PROPERTY OF FOUR-PORT ANTIRECIPROCAL CIRCUIT UTILIZING YIG AND STRIP LINE --- FILTER AND CIRCULATOR

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Abstract

The experimental results of the four-port antireciprocal bandstop=pass filter and the theory of tunable resonance type circulator with the properties of the four-port filter are discussed.

The filter operates for a 2-octave frequency range.

Introduction

Many papers concerning bandstop filters utilizing YIG have been recently reported with the development of microwave integrated circuits. Most of them are, however, reciprocal filters. Only a few of them are antireciprocal and their available frequency bandwidth is narrow ; about 1.3 : 1 [1]. The reason exists in the fact that it is difficult to obtain for a wide bandwidth the characteristic of a circularly polarized magnetic field required for the operation as an antireciprocal bandstop filter, specially when the circuit is composed of strip line.

In this report, taking notice that the directional coupler with coupled-transmission-lines keeps the phase difference between its outputs in 90 degree for a wide bandwidth [2], we will present an antireciprocal filter which is constructed of a directional coupler and a single YIG sphere.

The filter operates for a wide bandwidth of about 2 octaves as an antireciprocal bandstop filter. Moreover, one will recognize that the isolated port of a directional coupler has, at the same time, such a property as can be used as an output of an antireciprocal bandpass filter. We report here these useful experimental results of an interesting circuit and explain that the filter can be used as a tunable resonance type circulator.

Circuit Structure

(1) Filter

The four-port filter, as shown in Fig.1, consists of one or two directional couplers, a orthogonal coupling in order to obtain a circularly polarized magnetic field by means of microstrip lines and a single YIG sphere. The coupled-transmission-line directional coupler is characteristic of multioctave in a bandwidth, keeping the phase difference between Output Port 2' and Output Port 3' in 90 degree. The coupler, D_1 D_2, is here 3-dB one, a circularly polarized magnetic field is provided by beans of crossing at right angles two outputs from coupling region at the position where a YIG sphere is placed.

At zero applied field, when voltage V_1 is applied at Port 1 (Input), the coupled voltage at Port 2', the straight-through voltage at Port 3' and the voltage at Port 4 (Isolated Port) is $\frac{1}{2}V_1$, $-j\frac{1}{2}V_1$, 0, respectively, assuming L_1 = (a quater wavelength) to simplify the problem.

A dc magnetic field H_0 is then applied in perpendicular to the plane of RF circularly polarized field. As the field H_0 approached that necessary for YIG sphere resonance, Port 2' and Port 3' are characteristic of a bandstop filter because of the YIG sphere's resonant absorption and others, while the Isolated Port 4 has, however, an output response and is, at the same time, characteristic of a bandpass filter, Port 4 is always isolated, when H_0 is zero or far from the region of the field required for YIG resonance.

It may be considered that the reason why the output appears at Port 4 exists in the fact that the permeability of the YIG sphere changes in a very large value at its resonance, so the impedance level at the point of the orthogonal coupling does and large reflections take place [3] [4]. It is easily understood by simple calculation that the reflections don't come out at Port 1, but do come at Port-4 in the case of 3-dB coupling.

In the case of making use of Port 2' (or Port 3') as an Output Port of bandstop filter, at least 3 dB insertion loss cannot be avoided from the nature of this circuit. However this insertion loss will be eliminated by means of adding another coupler D_2 to this filter, that is, if the coupling k_2 is 3 dB, Port 2 is an Output Port and Port 3 is an Isolated Port as shown in Fig.1.

(2) Circulator

The realization of a new circulator will be possible by making use of the properties mentioned above. That is, when Port 1 is the input port, the output responce at each Port is

Port 1 $\quad V_1$ = unity (input signal)

Port 2 $\quad V_2 = -j\left(K_2\sqrt{1-K_1^2} + K_1\sqrt{1-K_2^2}\right)$

Port 3 $\quad V_3 = \left(K_1K_2 - \sqrt{1-K_1^2}\sqrt{1-K_2^2}\right)$

Port 4 $\quad V_4 = 0$ (Isolated Port)

where K_1 , K_2 ; coupling factor (assuming L_1 = L_2 = (a quater wavelength) to simplify the problem)

Therefore the condition that Port 3 must be satisfied for the perfect isolation ($V_3 = 0$) is given as follows :

$$K_1^2 + K_2^2 = 1 \qquad (1)$$

When the condition of (1) is satisfied, in the case where H_0 is far from the resonance field, the four ports are divided in two pairs by a symmetry line S-S' as shown in Fig.2 (a). In another case where H_0 is equal to that necessary for resonance, let's consider firstly when Port 1 is Input. As mentioned above, Port 2 becomes as Output Port. Secondarily when Port 2 is Input, the output of Port 1 is zero because of the antireciprocity of this circuit, that is, this circuit works as bandstop in this direction. Output appears at Port 3 because of bandpass characteristics, as shown in Fig.2 (b).

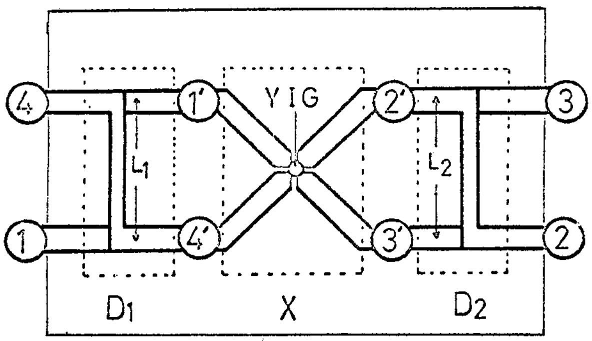
Since the frequency characteristic of the coupler as mentioned above is very wide, it is in principle able to make a wide bandwidth tunable circulator.

Experimental Results

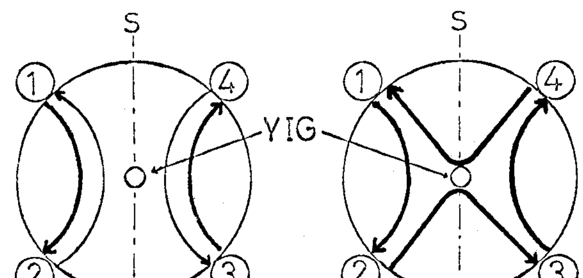
The four-port filter has the B.P.F characteristic at Port 4 as shown in Fig.3. Fig.4 indicates that the filter operates very widely as a bandstop filter ; 2—6.8 GHz the isolation more than 20 dB, 2—8 GHz the isolation more than 15 dB and the insertion loss 3—5 dB, which can be avoided by means of the added 3-dB coupler D_2, the input VSWR less than 1.6 (2—8 GHz). The performance of the BPF is not so wide as that of the BSF.

This four-port filter works as a tunable resonance type circulator, characteristic of which is shown in Fig.5. The tunable bandwidth of this circulator is about one octave, because the available bandwidth of the couplers are also one octave. The couplers here are only single-element and their bandwidth is about one octave. In principle, the wider the bandwidth of the couplers is designed, the wider the tunable bandwidth of the circulator can be.

This circulator is very simple but its characteristics are quite good.



D1,D2: DIRECTIONAL COUPLER
X : ORTHOGONAL COUPLING
FIG.1 SCHEMATIC 4-PORT FILTER



(a) H0 IS FAR FROM Hr.
(b) H0 IS EQUAL TO Hr.

FIG.2 PATH MODEL OF 4-PORT CIRCULATOR
Hr: THE FIELD FOR YIG RESONANCE

Conclusion

It has been found that the antireciprocal bandstop=pass filter can be obtained with a single YIG and two directional couplers and moreover the tunable four-port circulator can be also. Their tunable frequency range is very wide compared with the former one.

References

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[2] R. Levy, "Directional Couplers" Advances in Microwaves Vol 1, New York (Academic Press) pp 115-209 (1966)
[3] C. L. Hogan, "The Ferromagnetic Faraday Effect at Microwave Frequencies and its Applications" Bell System Tech. J. Vol 31, pp 1-31 (1952)
[4] C. L. Hogan, "The Ferromagnetic Faraday Effect at Microwave Frequencies and its Applications" Rev. Modern Physics, Vol 25 pp 252-263,January 1953

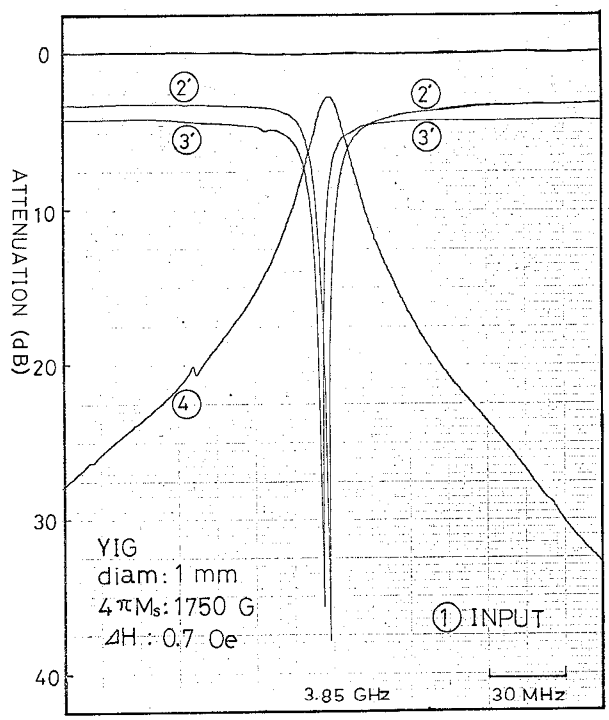

FIG. 3 OUTPUT RESPONSE OF THE 4-PORT FILTER

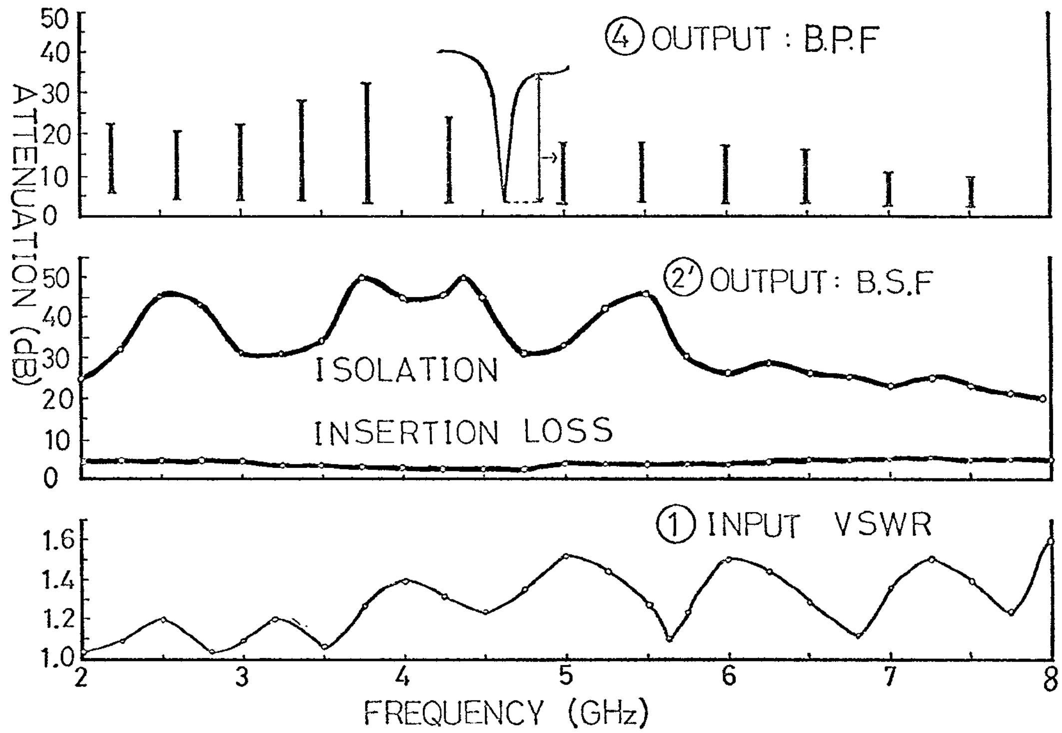

FIG.4 CHARACTERISTIC OF THE 4-PORT FILTER

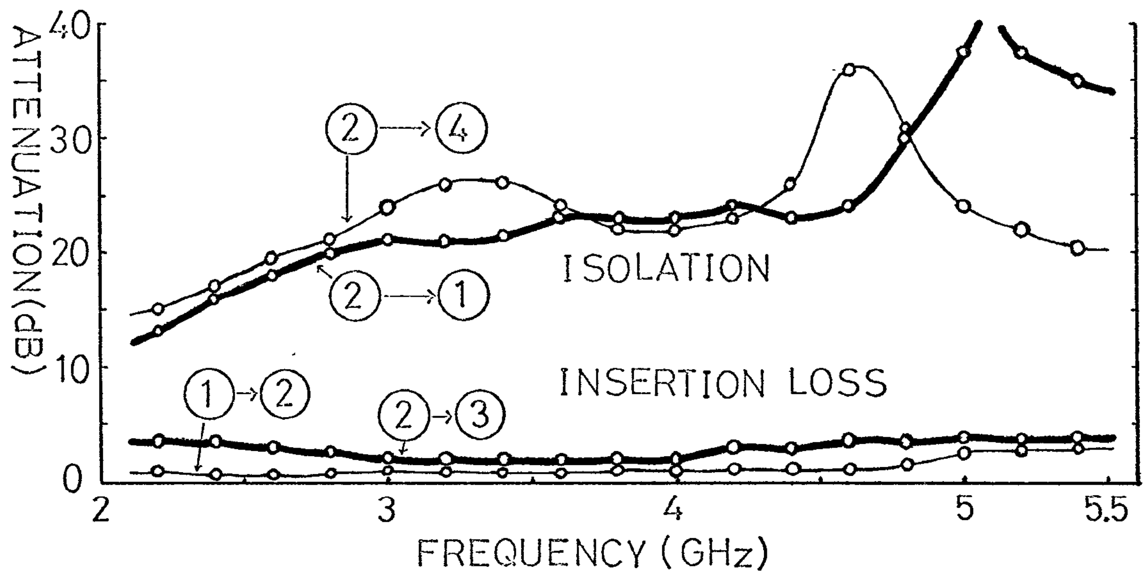

FIG.5 CHARACTERISTIC OF THE 4-PORT CIRCULATOR