Measurement of Ferrite Isolation at 1300 MC*

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Summary—**Optimum geometry for ferrite isolators at low microwave frequencies in rectangular waveguide is discussed and measurements are presented which show the feasibility of constructing a practical isolator at 1300 mc using commercially available ferrites.**

Further data for a narrower line-width ferrite are presented. The high-reverse to forward-loss ratios obtained are in accord with predictions from perturbation theory.

Introduction

Most of the effort of the Ferrite Application Section of the Solid State Group at Lincoln Laboratory, has been directed toward an investigation of the feasibility of constructing nonreciprocal devices at lower microwave frequencies. The device which probably can be most easily extended to operate at lower frequencies is the resonance isolator. The reason for this has been pointed out by Lax[1] who has shown that the optimum reverse-to-forward loss for a resonance isolator is inversely proportional to the square of the resonance line width, whereas corresponding figure of merit for a nonreciprocal phase-shift device, measured by the differential phase shift per unit average attenuation, is inversely proportional to the first power of the line width. This is in accord with the fact that at the present time the lowest frequency of commercially available resonance isolators is about 3000 mc, while the lowest frequency at which commercially available nonreciprocal phase-shift type devices operate, is approximately 6000 mc. In addition to line width, the other important limitation at low frequency is the low-field loss. However, by using geometries which require higher external fields for resonance, this loss sometimes may be reduced enough so that a practical device is possible. The measurements reported in this paper were performed for the purpose of testing the theoretical predictions expressed above and evaluating the performance of lower frequency resonance isolators.

Optimum Geometry at Low Frequencies in Rectangular Waveguide

The Kittel formula for the resonant frequency of a magnetically-saturated ellipsoidal sample shows that a thin slab magnetized perpendicular to its plane raises the magnetic field required for ferromagnetic resonance while magnetization parallel to its plane, lowers it. In order to avoid as much as possible low-field loss in the forward direction, one should use a high external dc field. Another reason for the use of a thin slab, magnetized perpendicularly, has been pointed out by Lax[1] who showed that the rf magnetic field inside the ferrite is most nearly circularly polarized for this geometry. Furthermore, at high powers, a thin slab attached to the guide wall will dissipate heat more efficiently. This geometry is also in accord with the skin depth considerations which show that if the ferrite is made too thick the electromagnetic wave will not penetrate the entire thickness and the additional material is not only ineffective, but also it inhibits heat conduction to the guide wall at high powers.

The distance between the ferrite slab and the side wall of the waveguide can be predicted approximately from perturbation theory. The criterion used is either minimum forward loss as used by Heller[2] or the maximum reverse-to-forward ratio used by Lax.[1] These two criteria give approximately the same results and are in accord with experimental evidence.

The waveguide used was the standard L-band waveguide (RG-69/U) with the height cut down to 1-inch O.D. This was done to reduce the gap dimensions of the magnet required and to increase the percentage of waveguide cross section filled with ferrite.

Measurements Using Ferramic R1

Measurements were made at 1300 mc, of forward and reverse attenuation as a function of applied magnetic field using a slab of Ferramic R1 (0.125 inch$\times$0.801 inch$\times$4.00 inches) placed 1.90 inches from the side wall of the guide. The reverse loss was 2.2 db and the forward loss was approximately 0.40 db giving a ratio of 5.5. The data are plotted in Fig. 1.

In order to improve the reverse-to-forward ratio, dielectric loading was used. When the dielectric, Stycast K-12, was placed between the guide center and the ferrite as described by Weiss[3] (Fig. 2), the forward attenuation was reduced to 0.29 db and the reverse attenuation was increased to 2.40 db resulting in a reverse-to-forward ratio of 8.3. These results are shown in Fig. 3.

The ratio was increased further by enclosing the ferrite in dielectric material as shown in Fig. 4. In this case the Stycast was longer than the ferrite and tapered to reduce reflections. For this arrangement the forward loss was 0.40 db, the reverse loss 4.60 db, and the ratio 11.5 (Fig. 5). Thus, it is possible, using this geometry and Ferramic R1, to achieve 10 db isolation with a forward loss of less than 1 db (Fig. 5).

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[1] B. Lax, "Loss characteristics of microwave ferrite devices," Proc. IRE, vol. 44, pp. 1368–1386; October, 1956.

[2] G. S. Heller, Quart. Prog. Rep. on Solid State Res., M.I.T. Lincoln Lab., Lexington, Mass., p. 55; November 1, 1955.

[3] M. T. Weiss, "Improved rectangular waveguide resonance isolators," IRE Trans., vol. MTT-4, pp. 240–243; October, 1956.

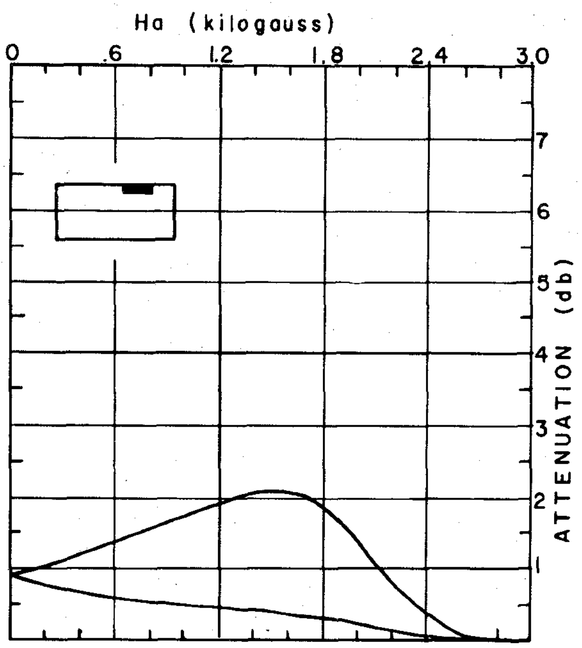

Fig. 1—Reverse and forward attenuation as a function of applied magnetic field for Ferramic R1 (0.125 inch×0.801 inch×4.00 inches) at 1300 mc.

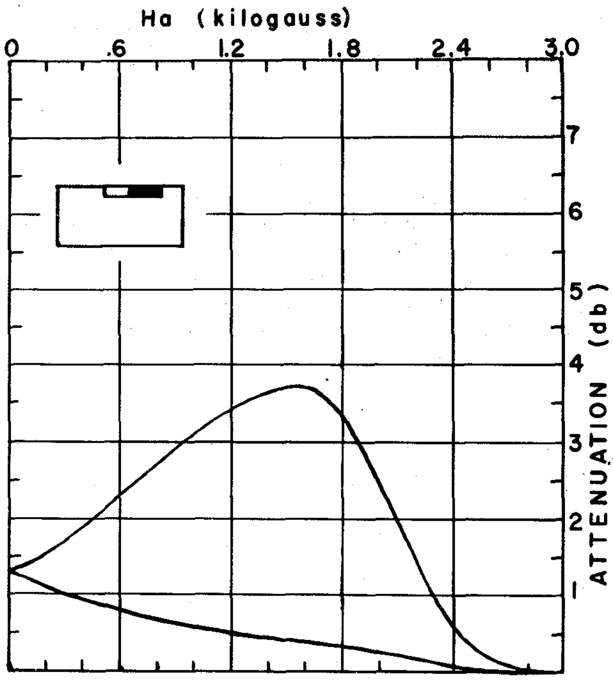

Fig. 3—Reverse and forward attenuation as a function of applied magnetic field for Ferramic R1 (0.125 inch×0.801 inch×4.00 inches) at 1300 mc in waveguide dielectrically loaded with Stycast K-12 (0.125 inch×0.801 inch×4.00 inches).

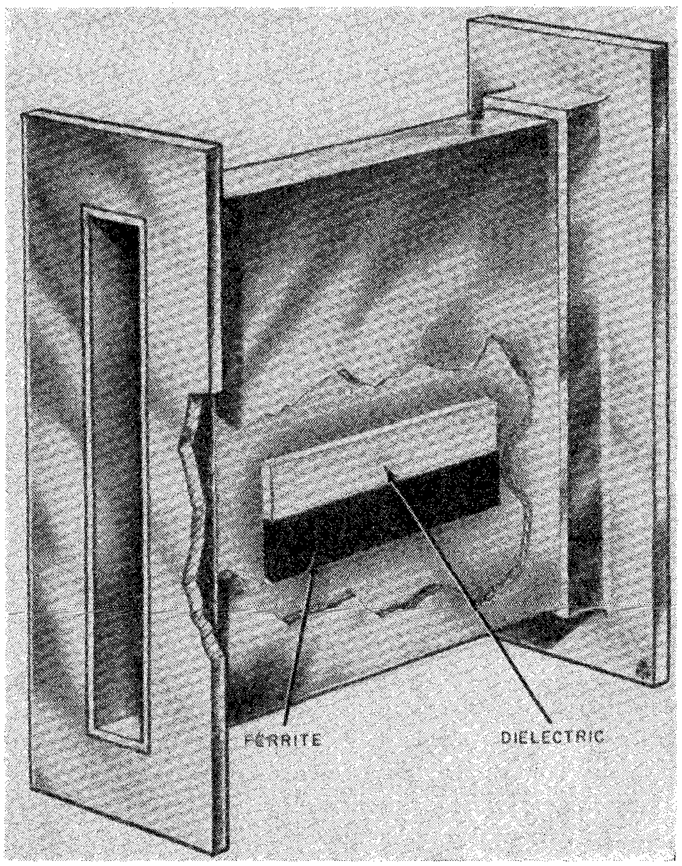

Fig. 2—Sample section showing ferrite sample and dielectric load.

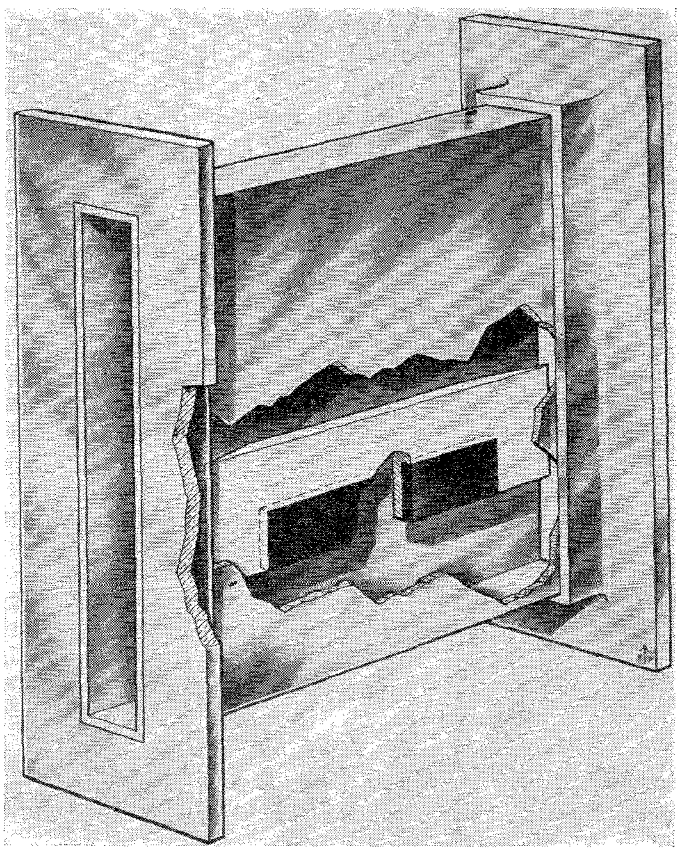

Fig. 4—Sample section showing ferrite sample and Stycast envelope.

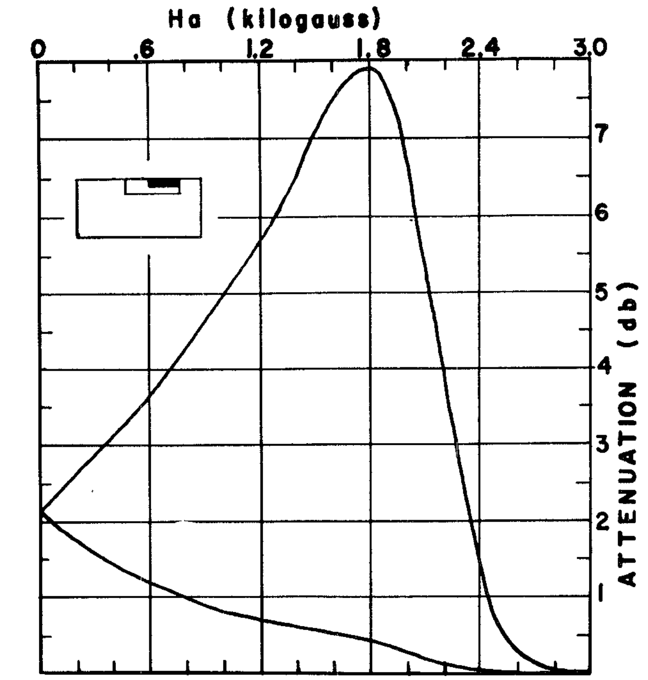

Fig. 5—Reverse and forward attenuation as a function of applied magnetic field for Ferramic R1 (0.125 inch×0.801 inch×4.00 inches) enclosed in Stycast K-12 (0.250 inch×1.602 inch×8.00 inches) at 1300 mc.

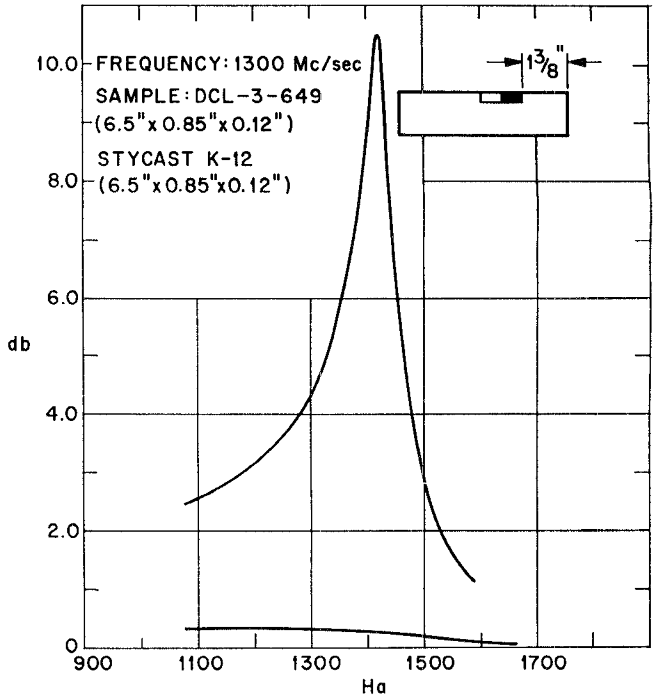

Fig. 7—Reverse and forward attenuation as a function of applied magnetic field for ferrite DCL-3-649 in waveguide dielectrically-loaded with Stycast K-12.

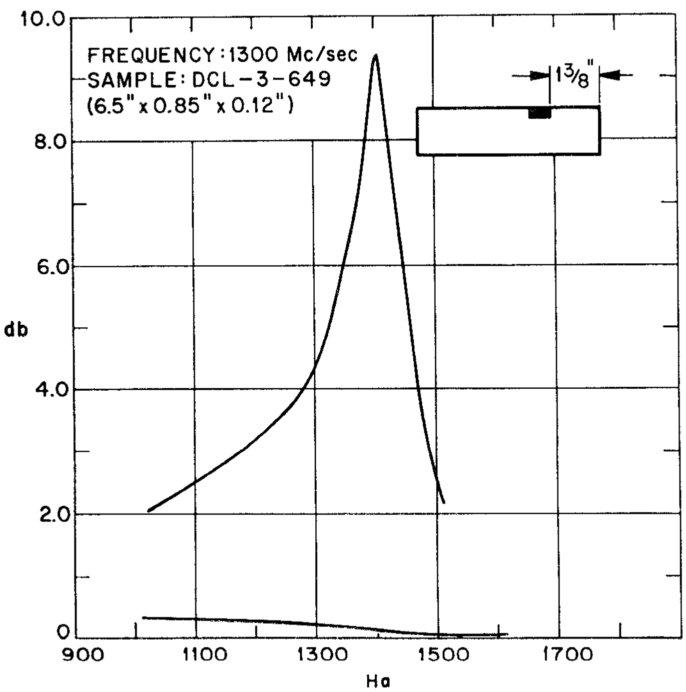

Fig. 6—Reverse and forward attenuation as a function of applied magnetic field for ferrite DCL-3-649.

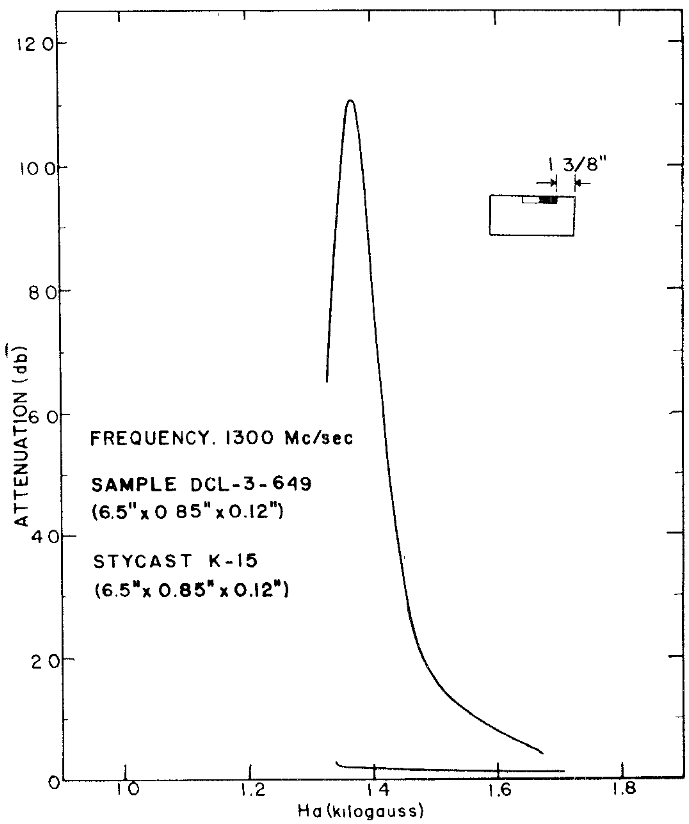

Fig. 8—Reverse and forward attenuation as a function of applied magnetic field for ferrite DCL-3-649 in waveguide dielectrically-loaded with Stycast K-15.

Measurements with Narrower Line-Width Ferrites

Dr. John Goodenough of these Laboratories kindly has supplied us with a ferrite which has a line width of one half to one third that of Ferramic R1. This Mn-Mg ferrite, DCL-3-649, has a saturation magnetization, $4\pi M$, of 1160 Gauss and a Curie temperature of 100°C. Although this low Curie temperature precludes use of this ferrite at high powers, the data presented here should point out the possibility of constructing low-frequency isolators with narrower line width materials.

A sample of this material, 6.5 inches long, consisting of three slabs placed end to end, was inserted in the same pinched-waveguide section described previously. The optimum reverse-to-forward ratio occurred when the sample was located $1\frac{3}{8}$ inches from the guide wall. The reverse loss for this geometry was 9.5 db and the forward loss was less than 0.20 db giving a ratio of approximately 50. (Fig. 6)

With Stycast K-12 loading, as shown in Fig. 2, the reverse loss increased to 10.5 db, but the forward loss also increased reducing the ratio to approximately 40. (Fig. 7)

Since narrower line-width ferrites would have larger rf permeabilities, dielectric loading of a higher dielectric constant was tried. Stycast K-15 produced a reverse loss of about 11 db and a forward loss small enough so that the ratio was greater than 70. (Fig. 8)

Measurement Techniques

Measurements were made with a bridge consisting of both coaxial and waveguide components as shown in Fig. 9. The attenuator section consisted of a vernier controlled resistor card moving across standard L-band waveguide and the phase shift was accomplished by the use of a variable length of coaxial line. Care was taken to eliminate reflections in the system, all waveguide to coaxial line transitions having a vswr of less than 1.05 at 1300 mc. The attenuator section was calibrated with a power meter and balance of the bridge could be obtained to a much higher accuracy than the attenuator calibration.

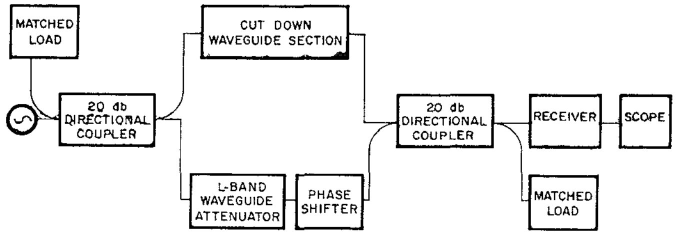

Fig. 9—Block diagram of microwave bridge used to measure attenuation in ferrite-loaded waveguide.

Conclusion

Using commercially available ferrite with the dielectric loading and favorable geometry it is possible to construct resonance isolators at frequencies as low as 1300 mc with a reverse to forward ratio of 10 and a reverse loss of less than 1 db. Narrower line width ferrites result in much larger ratios and these ratios are roughly inversely proportional to the square of the line width. With the advent of new narrow line width materials, such as yttrium-iron garnet, it should be possible to construct practical resonance isolators at even lower frequencies. However, rectangular waveguide will then become too unwieldy and probably it will be necessary to resort to physically smaller structures such as dielectrically loaded coaxial lines[4] or trough lines.[5]

[4] B. J. Duncan, L. Swern, K. Tomiyasu, J. Hannwacker, "Design considerations for broad-band ferrite coaxial line isolators," Proc. IRE, vol. 45, pp. 483–490; April, 1957.

[5] H. S. Keen, "Scientific Report on Study of Strip Transmission Lines," Airborne Instr. Lab. Rep. No. 2830-2; December 1, 1955.