

# 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

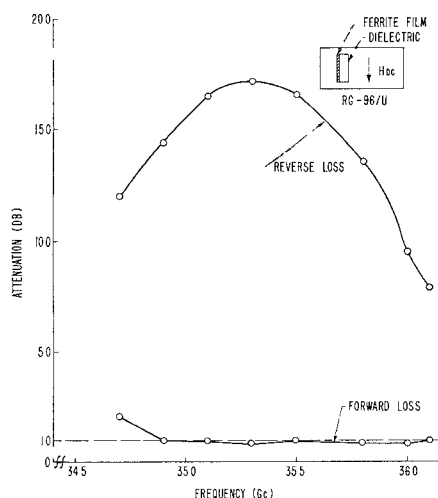


Fig. 1—Resonance isolator characteristics using a nickel ferrite film at millimeter wavelengths. Applied magnetic field 9.4 kilo-oersted.

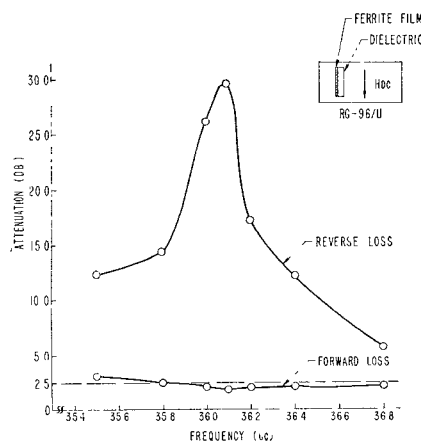


Fig. 2—Resonance isolator characteristics using a nickel-zinc ferrite film at millimeter wavelengths. Applied magnetic field 9.2 kilo-oersted.

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with an applied magnetic field of 9.4 kilo-oersted. 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-oersted.

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 oersted and  $4\pi M_s = 3600$  gauss. The nickel-zinc film has a linewidth = 1765 oersted and  $4\pi M_s$  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  $400^\circ\text{C}$  to  $700^\circ\text{C}$ . 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  $900^\circ\text{C}$  to  $1100^\circ\text{C}$  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.

W. WADE, JR.

T. COLLINS

R. STERN

U. S. Army Signal Res. and Dev. Lab.  
Fort Monmouth, N. J.

## 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<sup>1</sup> 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 anisotropy) 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 torques 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,<sup>2</sup> that we obtain a second easy axis displaced from the first by  $70\frac{1}{2}^\circ$ . 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.*<sup>3</sup> 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  $\theta$  between

\* Received July 9, 1962.

<sup>1</sup> Martin Auer, "Novel method to orient ferromagnetic single-crystal spheres," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES (Correspondence), vol. MTT-10, p. 88; January, 1962.

<sup>2</sup> *Ibid.*, see Fig. 2 on p. 88.

<sup>3</sup> 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.