A Degree-2 WRD750 Ridge Waveguide Junction Circulator Using a Gyromagnetic Post Resonator

J. Helszajn

Abstract—**An important circulator structure that has received little attention in the literature is the ridge waveguide one. The purpose of this contribution is to provide some preliminary experimental data on one degree-1 arrangement. It consists of using a simple gyromagnetic post with the direct magnetic field along its axis at the junction of three WRD750 double ridge waveguides. A quarter-wave coupled geometry using a dielectric filler between the ridges with a degree-2 frequency response is also described.**

I. INTRODUCTION

THE 3-port ridge junction circulator is an important component in the microwave industry. Although some commercial devices are available there is at first sight no design information for its construction. One possible geometry consists of a gyromagnetic post resonator with no variation of the alternating fields along its axis at the junction of the three waveguides. Fig. 1 illustrates the arrangement under consideration. This sort of structure may be described in terms of the radius of the ferrite resonator, by the coupling angle defined by the width of the ridges at the terminal planes of the resonator, and by the gyrotropy.

While no obvious guidance exists in the open literature on the design of a ridge circulator using a gyromagnetic post resonator, some pointers may be obtained by recognizing it is in many ways akin to the classic stripline device. Some representative references are given in [1]–[10]. The eigenvalues met in its description may therefore be taken to be identical to those met in connection with the classic stripline arrangement, except that the definition of stripline impedance is replaced by that of ridge waveguide. The solutions associated with its operation may also therefore be catalogued according to whether the effective permeability is positive or negative. This junction may be broadbanded in the conventional way with the help of one or more quarter-wave impedance transformers in one of two ways. In the first approach the impedance level of the transformer is obtained by using reduced-height ridges, while in the second configuration it is obtained by loading the ridges with a suitable dielectric material. The latter procedure allows its synthesis to proceed in a like fashion to that of the semitracking solution found in the design of wide-band stripline circulators. This letter presents some experimental results on a degree-2 quarter-wave coupled ridge waveguide circulator in WRD 750 D24 waveguide.

Manuscript received February 23, 1998.
The author is with Heriot-Watt University, Edinburgh EH14 4AS, U.K.
Publisher Item Identifier S 1051-8207(98)04203-2.

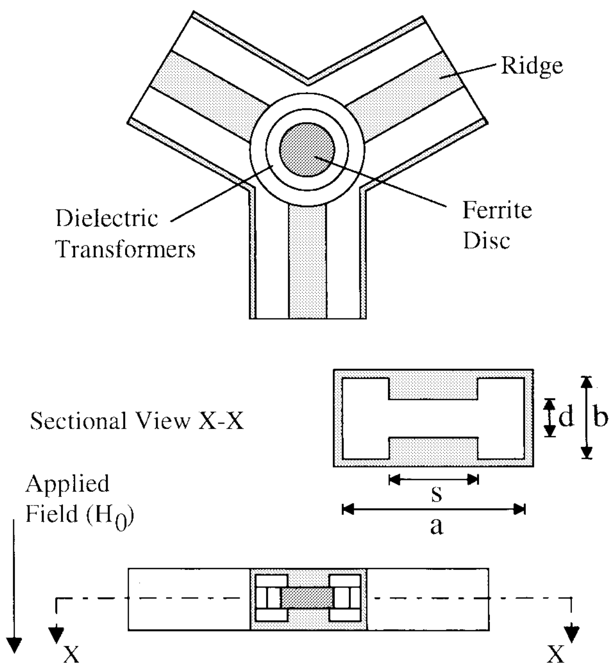

Fig. 1. Geometry of ridge circulator using gyromagnetic post resonator.

II. DEGREE-1 CIRCULATOR

The design of any junction circulator rests on a characterization of its degree-1 complex gyrator circuit and an understanding of the broad-band matching problem of a G-STUB load. While a comprehensive description of the operation of a ridge circulator using a postgyromagnetic resonator awaits a resolution, some preliminary results on one degree-1 arrangement in WRD750 is given here. Fig. 2 gives the return loss of such a circulator for ferrite radii (R) equal to 3.1 and 2.55 mm. The ferrite used was a manganese magnesium material with a magnetization (M_0) of 0.2150 T and a relative dielectric constant (ε_f) of 12.7. The insertion loss of each device was typically 1/2 dB and the bandwidths at the 3-dB points about 3%. The susceptance slope parameter (b') is in each case typically equal to 6.6. The radial wavenumbers associated with these two frequencies are in keeping with that of the dominant pair of degenerate modes in a simple dielectric post with top and bottom electric walls and a magnetic sidewall. Fig. 3 compares the relationship between radius and frequency in ridge and standard waveguides. The operating modes of the ridge waveguide circulator may therefore be taken as the split $TM_{1,\pm1,0}$ modes in a ferrite post with no variation of the electric field patterns along the axis of the

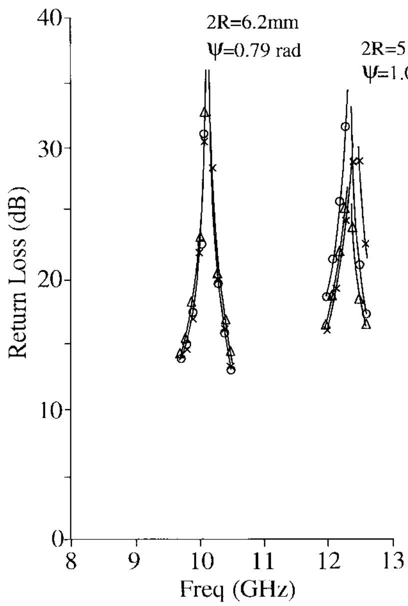

Fig. 2. Frequency responses of degree-1 ridge circulators.

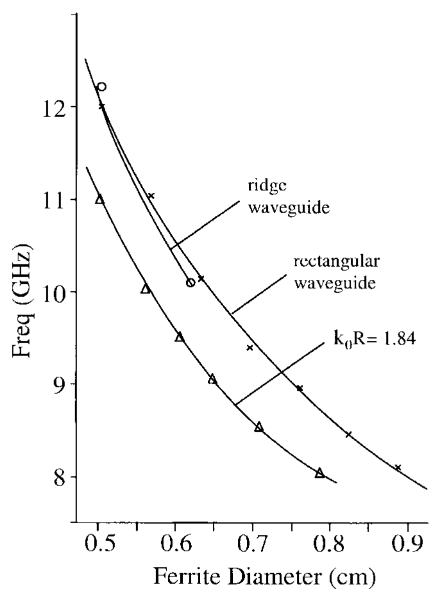

Fig. 3. Mode chart of degree-1 circulator.

disk. The coupling angles (ψ) established at the resonator terminals are 0.78 and 1.10 rad, respectively. A scrutiny of the sort of values met with stripline circulators suggests that these angles are somewhat oversized compared to common practice. A nonstandard waveguide may therefore be necessary in any optimum design. The details of WRD750 double ridge waveguide are specified by $s/a = 0.25$, $d/b = 0.42$, $b/a = 0.46$, and $a = 17.55$ mm. Its recommended frequency range is 7.50–18.00 GHz.

III. DEGREE-2 CIRCULATOR

Since the normalized complex gyrator circuit of the junction has not at this time been evaluated, a typical value of 3.75 has been assumed for the gyrator conductance (g) for the purpose of design. In practice, a typical transformer can

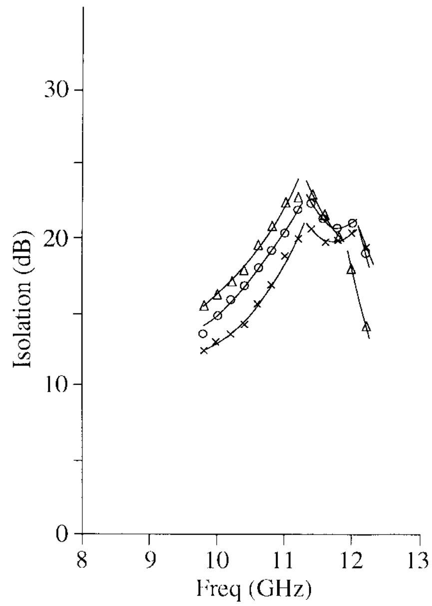

Fig. 4. Frequency response of degree-2 ridge circulator.

be implemented by either altering the details of the ridge waveguide or by using a dielectric filler between the ridges. The shortcoming of having recourse to the former option is that the complex gyrator circuit of this sort of junction is in practice, with the exception of the weakly magnetized case, dependent upon the coupling angle at the resonator terminals. The latter arrangement has therefore been adopted for the purpose of engineering. The frequency response of this arrangement which is illustrated in Fig. 4 is of degree-2. It is characterized by a return loss (RL) of about 23 dB over a 15% bandwidth. The coupling angle (ψ) established at the resonator terminals is 0.78 rad. The dielectric filler between the ridges has a relative dielectric constant (ε_r) equal to 4.0. The ferrite material employed in this work is a manganese magnesium one with a magnetization (M_0) equal to 0.2150 T and a relative dielectric constant (ε_f) equal to 12.7. The radius (R) of the ferrite resonator employed in obtaining this result is 6.20 mm. The direct magnetic field was established experimentally. Its normalized value $(\mu_0 H_0/M_0)$ is 0.42. In order to improve the gain-bandwidth of this sort of device it is necessary to increase the gyrotropy of the resonator. One way to do so is to recall that the gyrator conductance of the device is proportional to the gyrotropy. One means of enforcing this requirement is to utilize a higher value of dielectric constant for the dielectric filler. This may in the present situation be done by replacing the dielectric filler with a relative dielectric constant of 4.0 by one with a dielectric constant of 5.0 (for instance). The realization of a degree-3 instead of a degree-2 frequency response with this sort of junction may be readily realized by utilizing two *UE*'s (unit element) instead of one. Its implementation awaits resolution.

IV. CONCLUSIONS

A ridge junction circulator may be realized by either introducing a suitably magnetized gyromagnetic post resonator with top and bottom electric walls and a magnetic sidewall or an inverted turnstile resonator at the intersection of three ridge waveguides. The preliminary adjustment of one circulator using a post resonator with a degree-2 frequency response has been experimentally investigated in this letter. The use of an undersized ridge width at the resonator terminals is necessary in the design of any optimum degree-2 or degree-3 frequency response in order to satisfy the coupling angle requirement.

ACKNOWLEDGMENT

The author would like to thank Dr. G. Riblet of Microwave Development Laboratories, Needham, MA, for some helpful discussions.

REFERENCES

[1] J. W. Simon, "Broadband strip-transmission line Y junction circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-13, pp. 335–345, 1965.

[2] Y. S. Wu and F. J. Rosenbaum, "Wideband operation of microstrip circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, 1974.

[3] J. de Koning *et al.*, "Full band low loss continuous tracking circulation in K band," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, p. 152, 1977.

[4] S. Ayter and Y. Ayasli, "The frequency behavior of stripline circulator junctions," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, 1978.

[5] J. Helszajn, "Theory of tracking circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-29, pp. 700–712, July 1981.

[6] ——, "Synthesis of quarter-wave coupled circulators with Chebyshev characteristics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 764–769, 1972.

[7] G. Riblet, "Measurement of the equivalent admittance of 3-port circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, 1977.

[8] J. Helszajn, "Scattering matrix of junction circulator with Chebyshev characteristics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 548–554, 1975.

[9] R. Levy and J. Helszajn, "Specific equations for one and two section quarter-wave matching networks for stub-resistor loads," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 55–63, 1982.

[10] J. B. Davies and P. Cohen, "Theoretical design of symmetrical junction stripline circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-ll, pp. 506–512, 1963.