THE EFFECTS OF WIDTH MODES IN MAGNETOSTATIC FORWARD VOLUME WAVE PROPAGATION*

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ABSTRACT

Delay line amplitude ripple and out-of-band filter response in magnetostatic forward volume wave devices are shown to be due to the transduction and propagation of width modes, which at low wavenumbers have different phase and group velocities, but at high wavenumbers become degenerate. Various techniques which minimize the effects of width modes are suggested and results obtained on the preferential attenuation of higher order width modes by thin resistive strips are described.

INTRODUCTION

The effects of finite sample width on magnetostatic surface wave propagation has been discussed previously(1, 2) and under certain conditions gives rise to significant changes in wave velocity when compared to propagation in an infinite sample. Similar effects

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are observed with magnetostatic forward volume waves (FVW) and here measurements and calculations performed for FVW propagation in epitaxial YIG samples of different widths are described. The motivation for this study was the observation that FVW delay lines formed from strips of epitaxial YIG always show significantly more undesirable amplitude and delay ripple than is obtained when using only a limited area of a larger sample, e.g. a 1 cm propagation path in the center of a 2.5 cm diameter YIG disc.

DISPERSION

The dispersion relation for FVW propagation in a YIG film of finite width has been derived before$^{(3, 4)}$ and is given by

$$\tan(\beta N d) = \frac{\beta[\tanh(Nt) + 1]}{[\beta^2 - \tanh(Nt)]} \tag{1}$$

where $N = \left[k^2 + \left(\frac{m\pi}{w}\right)^2\right]^{1/2}$ and $\beta^2 = \frac{4\pi M H}{((\omega/\gamma)^2 - H^2)} - 1.$

m is an integer 1, 2, 3 etc. and k is the wavenumber in the direction of propagation, w is the YIG film width, d is the YIG film thickness and t is the spacing of a conducting plane from the YIG film. $4\pi M$, H, ω and γ are the saturation magnetization, internal magnetic field, signal frequency and gyromagnetic ratio respectively. Because the term tan (βNd) in equation 1 is multivalued, higher order thickness modes can result but here only the lowest order thickness mode is assumed.

The roots of the dispersion equation were computed and the variation of wavenumber with frequency for the m = 1, 3 and 5 width modes is shown in Figure 1. The YIG film was 18.3 μm thick, 1 mm wide and spaced from the ground plane by 0.635 mm. The frequency where k = 0 for a FVW in an infinite sample (or m = 0) is 9.002 GHz. Only the odd numbered width modes are shown in Figure 1 since it was assumed that even numbered modes would not be launched to a significant extent owing to the transducer symmetry. The frequency spacing between the m = 1 and m = 3 modes at k = 0 is approximately 140 MHz. m = 5, 7, 9 etc. modes are not shown but do exist and the spacing between adjacent modes slowly decreases with increasing mode number. Narrower samples result in a wider frequency separation and conversely width modes in wider samples have a smaller frequency separation. The corresponding variation in group delay with frequency for a 1 mm wide strip is shown in Figure 2. Note that the delay for each mode tends to infinity when k = 0 and the curves become virtually degenerate at high frequencies.

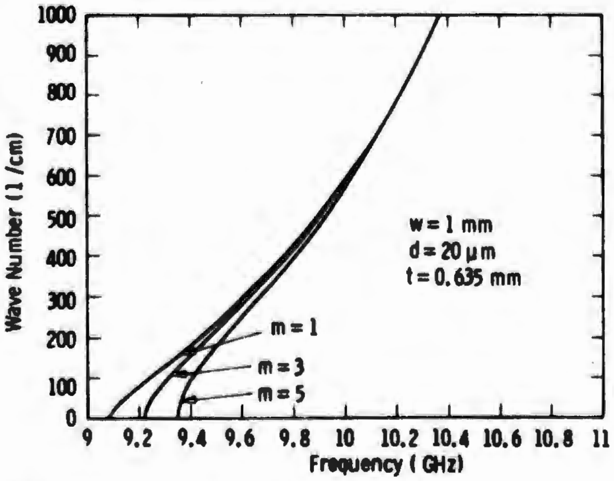


Figure 1. Variation of wavenumber with frequency for width modes m = 1, 3 and 5 in a 1 mm wide and 20 μm thick YIG film.

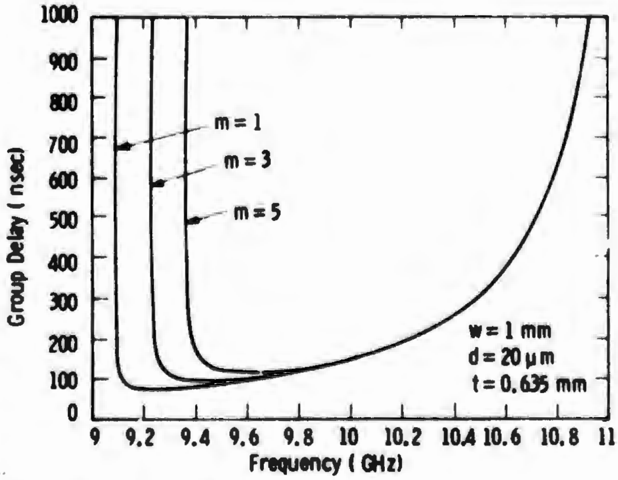
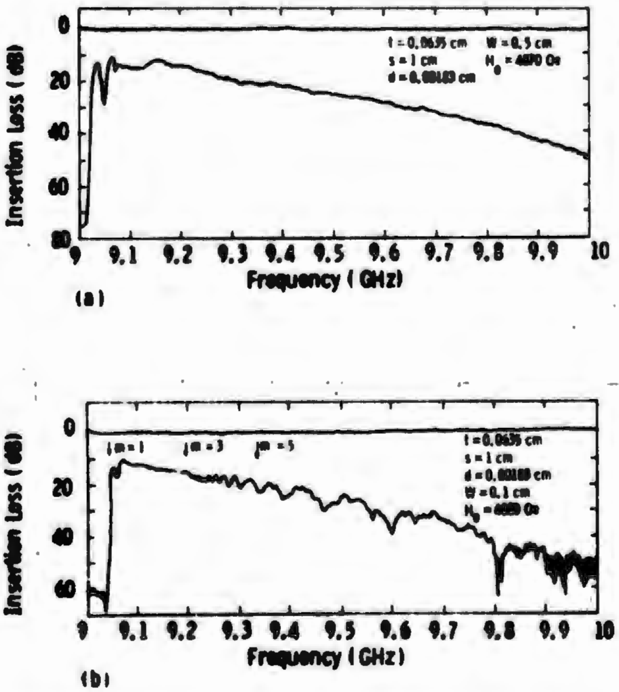


Figure 2. Variation of group delay with frequency for width modes m = 1, 3 and 5 in a 1 mm wide and 20 μm thick YIG film.

RESULTS

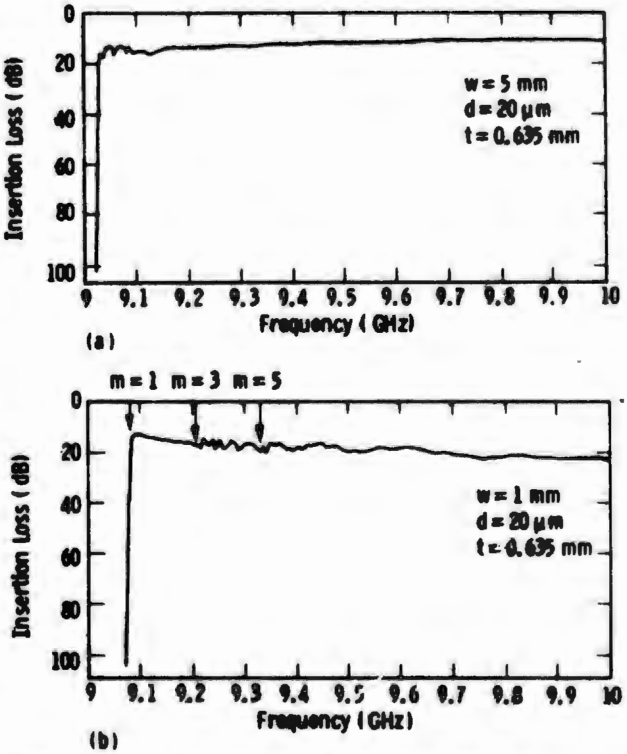
As mentioned earlier, delay lines formed from narrow YIG strips show significantly more ripple than delay lines using wide strips. This is illustrated in Figure 3a and b which shows the measured insertion loss as a function of frequency for YIG films of thickness (d) 18.3 μm and width (w) of 5 mm and 1 mm respectively. The transducers were 5 mm long and 50 μm wide, open circuited at one end and supported on an alumina substrate 0.635 mm thick. Apart from large amplitude ripple below 9.1 GHz, the response of the 5 mm wide delay line is relatively smooth. Results on 4, 3 and 2 mm wide samples of the same thickness showed progressively more severe ripple with a complicated



(a)

(b)

Figure 3. Measured variation of transmission loss with frequency in 18.3 μm thick YIG films: (a) width (W) = 5 mm; (b) width (W) = 1 mm.



(a)

(b)

Figure 4. Calculated variation of insertion loss with frequency in 20 μm thick YIG films: (a) width (W) = 5 mm, (b) width (W) = 1 mm.

structure. However the results on a 1 mm wide sample, Figure 3b, show clearly that the complicated ripple structure is due to interference between different width modes. The calculated low frequency limits for the width modes with m = 1, 3 and 5 are indicated by arrows in Figure 3b.

In order to further confirm that the observed ripple was due to width mode interference, the insertion loss was calculated with the radiation resistance(5) of each width mode weighted by the (Fourier coefficient)^2 of the assumed field distribution of the mode. The current distribution in the microstrip transducer was taken to be uniform along its length. The calculated results for 20 μm thick YIG films of width 5 mm and 1 mm are shown in Figure 4a and b respectively. Only the m = 1, 3 and 5 moves were included in the calculation but the results are in good qualitative agreement with the measurements shown in Figure 3. The most significant discrepancy is the difference in the increase in insertion loss with frequency between the calculated and measured results which is not related to the width modes being discussed here.

Narrow pass band characteristics can be obtained if the transducer is suitably spaced from the YIG film. The measured transmission loss as a function of frequency is shown in Figure 5 for an 18.6 μm thick YIG film, 1 mm wide. The gold transducers were 5 mm long, 0.635 mm wide on 0.635 mm thick alumina. The YIG film was spaced from the transducers by a glass slide 160 μm thick and the bias field was 4880 Oe. Note that a series of pass bands with increasing insertion loss are observed and correspond to the low wavenumber range of the m = 1, 3, 5, etc. width modes. Wider YIG strips yield reduced mode separation and henceoverlap of the pass bands and interference.

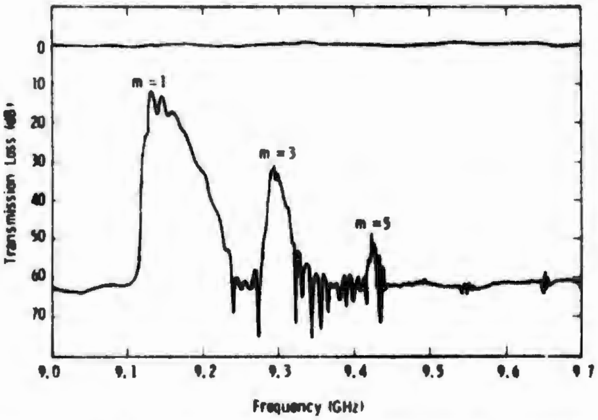


Figure 5. Measured transmission loss as a function of frequency for an 18.6 μm thick YIG film, 1 mm wide. Transducers were 5 mm long 0.635 mm wide on 0.635 mm thick alumina. YIG film spaced 160 μm from transducer and bias field 4880 Oe.

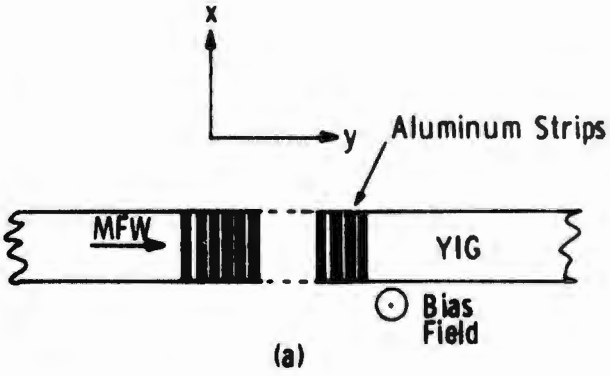


Figure 6. Aluminum strips for preferential attenuation of higher order width modes.

SUPPRESSION

In most applications the presence of width modes other than the lowest mode is not desired. The effects of width modes can be minimized through use of wide samples $\left(\frac{w}{d} > 500\right)$ or by use of absorbing techniques, such as bevelling, on all sample edges. In addition, a transducer current distribution which spatially matches the field distribution of the desired mode should result in preferential transducion of that mode. A further technique has been investigated which preferentially attenuates the higher order width modes. It was found that an array of thin aluminum strips evaporated onto the YIG as shown in Figure 6 were effective in preferentially attenuating the higher order width modes.

It has been shown(6) that the attenuation of FVW by a resistive plane in contact with a YIG film increases rapidly with wavenumber. Thus, the preferential attenuation properties of the aluminum strips can be qualitatively explained if each width mode is considered as having two componentns k_x and k_y. In all modes, providing the aluminum strip period is less than π/k_y, the aluminum strips have an infinite effective resistance and hence zero attenuation for waves directly along the y direction. However for waves directed along the x-direction, the aluminum strips have a finite effective resistivity and will thus attenuate the wave. For width modes, $k_x = \frac{m\pi}{w}$ so that in a 1 mm wide YIG strip, $k_x(m=1) = 10\pi$, $k_x(m=3) = 30\pi$ and $k_x(m=5) = 50\pi$ cm^{-1}. Thus modes with m > 1 are attenuated more than the desired m = 1 mode.

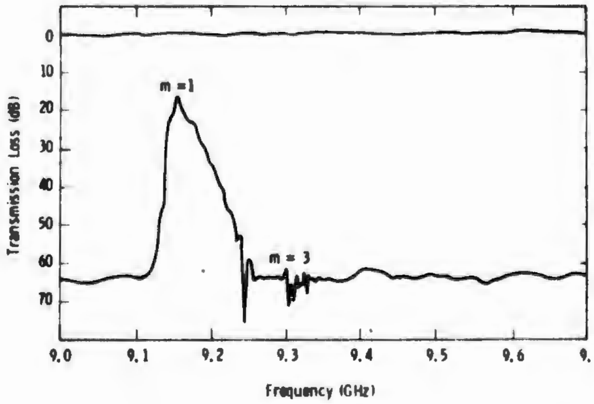


Figure 7. Attenuation of higher order width modes as a function of aluminum thickness. Measured on an 18.5 μm thick YIG film spaced from 0.635 mm wide transducers by 160 μm: (a) 18 strips; (b) continuous film of length equivalent to the strips.

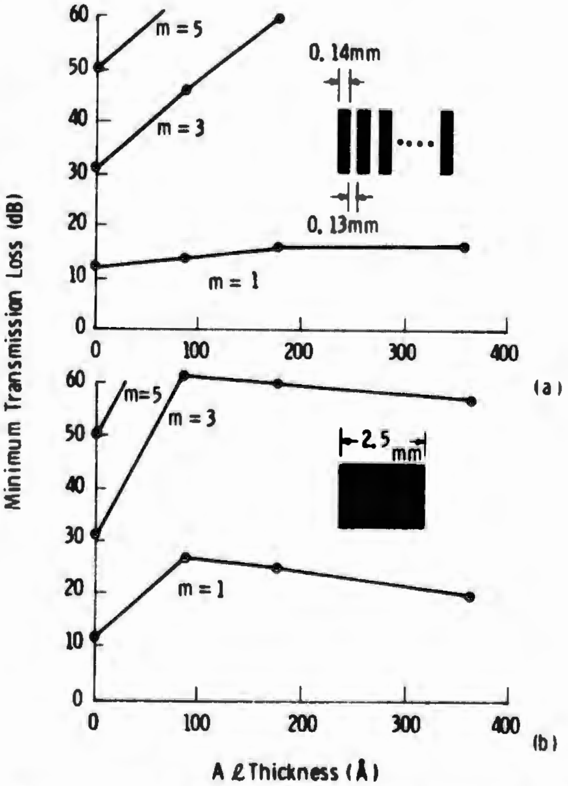


Figure 8. Measured transmission loss as a function of frequency for an 18.5 μm thick YIG film with the same parameters as in Figure 5, but with 18 aluminum strips 364Å thick evaporated onto the surface.

Measurements of the attenuation of the width modes as a function of aluminum thickness were performed using a delay line with the same parameters as Figure 5 and are shown in Figure 7. Aluminum was evaporated onto the YIG film through a shadow mask so as to produce an array of 18 strips, each 0.14 mm wide and separated by 0.13 mm. Viewed as a reflective array, these strips would have a stop band at $k = 150\ \text{cm}^{-1}$ which is well outside the delay line pass band. The minimum transmission loss for FVW propagating under the strips as a function of aluminum thickness is shown in Figure 7a. Note that there is only a slight increase in loss for the $m = 1$ mode but a significant increase for $m = 3$ and 5 modes. For comparison, the minimum transmission loss through a continuous aluminum film of length equivalent to the array of aluminum strips is shown in Figure 7b. Here the $m = 1$ mode as well as the $m = 3$ and $m = 5$ modes experience significantly increased attenuation with increasing aluminum thickness. The transmission loss of a delay line with 18 aluminum strips of thickness 364Å is shown in Figure 8. Other parameters are the same as in Figure 5. Note that the $m = 3$ mode is just visible and is approximately 50 dB below the $m = 1$ transmission peak.

CONCLUSIONS

Delay line amplitude ripple and out of band responses occuring in band pass filters(6) have been identified with higher order FVW width modes. Several techniques are available to minimize the effects of width modes, these include wide YIG samples, absorbing edges on the YIG and preferential transduction using a transducer current distribution which matches the fields of the desired mode. However in many situations space or other requirements may preclude the use of these techniques. Then structures, such as arrays of resistive strips may be used to preferentially attenuate the higher order width modes.

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