Nonreciprocal Attenuation of Ferrite in Single-Ridge Waveguide*

The nonreciprocal transmission characteristics of rectangular and cylindrical waveguides containing ferrites have been extensively studied and utilized in the construction of microwave phase shifters, gyrators, circulators, and isolators.[1-3] This note concerns the measurement of the nonreciprocal attenuation produced by ferrite in single-ridge waveguide transmitting dominant mode. In particular, three types of isolators in ridge waveguide are investigated including resonance-absorption isolators, field-displacement isolators,[4] and isolators operating at low-biasing magnetic fields. Fig. 1 shows the dimensions of the single-ridge waveguide used in the measurement.

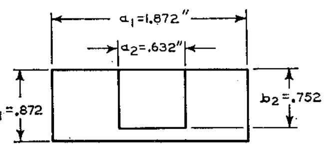

Fig. 1—Geometry of the single-ridge guide.

The cutoff frequencies[5] for the TE_{10} and TE_{20} modes are 1309 and 7008 mc per second, corresponding to cutoff wavelengths of 22.92 and 4.75 cm, respectively. Strong electric intensities exist in the constricted region between the ridge and the bottom guide wall. The two areas on each side of the ridge are inductive regions where the magnetic intensities are strong. However, the exact field distribution in the single-ridge waveguide is difficult to determine analytically.

H-Plane Isolators

Because a small ferrite produces negligible nonreciprocal attenuation and a large slab introduces anomalous modes in the guide, the 0.340×0.100×4-inch Ferramic R-4 slab used in Fig. 2 represents a compromise with regard to ferrite size. The slab is slightly tapered at both ends to give a VSWR below 1.10 over the 2200- to 4000-mc band. In the measurement, the slab is laid flat with its inner edge directly opposite the edge of the ridge, while the dc magnetic field is varied and the driving frequency is taken as a parameter. At this ferrite position, comparatively high reverse attenuation is produced at 3500 mc per second. However, high ratio of reverse to forward loss is obtained at 2250 mc; this is consistent with the prediction for rectangular guide, where for a ferrite located away from the side wall, the loss ratio becomes better when the frequency is close to the cutoff value than when it is remote from the cutoff.[3]

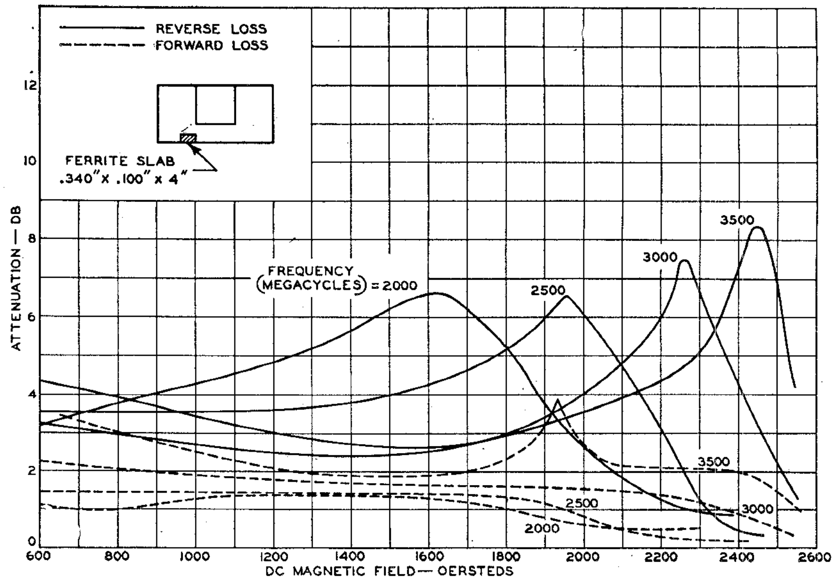

Fig. 2—Performance of *H*-plane isolator in ridge waveguide.

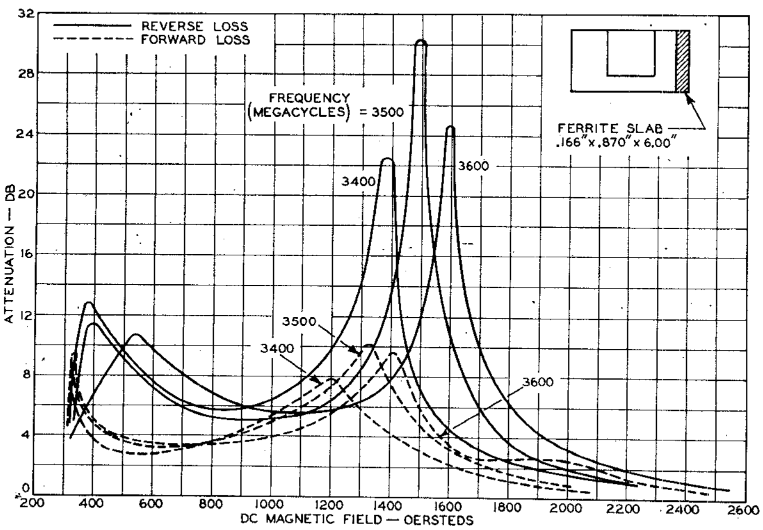

Fig. 3—Attenuation characteristics of *E*-plane isolator in single-ridge waveguide.

When the RF frequency is held constant at 3500 mc, the reverse-to-forward loss ratio gradually increases as the ferrite is displaced from the sidewall toward the ridge. The ratio reaches a maximum value 13.5 when the distance between the sidewall and the center line of the slab is 0.270 inch. If the ferrite is moved further toward the ridge, the peak reverse loss increases moderately, but the maximum forward loss increases in a greater proportion. The resonance magnetic field remains at 2460 oersteds irrespective of the ferrite position.

E-Plane Isolator

In the vicinity of the ridge, higher-order fields exist and the RF magnetic field does not assume a pure positive-circular polarization. Close to the sidewalls, the field distribution bears a strong resemblance to that existing in a rectangular guide. In Fig. 3, the 0.166×0.870×6-inch slab is placed against the sidewall; the ferrite in this position should disturb the field less than if it were placed anywhere else and should result in better heat dissipation.

Measurement reveals the two loss peaks illustrated in Fig. 3 when the dc magnetic strength increases, the frequency being held at 3500 mc. The first peak, having low reverse-to-forward loss ratio, occurs at 400 oersteds. As the magnetic field is increased to 1490 oersteds, the reverse loss reaches 30.6 db and the forward loss 4.4 db, providing a loss ratio of 7. The isolator performance deteriorates if the RF frequency departs from 3500 mc.

The resonant field H_{rez} increases with the driving frequency almost linearly as shown in Fig. 4. The magnetic intensities for producing resonance are lower than those required in *H*-plane isolators operating at corresponding frequencies. The bandwidth characteristic of this *E*-plane isolator for a

* Received by the PGMTT, August 10, 1959; revised, October 9, 1959.

[1] G. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Bell Sys. Tech. J.*, vol. 31, pp. 1-31; January, 1952.

[2] F. K. du Pré, "On the microwave Cotton-Mouton effect in ferroxcube," *Phillips Res. Repts.*, vol. 10, pp. 1-10; February, 1955.

[3] A. G. Fox, F. E. Miller, and M. T. Weiss, "Behavior and applications of ferrites in the microwave region," *Bell Sys. Tech. J.*, vol. 34, pp. 5-103; January, 1955.

[4] B. Lax and K. J. Button, "New ferrite mode configurations and their applications," *J. Appl. Phys.*, vol. 26, p. 1185; September, 1955.

[5] S. B. Cohn, "Properties of ridge waveguides," PROC. IRE, vol. 35, pp. 783-788; August, 1947.

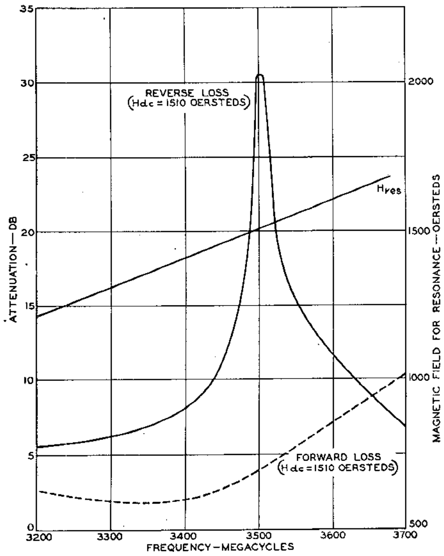

Fig. 4—Resonant magnetic field as a function of frequency, and frequency characteristics of E-plane isolator at fixed biasing magnetic field.

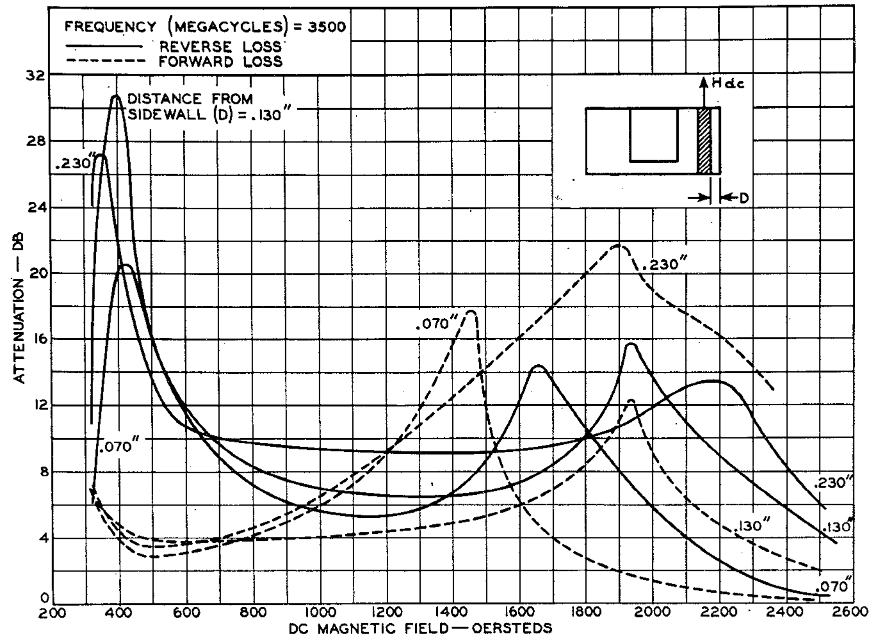

Fig. 5—Performance of medium-field E-plane isolator.

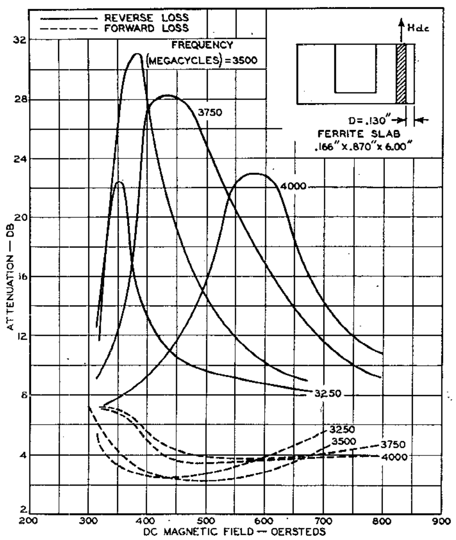

Fig. 6—Nonreciprocal loss of medium-field E-plane isolator as a function of dc magnetic field.

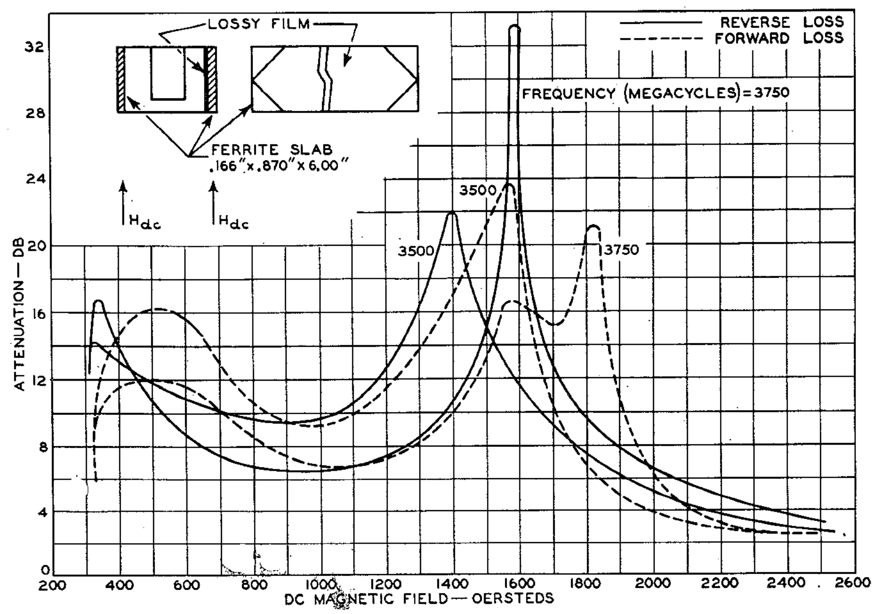

Fig. 7—Loss characteristics of field displacement isolators in ridge waveguide.

constant field of 1510 oersteds is depicted in Fig. 4. The reverse loss tends to drop abruptly for a slight deviation from 3500 mc; the forward loss begins to increase sharply after this frequency is exceeded.

Medium-Field E-Plane Isolators

If the E-plane isolator in Fig. 3 is separated from the guide wall by 0.07 inch, the reverse loss occurring at medium magnetic field and that caused by resonance absorption assume equal magnitude as shown in Fig. 5. This change constitutes a great enhancement of the medium-field nonreciprocal attenuation. When the ferrite is placed 0.130 inch from the wall, the medium-field loss becoming predominant at 380 oersteds produces a reverse loss of 30 db. The resonance absorption peak takes place at 1940 oersteds where the reverse loss reduces to 16 db. At this position, the medium-field E-plane isolator yields the best performance at 3500 mc. Fig. 6 illustrates the variation of reverse and forward loss for this isolator at a fixed location as a function of dc magnetic field for four frequencies. Above 3500 mc the maximum reverse loss decreases while the resonant magnetic strength increases. These effects are accompanied by a diminution of the loss ratio and a broadening of the loss curve. A lowering of the driving frequency also produces deleterious effect on the performance.

Field Displacement Isolator

When two $0.166\times0.870\times6$-inch ferrites are added to the ridge waveguide as shown in Fig. 7 and a resistive film having tapered ends is deposited on the outer face of one slab, the loss characteristics are measured as a function of the magnetic field at 3500 and 3750 mc. Although two loss peaks are discernible in Fig. 7, the reverse and forward losses are approximately equal, and the nonreciprocal effect is nearly obliterated. Elimination of the resistive film does not reveal any improvement or worsening in the nonreciprocal effect. Both thicker and thinner slabs have been measured for field displacement effect without disclosing significant changes. Thus the differential electric intensity near the outer face of one ferrite caused by the B mode of propagation in rectangular waveguide[4] is not strong in the single-ridge geometry.

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