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.

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.

[4] Manuscript received October 26, 1976.
H. I. Bassen is with the Division of Electronic Products, Bureau of Radiological Health, Food and Drug Administration, Rockville, MD 20852.

[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"

FRED E. GARDIOL

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.

Manuscript received December 10, 1976.
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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.

Whenever a gap, even a very narrow one, is present between dielectric and metal at the slab ends, the boundary condition on the normal electric field component specifies that this component is K' times larger in the air than in the dielectric. As a result, electrical breakdown in small voids can be expected to occur at a power level smaller than the one calculated by Findakly and Haskal by a factor of the order of $1/K'^2$.

The occurrence of gaps can, to some extent, be avoided by introducing low viscosity dielectric, such as silicone grease, within all cracks or crevices appearing at the dielectric-to-metal joint. However, dielectric losses within the filling material would increase somewhat the attenuation. On the basis of the theoretical analysis, loading a rectangular waveguide with a dielectric slab may look like a promising way to increase its power-handling capacity; considerable precautions would be required in practice to obtain a performance approaching the predicted one.

Reply[2] by H. M. Haskal[3] and T. K. Findakly[4]

The point raised by Prof. Gardiol is an important one. Intimate contact must be insured between the dielectric slab and the bottom and top walls of the waveguide to avoid local breakdowns. The contact surface which is critical for breakdown also carries an appreciable fraction of the microwave current so that greater attention to skin resistivity will be necessary than in microwave tube fabrication; long-term vacuum-tight seals are not required, however.

In the view of the authors it is useful to point out the high-power carrying capacity of the dielectric loaded waveguide in order to stimulate the development of fabrication techniques which can realize the full potential of the waveguide.

[2] Manuscript received December 10, 1976.
[3] H. M. Haskal is with the Department of Electrical Engineering, Tufts University, Medford, MA 02155.
[4] T. K. Findakly is with the Department of Electrical Engineering, Purdue University, Lafayette, IN 47906.

Discussion of "The Resonant Frequency and Tuning Characteristics of a Narrow-Gap Reentrant Cylindrical Cavity"

J. R. M. VAUGHAN

After programming the working equations given in the Appendix to this paper,[1] and finding that I could not reproduce the numerical results given in Table I, I have corresponded directly with the author. He informs me that there are four errors in the equation given on p. 187.

1) In the top line of the right-hand column, the sign preceding $\sin^2$ should be $-$ not $+$.

2,3) In the next line, $\pi - c$ should be $\pi - 2c$ in both places.

4) In the fourth line, the coefficient 0.01765 should be 0.03529.

With these corrections, I find that the computed frequency for case 1 of Table I agrees with Williamson's value within 0.6 percent. This is still some way from the claimed accuracy of 0.01 percent for the expression in the Appendix, but would be acceptable for most purposes.

I suggest that it is in any case more satisfactory to solve Williamson's (7) directly, rather than to use the complicated expressions in the Appendix, which have no apparent functional relation to the problem.

I find that about 25 terms of (7) are required, but this is less work than at first appears: After only 2 terms, x_m can be reduced to

$$-\frac{2}{q_m}\frac{K_1(q_m ka)}{K_0(q_m ka)}.$$

Then, when mc exceeds 10, the two Bessel functions of order 1/6 and 5/6 reduce to

$$J_{1/6}(mc) = \sqrt{2/\pi mc}\,\{(1 - 5/(9mc)^2)\cos(mc - \pi/3) + (1/9mc)\sin(mc - \pi/3)\}$$

$$J_{5/6}(mc) = \sqrt{2/\pi mc}\,\{(1 + 7/(9mc)^2)\cos(mc - 2\pi/3) - (2/9mc)\sin(mc - 2\pi/3)\}.$$

Using a computer, and these approximations for the higher terms, evaluation of (7) is quite straightforward.

Reply[2] by A. G. Williamson[3]

Because of circumstances at the time, the corrections were not immediately communicated and unfortunately the matter was subsequently unwittingly overlooked. I should like to thank Dr. Vaughan for remedying my oversight.

The aim of the Appendix expression was to provide a method suitable for the general narrow-gap case including the case where c is very small for which the direct solution of (7) requires a large number of terms. In specific cases, the parameters of the problem may be such that the direct solution of (7), incorporating the approximation mentioned for x_m, is quite satisfactory, as Dr. Vaughan correctly points out.

Manuscript received January 20, 1977.
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[1] A. G. Williamson, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 182–187, Apr. 1976.

[2] Manuscript received February 3, 1977.
[3] A. G. Williamson is with the Department of Electrical Engineering, University of Auckland, Auckland, New Zealand.