smallest $4\pi M_s$ while the ones farthest from the narrow wall are the remaining two ferrites.

The relatively small observed shift of the CP planes as compared to the theoretical empty waveguide can probably be interpreted as being due in part to an effective decrease in the waveguide cutoff frequency caused by the presence of the ferrites and, hence, to a decrease in the shift with frequency of the positions of the CP planes. Also, since ferrites are dielectrics, exhibiting high dielectric constants, it follows that under certain conditions as encountered here they may tend to concentrate the microwave field and hence further reduce the shift of the planes of CP. The magnitude of the effects are, of course, dependent upon the quantity of ferrite present in the waveguide. Similar effects have been observed by other workers including Vartanian[5] who placed an additional dielectric other than ferrite into the waveguide.

An additional important feature of this isolator which aids in maintaining an almost constant reverse attenuation over the entire bandwidth is the use of high $4\pi M_s$ ferrites to obtain differential attenuation at the low end of the frequency band and low $4\pi M_s$ ferrites to achieve the same characteristics at the high end of the band. The need for higher $4\pi M_s$ ferrites to maintain the desired reverse-wave attenuation at the low end of the operating band stems from the decrease in resonance attenuation with frequency for a constant $4\pi M_s$ ferrite and the increase in resonance attenuation with ferrite $4\pi M_s$ for a constant frequency.

A photograph of the 8.2 to 12.4-kmc high-power isolator is shown in Fig. 3 and its configuration; low-power attenuation characteristics and maximum VSWR are depicted in Fig. 4. High-power tests have been conducted on this isolator without the use of liquid cooling which indicates that average powers in excess of 250 watts, with peak powers in excess of 250 kw, can be propagated continuously without deterioration of attenuation below approximately 10 db when looking into a load VSWR of 3:1. Higher microwave power levels can be propagated when the isolator is liquid cooled, or the microwave circuit in which the isolator is located is terminated in a better matched load.

While the effect of ferrite resonance linewidth was not treated in this paper it can play an important role in the design of the broad-band isolators. This effect can generally be compensated for by varying the number of different $4\pi M_s$ ferrites used to cover the desired frequency band and their size, provided extremely broad resonance linewidth ferrites are not used. In the present application ferrites characterized by moderate resonance linewidths were used.

CONCLUSIONS

The design of broad-band isolators in rectangular waveguide can be achieved by using ferrites of different or varying $4\pi M_s$, each of which is located in a plane of microwave H-vector circular polarization in rectangular waveguide at its resonance frequency. Under ideal conditions, for a given desired operating bandwidth the values of ferrite $4\pi M_s$ and ferrite waveguide location can be determined with a fair degree of accuracy. In many nonideal conditions the same quantities can be determined to an order of magnitude. By proper selection of ferrite configuration very high-power operation can be effected. Using the information thus derived an extremely broad-band high-power X-band rectangular waveguide isolator was constructed which operates over a 45 per cent bandwidth with a forward-wave attenuation of less than 1.0 db and a reverse-wave attenuation in excess of 10 db.

ACKNOWLEDGMENT

The authors wish to express their gratitude to L. Swern for his generous contributions in technical discussions during the course of this work.

Correction

Robert E. Collin, author of "A Simple Artificial Anisotropic Dielectric Medium," which appeared on pages 206–209 of the April, 1958 issue of these TRANSACTIONS, wishes to make the following correction to his paper.

Eq. (13) on page 208 is incomplete and it should be replaced by

$$k_0S < \frac{2}{\sqrt{\kappa}(1+n_x)}.$$