A Duplexer Using the Zero Permeability Characteristics of Ferrite*

It has been shown by Polder[1] and others[2] that a ferrite material can be made to exhibit an effective zero permeability to a wave that has a positive sense of circular polarization (positive wave) and a corresponding nonzero permeability to a wave with polarization in the negative sense (negative wave). Melchor, *et al.*,[3] and Duncan and Swern[4] have demonstrated that a ferrite material which is magnetically biased such that the real part of its positive wave permeability is zero will largely exclude the positive wave. The negative wave, however, will be concentrated in the ferrite; and, under certain conditions of ferrite geometry and operating frequency, the negative wave will propagate through the ferrite in a dielectric mode.

This note describes a duplexer which utilizes this differential interaction in ferrite when biased to, or in the region of, zero permeability. Fig. 1 shows a diagrammatic sketch of a duplexer which uses these principles.

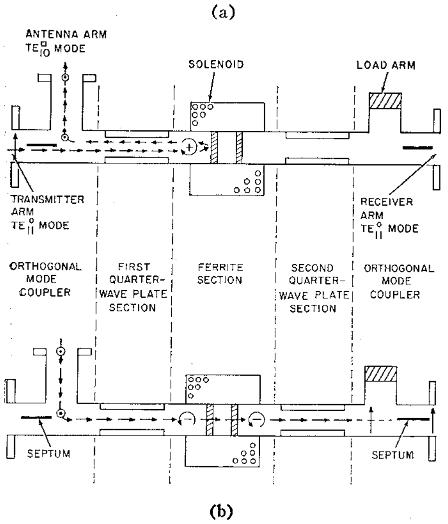

Fig. 1—Diagrammic sketch of a "zero permeability" duplexer. (a) Transmit case. (b) Receive case.

The design of this structure is such that a linearly polarized wave entering the transmitter arm will propagate through the orthogonal mode coupler with negligible coupling to the antenna arm, and will become circularly polarized in the positive sense before entering the ferrite section of the waveguide. The ferrite section consists of one or more ferrite disks which completely fill the cross section of the waveguide as shown in Fig. 1. A solenoid or a cylindrical magnet is used to produce a longitudinal magnetic field to bias the ferrite disks to the region where the real part of the effective ferrite permeability is essentially zero. As discussed in the first paragraph, the positive wave will be almost totally excluded from and, hence, reflected by the ferrite. The reflected wave will propagate through the first quarter-wave plate section which reconverts the wave to linear polarization, oriented 90° with respect to the incident linearly polarized wave. At the orthogonal mode coupler, the wave is then coupled into the antenna arm with negligible losses. The orthogonal mode coupler on the receiver end provides a load for any positive wave energy that is propagated through the ferrite section.

A wave entering the antenna arm will be coupled into the circular waveguide and will propagate into the ferrite section with a negative sense of circular polarization. Since the effective permeability for the negative wave is greater than unity (at the same magnetic bias for zero positive wave permeability), the wave will propagate through the ferrite section if the width and spacing of the disks are such that a proper impedance match is achieved. If the dielectric and magnetic losses of the ferrite material are low, the wave willl be only slightly attenuated when it emerges from the ferrite section. The emergent wave, after propagating through the second quarter-wave plate section, will be reconverted to a linearly polarized wave at the receiver arm oriented perpendicular to the septum in the orthogonal mode coupler. Thus, loss to the load arm is negligible.

Fig. 2 shows an experimental X-band "zero permeability" duplexer. Representative data taken on a similar duplexer designed for 9.2 Gc are given in Fig. 3. The ferrimagnetic material used in this particular unit was yttrium-iron garnet. At 9.2 Gc, the transmitter-to-antenna loss was 0.4 db with a corresponding receiver arm isolation of more than 30 db. The transmitter-to-antenna insertion loss remained well below 1.0 db from 9.0 to 9.7 Gc. Subsequent tests have shown that this loss remains below 1.0 db over a 10 per cent bandwidth. Beyond a 10 per cent bandwidth, the higher loss was due primarily to the narrow bandwidth of the quarter-wave plates used in the experimental work.

The antenna-to-receiver insertion loss at 9.2 Gc was also 0.4 db and remained below 1.0 db over a bandwidth of approximately 5 per cent. Increased loss beyond this bandwidth is due principally to the fixed ferrite geometry and spacing with the narrow-band quarter-wave plates contributing to some degree.

A duplexer of this design offers a definite advantage in that high power effects are minimized since the microwave energy associated with high peak power does not propagate through the ferrite. However, there is some magnetic coupling into the ferrite surface; but, by careful selection of ferrite material and geometry, the magnetic biasing field can be kept well below the field which will give rise to subsidiary resonance losses.

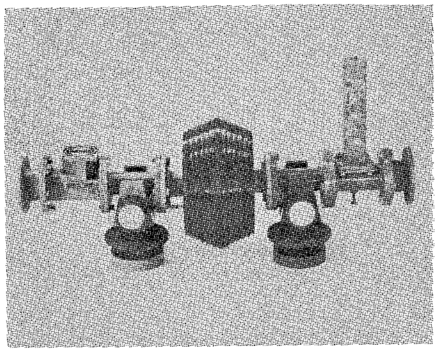

Fig. 2—An experimental X-band zero permeability duplexer.

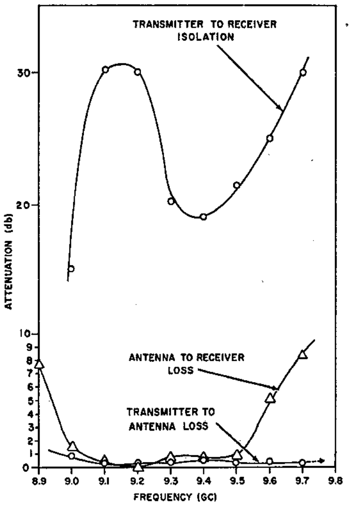

Fig. 3—Characteristics of a zero permeability duplexer using two thin disks of yttrium-iron garnet. $H_{dc}=925$ gauss.

The duplexer with characteristics shown in Fig. 2 was tested without cooling or pressurization at 250 kw peak (100 w average) at 9.2 Gc with no deleterious effects noted.

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[1] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40, pp. 99–114; January, 1954.

[2] See, for example, C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Rev. Mod. Phys.*, vol. 25, pp. 253–263; January, 1953.

[3] J. L. Melchor, W. L. Ayres, and P. H. Vartanian, "Energy concentration effects in ferrite loaded waveguides," *J. Appl. Phys.*, vol. 27, pp. 72–77; January, 1956.

[4] B. J. Duncan and L. Swern, "Effect of zero ferrite permeability on circularly polarized waves," PROC. IRE, vol. 45, pp. 647–655; May, 1957.

A Series-Connected Traveling-Wave Parametric Amplifier*

INTRODUCTION

The conventional parametric amplifier consisting of a single variable element with

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