MAGNETICALLY TUNABLE STRIPLINE Y CIRCULATOR

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Abstract A stripline Y junction circulator loaded with TDC resonators achieved magnetically tunable operation in UHF. Its frequency band was wider than octave band, 0.4 to 1.1 GHz. Its constituent operation had a frequency band of less than 100 MHz, insertion losses were less than 1.5 dB, and isolation more than 25 dB. Experimental analysis of the magnetically tunable operation, and theoretical analysis of EM fields of resonant modes, eigenvalues, and perfect circulational modes are presented.

1 Introduction

A new versatile use of a stripline Y circulator is its application to frequency band selection in UHF. This is achived by a stripline Y junction circulator with three YIG discs tightly coupled resonators (TDC resonator). As is well known, most of stripline Y circulators are made, using monodisc resonators, and a number of resonant modes that exist in the monodisc resonator naturally take part in circulator operations [1, 2, 3]. Even if a circulator is adjusted at selected points of the most desirable operation, only a slight change of biasing magnetic field tends to affect the operation. It is, therefore, far from being magnetically tunable.

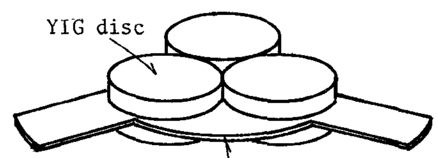
A circulator of the present concern was made replaced with, at first, tri-discs and later, three partially scraped YIG discs. To increase the effect of mutual coupling, an idea to scrape a YIG disc partially on its periphery is actually applied to. They are positioned in the circular center conductor as shown in Fig. 1.

In the experiments, the magnetically tunable operation was analyzed. The operating points of the constituent operation that moved with the biasing magnetic field intensity were plotted upon the mode chart, and they were traced only between the resonant frequency curves of the lowest pair in the TDC resonator.

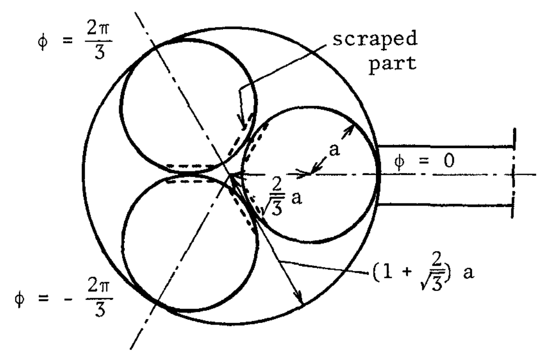
Theoretical analysis of the TDC resonator discloses that there exist resonant modes N = 0, ± 1, ± 3, and others, but not N = ± 2. This eventuates mode 1 circulation which mode pair N = ± 1 play solely, without intervention of any neighboring operation that mode pair N = ± 2 contribute particularly. The resonant modes in the TDC resonator are derived to have lower eigenvalues than those of corresponding resonant modes in a monodisc resonator. The above noted results are proved to agree to the experimental results.

2 Experiments

The geometrical configuration of a TDC resonator is shown in Fig. 1-b. Dimensions of the TDC resonator are such that diameter of each disc is 20 mm, its thickness 2.5mm, scraped depth 1.0mm, and diameter of the center conductor for the TDC resonator is about 42 mm. The specifications of YIG ferrite are $4\pi M_s$ = 950 Gauss, and ε = 14.5.



(a)



(b)

Fig. 1 (a) The stripline Y junction used in the experiment, and (b) the TDC resonator

A mode chart of resonant modes in the TDC resonator is obtained by measurement of resonant frequency with biasing magnetic field intensity as shown in Fig. 2. It is recognized that (1) the lowest resonant modes of N=± 1 in the TDC resonator appeared in lower frequencies than the lowest modes of n=± 1 in the monodisc resonator,
(2) separation of resonant frequencies between N=+1 and -1 is almost constant and its magnitude is much less than that for n=+1 and -1, and
(3) the secondary mode of the TDC resonator appeared far in higher frequencies, and did not intersect any modal curve of N=± 1, while the second mode of n=+2 of the monodisc resonator did clearly intersect the modal curve of n=-1.

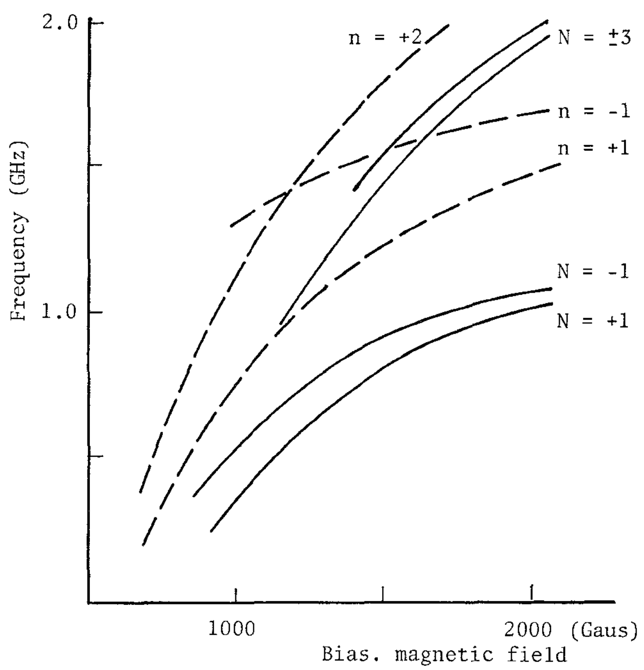


Fig. 2 Mode chart of TDC resonator (solid lines) and monodisc resonator (broken lines)

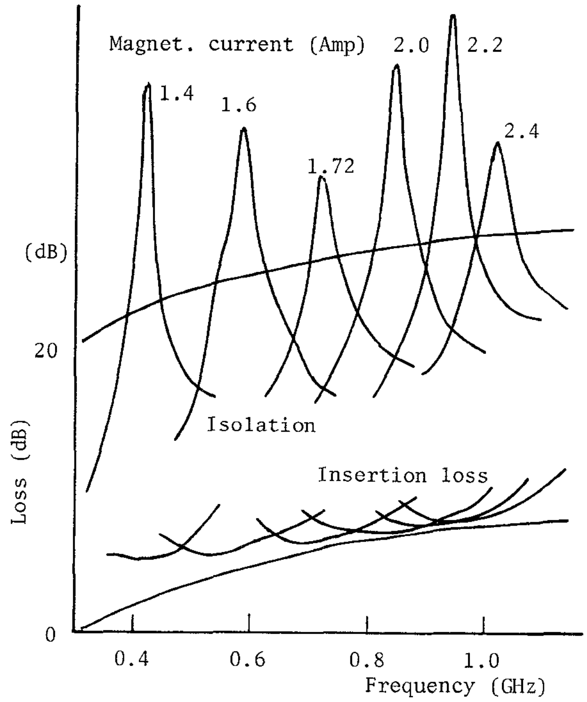


Fig. 3 Example of the magnetically tunable operation of the stripline Y circulator

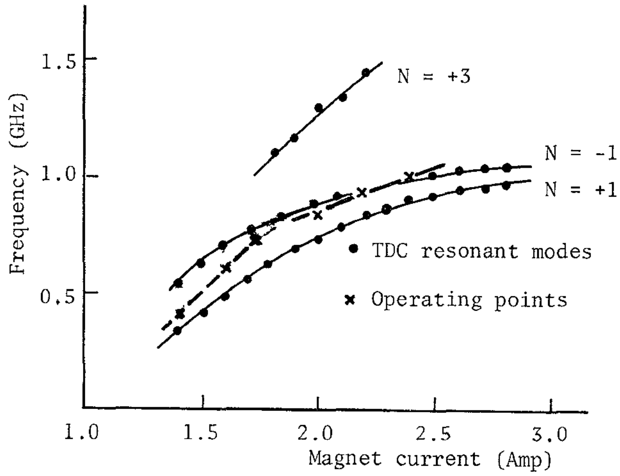


Fig. 4 Comparison of the TDC resonant mode and operating points of the magnetically tunable operation

As to the secondary mode, it will be mentioned that it is the third mode, and the second mode is absent.

One of the magnetically tunable circulator operations is demonstrated in Fig. 3. As the biasing magnetic field intensified, an incessant constituent operation having a narrow frequency band of about 100 MHz moved almost linearly toward higher frequencies. It covered the operating frequency band from 0.4 to 1.1 GHz, wider than octave band. The constituent operation had such features that insertion losses are less than 1.5 dB, gradually decreasing to 0.3 dB in higher frequencies, and isolation more than 25 dB.

Granting that an operating point of a circulator action agrees practically with a frequency of maximum isolation in a given biasing magnetic field intensity, operating points of the magnetically tunable operation can be plotted superimposed in the mode chart as shown in Fig. 4. It is obviously found that all of the operating points lie between two modal curves of N=+1 and -1. This proves that mode 1 operation of perfect Y circulation plays an exclusive role in the magnetically tunable operation.

3 Theoretical Analysis of TDC Resonator

To proceed to analyze a TDC resonator, we assume that a TDC resonator can be resolved into three of monodisc resonator, each of which is placed at an off-center position of rotational symmtery as shown in Fig. 1-b. Derivation of the EM fields in an eccentrically placed monodisc resonator can be worked out, first, in converting the well known EM Fields of a monodisc resonator into those of eccentricity, by help of addition theorem of Bessel function (4). The boundary condition of continuity can be applied to the E field at a contact point of two discs, which gives us an equality relation of amplitude coefficients. Next, we can joint the respective H fields of three monodisc resonators eccentrically placed around the center conductor to get the H field in the TDC resonator.

Azimuthal and radial components of H field in the TDC resonator are discribed in terms of series of increasing t value. t is defined by $t = r_0/r$, where r_0 is the distance of eccentricity, and r the distance from the center. Three cases of joints, in phase, positive and negative phases, are indispensable to obtain such coupled modes in the TDC resonator. We can get the consistent EM field expressions for modes N = 0, ±1 and other higher modes except N = ±2.

Now we can introduce the EM fields in the TDC resonator as follows:
for the 0th mode,

$$E_{z0} \simeq 3\, a_0 J_0(Z),$$

$$H_{\phi 0} \simeq -j3\, \frac{a_0}{\zeta_e} J_0'(Z), \quad (1)$$

$$H_{r0} \simeq -3\, \frac{a_0}{\zeta_e}\, \frac{\kappa}{\mu} J_0'(Z),$$

for the ± 1st modes,

$$E_{z(\pm 1)} \simeq 3\, a_\pm J_1(Z)\, e^{\pm j\phi},$$

$$H_{\phi(\pm 1)} \simeq -j3\, \frac{a_\pm}{\zeta_e} [J_1'(Z) \mp \frac{\kappa/\mu}{Z} J_1(Z) \mp j\frac{1}{Z} L(t,\ \phi) J_1(Z)]\, e^{\mp j\phi}, \quad (2)$$

$$H_{r(\pm 1)} \simeq \pm 3\, \frac{a_\pm}{\zeta_e} [\frac{1}{Z} J_1(Z) \mp \frac{\kappa}{\mu} \{J_1(Z) \mp j\frac{1}{Z} L(t,\ \phi) J_1(Z)\}]\, e^{\mp j\phi},$$

$$L(t,\ \phi) = \frac{\mathrm{cosec}\ 3\phi}{t} - \cot 3\phi, \quad (3)$$

where $Z = kr$, $t = Z_0/Z = r_0/r\ (<1)$,

$$k = \omega\sqrt{\varepsilon_0 \varepsilon \mu_0 \mu_e}\ , \quad \zeta_e = \sqrt{\mu_0 \mu_e / \varepsilon_0 \varepsilon},$$

J_0, J_0', J_1, J_1' are Bessel functions of 0th and 1st orders, and the primes denote their first derivatives.

The behavior of $L(t, \phi)$ is shown in Fig. 5. From this sketch, we can see that L vanishes at each point of $\phi = 0$, $+2\pi/3$, and $-2\pi/3$ for all of t, where three junction ports are assumed to connect to the center conductor. Therefore, we can presuppose that the role which L plays does not superficially affect not only measurement of resonant frequencies, but also circulator operation.

The resonant modes of the TDC resonator are determined by applying the boundary condition of a magnetically short-circuited edge at the periphery of the center conductor of the present interest, which is $H_\phi(Z_2) = 0$, where Z_2 is $(1 + 2/\sqrt{3})$ ka. We can get from Eqs. (1) and (2) the characteristic equations for the 0th mode,

$$J_0'(Z_2) = 0, \quad (4)$$

for the ± 1st modes,

$$J_1'(Z_2) \mp \frac{\kappa/\mu}{Z_2} J_1(Z_2) = 0. \quad (5)$$

For the ± 3rd modes, we have

$$J_3'(Z_2) \mp \frac{\kappa}{\mu} \frac{3}{Z_2} J_3(Z_2) = 0. \quad (6)$$

We can calculate from Eqs. (4), (5) and (6) the eigenvalues of the resonant modes and plot them in the ka versus κ/μ chart as shown in Fig. 6. The difference between the TDC and monodisc resonators comes from the fact that the ka values of the TDC resonator are devaluated by $1/(1 + 2/\sqrt{3})$ from those of the monodisc resonator. Theoretical separation of the eigenvalues of two modes N = +1 and -1 is thus reduced by almost half from counter two modes of n = +1 and -1 in the monodisc resonator, while the experimental separation in the mode chart shown in Fig. 2 is found to be more reduced to about 1/3.

We can further calculate the perfect circulational condition of the stripline Y junction with the TDC resonators, regarding mode 1 [refer to Eqs. (9)-(13) in [3]]. and the mode 1 curves can be found in the region marked by the resonant curves of N = +1 and -1. This agrees to the experimental results of the mode 1 operation which are indicated by the plotted operating points shown in Fig. 4

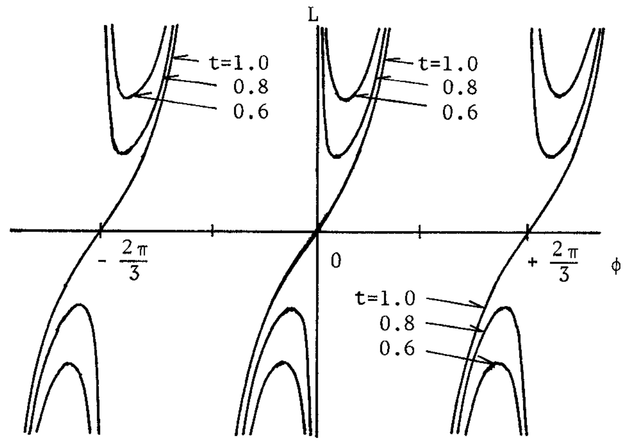


Fig. 5 Sketch of the behavior of $L(t, \phi)$ as a function of t (= r_0/r)

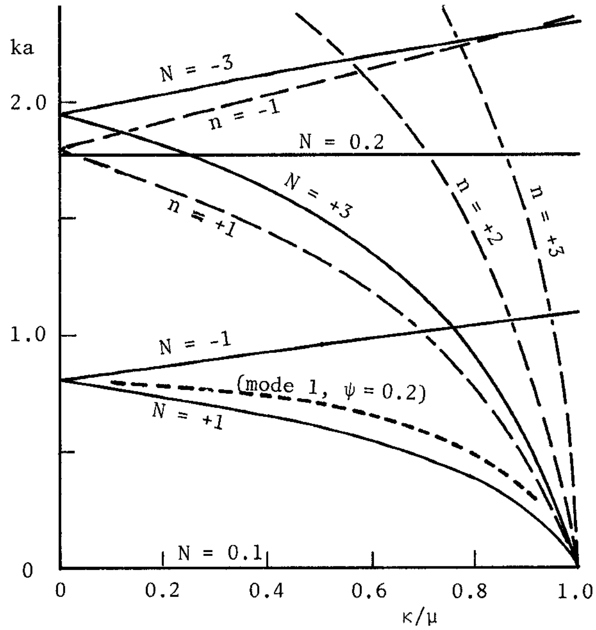


Fig. 6 Comparison of the ka versus κ/μ relations of TDC and monodisc resonators. Solid and broken lines, respectively, correspond to TDC and monodisc resonators, and indices refer to modal orders. A dotted line indicates one of the mode 1 curves of perfect circulation

4 Conclusion

In this paper we disclosed a magnetically tunable operation of stripline Y junction loaded with the TDC resonators. The TDC resonator is composed of three YIG discs eccentrically placed in the circular center conductor. Experiments and theoretical analysis clarified the essential role of the coupled resonant modes in a TDC resonator in achieving the magnetically tunable operation.

The above notes are itemized as follows.

1. The resonant modes in the TDC resonator have lower eigenvalues than those of the monodisc resonator, and its correspondence is also found in the mode chart (see Figs. 2 and 6).
2. The resonant mode pair of N = +2 and -2 is absent in the TDC resonator and it is also proved in the mode chart (see Figs. 2 and 4).
3. The perfect Y circulation of mode 1 is assumed to take place in the region between the resonant curves of N = +1 and -1, which is drawn for ψ = 0.2, half the angle subtending the width of a connected stripline to the center conductor, and it is proved to agree to the plot of the operating points of the magnetically tunable operation.

There are, however, some problems to solve. They are to analyze the perfect circulation conditions including L that is defined in Eq. 3, dependence of stripline width of large angles, and input impedance characteristics.

References

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