Microwave Transmission Through Normal and Tumor Cells

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Abstract—**The role of standing waves in the microwave measuring systems used in the study of normal and tumor cells is discussed. A pronounced cyclic variation in measured power as a function of frequency through biological materials has been reported in curves published for two frequency ranges: 66–76 GHz and 76–86 GHz. The materials studied included a variety of normal and tumor cells and compounds such as guanine and guanylic acid. A condition for cyclic and multiple resonances in a waveguide system is satisfied when at least two impedance discontinuities giving rise to reflections are present. When we have only two discontinuities, the distance between them may be calculated from the operating frequency and the separation between frequencies for maximum power transmission through a branch of the measuring system. In the resulting standing-wave pattern, the effect of introducing the organic or biological sample with losses over a wide frequency range into the measuring system is to reduce the magnitude of the maxima in the standing-wave pattern and to increase the magnitude of the minima. To distinguish between losses due to the sample and the frequency selectivity of the microwave measuring system, one sound procedure is to adjust the system for unity standing-wave ratio (SWR). After this is done, if one still observes a frequency-dependent absorption which arises on introducing the sample or by use of a comparison method employing two samples, the results will no longer be ambiguous. The ambiguity in results reported in the literature will be resolved when effective methods are used to control the frequency selectivity of the equipment.**

DIFFERENCES IN microwave transmission through tumor cells compared to transmission through normal cells have been reported several times in the literature. Webb and Booth [1] worked in the frequency range from 66 to 76 GHz and Stamm *et al.* [2] worked in the range from 76 to 86 GHz. The reports have a common feature, namely, the measurements show a periodic variation in power through the system as a function of frequency. Four maxima are found between 67 and 76 GHz in [1], and six maxima are shown in one curve between 77.5 and 84 GHz in [2]. In [1], the spacing between transmission windows is approximately 2.0 GHz, and in [2], it is approximately 1.3 GHz.

These results are what one would expect if there were two impedance discontinuities in the system separated by a distance L so that reflections occur at these discontinuities, resulting in a standing-wave pattern and in periodic frequency selectivity in the transmission system which contains the sample. The condition for resonance, namely, transmission with maximum amplitude, is

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$$L = n\lambda_g/2 \tag{1}$$

where λ_g is the wavelength in the guide, and n is integral if the phase shift on reflection at each discontinuity is either zero or π. n may be nonintegral in the presence of appropriate phase shifts on reflection.

λ_g, the wavelength in the guide, is

$$\lambda_g = (c/f)\left[1-(f_o/f)^2\right]^{-1/2} \tag{2}$$

where f is the operating frequency while f_o is the cutoff frequency, which is approximately 48.4 GHz for the standard guide used at these frequencies and has an inside width of 0.122 in, and c is the speed of light.

It may be shown that

$$L = \frac{c}{2}\frac{dn}{df}\left[1-(f_o/f)^2\right]^{1/2} \tag{3}$$

and

$$n = f\frac{dn}{df}\left[1-(f_o/f)^2\right]. \tag{4}$$

n will change by one integer as we go from one longitudinal waveguide mode to the next. We may use the approximation $\Delta n/\Delta f = dn/df$ over a range of frequencies such that f is considerably larger than f_o, where $\Delta n = 1$ and Δf is the corresponding frequency interval.

In the experiments in [1], we take $\Delta n = 1$, $f = 75$ GHz, and from the published curves, take $\Delta f = 2.0$ GHz. n is then calculated to be approximately 22 and L is very nearly 5.8 cm. In the results reported in [2], we take $\Delta n = 1$, $f = 80$ GHz, and from the published curve take $\Delta f = 1.3$ GHz. n is then calculated as approximately 39 and L as 9.2 cm. Using the results in [1], one may infer that the cyclic differential transmission reported could result from a resonance in the waveguide which arises from reflections from two impedance discontinuities separated by a distance of 5.8 cm. Stamm *et al.* [2] used a bridge, and the inference is that impedance discontinuities in the loop formed by the bridge are separated by some 9.2 cm, also recognizing that the side arms leading to the source and to the detector may introduce impedance discontinuities at the waveguide junctions involved.

The purpose of this paper is to point out the need for caution in interpreting the results that have been reported. Curves displaying a cyclic resonance are displayed in [1] for eight different test substances including a variety of normal and tumor cells as well as such compounds as

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guanine and guanylic acid, and these curves have a remarkable similarity. It would be a striking coincidence if these diverse materials were characterized by similar frequency characteristics. The corresponding curves in [2] display some dissimilarity, but a cyclic character is apparent in most of them. For results of such transmission tests to be convincing, they should be attributable without ambiguity only to the material under study, rather than to possible frequency selectivity of the microwave system. Unfortunately, the authors are not clear on the effectiveness of the means they use to control standing waves, nor do they give a numerical value for the SWR in the system, which ideally is unity.

In the standing pattern which arises from two impedance discontinuities separated by distance L, the effect of introducing a sample of material having losses over a wide frequency band, e.g., more than 10 GHz, is to reduce the magnitude of the SWR. That is, the maxima in the standing-wave pattern are reduced, and the minima will be increased. The above statement is true if the placement and the dimensions of the sample are such that losses are introduced in all the longitudinal waveguide modes on which measurements are taken. This is the case when the sample is incorporated in an iris or window that couples one portion of the guide to a second portion. When differential power measurements are made, by use of a bridge or substitution of one sample for another, these conclusions are still valid except, when one sample is substituted for another, there must be differences in relative losses introduced, for example, resulting from a difference in water content, or in sample configuration.

When, in a microwave system showing no frequency selectivity, over a range of interest which occurs when the SWR is unity, we still observe in a measurement a frequency selectivity owing to the introduction of a sample or the substitution of one sample for another, then we may attribute the observed selectivity to the material rather than to the measuring system. The results reported in [1], [2] thus are ambiguous, and the ambiguity will be resolved only when they present more information on the procedures used to control frequency selectivity in their measurements.

References

[1] S. J. Webb and A. D. Booth, "Microwave absorption by normal and tumor cells," *Science*, vol. 174, p. 72, Oct. 1, 1971.

[2] M. E. Stamm, W. D. Winters, D. L. Morton, and S. L. Warren, "Microwave characteristics of human tumor cells," *Oncology*, vol. 29, p. 294, 1974.