Correspondence

Millimeter Resonance Isolator Using Chemically Deposited Ferrite Films*

An experimental resonance isolator showing the feasibility of newly developed chemically deposited ferrite films, was made in the 35-Gc region. Included in this letter are two graphs showing the isolation characteristics that were obtained and also a brief description of the film preparation techniques.

The characteristics obtained of the resonant isolator using chemically deposited nickel and nickel-zinc ferrite films are presented in Figs. 1 and 2. At 35.3 Gc the nickel film has a reverse-to-forward ratio of 19 to 1

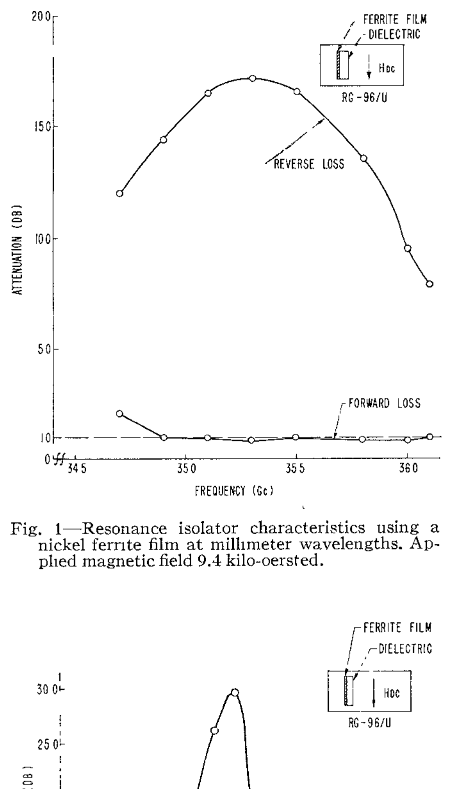

Fig. 1—Resonance isolator characteristics using a nickel ferrite film at millimeter wavelengths. Applied magnetic field 9.4 kilo-oersted.

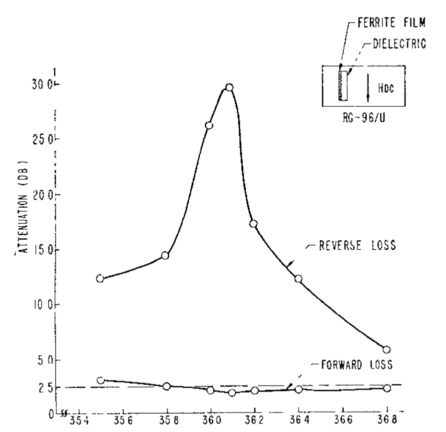

Fig. 2—Resonance isolator characteristics using a nickel-zinc ferrite film at millimeter wavelengths. Applied magnetic field 9.2 kilo-oersted.

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with an applied magnetic field of 9.4 kilo-oersteds. Similarly the nickel-zinc film measured at 36.1 Gc yielded a 16 to 1 reverse-to-forward loss ratio with an applied magnetic field of 9.2 kilo-oersteds.

The nickel film is 36.9 microns thick and the nickel-zinc film is 36.0 microns thick. Both were deposited on $0.021 \times 0.120 \times 1.0''$ 96 per cent alumina substrates. At X band the nickel film has a linewidth of 1725 oersteds and 4π Ms = 3600 gauss. The nickel-zinc film has a linewidth = 1765 oersteds and 4π Ms of 4800 gauss. X-ray diffraction analysis was also performed on the films to verify their crystal structure.

The films are made from nitrate solutions. Ferric nitrate and nitrates of nickel and zinc are dissolved at room temperature in a solvent such as alcohol. The individual solutions are analyzed and combined in a stoichiometric ratio according to formulation. The substrate is then coated with this solution and subjected to a preliminary firing at 400°C to 700°C. This process is repeated several times until the desired thickness is reached. The coated substrate is then fired in a suitable atmosphere at temperatures ranging from 900°C to 1100°C from 1 to 2 hours.

The preliminary nonreciprocal isolation characteristics of these new chemically deposited ferrite films are encouraging, and these films may have importance for applications in isolators, masers, circulators, switches and variable attenuators in the millimeter and submillimeter wave regions.

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A Device for Rapidly Aligning and Mounting Ferromagnetic Single Crystals Along Any Desired Axis*

A new type of device has been developed that locates the axes of a ferromagnetic crystal quickly and easily, without the usual time-consuming X-ray procedures. This device makes it possible to quickly find any desired axis of a ferromagnetic crystal and provides a convenient method of mounting the crystal on a rod along this axis.

The technique developed makes use of a suggestion by Auer[1] to the effect that the principal axes of a ferromagnetic single crystal can be found by geometrical construction once the angles of the easy axes of magnetization have been located. In Auer's method the locations of the easy axes are placed on the crystal by means of a marking needle and the desired axis is deduced from these markings.

Briefly, the procedure which has been developed by the authors is as follows. The ferromagnetic sample, in this case a YIG sphere, is mounted on a small dimpled rod which is placed in the center between the pole pieces of a magnet. The magnet is placed on a rotating mount as shown in Fig. 1 so that the field can be oriented in any desired direction with respect to the crystal. The crystal is placed on the dimpled rod, and turns until an easy axis (of which there are four in a cubic crystal with negative anistropy) comes into coincidence with the direction of the magnetic field. After this first orientation is completed, the sphere is attached (by means of some easily soluble glue, wax, etc.) to a wire which is placed in a radial hole along the easy axis in the side of the aligning jig as shown in Figs. 2 and 3. This wire is free to turn in the radial hole under the influence of the small torgues exerted on the ferromagnetic sample by an applied dc field. This step locates and retains one of the easy axes.

The next step is to rotate the magnet by an amount that depends on the crystal axis which one is trying to locate. We were interested in locating the [110] axis (the face diagonal), which requires, as shown by Auer,[2] that we obtain a second easy axis displaced from the first by $70\frac{1}{2}°$. This second angle is accurately located by means of the milling head protractor shown in Fig. 1. The ferromagnetic sphere rotates on the wire to which it was attached in the previous step, so that the second easy axis is now placed along the dc field. The final step in our case was to attach the sphere to a quartz rod along the [110] axis. A radial hole was drilled in the side of the alignment jig along the bisector of the angle between the two easy axes. The radial hole, and the rod that it holds in position, are shown in Fig. 2. The sample is attached to the quartz rod (or other holder) with a drop of cement and the wire is taken off.

Using this technique we have aligned a yttrium-iron-garnet sphere and have made measurements of its first-order anisotropy constant K_1/M_0 using the standard method outlined by Yager, *et al.*[3] The results of these measurements, reduced to the final form from which the anisotropy constant is determined, are shown in Fig. 4, which is a plot of the fields required to resonate the sample as a function of the angle θ between

* Received July 9, 1962.

[1] Martin Auer, "Novel method to orient ferrimagnetic single-crystal spheres," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES (*Correspondence*), vol. MTT-10, p. 88; January, 1962.

[2] *Ibid.*, see Fig. 2 on p. 88.

[3] W. A. Yager, J. K. Galt, F. R. Merritt and E. A. Wood, "Ferromagnetic resonance in nickel ferrite," *Phys Rev.*, vol. 80, pp. 744–748; November 15, 1950.

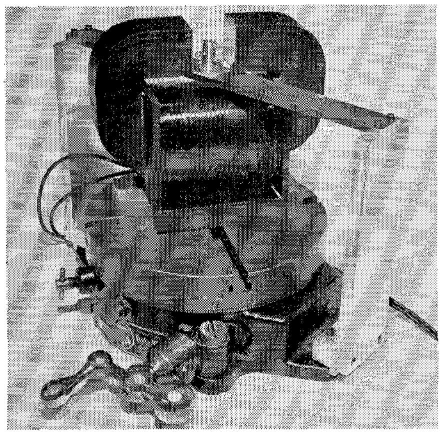

Fig. 1—Device for orienting ferromagnetic single crystals using rotating electromagnet.

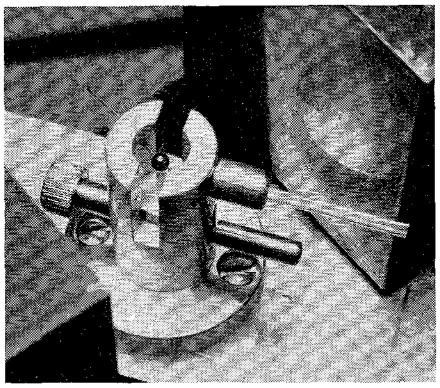

Fig. 2—Aligning jig showing YIG sphere attached to wire along one easy axis and quartz rod along [110] axis.

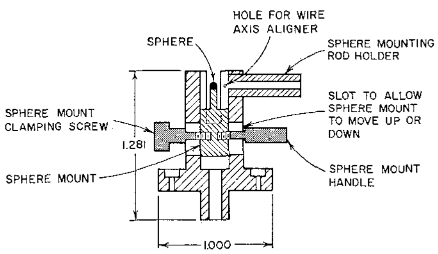

Fig. 3—Construction of aligning jig for mounting crystal along [110] axis.

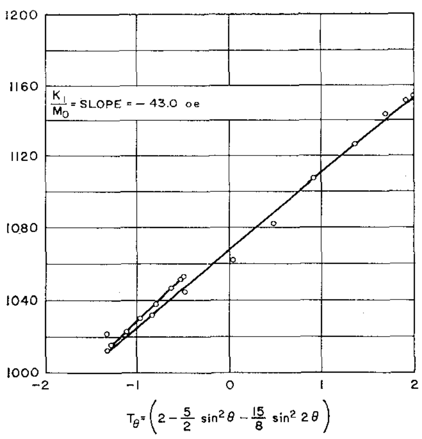

Fig. 4—Measurement of first-order anisotropy constant of yttrium-iron-garnet at $T=25.6°C$.

a [100] axis of the sample and the dc magnetic field. These measurements were performed at $f_0=3$ Gc using a crossed-strip-line coupler that is similar to the crossed-guide coupler which was described elsewhere.[4] The value of K_1/M_0, which was determined from the slope of this plot, is equal to −43.0 oersteds measured at an ambient room temperature of 25.6°C. This value of K_1/M_0 agrees very well with the value measured by Dillon,[5] $K_1/M_0 \cong -42.5$ oersteds; very well with the value of $K_1/M_0 = -43.2 \pm 0.1$ oersteds measured by Hill and Bergman;[6] not as well with the value $K_1/M_0 \sim -25$ oersteds reported by Rodrique, *et al.*,[7] and fairly well with the value of $K_1/M_0 = -35$ oersteds reported by Czerlinsky and Field.[8]

We have also measured the anisotropy constant K_1/M_0 of 600 and 950 gauss gallium-substituted yttrium-iron-garnet.[9] The results of these measurements are shown in Table I below.

TABLE I
ANISOTROPY CONSTANTS OF GALLIUM-SUBSTITUTED YTTRIUM-IRON-GARNET

M_0	T	K_1/M_0
600 gauss	22.9°C	−55.8 oersteds
950±50 gauss	25°C	−41.7 oersteds

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[4] P. S. Carter, Jr., "Design Criteria for Microwave Filters and Coupling Structures," Stanford Res. Inst., Menlo Park, Calif., Tech. Rept. 8, Contract DA-36-039, SC-74862, SRI Project 2326; October, 1959.

[5] J. F. Dillon, "Ferrimagnetic resonance in yttrium iron-garnet," *Phys. Rev.*, vol. 105, pp. 759–760; January 15, 1957.

[6] R. M. Hill and R. S. Bergman, "Nonlinear response of YIG," *J. Appl. Phys.* vol. 325, pp. 227–228; March, 1961.

[7] G. P. Rodrique, H. Meyer and R. V. Jones, "Resonance measurements in magnetic garnets," *J. Appl. Phys.* vol. 315, pp. 376–382; May, 1960.

[8] E. R. Czerlinsky and W. G. Field, "Magnetic Properties of Ferrimagnetic Garnet Single Crystals," Electronic Material Sciences Lab., Electronics Res. Directorate, Air Force Cambridge Res. Ctr., L. G. Hanscom Field, Bedford, Mass. (Unpublished.)

[9] These materials were purchased from Microwave Chemical Co., New York, N. Y.

Millimeter Wave Cavity Coupling by Quarter-Wave Transformer*

INTRODUCTION

In order to use high mode-order microwave cavities (Fabry-Perot,[1] confocal,[2] or biconical spherical[3] resonators) to achieve either high field intensities or high selectivity with low transmission losses, it is necessary to couple power into the resonators efficiently. This may be accomplished if the coupling system acts as a transformer matching the lossy elements of the cavity to a source of input power, and if the coupling system has an aperture large enough to make diffraction losses negligible.

This note describes an easily designed coupler which satisfies these requirements. It is essentially a series iteration of parallel plane waveguides, each λ/4 long. The fundamental design principles of this coupler are described and applied to the particular case of a bisected confocal resonator. Experimental evaluation verifies the efficacy of both the transformer and the approximations used in its design.

PRINCIPLES OF TRANSFORMER DESIGN

The essence of electromagnetic cavity coupling is the establishment of a balance between the power passing inward through the coupling aperture and that power lost to the cavity walls and its filling materials. Thus a cavity of volume V enclosed by the lossy surface S and coupled by the aperture A satisfies the following balance:

$$\tfrac{1}{2}\,\mathrm{Re}\int_A \boldsymbol{E}_A \times \boldsymbol{H}_A^* \cdot d\boldsymbol{A} = \tfrac{1}{2}\,\mathrm{Re}\int_S \boldsymbol{E} \times \boldsymbol{H}^* \cdot d\boldsymbol{S} + \tfrac{1}{2}\,\mathrm{Re}\int_V \sigma \boldsymbol{E} \cdot \boldsymbol{E}^* dV. \quad (1)$$

Let consideration be given just to the condition of resonance, when $\boldsymbol{E}_A \times \boldsymbol{H}_A^*$ is purely real. Since the coupler will have a very low impedance and will be considered essentially as a perturbation, let the field amplitudes within the cavity be characterized by $\boldsymbol{H}_A$, the average magnetic field at the surface of the cavity in the aperture region. The definition of K, the total loss factor, is

$$K\boldsymbol{H}_A \cdot \boldsymbol{H}_A^* = \mathrm{Re}\int_S \boldsymbol{E} \times \boldsymbol{H}^* \cdot d\boldsymbol{S} + \mathrm{Re}\int_V \sigma \boldsymbol{E} \cdot \boldsymbol{E}^* dV. \quad (2)$$

In most cases, this quantity includes losses due to

1) Finite surface resistance of metallic walls.
2) Diffraction at the ends of an open cavity.
3) Any coupling apertures other than the one under consideration.
4) Losses coupled by the media filling the cavity.

The last category should include crystals, plasmas or any other system driven by the cavity fields.

The coupling electric field $\boldsymbol{E}_A$, assumed to be perpendicular to $\boldsymbol{H}_A$, is regarded here as a perturbation only. If the fields across the aperture are approximately constant, its magnitude must satisfy the following power balance:

$$\tfrac{1}{2}E_A H_A^* A = \tfrac{1}{2} K H_A H_A^*. \quad (3)$$

* Received July 20, 1962. This work was supported by the Air Force Office of Scientific Research under Grant AF 62-287.

[1] W. Culshaw, "High resolution millimeter wave Fabry-Perot interferometer," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-8, pp. 182–189; March, 1960.

[2] G. D. Boyd and J. P. Gordon, "Confocal multimode resonator for millimeter through optical wavelengths," *Bell Sys. Tech. J.*, vol. 40, pp. 489–508; March, 1961.

[3] W. Culshaw, "Resonators for millimeter and submillimeter wavelengths," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-9, pp. 135–144; March, 1961.