiature diode chip even if the antenna is insulated. An optimum size for an antenna is therefore on the order of 0.1 wavelength in the highest dielectric constant medium to be encountered. We have encountered difficulties at frequencies below 1000 MHz in making our probes response independent of the media due to this fact. No boundary effects were seen, however, at any frequency, due to proper use of insulation. The use of a relatively large low-dielectric-constant insulator will also cause internal field perturbations. We have theoretically analyzed the perturbation effects of low-dielectric-constant insulators in various sizes of muscle-tissue spheres,[5] and have determined that an insulator whose dimensions exceed one-quarter of the internal wavelength will significantly alter the internal field distribution throughout the larger biological body.

[5] H. Bassen, P. Herchenroeder, A. Cheung, and S. Neuder, "Evaluation of an implantable electric field probe within finite simulated tissues," presented at USNC/URSI Annual Meeting, Amherst, MA, Oct. 1976.

Comment on "On the Design of Dielectric Loaded Waveguides"

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In the above paper,[1] the authors show that, by loading a rectangular waveguide with an *E*-plane dielectric slab, its theoretical power-handling capacity can be significantly increased. Their conclusion may come as a surprise to experimenters designing high-power *E*-plane devices such as ferrite isolators or phase shifters. It is a well-known fact that such structures tend to exhibit breakdown at power levels well below those of the empty waveguide.

This apparent discrepancy stems from the fact that the theoretical model used by Findakly and Haskal is a rather simplified representation of the structures encountered in real life. A mechanical joint without any gaps between the dielectric slab and the metal walls would be difficult to realize, except for short test sections. In high-power devices, the difference in thermal expansion coefficients prevents the realization of a perfect mechanical fit over an extended temperature and power range.

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[1] T. K. Findakly and H. M. Haskal, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 39–43, Jan. 1976.