Improved Rectangular Waveguide Resonance Isolators*

MAX T. WEISS†

Summary—**The early resonance isolators, using nearly full waveguide height ferrite slabs, gave a high reverse loss per unit length but a disappointingly low reverse-to-forward loss ratio. By substantially reducing the height of the ferrite slabs, the reverse-to-forward loss ratio can be increased at the expense of reverse loss per unit length. More recently, it has been found that the addition of certain dielectric loading in rectangular waveguide resonance isolators results in generally improved performance. Thus, the reverse-to-forward loss ratio of these isolators is high (150 to 1 at X band) and the reverse loss per unit length is also high (20 db/inch at X band). The broad-banding problem will also be briefly discussed.**

INTRODUCTION

WITH THE realization of nonreciprocal behavior of ferrites in rectangular waveguides[1] several years ago, it had been expected that the resonance isolator would prove to be a simple and effective device. It was indeed simple since it merely involved the placing of a thin ferrite slab in a rectangular guide, as shown in Fig. 1, and the application of magnetic field sufficient to give ferromagnetic resonance at the operating frequency. However, it was not very effective, with the best backward-to-forward loss ratio in db being only about 20 to 1. For a thick ferrite slab, the forward loss would be expected to be larger since not all of the ferrite can be at the point of pure circularly polarized rf magnetic field. The early work of Fox[2] on resonance isolators showed, however, that making the ferrite slab thin did not entirely eliminate the presence of considerable forward loss. It was further observed that for ferrite slabs extending completely from top to bottom of the waveguide, the back-to-forward ratio was much poorer than for ferrite slabs with heights substantially less than the full waveguide height.

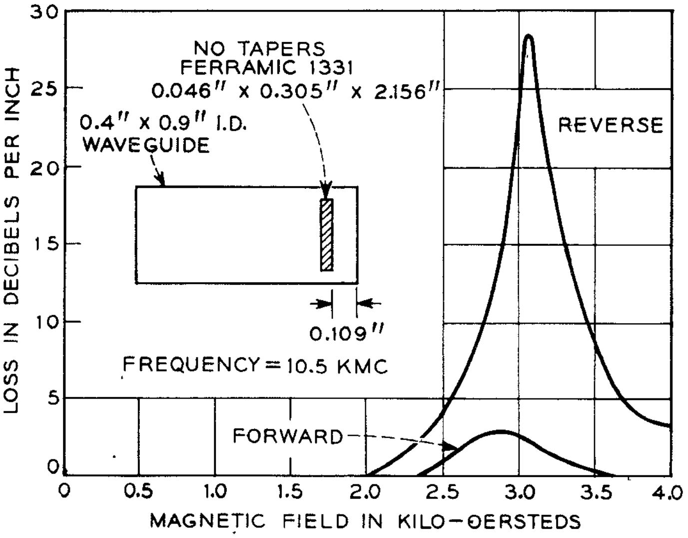

Fig. 1—Performance of an early resonance isolator.

H-PLANE FERRITE SLAB ISOLATOR

Recently, reduction of the height of the ferrite slab has been carried to a successful extreme in commercial high power resonance isolators. In these isolators the ferrite slabs are placed in the *H*-plane on the top and bottom walls of the waveguide as shown in Fig. 2. This not only permits better heat dissipation for high power applications, but also results in better performance. The data taken by us of forward and reverse loss as a function of applied magnetic field for this configuration are also shown in Fig. 2 for 10.5 kmc operation. It is seen that at a field of 4800 oersteds, the reverse loss is 29 db with a forward loss of less than 0.4 db, giving a ratio of about 75 to 1. The side wall to ferrite spacing for the above isolator was found not to be too critical with results remaining substantially the same for spacings varying between 0.100 inch and 0.120 inch.

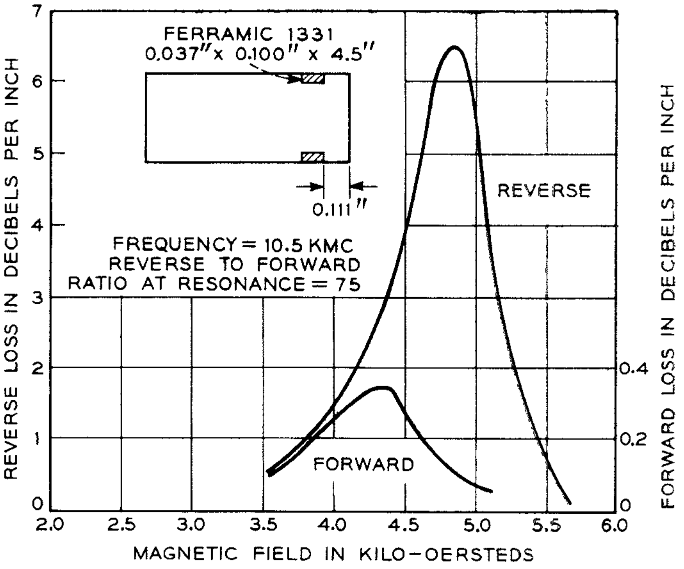

Fig. 2—Performance of an *H*-plane resonance isolator.

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† Bell Telephone Labs., Inc., Holmdel, N. J.

[1] N. G. Sakiotis and H. N. Chait, "Properties of ferrites in waveguides," IRE TRANS., vol. MTT-1, pp. 11–16; November, 1953.

[2] A. G. Fox, S. 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.

The above results for the *H*-plane isolator are to be compared with the results for the more usual type of *E*-plane isolator shown in Fig. 1, with a reverse-to-forward loss ratio of only about 10 to 1. Although better ratios have been obtained with lower saturation ferrites, these ratios never exceeded about 25 to 1.

The improved performance of the *H*-plane isolator is obtained, however, at the expense of several disadvantages. Not only is the magnetic field strength required higher (4.8 kilo-oersteds as compared to 3 kilo-oersteds) but the magnetic field must be applied over a larger volume. The high field requirement is due to the high dc demagnetizing factor for the *H*-plane configuration. Furthermore, the reverse loss per unit length of isolator is much smaller: only about 6.5 db/inch compared to 29 db/inch for the *E*-plane isolator.

Ferrite-Dielectric Isolator

In order to increase the reverse loss/unit length for the *H*-plane isolator, high dielectric constant material was added to the ferrite, as shown in Fig. 3. The purpose of the dielectric was to concentrate more of the rf energy near the ferrite and to eliminate edge effects. The dielectric used was Stycast K-12 having a dielectric constant of 12 manufactured by Emerson and Cuming of Canton, Mass. Ferroxdure is also satisfactory since it has a high dielectric constant with an rf permeability of very nearly unity at frequencies below 24,000 mc. It is seen that the reverse loss for this configuration has increased from 6.5 db/inch to over 11 db/inch, while the forward loss actually decreased somewhat, thus resulting in increasing the reverse-to-forward loss ratio to 150 to 1.

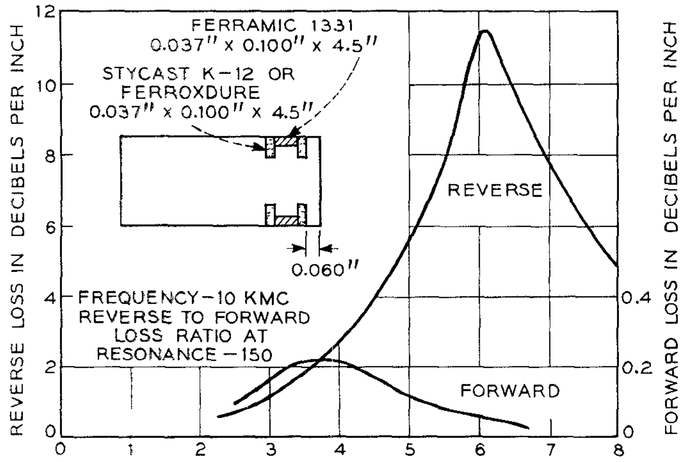

Fig. 3—Performance of an *H*-plane ferrite-dielectric resonance isolator.

Split-Ferrite *E*-Plane Isolator

In order to reduce the applied magnetic field strength required to produce resonance, one must go back to the *E*-plane type of isolator, which has a much lower dc demagnetizing factor and smaller air gap as shown in Fig. 4. As one can see, the magnetic field requirement is reduced to 3400 oersteds, but with no dielectric loading, the loss per inch is only 8 db, while the ratio is 60.

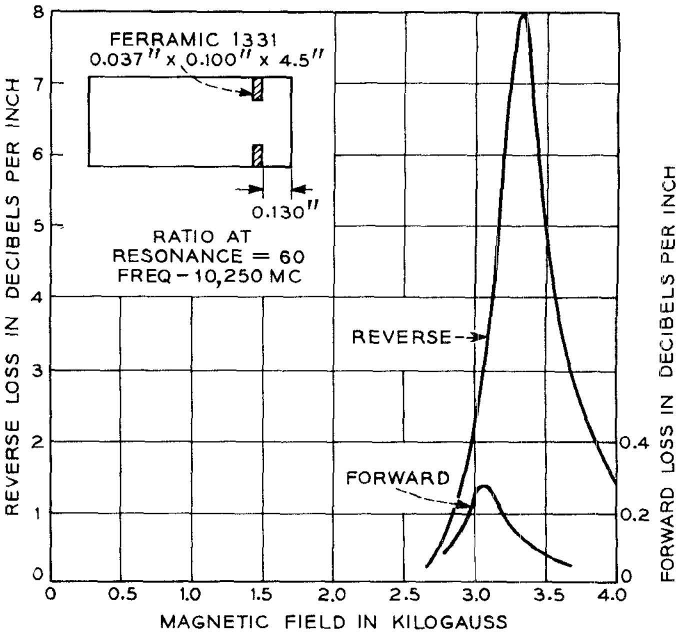

Fig. 4—Performance of a split-ferrite *E*-plane isolator.

To increase the reverse loss per unit length value as well as to improve the reverse-to-forward loss ratio, one can add Stycast on both sides of the ferrite as shown in Fig. 5. For this configuration the magnetic field requirement is 3500 oersteds, the reverse-to-forward loss ratio is better than 130 to 1, while the peak loss has risen to about 14 db/inch. One gets similar results by placing all the Stycast on one side, as shown in Fig. 6.

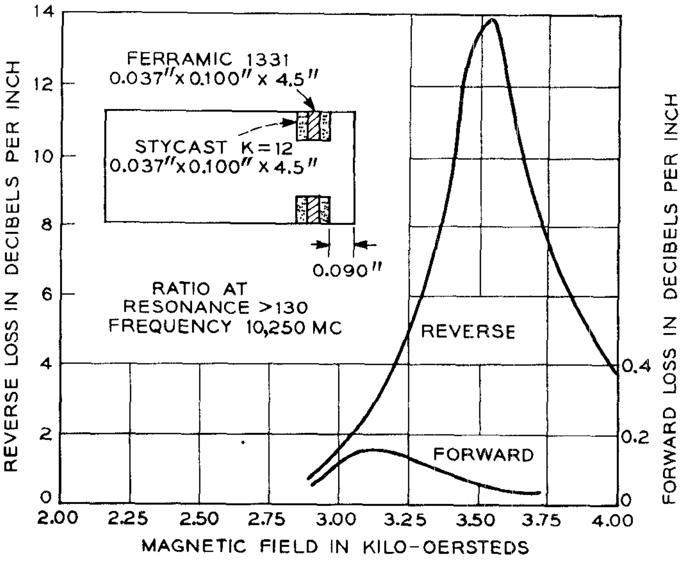

Fig. 5—Performance of a split-ferrite and dielectric *E*-plane isolator.

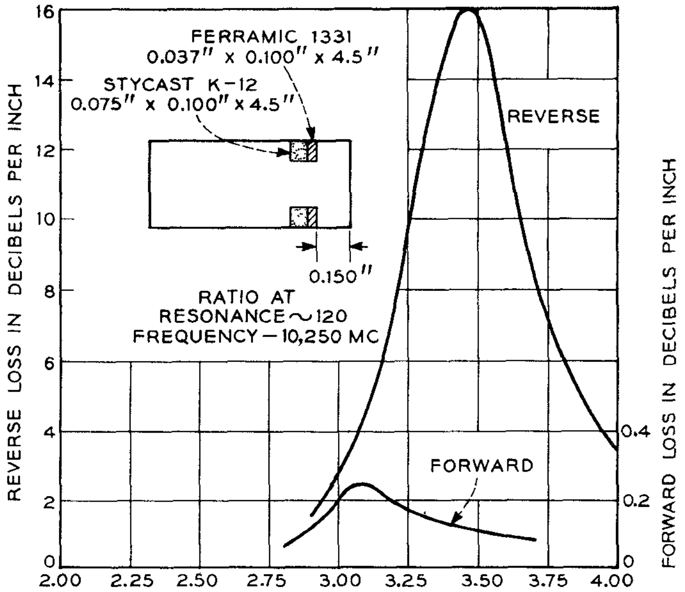

Fig. 6—Performance of a split-ferrite E-plane isolator with all the dielectric on one side.

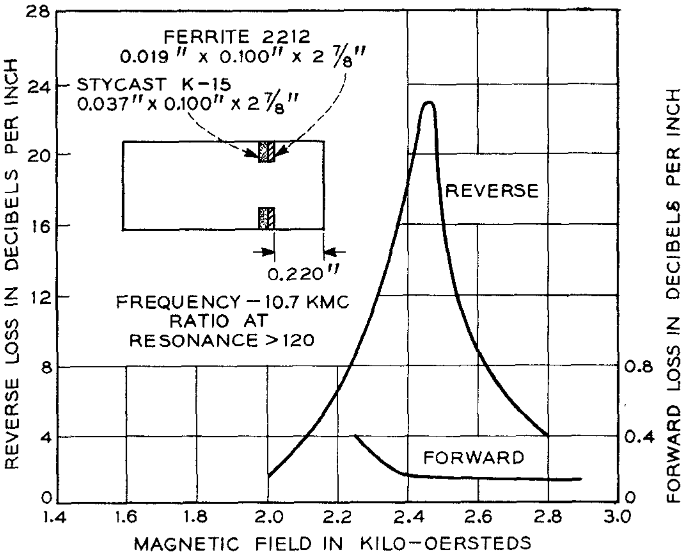

Fig. 7—Performance of a dielectric and split-ferrite E-plane isolator using a high saturation magnetization ferrite.

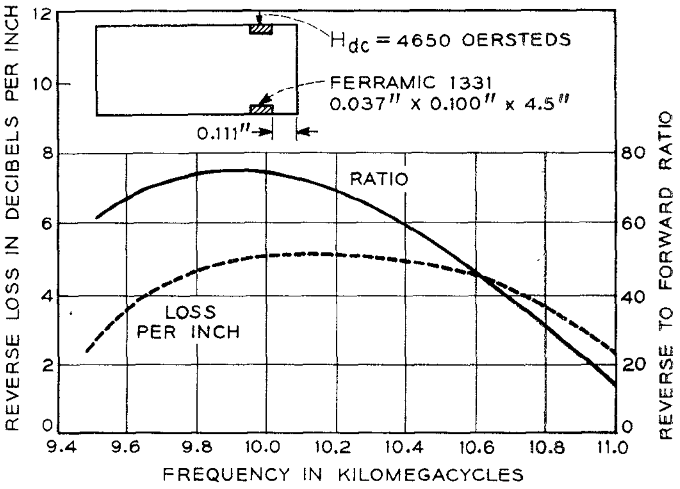

Fig. 8—Frequency response curves for the H-plane isolator of Fig. 2.

In order to reduce further the magnetic field requirement, a high saturation ferrite (No. 2212 produced by L. G. Van Uitert of the Metallurgical Research Department) having a saturation magnetization of about 4500 gauss was used. Experiments showed that this material required a higher dielectric constant material for dielectric loading and therefore Stycast K-15 with $\epsilon = 15$ was used. It was also found that best results were obtained with the Stycast on only one side of the ferrite, as shown in Fig. 7. The magnetic field requirement dropped to 2500 oersteds, the peak loss for a $2\frac{7}{8}$ inches sample was over 70 db, giving a loss per inch of over 23 db. The forward loss also remained quite low at about 0.25 db. However, Stycast K-15 appears to have an appreciable dielectric loss, so that the total forward loss was about 0.5 db, resulting in a reverse-to-forward ratio of about 140 to 1.

Broad-banding Problems

Since the peak resonance loss in a ferrite occurs at increasing values of applied magnetic field for increasing operating frequencies, it is evident that a resonance isolator is not inherently a broad-band device. Fig. 8 is a plot of reverse loss/inch and reverse-to-forward loss ratio as a function of frequency over a 9.5 kmc to 11 kmc band for an H-plane ferrite slab isolator. It is seen that between 9.65 and 10.65 kmc the loss/inch remains above 4 db while the reverse-to-forward loss ratio remains above 40 to 1.

Fig. 9 shows similar curves for a split ferrite E-plane isolator using Ferramic 1331. Although these curves are much more peaked, this configuration still gives substantially better over-all performance over the 9.5 to 10.4 kmc region. The frequency response curves for an isolator using Ferrite 2212 are shown in Fig. 10 for the 11 kmc band. In all of the above isolators the applied magnetic field was chosen to give equal loss/inch values at the two ends of the band. Over narrower bands, one could obtain better results by choosing appropriate applied fields.

An attempt to improve the broad-band performance of a Ferrite 2212 isolator was made by using different thicknesses of ferrite for the top and bottom slabs as shown in Fig. 11. With a top slab thickness of 0.016 inch and a bottom slab thickness of 0.019 inch, the resonance curve of loss vs applied field became double peaked. The resulting reverse loss and reverse-to-forward loss ratio as a function of frequency over a 10.7 kmc to 11.7 kmc band is shown in Fig. 11. As can be

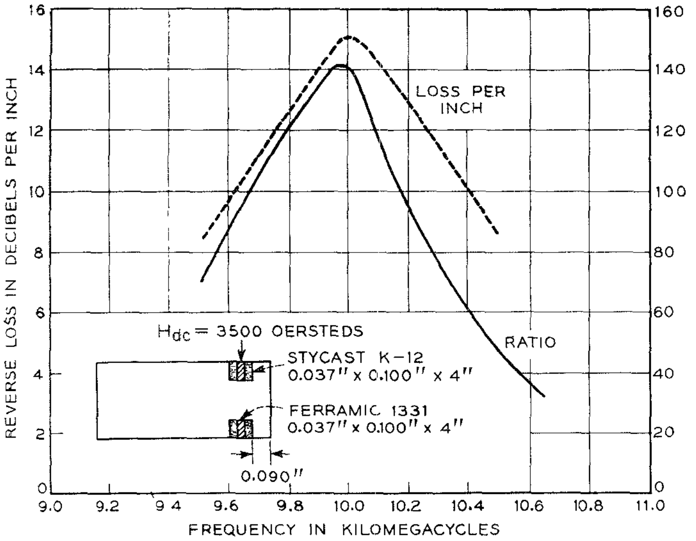

Fig. 9—Frequency response curves for a split-ferrite and dielectric E-plane isolator.

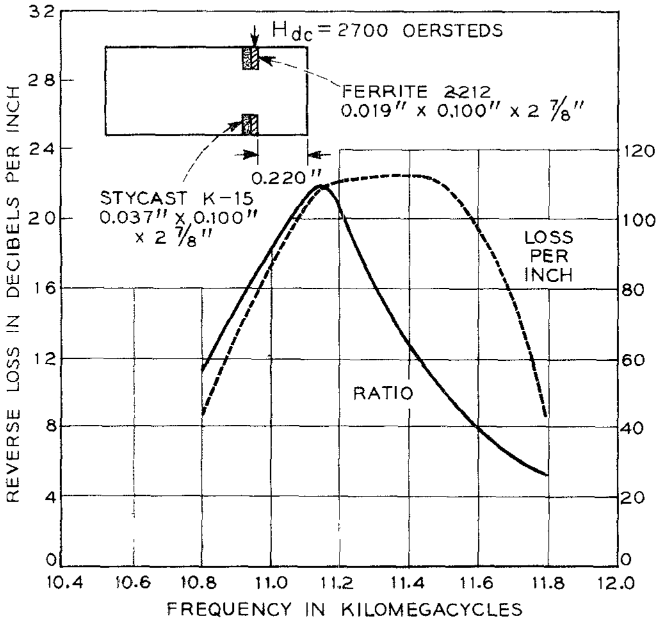

Fig. 10—Frequency response curves for a split ferrite and dielectric E-plane isolator.

seen, these curves are substantially flatter than those shown in Fig. 10 where no attempt was made to broad-band the device.

Other possible broad-banding schemes might include tapering of the ferrite slabs, tapering of the magnetic field by means of tapered pole faces, using different types of ferrite, or using different thicknesses and heights of ferrite in tandem. Some of these schemes have been investigated, but all require substantial development time for improved results.

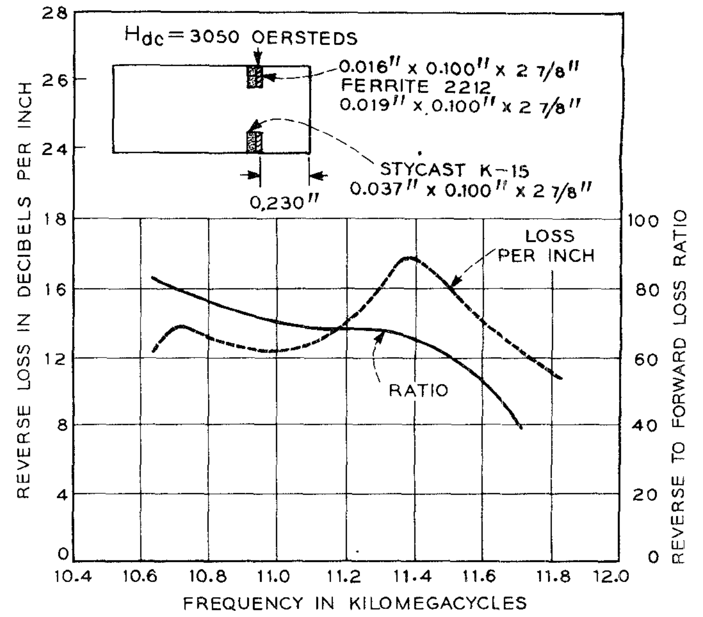

Fig. 11—Frequency response curves for a split-ferrite isolator constructed with different ferrite thicknesses on top and bottom.

EXPLANATION

A theoretical explanation for the improved performance of the dielectric loaded resonance isolators which have been described is not possible at present, since even a good qualitative theory appears to be extremely difficult to formulate for the ferrite configurations used. One can, however, say that the dielectric loading causes the electromagnetic energy to concentrate in the ferrite, thus increasing the loss per unit length in the reverse propagation direction. One could also use a qualitative perturbation argument to explain the excellent reverse-to-forward loss ratios obtained. These perturbation arguments can show that the dielectric loading causes the rf magnetic field to be circularly polarized over a wider cross-section of the waveguide. However, it seems to me that perturbation theory is not quite valid when ferrites are operating near resonance.