A NEW CONCLPT FOR BROADBANDING THE FERRITE SUBSTRATE CIRCULATOR BASED ON EXPERIMENTAL MODAL ANALYSIS

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Summary

The electrical characteristics of the ferrite substrate microstrip circulator having wider magnetized region than conventional one have been studied. This work enables us to compose a compact and simplified wideband circulator without the impedance matching networks. The electric field measurement shows that the wideband characteristics are realized by the combination of the conventional n=1 mode and a nonresonant mode different but compatible to the former. A C-Band version measuring 15 mm in diameter offers more than 20 dB isolation and an insertion loss less than 0.5 dB over a bandwidth of 50 percent or more with the center frequency of 6.3 GHz.

Introduction

The broadband circulators so far offered for market have been composed of the junction contributing to the circulation and of the broadband impedance transformer inserted in each port. This is also the case with the so-called ferrite substrate circulator in which both a metalic junction and transformers are printed on the substrate with the magnetized region restricted just beneth the junction.[1] The performance of this class of circulator has reportedly been in sufficient agreement with the predictions based on the theory offered by Fay.[2] Consequently, the additional studies for further enhancement of the bandwidth of circulators have not been conducted including the ferrite substrate version. The present study is devoted to the fulfilment of the requirement of broadbanding by means of an approach appreciably different from the conventional in that the magnetized region is widened substantially more than those in conventional type. From the experimental studies, with emphasis placed on the modal analysis, the conclusion has been drawn that the combination of two adjacent modes realizes the broadbanding up to about 50 percent, enabling us to compose a compact and simplified circulator free of the bulky transformers.

Circulator Characteristics

Most of experiments have been carried out at C-Band on such circulators as shown in Fig. 1. Apparently, the configuration of the experimental circulator is the same as that of the conventional version except for the wider magnetized region, the utilized ferrimagnetic material being YIG posessing the saturation magnetization of 1750 G. The characteristics of the circulator are sensitive to the diameter of the magnetized region (D), the diameter of the center conductor (d), the width of the microstrip (w) and the thickness of the substrate (t). In the experiments, the ratio (D/d) has been varied from 1.5 to 2.5 by varying the disk diameter from 12 to 20 mm with the disk conductor diameter kept at 8 mm while the ratio (w/t) has been varied from 0.7 to 1.3 by varying the width of microstrip from 1 to 2 mm width the substrate thickness kept at 1.5 mm. The equi-isolation curves experimentally obtained and within which the isolation exceeds 20 dB are plotted in terms of magnetic field strength and the frequency in Fig. 2 with the ratio of (D/d) as the parameter. Evidently the bounded domain expands as the value of (D/d) increases in so far as this value is less than 1.9. Once this value exceeds 1.9, the domain splitts into two zones. The relative bandwidth defined as the ratio of the maximum bandwidth of 20 dB isolation (Δf) to the center frequency (f) is plotted in Fig. 3 in terms of (D/d) and (w/t). From the figure, it is evident that the relative bandwidth is maximized at a given value of (D/d), D/d=1.9 in this case, for a given value of (w/t). This indicates the role played as the impedance transformer by the microstrip is not so important as that of the conventional broadband circulator. Fig. 4 shows the isolation characteristics of a hexagonaly shaped circulator in which the portions persumed not to contribute to the circulation are cut out. Comparison is made in the same figure with the isolation characteristics of the disk circulator with both the junction diameter and the microstrip length kept unchanged. These two curves apparently do not overlap. If the realized broadbanding should have been accomplished by the magnetized microstrip functioning as a class of broadband impedance transformer, these two curves should coincide with each other. Consequently we have been led to the assumption that also the magnetized region outside the junction plays an important role for the broadbanding.

Electric Field Measurement for the Modal Analysis

The electric field parallel to the applied magnetic field has been measured along top face of the circulator having maximum bandwidth. As shown in Fig. 5 the apparatus for the electric field pattern measurement is the combination of a pantograph and a rotating disk enabling the tip of the probe to be moved circularly. The field strength has been recorded by X-Y recorder as a function of angle for the field pattern mapping on the polar coordinate, mapped pattern being shown in Fig. 6. At the higher band edge the electric node coincides with the isolated port, suggesting that the n=1 mode defined by Fay is dominant. In contrast with foregoing, around the lower band edge the field pattern is frequency-sensitive, the electric field extending to the edge of the ferrite in a substantial intensity, no mode relevant to this field pattern having been identified as yet. Between the bands quoted the field pattern changes smoothly from that for the lower band edge to that for the higher band edge. The absence of the mode in the lower band qualifies us to claim that the observed field does not stem from any one or any combination of the dielectrically resonant modes satisfying the condition, $\partial Ez/\partial z=0$, and admitted as basic to the circulation. The appropriate mode, if any, should be such as merging the n=1 mode at the higher band edge.

Concluding Remarks

The realized broadbanding of the experimental circulator may be ascribed to the frequency sharing by the two different but compatible modes. The widened magnetized region results in a novel mode in the lower frequency range. The proper selection of the value of (D/d) realizes a mode at the lower frequency region merging the conventional mode, reducing the role played by the microstrip to be less important for the broadbanding. On the basis of these results we have fabricated a compact broadband circulator. A C-Band version measuring 15 mm in diameter offers more than 20 dB isolation and an insertion loss less than 0.5 dB over a bandwidth of 50 percent or more with the center frequency of 6.3 GHz, in contrast with the diameters around 20 mm as obtained by the conventional design with the impedance matching networks.

Acknowledgments

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References

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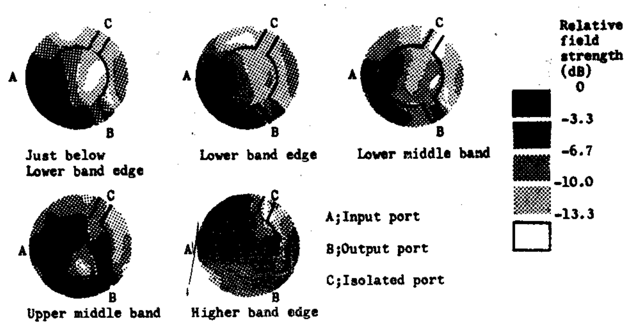

Fig. 6. Mapps illustrating the change of the electric field pattern as the frequency variation.

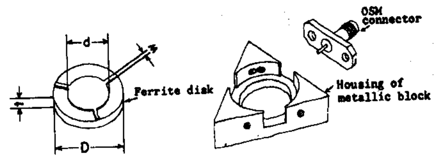

Fig. 1. Exploded view of experimental circulator.

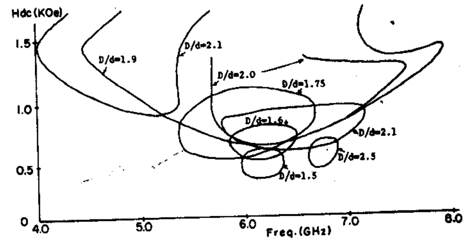

Fig. 2. 20 dB equi-isolation curves on the magnetic field strength-frequency plane.

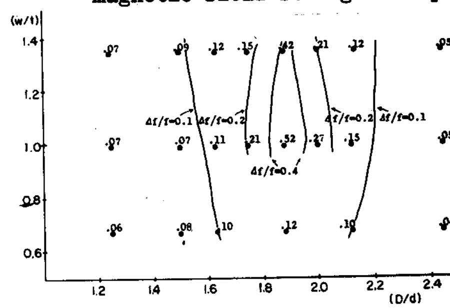

Fig. 3. The relative bandwidth as plotted on the (w/t)-(D/d) plane.

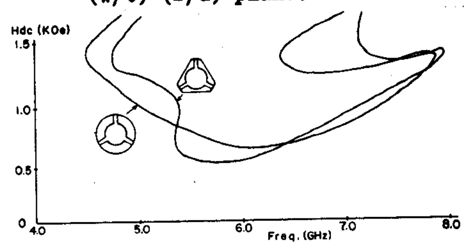

Fig. 4. 20 dB equi-isolation curves for the hexagonally shaped circulator compared with that for the disk circulator.

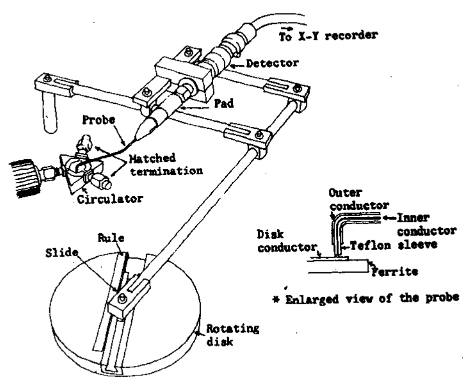

Fig. 5. Electric field measuring apparatus.