Size Effect in the Measurement of Microwave Permeability of Ferrites*

In the usual method of measuring the tensor permeability of ferrites at microwave frequencies, a small sample of the material is placed in a suitable cavity, and the change in resonant frequency and Q of the cavity, caused by the presence of the ferrite, are measured. The measured quantities are related to the quantities of interest—real and imaginary parts of permeability—by equations derived through perturbation theory.[1]

In the derivation of these equations, certain assumptions are made about the effect of insertion of the sample in electromagnetic fields of the cavity. A simple way of stating it is to assume that the fields of the cavity are unchanged, except in the volume occupied by the sample, though there are less restrictive formulations. Therefore, the fields inside of the sample are uniform and thus may be calculated as a static problem from the unperturbated fields in the cavity. Both of these assumptions are approximations, and are more accurate as the sample size decreases.

Although the effect of the finite sample size has been calculated by several investigators, the resulting formulas do not readily lend themselves to computations. As a practical problem, in the comparison of a number of ferrite materials, it is of interest to know how large a sample could be used to obtain the measurements, yet apply the simple perturbation assumptions with confidence. That is, the perturbation formulas are valid for a sample which is sufficiently small. How small is small?

In an attempt to provide a partial answer to this problem, measurements were made on spheres of two typical polycrystalline ferrite R-1, a magnesium manganese ferrite and yttrium iron garnet. The measurements were made by mounting the sample in the center of an X-band TE_{102} rectangular cavity; and the change in the insertion loss as a function of the applied magnetic field was measured. The quantity obtained is u'', the imaginary part of the diagonal element of the permeability tensor. The values of u'' were calculated from the equation

$$u'' = \left(\frac{V_0}{V} - 1\right)\frac{V_c}{4Q_uV_s\left[1 - \left(\frac{\lambda_0}{2_a}\right)^2\right]}.$$

where V_0/V_1 is determined from the ratio of the insertion loss of the cavity at very large static field to the insertion loss at a particular field; Q_u is the unloaded Q of the cavity; V_c and V_s are volume of the cavity and the sample, respectively. This formula gave values of u''_{max} and line width which were independent of size, within experimental uncertainty, for all the samples.

It appears that the largest sizes considered were "small" within the context of perturbation theory. The size of the samples were limited by the sensitivity of the apparatus, *i.e.*, by the largest insertion loss that could be measured using the apparatus shown in Fig. 1. The measured line width and u''_{max} as a function of sample size are shown in Figs. 2 and 3 for R-1 and YIG,

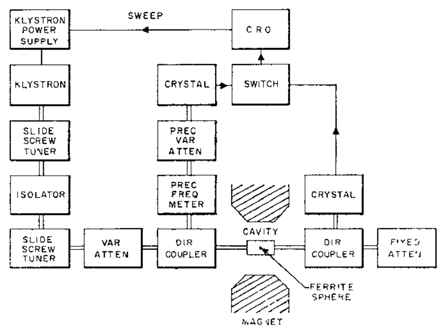

Fig. 1—Block diagram of the apparatus.

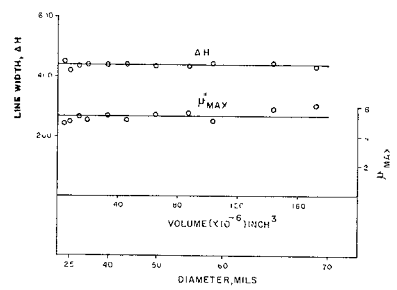

Fig. 2—Line width and u''_{max} as a function of size for R-1 ferrite.

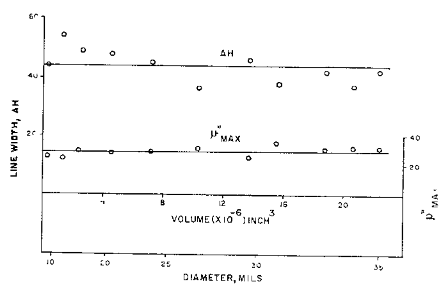

Fig. 3—Line width and u''_{max} as a function of size for YIG ferrite.

respectively. The largest sizes measured were 0.035 inch in diameter for YIG, and 0.069 inch in diameter for R-1. These samples were ground to smaller sizes, so that all the measurements could be made on the same sample of ferrite.

The scatter in the measurements was partly due to the change in Q of the cavity, as it was disassembled and reassembled whenever a different size sample was placed in the cavity, and partly due to fluctuations in the static field. The latter was particularly serious for the measurements made on YIG samples.

This paper extends the measurements to larger size samples, in order to compare the experimental results with the calculated values of size effect. The experimental results obtained thus far indicate that the measured values of line width and permeability are independent of size for samples of appreciable volume. These results can be compared to those of Spencer, *et al.*, on R-1[2] and of Stinson on YIG.[3] Stinson's measurements, however, were made by a different technique.

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[1] J. O. Artman and P. E. Tannenwald, "Measurement of susceptibility tensor in ferrites," *J. Appl. Phys.*, vol. 26, pp. 1124–1132; September, 1955.

[2] E. G. Spencer, R. C. LeCraw, and L. A. Ault, "Notes on cavity perturbation theory," *J. Appl. Phys.*, vol. 23, pp. 130–132; January, 1957.

[3] D. C. Stinson, "Experimental techniques in measuring ferrite line widths with a crossguide coupler," 1958 WESCON CONVENTION RECORD, pt. 1, pp. 147–150.

Cutoff Variable Reactor*

When relatively high positive reactance is required for coaxial line circuits, the cutoff variable reactor can economize space. In Fig. 1, a schematic diagram of the cutoff variable reactor is shown. For $z<0$, there is the coaxial line; and for $z>0$, there is the cylindrical waveguide operated in cutoff region with the variable shorting plunger shorting the waveguide at the distance s. For simplicity, it is assumed that there is TEM mode alone on the coaxial line and TM_{01} mode alone in the waveguide. The wave equation of H can be solved under these assumptions, together with the following boundary conditions:

$$\left[\frac{\partial H_\phi}{\partial z}\right]_{z=s} = 0 \tag{1}$$

and the input current,

$$I = \oint_{c_1}[H_\phi]_{z=0}\rho d\phi = -\oint_{c_2}[H_\phi]_{z=0}\rho d\phi. \tag{2}$$

The integral contours C_1 and C_2 are shown in Fig. 2. The solution is

$$H_\phi = A\{I_1(\sigma\rho) + BK_1(\sigma\rho)\} \cdot \sin\left\{\frac{\pi}{4}\left(\frac{z}{s} + 1\right)\right\}, \tag{3}$$

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