MICROWAVE DEVICES BASED ON MAGNETOSTATIC WAVE REFLECTING ARRAYS

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Abstract

A novel concept for analog signal processing at microwave frequencies is described utilizing magnetostatic wave propagation in reflecting arrays formed on epitaxial YIG. Results for S-band notch filters and resonators together with a non-recursive transversal filter realization are given.

Introduction

Magnetostatic wave propagation in epitaxial yttrium iron garnet (YIG) films yield wavelengths of between 10 μm and 1mm with operating bandwidths up to 2 GHz at microwave frequencies, Fig. 1, and thus advantageously microminiature but readily fabricable device structures. Previous work has concentrated on using these basic propagation characteristics to realize modest performance delay lines and chirp matched filters for analog signal processing requirements.(1) The current work deploys magnetostatic wave propagation in reflecting arrays, similar in concept to those used so successfully with surface acoustic wave (SAW) propagation for resonator-frequency filters and chirp matched filters at I.F. frequencies.(2) Results of initial experiments conducted in this way at microwave frequencies on notch filters and planar resonators are given. A technique for configuring non-recursive transversal filters is described which should allow device realizations of integrated tunable filter banks with individual bandwidths down to 1 MHz and high performance chirp matched filters with bandwidths exceeding 1 GHz.

Notch Filter

The basis of the reflecting array configuration for magnetostatic waves at microwave frequencies is shown in Fig. 2. Regular grooving of the upper surface of the epitaxial YIG film essentially allows transmission line sections of two different characteristic impedances to be cascaded. Then, strong reflection can occur at normal incidence for frequencies where the phase shift per period is an integer multiple 'n' of π.

In the specific experiments with magnetostatic surface waves (MSSW) the reflecting array comprised 20 selectively etched 4mm length grooves, each 1 μm deep and 30 μm wide, and each separated by 120 μm in a 9-μm thick YIG film grown by liquid phase epitaxy on gadolinium gallium garnet (GGG). Two aluminum microstrip transducers, 3mm long by 30 μm wide and 1 cm apart in the direction of propagation, were deposited parallel to the grooves on either side of the reflecting array. The transmission characteristics were measured from 2.5 GHz to 3.5 GHz for a magnetic bias field, applied parallel to the grooves of 380 Oe. Three distrinct notches were evident corresponding to n=1, 2, 3. Notch depths, basewidths and frequency spacings were typically 12 dB, 35 MHz and 175 MHz respectively. Detailed results(3) are in good agreement with theory for a characteristic impedance change between grooved and ungrooved regions of 10%.

One-Port Resonator

A 38 groove array was used. Otherwise the dimensions and magnetic bias field were similar to those of the notch filter experiments. The MSSW transducer position, midway between two centrally located grooves, and the corresponding return loss and Smith Chart displays are shown in Fig. 3. Superimposed on the absorption due to the magnetostatic wave passband are the n=1 and n=2 modes which cause a Fabry-Perot type resonator action. These modes occur at idential frequencies to their counterparts in the notch filter experiments and the basewidths are similar. From the Smith Chart display, mode 2 is identified as a genuine cavity resonance. The experimental unloaded Q for this undercoupled resonator is 550. This value is in good agreement with theory derived earlier for the radiation Q of SAW resonators.(4) In principle, planar MSSW resonators should tune over at least 2 GHz to 12 GHz with low insertion loss, precisely controllable bandshape characteristics and high rejection of spurious modes. Thereby, they could offer performance advantages over YIG multipole filters based on ferromagnetic resonance in spheres.

Non-Recursive Transversal Filter

Potentially a planar non-recursive transversal filter at microwave frequencies is realizable using isotropic magnetostatic forward volume waves (MSFVW, see Fig. 1) obliquely incident on a suitable reflecting structure so that a 90° overall deflection of the wave energy results, as shown in Fig. 4. Reflecting array structures under study for MSFVW include grooves, dielectrically spaced metal overlays, metal dot arrays and magnetization perturbations. Just as in the SAW reflecting array compressor,(2) the dimensions of the reflecting array permit independent amplitude and phase control. However, here the inherent dispersive nature of MSFVW must be taken into account in array design.

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Conclusions

It has been demonstrated here that magnetostatic wave reflecting arrays formed in epitaxial YIG can perform frequency filtering at microwave frequencies. Further development of these concepts should allow the realization of a broad range of prescribed analog signal processing functions on a single chip. These functions include tunable multipole frequency filters and filter banks, tunable high-Q resonators, single mode frequency agile high short-term stability oscillators, and matched filters such as chirp filters exceeding 1 GHz bandwidth with -30 dB time-sidelobes. The operating bounds for these devices in the frequency range 1 GHz to 15 GHz will be geared by magnetostatic wave delays in the range 50 nsec/cm to 1 μsec/cm coupled with their propagation loss of typically 15 dB/μsec at 10 GHz.

References

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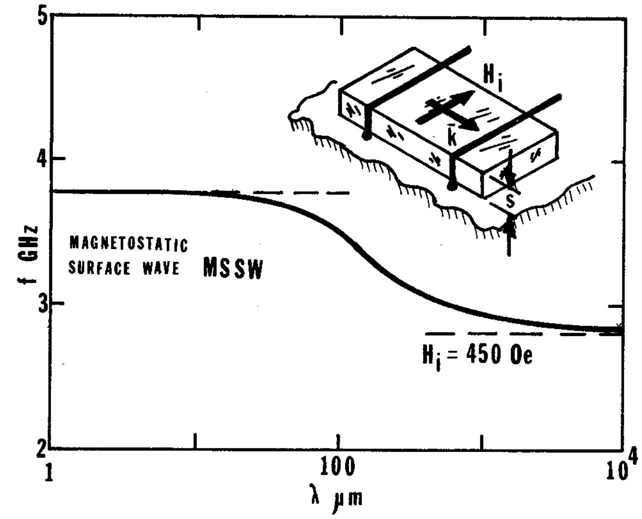
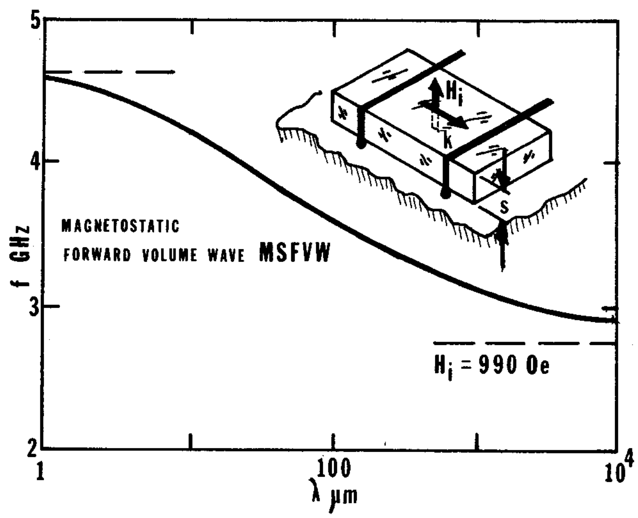
2. R. C. Williamson, Proc. IEEE, 64, pp 702-710 (1976).
3. C. G. Sykes, J. D. Adam and J. H. Collins, Appl. Phys. Letters, 29, pp 388-391 (1976).
4. G. L. Matthaei, B. P. O'Shaughnessy and F. Barman, IEEE Trans. SU-23, pp 99-107 (1976).



Dispersion Relation

$$\exp(2ks) = \frac{(\omega_M/2)^2}{(\omega_o + \frac{\omega_M}{2})^2 - \omega^2}$$



Dispersion Relation

$$\tan\left(\frac{ks}{2b}\right) = \sqrt{\frac{\omega^2 - \omega_o^2}{\omega_o^2 + \omega_o\omega_M - \omega^2}}$$

Parameters: $\omega_o = \gamma H_i$; $\omega_M = \gamma M_s$

$\gamma \sim 2.8$MHz/Oe; $M_s = 1760$ Oe (YIG)

Fig. 1 TYPICAL FREQUENCY - WAVELENGTH DEPENDENCE FOR MSSW AND MSFVW FOR S = 10 μm YIG FILM

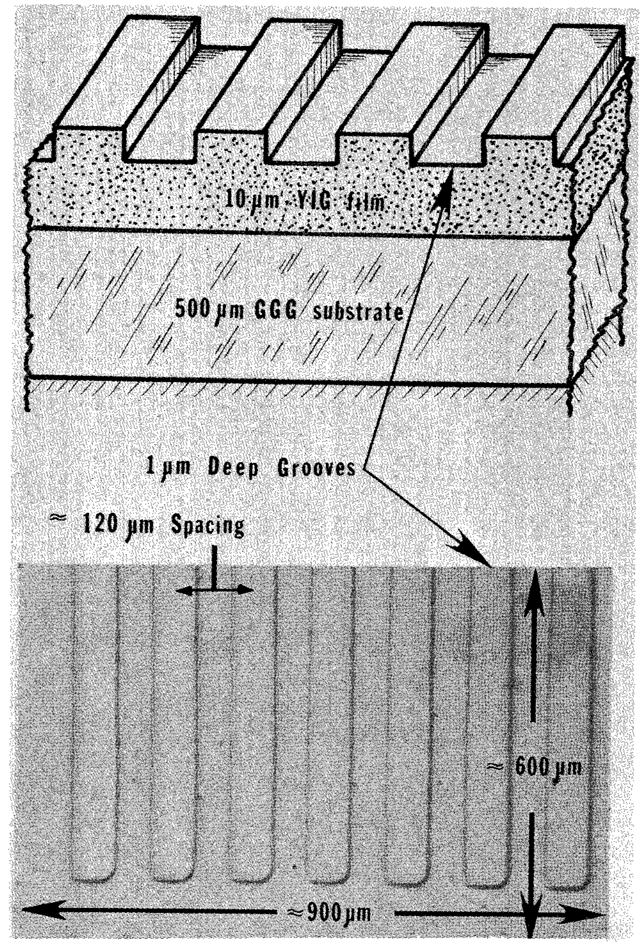
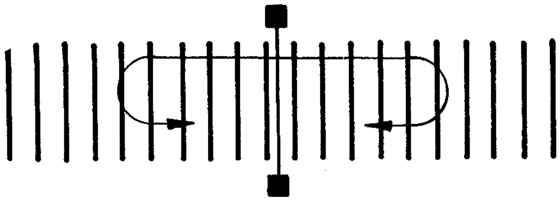
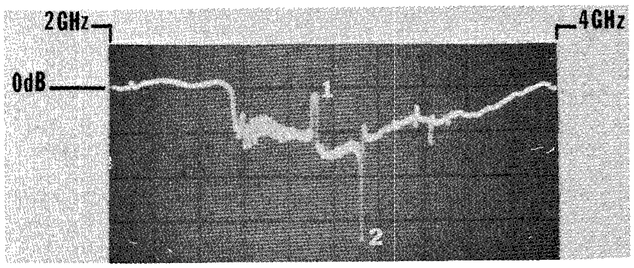


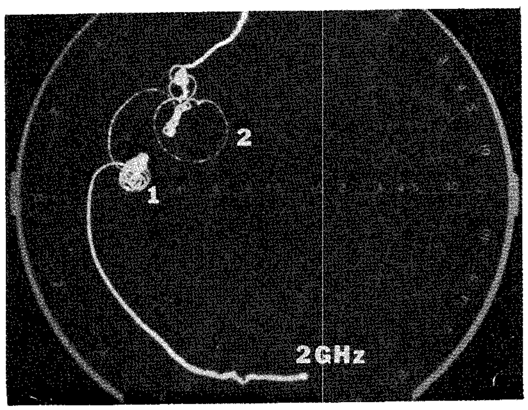
Fig. 2 GROOVED PERIODIC ARRAY IN A 10 μm YIG FILM ON A GGG SUBSTRATE.
PHOTOGRAPH IS A PORTION OF AN ACTUAL 40 GROOVE ARRAY OF TOTAL LENGTH 4.8 mm
DIMENSION SHOWN ARE REPRESENTATIVE



Planar Single Port Resonator



Return Loss, Vertical 2.5 db/CM
Horizontal 200MHz/CM, H_o=390 Oe



Smith Chart of Transducer Input Impedance
Z_o = 50 Ω, f = 2 - 4 GHz, H_o = 390 Oe

Fig. 3 PLANAR SINGLE PORT RESONATOR CHARACTERISTICS

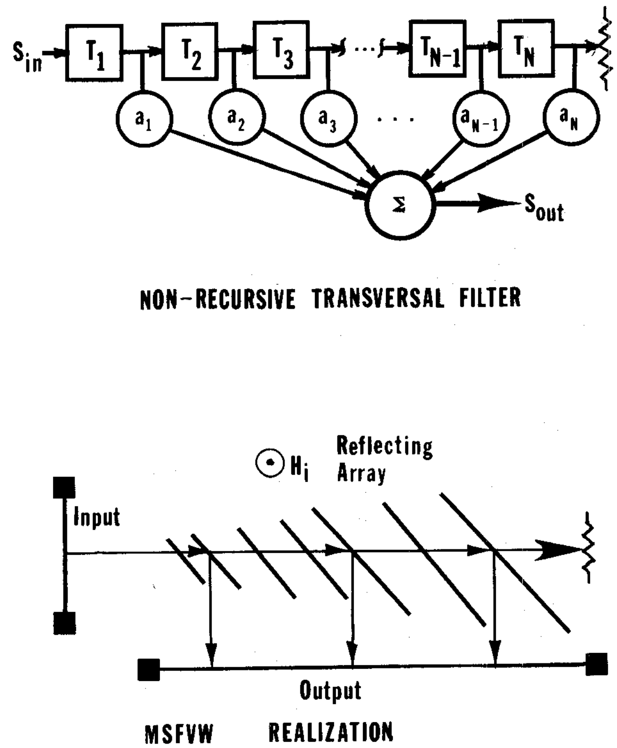


Fig. 4 MSFVW REALIZATION OF MICROWAVE NON-RECURSIVE TRANSVERSAL FILTER