MAGNETOSTATIC WAVE REFLECTIVE ARRAY FILTER

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ABSTRACT

Results from experimental and theoretical studies, carried out in the 3 GHz region in epitaxial YIG, on tunable magnetostatic forward volume wave (MSFVW) oblique incidence reflective array filters are reported. Uniform reflecting gratings consisting of either metal bars or metal dot arrays have been studied as MSFVW reflectors and yield an octave tunable bandpass filter. Width weighting of the bar widths has yielded significant reduction in side lobe levels of these bandpass filters. Initial experiments on double reflection from a pair of 10 element metal bar reflecting arrays has been carried out. A graded 14 element metal bar reflecting array has yielded a constant 100 nsec delay 400 MHz bandwidth linear phase filter with a phase ripple of $\pm 15^{\circ}$ from linear. This is the first reported controlled dispersion MSFVW filter. Initial studies of quadratic phase MSFVW filters are reported.

Introduction

Surface Acoustic Wave (SAW) RAF's (reflective array filters) which operate very effectively in the VHF/UHF range experience significant technical difficulties[1] as the operating frequency is increased above 1GHz and bandwidths greater than 300 MHz are required. In particular, operation above 3 GHz requires submicron device dimensions and the corresponding propagation loss is high. Recently, it has been proposed and demonstrated that quasi-isotropic magnetostatic forward volume waves (MSFVW) propagating in liquid phase epitaxial YIG can be obliquely reflected by arrays similar to those used in SAW RAF's to provide bias field tunable, compact, nonrecursive transversal 'filters' at microwave frequencies (1-20GHz). This technology is achieved without resorting to submicron photolithography.

This paper describes the status of new reflective array filter technology, with similarities to SAW devices, which is based on MSW (magnetostatic wave) propagation in low linewidth ($\Delta H < 0.5$ Oe) thin film YIG grown by liquid phase epitaxy (LPE)[3]. MSW are slow, dispersive, magnetically dominated electromagnetic waves propagating in a magnetically biased ferrite material at microwave frequencies (1-20 GHz). Such MSW propagation in a free ferrite slab has been treated theoretically by Damon and Eschbach,[4] who considered three principal bias field, $\bar{H}_0$, orientations with the wave vector $\bar{k}$, in the plane of the slab. Of particular interest for this work is the magnetostatic forward volume wave (MSFVW) occurring when $\bar{H}_0$ is parallel to $\bar{n}$, the unit normal to the slab surface. The propagation behavior of these MSFVW nominally isotropic in the plane of the film. The MSFVW is characterized by magnetic energy which is distributed transversly across the volume of the film and multiple modes resembling those seen in EM wave propagation between parallel metal plates. The lowest order mode has a single half-sinusoid variation across the film with an exponential decay into the dielectric on either side of the film; the external part of the field permits spatial tapping and transversal filter applications. The lowest order mode dominates MSFVW propagation since it is the mode which is most strongly coupled to the surface microstrip couplers used[5]. The dispersion and delay characteristics of MSFVW are presented in Fig. 1.

As in the SAW case, an MSW RAF consists of an input, output transducer pair which performs limited bandpass shaping and one or more reflective arrays which performs the majority of the transversal filtering. Figure 2 shows a simple single reflection oblique incidence filter schematically. Reflecting arrays utilized thus far consist of either metal bars or dots. Etched groove arrays have proved unusable due to mode conversion to transverse standing spinwave resonances occurring at the etched steps.

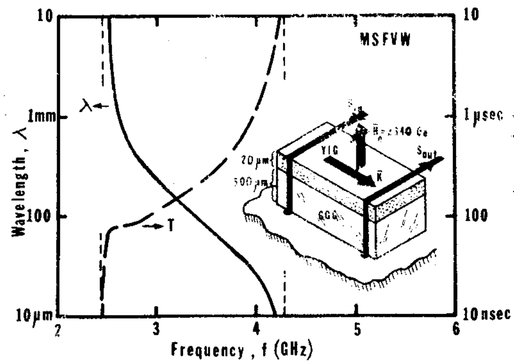

Fig. 1 Dispersion characteristics of MSFVW in a YIG plate with ground plane in close proximity.

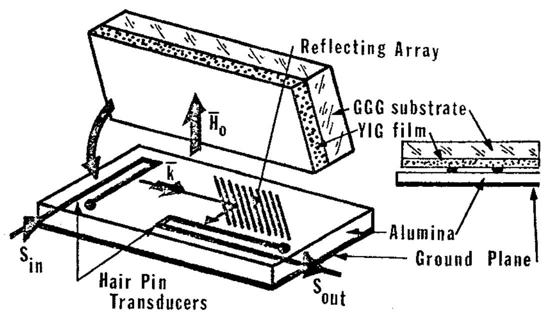

Fig. 2 Schematic of oblique incidence reflective array filter.

conversion to transverse standing spinwave resonances occurring at the etched steps.

The single reflector has been used initially since it is simpler to construct and simplifies analysis. The transducers have in general been single loops with periodicity chosen to maximize transmission at the filter center frequency and minimize generation at long wavelengths (k=0). The filters retain the desirable features of tunability and microwave frequency operation, associated with previous YIG technology, however, as seen in Figure 1, submicron wave lengths are not required and broad bandwidths are possible.

Modeling and Theory

A simple theory for a single 90° oblique incidence reflection N element array transfer function has been developed in the general form

$$H(w) = \sum_{n=1}^{N} R_n \left(\prod_{m=1}^{n-1} T_m \right) e^{-jk\left[x_0+x_n-\left(\sum_{m=1}^{n-1} W_m\right)\right]} \qquad (1)$$

where R_n and T_n are respectively the reflection and transmission coefficients for the n-th array element, k is the propagation wave number in the unmetalized YIG, x_0 is the distance from the array to the output transducer, x_n is the distance from the input transducer to the n-th array element and W_n is the n-th array element width along the incident wave direction. The reflection coefficient is determined as

$$R_n = 2j\rho e^{-j(\frac{KW_n}{4})} \sin(\frac{KW_n}{4}) \quad (2)$$

where $\rho = C(Z_m - Z_o)/(Z_m + Z_o)$. The subscripts m and o denote respectively wave impedances in the metalized and unmetalized YIG regions as defined by Sawado[6] and C is a complex constant determined experimentally. For a uniform grating (i.e., element widths and spacings equal to W) the general transfer function can be reduced to a normalized transfer function

$$H_o(w) = \sin(\frac{KW}{4}) \frac{\sin N(\frac{KW}{2})}{\sin(\frac{KW}{2})} e^{-jK(x_1 - \frac{1}{2}(N-1)W + x_o)} \quad (3)$$

where it is assumed $T_n^N \lessapprox 1$ and

$$T_n^2 = 1 - R_n^2 \quad (4)$$

Experimental Results

The theoretical results for a uniform 14 period array with W=210μm is shown in Fig. 3 with the measured experimental results. Note, that the peak response occurs at an incident wavelength of W the first side lobe is approximately 13db down.

An effective technique for amplitude weighting has been theoretically evaluated and tested experimentally. The technique utilized is width weighting of the metallic reflecting stripes. This technique overcomes the problems associated with apodization when element length weighting is used. Fig. 4 shows the theoretical and experimental response characteristics of an 11 element triangular weighted reflective array. Element width were varied from zero to λ and back to zero across the 11 period array the significant reduction in the side lobe can be seen.

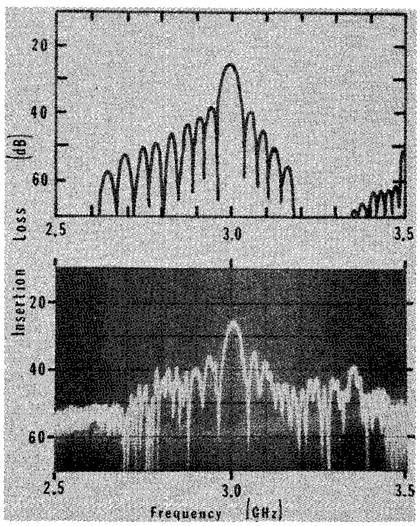

Fig. 3 Theoretical and experimental results of a 14 element uniform reflective array filter.

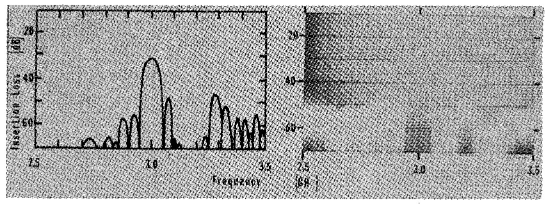

Fig. 4 Theoretical and experimental insertion loss (db) versus frequency (GHz) for 11 element triangle weighted oblique incidence reflective array filter. Transducer effects are included.

A 20 period oblique incidence reflective dot array has been fabricated and experimentally evaluated. The dots were ∿100μm in diameter and were randomly placed along oblique angle lines spaced by 300μm. There were typically 22 dots/line. Input and output was accomplished by orthogonal loop transducers. Insertion loss was 32db with a bandwidth of 40MHz. Side lobes were 14db down from the main peak. Simple theory based on the ratio of the dot array to an equivalent metal line gives a bandwidth in good agreement with theory. This technique offers a simple weighting system applicable to shaped bandpass filters.

The majority of SAW reflective array devices rely on a double reflection from a pair of oblique incidence reflectors. A ten element double reflecting array device is shown in Figure 5, as well as the response of this device with a 16μm thick YIG film. The response of this device is in good agreement with a simple double reflection theory which predicts a 50MHz main lobe bandwidth and insertion loss of 35db.

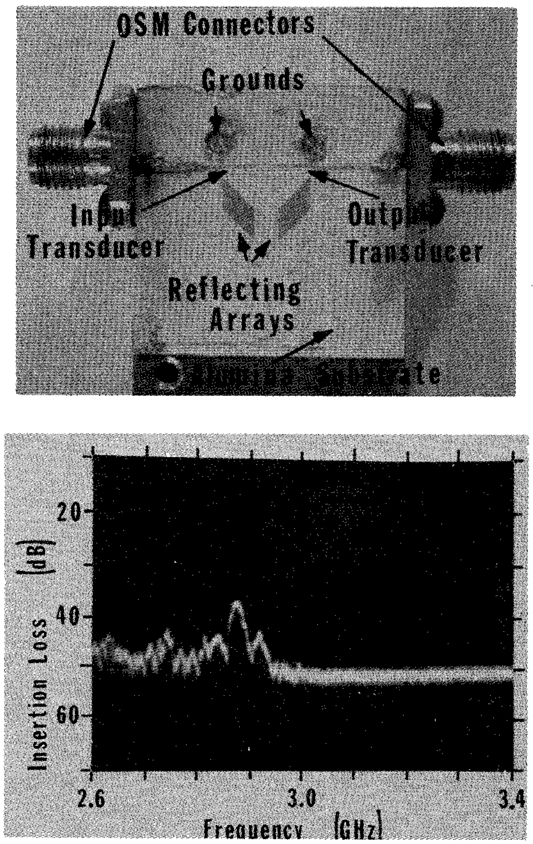

Fig. 5 Double reflective array device (YIG film removed) and insertion loss (db) versus frequency (GHz) for a 16μm film.

As a next step a simple reflecting array has been designed to remove the dispersion from an MSFVW delay line over a limited bandwidth (350Mhz). This array consisted of 14 periods of 4μm thick aluminum reflectors λ wide. Spacing was graded from 600μm to 200μm to remove MSFVW dispersion so producing a linear phase characteristic. There was no amplitude weighting (uniform 3mm aperture reflectors). The experimental configuration is as shown in Fig. 2. The theoretical and experimental insertion loss versus frequency characteristic and the theoretical and experimental group delay compared with that of a conventional 1 cm path MSFVW delay line, are shown in Fig. 6. It can be seen that the insertion loss and group delay characteristics are in good agreement with theory considering the terminations were far from perfect. The phase error from linear was ±15°.

Finally a simple narrow band "UP CHIRP" filter has been fabricated with a differential delay 100nsec. and a bandwidth of 100MHz, and further analysis of this device is under way.

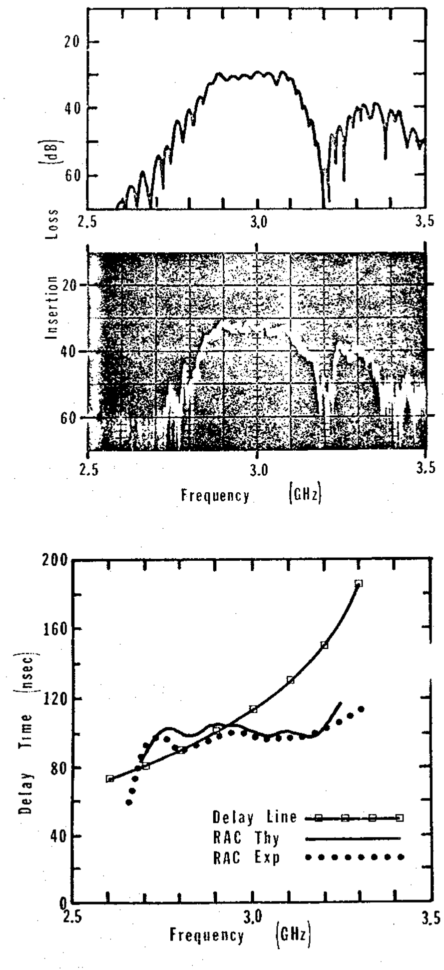

Fig. 6 Theoretical and experimental insertion loss (db) versus frequency (GHz) of a graded periodicity reflective array, and theoretical and experimental group delay (Nsec) versus frequency (GHz) of the graded array compared with that of a 1cm long MSFVW delay line.

Summary and Future Trends

A number of oblique incidence reflective array devices have been designed and evaluated; these include a 400 MHz bandwidth linear phase non-dispersive filter and an amplitude weighted bandpass filter with better than 20db sidelobe levels, and a simple "UP CHIRP" filter has been built. Theoretical calculation have shown that time-bandwidth products of greater than 1000 are possible with this technology.

Thus, MSW device research has taken further significant steps toward providing the basis for sophisticated analog signal processing technology, like SAW, but at microwave frequencies, with the additional advantage of tunability. While problems still remain, further work should continue to be very fruitful.

Acknowledgements

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