Correspondence

Ferrite Shape Considerations for UHF High-Power Isolators*

Ferrite isolators deteriorate at high microwave power levels due to the gyromagnetic saturation phenomena described by Suhl.[1] The onset of this deterioration is particularly detrimental to isolator performance when the main and subsidiary resonances coincide. At microwave frequencies the coincidence effect can generally be avoided if thin transversely magnetized ferrite slabs are used. However, at frequencies below 1 kMc, the finite slab thickness can contribute to main-subsidiary resonance coincidence unless care is taken to choose the proper length and width dimensions of the slab. The following calculations specify the ferrite slab shape needed to avoid this coincidence in UHF ferrite isolators.

The main and subsidiary resonances occur at magnetizing fields H_{res} and H_{sub}, respectively. Coincidence effects are avoided provided that,

$$H_{\text{res}} \geq H_{\text{sub}} \tag{1}$$

where

$$H_{\text{res}} = \left(N_z - \frac{N_x + N_y}{2}\right)4\pi M_s + \sqrt{\left(\frac{N_x - N_y}{2}\right)(4\pi M_s)^2 + \left(\frac{\omega}{\gamma}\right)^2} \tag{2}$$

$$H_{\text{sub}} = \frac{\omega}{2\gamma} + N_z\, 4\pi M_s. \tag{3}$$

By substituting (2) and (3) into (1),

$$\frac{\omega}{\gamma} \geq \frac{4\pi M_s}{3}\left[N_x + N_y + \sqrt{N_x^2 + N_y^2 + 14 N_x N_y}\right]. \tag{4}$$

Where

ω = applied angular frequency
γ = the gyromagnetic constant
$4\pi M_s$ = the saturation magnetization
$N_x + N_y + N_z = 1$ are the demagnetizing constants. The z direction is taken as the direction of magnetization.

The demagnetizing constants worked out by Osborn[2] for the general elipsoid are used in calculating the minimum frequency prior to main-subsidiary coincidence for particular ferrite shapes. The results are plotted on Fig. 1 and the ferrite-waveguide geometry is shown in Fig. 2.

Note that the minimum frequency for a particular material and T/L ratio occurs when $W/L = 1$. Now, suppose it is desired to make a YIG 400 Mc high-power isolator with $\frac{1}{8}$ inch thick slabs. The useful width

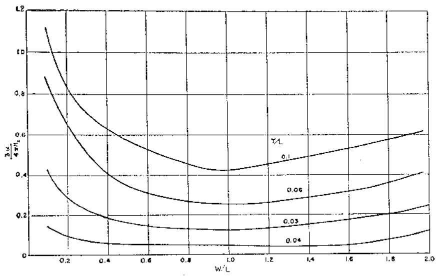

Fig. 1—Critical frequency ratio for the onset of main and subsidiary resonance coincidence as a function of ferrite shape.

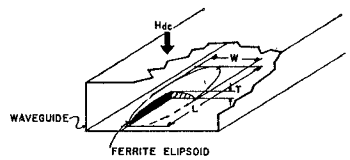

Fig. 2—Ferrite-waveguide geometry.

W is on the order of 3 inches, and the $4\pi M_s \approx 1800$ gauss, $\gamma \approx 2\pi \times 2.8 \times 10^6$ radians per oersted. The value of $3\omega/\gamma 4\pi M_s$ is 0.24, which is entered on the ordinate of Fig. 1. Only those shapes that fall below 0.24 should be considered for the isolator application. Thus, the T/L ratio should be less than 0.06 or $L \geq 2$ inches. If a length of 4.2 inches is chosen, then $T/L = 0.03$, and $W \geq 0.84$ inch.

In conclusion, it has been shown that the ferrite thickness of a ferrite slab causes a contribution to the demagnetizing fields that may produce main-subsidiary resonance coincidence at UHF frequencies. However, an appropriate slab geometry can be specified that eliminates this possibility.

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[1] H. Suhl, "The nonlinear behavior of ferrites at high microwave signal levels," Proc. IRE, vol. 44, pp. 1270–1284; October, 1956.

[2] J. A. Osborn, "Demagnetizing factors of the general ellipsoid," *Phys. Rev.*, vol. 67, pp. 351–357; June, 1945.

Measurement Technique for Narrow Line Width Ferromagnets*

Measurement of the line width of a ferromagnetic resonance curve using the now well-known cavity perturbation technique[1] offers some difficulty in the case of very narrow line width samples. Because of their large magnetic susceptibility, such samples produce a large effective filling factor with respect to the cavity. For example, the filling factor for a small ferromagnetic sample in a nondegenerate rectangular cavity reduces to

$$\eta = \chi\left[h^2 V_s/2 \int_{V_c} h^2 dv\right] \propto \chi V_s/V_c$$

where χ is the scalar magnetic susceptibility, V_s is the volume of the small sample, V_c is the cavity volume and h is the microwave magnetic field. Since the perturbation equations for cavity frequency shift and Q change are

$$\frac{\Delta\omega}{\omega} = \text{Re}\,(\eta) \,\alpha\, \chi' V_s/V_c$$

$$\Delta\left(\frac{1}{2Q}\right) = I_m(\eta)\, \alpha\, \chi'' V_s/V_c$$

large values of χ must be offset by increasing the size of the test cavity in order to reduce the ratio V_s/V_c if the perturbation is to remain small. When a 0.020 inch yttrium-iron-garnet sphere of the order of 1-oersted line width is to be placed in a simple X-band brass cavity, it is found that a cavity length greater than $50\lambda_g$ may be required to insure a sufficiently small perturbation of the fields in the cavity. The situation may be alleviated somewhat by rotation of H, the dc magnetic field, thereby reducing from 90° the angle between H and h. This procedure, which decouples the sample and effectively reduces V_s, normally precludes controlling the crystalline orientation of the sample under study.

The cavity perturbation method may be avoided if instead the sample is placed in a geometry whereby its magnetic resonance is characterized by reradiation of incident power into a region that is normally isolated when H is moved off-resonance.[2,3] An example of this idea is the cross-guide coupler suggested by Stinson.[3] By detection of the power coupled into the crossed guide, a resonance response curve is easily obtained from which the line width may be measured directly as the width at a certain fraction of the peak value of the curve. A possible disadvantage of this scheme is that the sample is located in a hole common to both guides and may be subject to undesirable nonuniform microwave fields. Furthermore, the mechanism for reradiation by the resonant spin system into the secondary guide may be accompanied by significant radiation damping which would show up as a line broadening in narrow line width samples.

The technique described below has been found satisfactory for line width measurements of fractional linewidth samples in the size range 0.015 inch or larger. As shown in the schematic of Fig. 1, the sample is placed in the transverse, uniform microwave magnetic field at a distance $n\lambda_g/2$ from the short

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[1] J. O. Artman and P. E. Tannenwald, "Microwave Susceptibility Measurements in Ferrites," M.I.T. Lincoln Lab., Lexington, Mass., Tech. Rept. No. 70; October 1954.

[2] J. I. Masters and R. W. Roberts, *J. Appl. Phys.*, vol. 30, pp. 1795–1805; April, 1959.

[3] D. C. Stinson, "Ferrite line width measurements in a cross-guide coupler," IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 446–450; October, 1958.

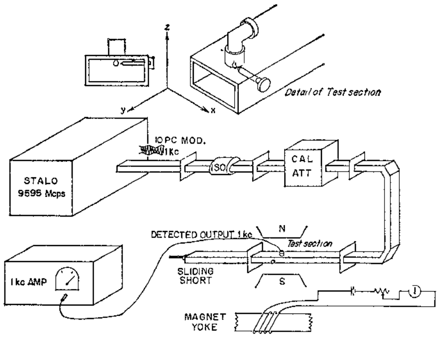

Fig. 1—Circuit for line width measurement

in a shorted X-band waveguide. A nearby pickup coil, which senses the precessing dipolar field of the magnetic sample, is oriented so that the plane of the loop and h are parallel, producing a negligible coupling to the transverse microwave field. When H is near resonance a voltage is induced in the loop. Since h is kept sufficiently small to insure linearity, this voltage is proportional to h.

The definition of line width depends on the type of response of m to h as dictated by the geometry of the system. In general, assuming $h_x = h_0 e^{j\omega t}$, $h_y = -jh_0 e^{j\omega t}$, $h_z = 0$, $\boldsymbol{m} = (\chi)\cdot\boldsymbol{h}$ where the elements of the antisymmetric dyadic are complex, substitution yields the circular precession

$$m_x m_x^* = m_y m_y^* = h_0^2\{ |\chi_{xx}|^2 + |\chi_{xy}|^2 + j\chi_{xx}\chi_{xy}^* - j\chi_{xy}\chi_{xx}^* \}.$$

However, in the use of linear polarization ($h_x = h_0 e^{j\omega t}$, $h_y = h_z = 0$) employed here, there results:

$$m_x m_x^* = h_0^2 |\chi_{xx}|^2 \qquad m_y m_y^* = h_0^2 |\chi_{xy}|^2.$$

Now the spacial relationship of the loop and sample is such that only the projection of the motion along the y direction is effective. Therefore, the induced voltage depends upon the absolute value of the off-diagonal component of (χ), *i.e.*, $E \propto h_0\sqrt{|\chi_{xy}|^2}$ which may be expressed in terms of its absorptive component, χ_{xy}', whereby the line width may be defined. In general $|\chi|^2 = \chi'^2 + \chi''^2$ where we have dropped the xy subscript for convenience. In particular,

$$|\chi|^2_{\Delta H} \cong [\chi'_{max}/2]^2 + [\chi''_{max}]^2 \cong 2[\chi'_{max}/2]^2$$

when H is set for $\frac{1}{2}$ of the peak of the absorption curve.[4] Also $|\chi|_{max}^2 = \chi_{max}'^2$. The indicated approximations are very good for narrow line width samples yielding

$$|\chi_{xy}|_{\Delta H} = |\chi_{xy}|_{max}/\sqrt{2}.$$

However, since the measurement of the response is normally read from a calibrated attenuator, the observed response as H varies is of the form $h_0^2|\chi_{xy}|^2$, and the line width is therefore measured at 3 db below the peak of the response curve.

A simple circuit assembled for these measurements is shown schematically in Fig. 1. The CW source is a Stalo, L. F. E. 814X−21, operated at 9600 Mc and internally modulated at 1 kc. The sensitivity gained by modulation allows the use of signals as small as the order to 1 moe to avoid any saturation or heating effects. The signal is fed through an isolator and calibrated attenuator to a test section terminated in a sliding short. The correct position of the sliding short is found by substitution of an electric probe for the loop and adjusting for a null in the electric probe output. The correct loop orientation is then found by rotation of the loop for minimum leakage of the microwave field with $H = 0$, which is about 30 db below the loop output when H is ad justed for resonance.

The loop output is demodulated by a tuned crystal detector and the remaining 1 kc signal is amplified and read on a voltmeter.

Line width measurements are made by noting the field required for resonance and the associated voltmeter readings at attenuator settings of 0 db and 3 db. Twice the difference between the field for resonance and the field required to produce the latter voltmeter reading with the attenuator set at 0 db is the measured line width. Measurements of ΔH were made in this experiment by producing field increments with an accurately measured dc current passed through a coil of some 50 turns wound around the yoke of a 6-inch Varian magnet. An H vs current curve was established using a precision NMR gaussmeter and is a straight line for the current range in question. It has been found that the accuracy (± 0.01 gauss) and ease of this method of measuring changes in H exceeds the method of direct measurements of H with the gaussmeter.

As anticipated, the distance between the loop and sample is an important consideration. The sample is cemented to a quartz post which may be extracted and rotated by known amounts. In a previous paper,[5] it has been shown that currents in the loop will produce fields that will damp the motion of the resonant sample. Although the formulas of this paper appear not to apply here because of the uncertainty in the phase relationship between loop voltage and current, decoupling of the sample and loop by increasing their spacing will reduce the damping. The sample is thus extracted as far from the loop as possible without reducing the signal-to-leakage ratio in the loop output below an arbitrary figure of 30 db. For two single crystal YIG sphere samples tested, a spacing of greater than 5-sphere diameters was used. The results of a comparison between the cavity perturbation method and the loop method are given below:

Sample	*Diameter in Inches*	*X-Band Cavity*	*X-Band Loop Method*
A	0.015	0.63 oe	0.65 oe
B	0.020	0.64 oe	0.67 oe

Sample A was grown in the Air Force Cambridge Research Center and polished by a novel manual process to be described in a later letter. Sample B was purchased as a polished sphere from Microwave Chemicals, Inc., New York, N. Y. The dependence of line width on crystal orientation was eliminated from the comparison by averaging over many orientations in each case.

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[4] A relationship between absorption and dispersion that approximately satisfies the Kramers-Kronig formula is assumed.

[5] N. Bloembergen and R. V. Pound, "Radiation damping in magnetic resonance experiments," *Phys. Rev.*, vol. 95, pp. 8–12; July, 1954.

Multidiode Switches*

The impedance of crystal diodes is known to depend on the applied bias voltage. This has suggested the use of diodes as switching elements in the control of microwave signal transmission. In the simplest form, the diode switch consists of a transmission line which is shunted by a diode. Coaxial cables[1] as well as waveguides[2–5] have been used for the transmission lines that are shunted by point-contact[1–5] and *p-i-n* diodes.[6] Slab line or coaxial switches where a diode is inserted in series with the center conductor of the line have also been developed.[7]

This note examines the feasibility of multidiode shunt or series type switches. After establishing equivalent circuits representative of the diodes in the "on" and "off" states of the switch, a specific realizable single diode switch is assumed for the calculations. Characteristics of a multipole switch which consists of a number of diodes in individual transmission line branches are derived for the two switch types. Several measurements made on an 8-diode series switch will be described thereafter.

Shunt-Type Diode Switches

The diode switch configuration consisting of a diode which shunts a transmission line will be considered first for multidiode

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