A 0.5-4.0 GHz TUNABLE BANDPASS FILTER USING YIG FILM GROWN BY LPE

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ABSTRACT

A tunable bandpass filter using YIG film grown by LPE has been developed. Over the wide tuning range from 0.5 GHz to 4.0 GHz, low insertion loss and high spurious suppression have been achieved. The performance of this filter satisfies the requirements for use as a tracking preselector in a microwave spectrum analyzer.

INTRODUCTION

Microwave devices using YIG films have advantages over devices using YIG sphere technology in batch production, lower cost and compatibility with microwave integrated circuits. Although considerable work has been done on magnetostatic-wave (MSW) devices utilizing YIG film, a persistent problem is the high insertion loss of these devices when applied to microwave bandpass filters [1,2].

We have previously reported a 1.575 GHz fixed-frequency bandpass filter using the uniform precession mode of perpendicular resonance of YIG film to achieve a low insertion loss [3]. Forming a circular groove on the surface of the YIG disk allowed us to solve the inherent problem of spurious responses due to higher order magnetostatic modes, and a high spurious suppression has been achieved. This paper describes the application of this technique to a bandpass filter tunable over the frequency range from 0.5 GHz to 4.0 GHz. A new design approach and the fabrication of the YIG-tuned filter (YTF) to realize the very low operation frequency of 0.5 GHz and wide tuning range of 3 octaves are also described.

DEVICE FABRICATION

The configuration of the two-stage filter is shown in Fig. 1. Two YIG disk resonators were fabricated from lanthanum-substituted yttrium iron garnet (La:YIG) film epitaxially grown on a (100) gadolinium gallium garnet (GGG) substrate. Lanthanum was substituted to match the lattice constant of YIG film with that of the GGG substrate. (100) YIG film was chosen in order to minimize the low frequency limit of the resonance and to obtain the higher unloaded Q, especially in the low frequency range below 1 GHz. A grooved circle concentric with the center of the disk was formed photolithographically on the surface of the disk [3]. The position of the groove is calculated using magnetostatic mode theory at the node of the uniform precession mode of perpendicular

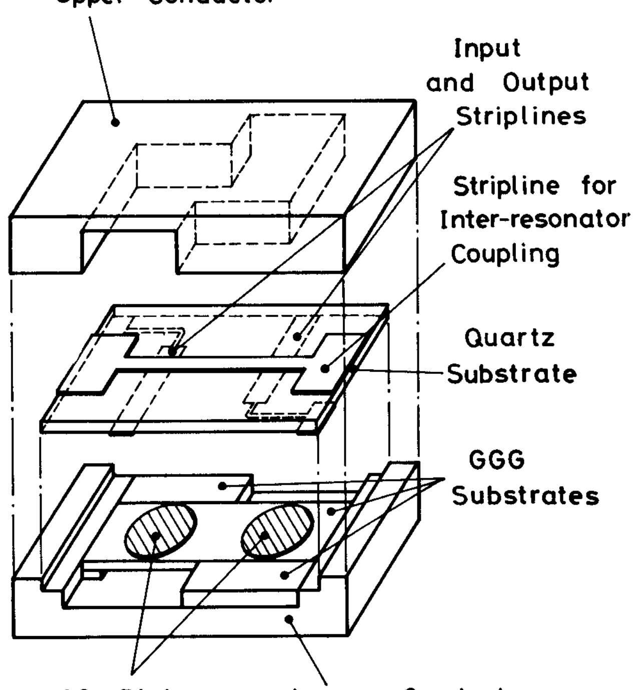

Fig.1 Configuration of the two-stage filter

resonance [4]. Here the rf magnetization of the higher order magnetostatic modes of perpendicular resonance has a finite amplitude. Hence, as the magnetization is pinned at the groove, suppression of the higher order magnetostatic modes is achieved. As this spurious suppression technique is based on magnetostatic mode theory, it has intrinsic broadband characteristics and works efficiently for a tunable filter. The disks were 2.5 mm in diameter and 40 microns thick. The distance between the centers of the disks was 5 mm.

Input, output and inter-resonator coupling striplines were formed photolithographically on a quartz substrate. The inter-resonator coupling stripline was grounded at both ends in the conventional manner. The ends of the input and output striplines were grounded via narrow portions which were bent 90 degrees, thus limiting the direct coupling between the input and output striplines generated by the rf magnetic field and improving the filter's isolation characteristics.

A shielded suspended stripline structure was adopted because of the following advantages :

1) The rf electromagnetic field is not disturbed by external conductors such as a magnetic yoke or coils.

2) The width of the 50 ohm stripline is kept wide in order to make the electromagnetic coupling to the YIG disk resonator strong, and together with the grooved circle, to improve spurious suppression.

3) The additional two air gaps of this structure and the fact that the striplines can be positioned either above, below, or between the dielectric substrates give much greater flexibility in determining the structure parameters which will optimize the strength of the couplings.

A biasing magnetic field of about 1910 Oe for 0.5 GHz and 3160 Oe for 4.0 GHz was applied perpendicularly by a tuning magnet.

DESIGN OF THE MULTI-OCTAVE YTF

From the equivalent circuit of the filter shown in Fig. 2, the coupling coefficient k between the two YIG disk resonators is obtained as

$$k = \frac{\cos^2(\beta_c l_o)}{Q_{e2}\sin(\beta_c l_c)}, \qquad (1)$$

where Q_{e2} is the external Q corresponding to the coupling of the resonator to the inter-resonator coupling stripline, l_o is the distance from the center to the edge of the disk, and $l_c = 2l_o+l_d$ is the length of the inter-resonator coupling stripline. When l_o is sufficiently small, as it is in this case, equation (1) can be expressed as

$$k = \frac{V_c}{Q_{e2}2\pi f\sqrt{\varepsilon_{eff}}\,l_c}, \qquad (2)$$

where V_c is the velocity of light, and ε_{eff} is the effective dielectric constant of the inter-resonator coupling stripline. From equation (2), it can be seen that k is inversely proportional to frequency.

The unloaded Q of the YIG resonator can be written as

$$Q_u = \frac{f - f_{min}}{\gamma\Delta H}, \qquad (3)$$

where f is the resonance frequency, f_{min} is the lowest resonance frequency, γ is the gyromagnetic ratio, and ΔH is the resonance linewidth. When the perpendicular resonance of a (100) YIG disk whose aspect ratio (thickness/diameter) is about $1.6\mathrm{x}10^{-2}$ is used, f_{min} is as low as 100 MHz, and the value of $k-1/Q_u$ is approximately inversely proportional to frequency, as is shown in Fig. 3.

When the ends of input and output striplines are grounded at the edge of each YIG disk, as is commonly done, $Q_{e,i/o}$, the external Q of the input and output ports remains approximately constant, as is shown in Fig. 3, so the filter is overcoupled at the lower frequency of the tuning range and undercoupled at the higher frequency of the tuning range, thus limiting the useful tuning range [5].

The ends of input and output striplines were extended beyond the edge of the YIG disk. Then, the $Q_{e,i/o}$ has the following frequency dependence

$$Q_{e,i/o} = Q_{e1}/\cos^2(\beta_{i/o}l_o+\beta_{xt}l_{xt}), \qquad (4)$$

where Q_{e1} is the external Q corresponding to the

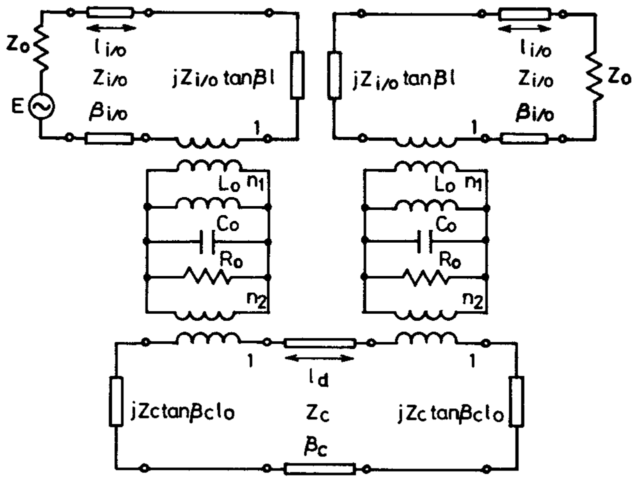

Fig. 2 Equivalent circuit of the two-stage filter

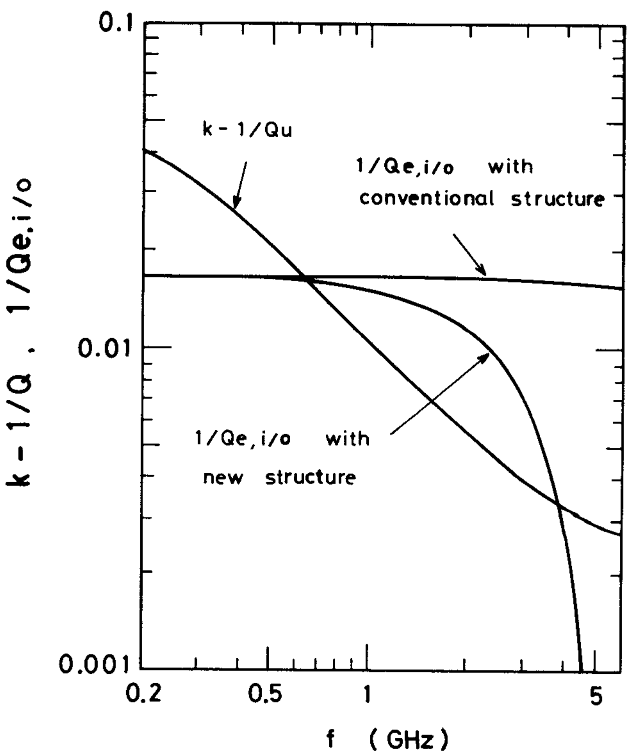

Fig. 3 Frequency dependence of $k-1/Q_u$ and $1/Q_{e,i/o}$

coupling of the resonator to the input and output striplines, $\beta_{i/o}$ is the phase constant of the input and output striplines, β_{xt} is the phase constant of the extended portion of the stripline, and l_{xt} is the length extended. Now, the critically coupled condition

$$k \sim 1/Q_u + 1/Q_{e,i/o} \qquad (5)$$

can be essentially realized in the wide frequency range, as is shown in Fig. 3. Figure 4 compares the results of simulation between the filters with and without line extension.

This broadband technique has the following advantages :

1) The spurious responses of the filter become relatively strong when the filter is undercoupled. As the filter is essentially critically coupled in the wide center portion of the tuning range and overcoupled at both ends of the tuning range, it serves to improve spurious suppression.

2) As both the coupling coefficient k and the external Q, $Q_{e,i/o}$, are approximately inversely proportional to frequency, the 3dB bandwidth of the filter remains constant.

PERFORMANCE

Figure 5 shows the transmission and reflection response of the filter measured at 2 GHz, the mid-frequency of the tuning range. Figure 6 shows the change of the transmission response when the

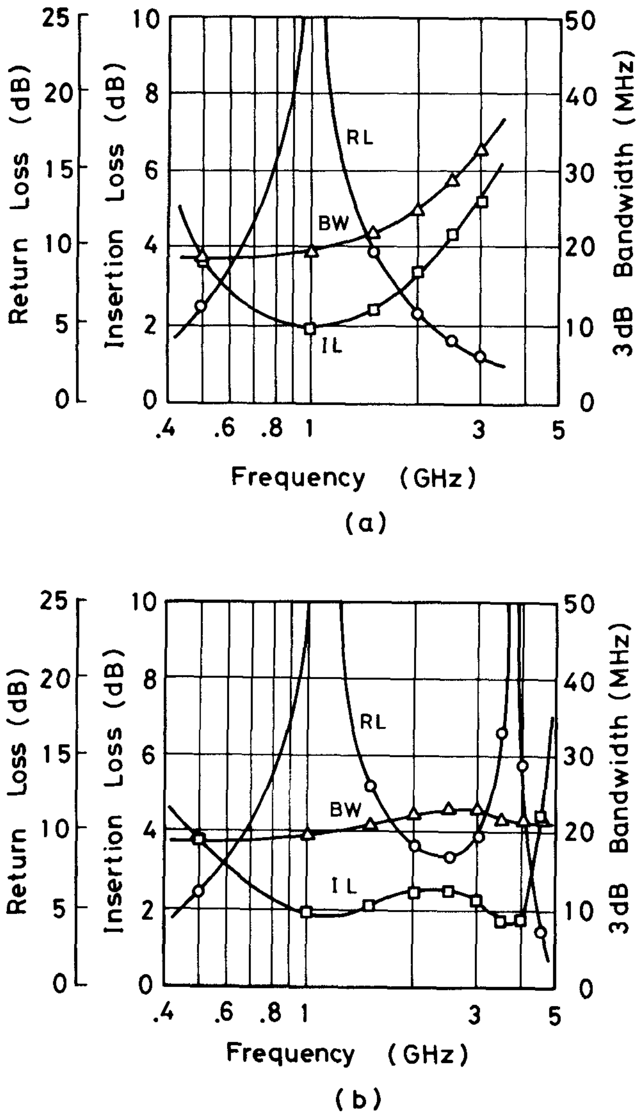

Fig. 4 Simulation results of the filter
(a) without line extension
(b) with line extension

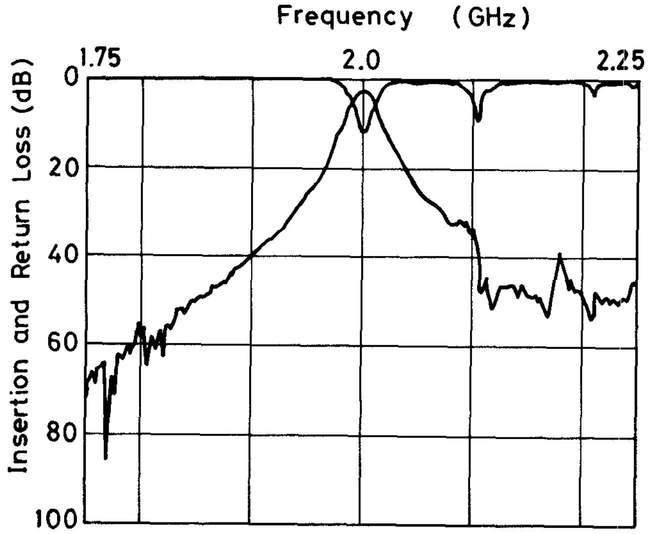

Fig. 5 Transmission and reflection response of the filter measured at 2 GHz

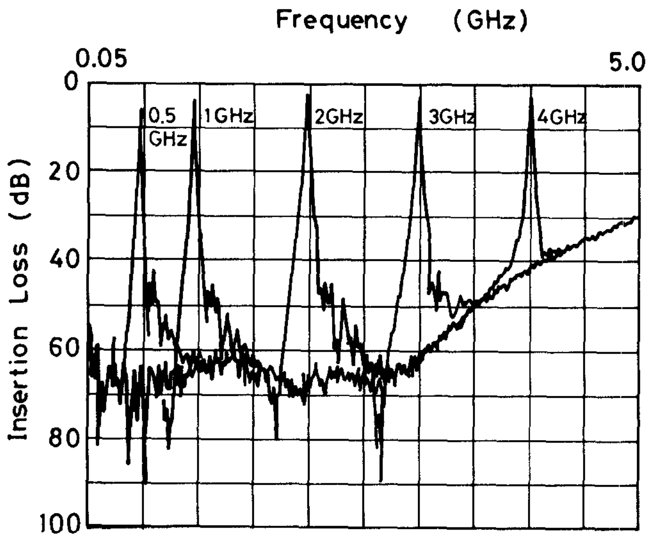

Fig. 6 Transmission response of the filter when tuned from 0.5 GHz to 4.0 GHz

filter's center frequency is tuned from 0.5 GHz to 4.0 GHz. The frequency dependence of insertion loss, return loss and 3dB bandwidth is shown in Fig.7. It agrees well with the simulaton result shown in Fig. 4 (b). The characteristics of the filter are summarized in Table I. A low insertion loss of less than 3dB except at 0.5 GHz, and a high spurious suppression of more than 35 dB have been achieved. The limiting level of the filter is 0 dBm even at the lowest frequency of 0.5 GHz. This limiting level is substantially higher than that of the YIG sphere filters operating in this frequency range. This is because, for YIG spheres low level coincident limiting occurs for power levels of -20 dBm at frequency below $(2/3)\gamma 4\pi M_s$ which is 3.3 GHz in pure YIG [6]. In contrast, coincident

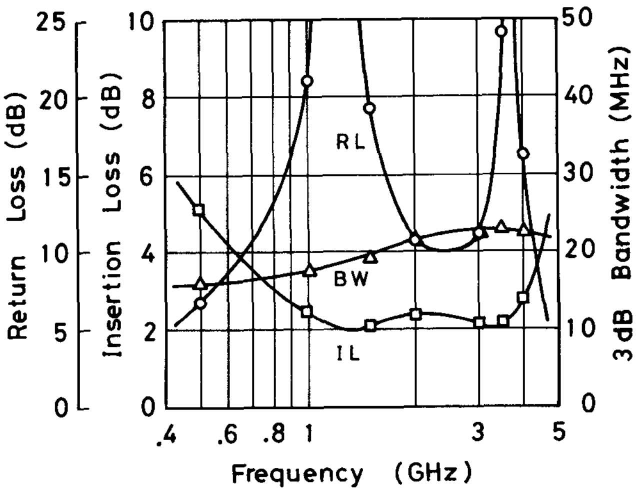

Fig. 7 Frequency dependence of the filter's characteristics

Table I Characteristics of the 0.5-4.0 GHz tunable bandpass filter

Frequency range (GHz)	0.5 - 4.0
Insertion loss (dB)	2.0 - 2.8 (1.0 - 4.0 GHz) 5.0 (at 0.5 GHz)
Return loss (dB)	>10 (1.0 - 4.0 GHz) 6.7 (at 0.5 GHz)
3 dB bandwidth (MHz)	16 - 23
Isolation (dB)	>50 (≤3.5 GHz) 43 (at 4.0 GHz)
Off-resonance spurious(dB)	> 35
Skirt spurious (dB)	< 10
Limiting level (dBm)	> 0

limiting does not occur in the perpendicular resonance of YIG disks. This is another remarkable advantage of filters using the perpendicular resonance of YIG film.

CONCLUSION

A 0.5-4.0 GHz tunable bandpass filter using A YIG film grown by LPE has been developed. A technique for designing a multi-octave YTF has been developed and applied to the filter. Low insertion loss and high spurious suppression have been achieved, and the performance of this filter satisfies the requirements for use as a tracking preselector in a microwave spectrum analyzer. It has been possible for the first time to take the advantage of the very low resonance frequency of YIG film to realize a low-frequency preselector filter.

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