DIPLEXER AND BROADBANDING OPERATIONS OF STRIPLINE Y-JUNCTION CIRCULATORS

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Abstract

Diplexer and broadbanding operations of stripline Y-junction circulators are reported. The former is realized, involving a combination of positive-sense and negative-sense circulations, in the Y-junction loaded with conductor-ferrite composites. The latter is performed with conductor-dielectric-ferrite composites. The frequency band, changeable with a biasing magnetic field, reached 45 percent in the experiment when four circulations were put into use. These operations are treated only above resonance.

Introduction

Recently the double circulation frequency operation (DCFO) of stripline Y-junction circulators has been reported.[1 2] DCFO is obviously application of higher order modes of perfect circulation in the Y-junction, which is exemplified in the case of the dielectric-ferrite composite. The composite has been made by combining a dielectric puck and a ferrite ring. Now, if a conductive post is inserted at the center in the dielectric puck and if the radius of the post is gradually increased, then at first when the post is merely a thin pin, a DCFO appears under a comparatively low biasing magnetic field and multiple circulation frequency operations (MCFO) appear as the biasing magnetic field increases. DCFO and MCFO have in common less isolations in inter-circulation-frequency regions. When the post becomes a little thicker, a less isolation in an inter-circulation-frequency region is improved to the 20 dB level and consequently all of the separate frequency bands join a single wide band. This broadband is changeable with a biasing magnetic field. Finally, at the extremity in increasing the post radius when the dielectric portion is completely replaced by the conductor, a diplexer operation possibly appears.

Both the diplexer and the broadbanding operations can be theoretically dealt with from the view point of DCFO of MCFO. They are discussed, with experimental results and computed results given for comparison. In this paper, the term circulation mode and labeling of them are adopted for convenience sake to sort the variety of circulations, according to Davies and Cohen.[3]

Broadbanding Operation

Broadbanding of the stripline Y circulator has long received much attention.[4 5 6] It was attempted with the Y-junction loaded with disk ferrites, by applying only externally connected broadbanding transformers for impedance matching. Recently Wu and Rosenbaum demonstrated the wideband operation of a Y circulator.[7] All of the broadbanding attempts, however, fall within the scope of the operation in which only the lowest order mode of circulation, mode 1, plays the central role. They are also closely connected with the disk ferrite loaded in the Y-junction.

This author has very recently demonstrated that substitution of the dielectric-ferrite composite for the disk ferrite is effective in achieving DCFO and MCFO.[1 2] In these operations, less isolations in inter-circulation-frequency regions produce separate frequency bands. Such less isolations are actually improved by inserting a thin conductive post at the center of the dielectric-ferrite composite as shown in Fig. 1-b. This broadbanding operation retains the good feature of the DCFO and MCFO, in that the number of circulation frequencies can be changed with a biasing magnetic field and therefore the total frequency band can be changed.

(1) Experimental example

An experimental example is demonstrated in Fig. 2. The composite used was made by combining a conductive post (radius 1.5 mm) and a ferrite ring with outer and inner radii of 10 mm and 3 mm, respectively. The dielectric between them was air. The ferrite material was Al-YIG, specifications of which were that the saturation magnetization $4\pi M_s$=1200 Gauss, and the specific permittivity ε=14.5. The composite was 2.5 mm thick and the stripline width coupled to the Y-junction was about 11 mm.

The circulator action was featured by four peaks of isolation and its insertion losses showed a tendency to increase slightly in the vicinity of the highest circulation frequency. The total frequency band reached 45 %. On the other hand, when the circulator action showed a DCFO under a low biasing magnetic field, the total frequency band was 33 %. Consequently, the frequency band was almost continuously changed from 33 % to 45 % as the biasing magnetic field was increased. It was remarked that simple stripline tapers were used to connect the Y-junction to external circuits, and no broadbanding impedance matching transformers were used.

(2) Identification of circulation modes

Operating points were measured from isolation peaks. They are plotted superimposed on the mode chart as shown in Fig. 3, in order to identify circulation modes. One can distinguish circulation modes 1, 1A, 1B, 3 and 2A with reference to resonant mode curves. Computed results of the first circulation condition are presented in Fig. 4, in which loci of constant internal magnetic field intensity are superposed using the Polder's equations.[8] One can speculate about theoretical operations from the intersections of the curves of the first circulation condition and the loci of internal magnetic field intensity, and also one can expect some desirable performances. These considerations lead to confirmation of the experimental results presented in the mode chart shown in Fig. 3. When the magnetic field is low, the operating points of modes 1 and 1A give a broadband operation showing two peaks of isolation. When the magnetic field is increased to a slight degree, mode 3 comes to join in the broadband operation, so that three modes 1, 1A and 3 play their roles and the isolation is characterized by three peaks. When the magnetic field is increased still further, the fourth operating comes within the circulation, and four peaks appear. The largest broadbanding performance is realized.

Diplexer Operation

A diplexer operation is the simultaneous operation of the circulation modes of both positive and negative directions. Such a diplexer operation has been realized in a simple Y-junction circulator loaded with disk ferrites, first by Brown and Clark[9] and later by Kint and Schanda.[10] Their diplexers have the common features that they have one circulation below resonance and the other above resonance, with the direction opposite that of the circulation below resonance. They operate simultaneously and they are inherently separate from each other by ferromagnetic resonance absorption, so that separation of the center frequencies for the two circulations is almost constant in accordance with the variation of saturation magnetization of the ferrite with a constant dimension. Apart from such diplexer operation, one can realize a diplexer operation, exclusively above resonance or below resonance, as a facet of DCFO or MCFO, by utilizing a combination of two opposite circulation modes.

It is found that combinative operations of positive-sense and negative-sense modes depend on the composite loaded in the Y-junction, assuming a diplexer operation. As with the conductor-ferrite composite shown in Fig. 1-c, a conductor puck inserted in the ferrite ring is effective in meeting the junction intrinsic wave impedance ratio Z_e/Z_d in the second circulation condition regarding modes 1A, 2A and 2B. Mode 1B exists close to mode 1A and mode 2B is close to mode 2A.

(1) Experimental example

An experimental example is shown in Fig. 5. The composite used was a conductor-ferrite composite made from a conductive puck and a ferrite ring. Specifications of the composite were that the saturation magnetization $4\pi M_s$=1200 Gauss, the specific permittivity ε= 14.5, the radius of the ring r_2=10 mm, r_1/r_2=0.3, and the thickness was 2.5 mm. The half coupling angle ψ was about 0.6.

It clearly shows the diplexer operation which involves two circulations of positive and negative senses. The positive-sense circulation in the low frequency has a single wide band, but the negative-sense circulation in the high frequency has two separate narrow bands.

(2) Identification of circulation modes

To idenfy circulation modes, measured curves of isolation peaks are plotted superimposed on the mode chart of the conductor-ferrite composite as shown in Fig. 6. Several operation curves are shown. Two operation curves corresponding to modes 1 and 1B appear in the region bounded by the resonance curves n=+1, -1 and +2. They are observed when the biasing magnetic field intensity is low. When the magnetic field intensity is increased after one of the resonance curves n=-1 and n=+2 crosses the other, the diplexer operation appears and corresponding operation curves are plotted. In comparing the computed results of the first circulation condition shown in Fig. 7, one can conclude that modes 1A(-) and 2A(+) with 2B(+) play their respective roles in the diplexer operation.

Conclusions

Broadbanding and diplexer operations of stripline Y-junction circulators are presented and dealt with from the view point of DCFO or MCFO. The broadbanding is realized by utilizing a conductor-dielectric-ferrite composite, in which circulation modes 1, 1A, 3 and 2A play their distinct roles. It can be said that when more circulation modes are used, a broader frequency band can be obtained. The frequency band is changeable with a biasing magnetic field. The circulator of this art has the performance advantage that it is compact, easy to adjust, and there is no need of broadbanding impedance matching networks externally connected.

The diplexer operation is demonstrated, by using a conductor-ferrite composite, in which circulation modes 1A(-), 2A(+) and 2B(+) play their respective roles. The frequency band of mode 1A(-) is wider than that of mode 2A(+) or 2B(+). The operation of this kind seems promising in signal processing, such as frequency band synthesis and selection.

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References

1. T. Nagao, "Possibility of double circulation frequency operation of stripline Y-junction circulator," Digest of 1975 IEEE-MTTS Internat. Microwave Sympo., pp. 254-256, May 1975.
2. T. Nagao, "Double circulation frequency operation of stripline Y-junction circulators," to appear in IEEE Trans. on Microwave Theory and Tech., vol. MTT-25, Mar. 1977.
3. J. B. Davies and P. Cohen, "Theoretical design of symmetrical junction stripline circulators," IEEE Trans. on Microwave Theory and Tech., vol. MTT-11, pp. 506-512, November 1963.
4. J. W. Simon, "Broadband strip-transmission line Y-junction circulators," IEEE Trans. on Microwave Theory and Tech., vol. MTT-13, pp. 335-345, May 1965.
5. L. K. Anderson, "Analysis of broadband circulators with external tuning elements," IEEE Trans. on Microwave Theory and Tech., vol. MTT-15, pp. 42-47, January 1967.
6. E. Schwartz, "Broadband matching of resonant circuits and circulators," IEEE Trans. on Microwave Theory and Tech., vol. MTT-16, pp. 158-165, March 1968.
7. Y. S. Wu and F. J. Rosenbaum, "Wideband operation of microstrip circulators," IEEE Trans. on Microwave Theory and Tech., vol. MTT-22, pp. 849-856, Oct. 1974.
8. D. Polder, "On the theory of ferromagnetic resonance," Phil. Mag., vol. 40, pp. 99-115, January 1949.
9. J. Brown and J. Clark, "A unique solid-state diplexer," IRE Trans. on Microwave Theory and Tech. (Corresp.), vol. MTT-10, p. 298, July 1962.
10. L. V.d. Kint and E. Schanda, "A microwave quadruplexer," IEEE Trans. on Microwave Theory and Tech.(Corresp.), vol. MTT-11, pp. 90-92, January 1963.

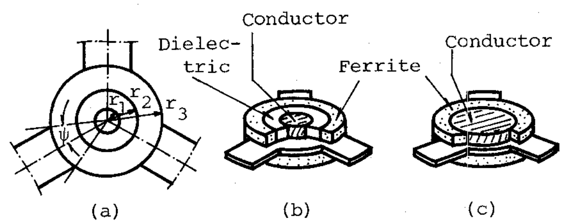

Fig. 1 (a) geometry of the stripline Y-junction, (b) and (c) configurations of the Y-junctions loaded with conductor-dielectric-ferrite composites and conductor-ferrite composites, respectively.

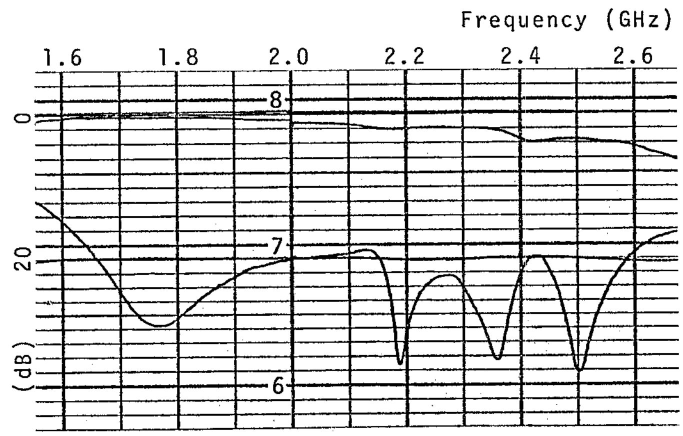

Fig. 2 An experimental example of the broadbanding operation when four circulation modes are put into use.

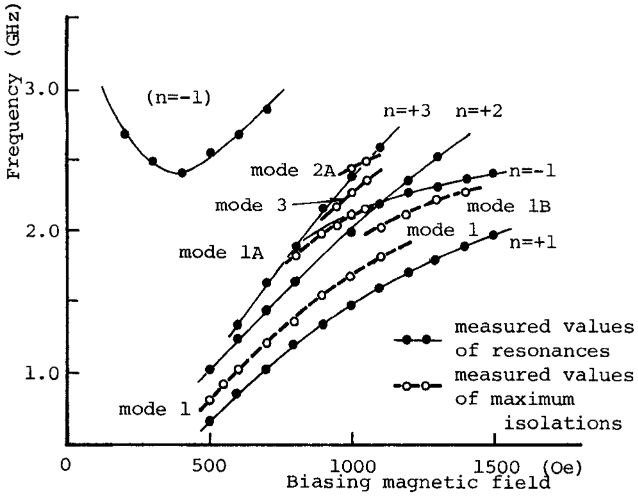

Fig. 3 Identification of circulation modes in the mode chart, in the case of the Y-junction loaded with the conductor-dielectric-ferrite composites. A number in parentheses shows a resonant mode below resonance.

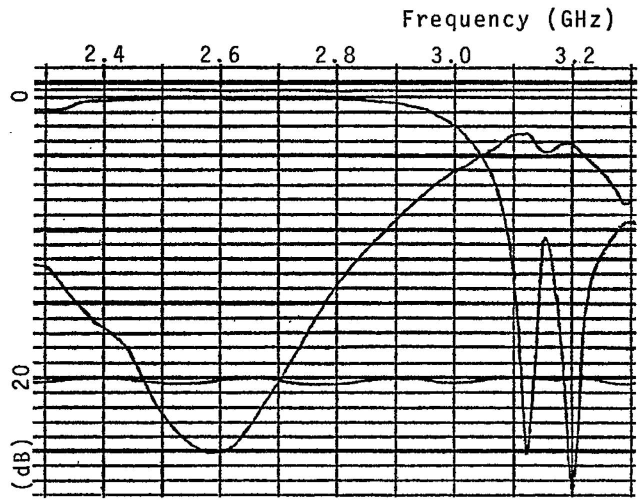

Fig. 5 An experimental example of the diplexer operation.

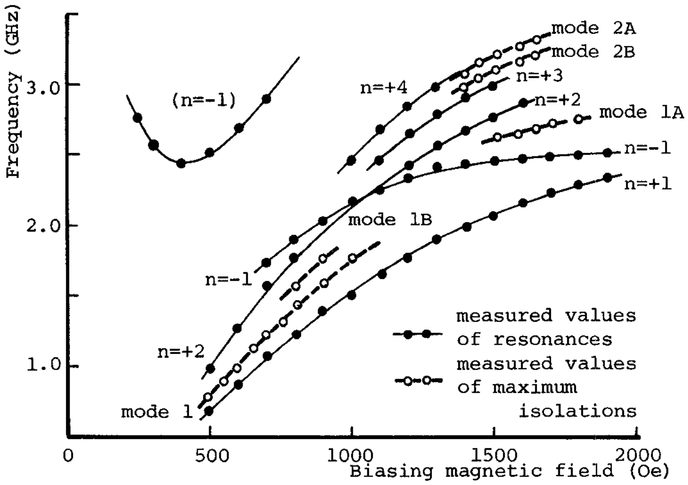

Fig. 6 Identification of circulation modes in the mode chart, in the case of the Y-junction loaded with the conductor-ferrite composites. A number in parentheses shows a resonant mode below resonanc.

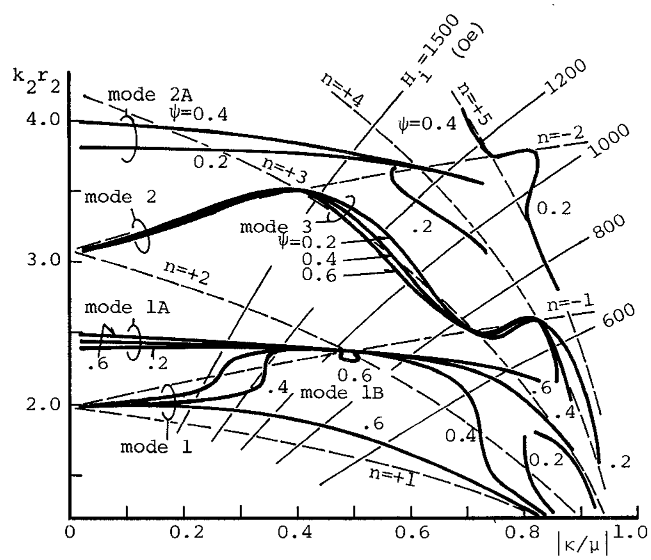

Fig. 4 The wave propagation constant radius product k_2r_2 versus anisotropic splitting factor $|\kappa/\mu|$ relationship of the first circulation condition, in the case of the Y-junction loaded with the conductor-dielectric-ferrite composites. Thin lines show loci of constant internal magnetic field intensity H_i. Broken thin lines show resonance curves. The + and - signs denote clockwise and counterclockwise rotating modes, respectively. A number after a sign denotes the order of resonant modes. ψ is half the angle subtending the stripline at the center conductor.

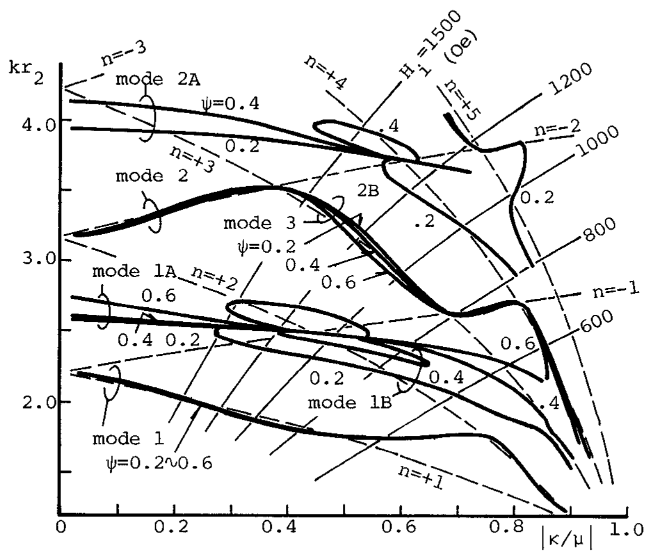

Fig. 7 Computed results of the first circulation condition in the case of the Y-junction loaded with the conductor-ferrite composites. Thin lines show loci of constant internal magnetic field intensity H_i. Broken thin lines show resonance curves. The + and - signs denote clockwise and counterclockwise rotating modes, respectively. A numbers after a sign denotes the order of resonant modes. ψ is half the angle subtending the stripline at the center conductor.