MAGNETOSTATIC SURFACE WAVE DELAY LINES

James C. Sethares and Martin R. Stiglitz
Air Force Cambridge Research Laboratories (AFSC)
Laurence G. Hanscom Field, Bedford, Massachusetts 01730

Abstract

Measurements have been made of insertion and propagation loss of MSSW delay lines at microwave frequencies. Loss data are compared with recent theory and the frequency independent MSSW damping parameter λ is calculated to be 0.88×10^4 Hz.

Introduction

For direct signal processing at frequencies above a few GHz, magnetic surface wave devices are now superior to acoustic surface wave (ASW) devices. While operation of ASW devices is well established below 3 GHz, above this frequency their losses become prohibitively large and device operation impossible. Magnetic surface wave devices on the other hand operate well into the X band region to at least 15 GHz. In addition, MSSW devices possess unique features such as non-reciprocity and electronic tunability not possessed by their acoustic counterparts. The practical use of MSSW at high frequencies was recently demonstrated by one of the authors (Sethares) and by Merry[1]. Propagation losses were reduced by a factor of 1000 over the best previously obtained by Adam[2]. This was done by reducing surface losses with optical polishing techniques followed by suitable chemical polishing to remove the Bilbe[3] layer caused by the optical polish. We have subsequently extended this work. Measurements have been made of insertion, coupling, and propagation loss of tunable microwave magnetic delay lines, and we have related our experimental data with the recent theory of Vittoria and Wilsey[4]. Electronically tunable delay lines from 0 to 1.5 μsec in the frequency range 4-12 GHz have been demonstrated. Coupling losses are found to be inherently low - less than 4 dB for one way coupling. Propagation losses were found to be less than 30 dB/μsec over the same frequency range. A comparison of our experimental values of attenuation α(dB/μsec) versus frequency with the theory of Vittoria and Wilsey[4] yields a value of $\lambda = 0.88 \times 10^4$ Hz for their MSSW frequency independent loss parameter. This compares favorably with their estimated value of 1.163×10^4 Hz calculated on the basis of ferromagnetic linewidth alone.

Most of the experiments were performed on 10x2x 0.5mm slabs of single crystal YIG mechanically and chemically polished on both broad surfaces. Crystallographic orientation of the YIG is such that slab edges are [100], [010] and [001] directions. Samples were mounted in a 50 Ohm microstrip module as shown in Figure 1. Microwave absorbent material was placed between the parallel microstrip conductors, 1 mm above the YIG slab, for leakage pulse absorption. The absorbent material is not shown in the figure. Coupling strips are 1.6 x 0.025 mm, the substrate thickness is 1.6 mm and it's relative dielectric constant 10. RF pulses of approximately 150 nsec width were launched at one end and propagated along the long axis of the YIG slab. Slide tuners at the input and output terminals of the microstrip module were employed to maximize rf coupling to the YIG and minimize the leakage pulse (direct rf transmission from input to output conductor of the microstrip lines as seen in the photographs of Fig.2). In the experiments reported here we measured the insertion loss of a pulse delayed 0.4 μsec and the dB/μsec attenuation of the first pulse. From these measurements an upper limit of 4 dB is placed on one way coupling loss. Fig. 2 presents oscillographs of a Magnetic Surface Wave Delay Line at 6.5 GHz. The upper trace of Fig. 2 shows the leakage pulse on the left and 0.7 microseconds later the first detected pulse. The pulse delay was controlled by the dc bias field, which was varied around 1820 Gauss, for a frequency of 6.5 GHz. When the bias field was increased to 1825 Gauss, as shown in the center trace, two additional echoes appeared at the right. The second pulse, 0.6 μsec after launching, had made a complete round trip around the YIG slab and the third pulse, 1.2 μsec after launching had made 2 round trips. By increasing the bias field, more and more echoes appear and "bunching" can be noted, as the time delay of the magnetostatic surface wave modes decreases with increasing bias fields. The delay of the first round trip pulse is twice that of the first pulse.

Since the MSSW travels along the surface only in the $\vec{H} \times \vec{n}$ direction, where $\vec{n}$ is the normal to the slab surface, the MSSW delay line is a unidirectional device where the direction of the wave propagation is determined by the polarity of the biasing field. If it is desired to suppress all echoes and have only the first delayed pulse appear at the output terminal, roughing one of the slab surfaces will accomplish that goal. Insertion losses between 4 and 10 GHz at 0.4 μsec delay were around 25 dB and the attenuation of the first pulse, delayed by decreasing the bias field, was in the range from 20 to 30 dB/μsec. The dc magnetic field increased almost linearly with frequency, for a constant delay of 0.4 μsec, at a rate of 387 Gauss/GHz. At 5 GHz it was 1280 Gauss. In order to maintain a constant delay over a GHz bandwidth requires a change in biasing field of about 400 oersteds.

In Fig. 3 we compare our measurements of propagation loss, α(dB/μsec), as a function of frequency with theory. The solid curve gives the experimental values. As shown by the solid curve, below approximately 4 GHz the attenuation increases rapidly and at about 2 GHz the attenuation is large enough so that no waves are observed. The sharp increase in attenuation below 4 GHz is attributed primarily to domain formation due to incomplete magnetic saturation. Above 4 GHz the loss closely follows the relation $\alpha = Af + \alpha_o$ with $A = 1.2$ (dB/μsec)/GHz and $\alpha_o = 15$ dB/μsec. The dashed line is a plot of Af, that is the frequency dependent part of α; the frequency independent part α_o has been subtracted out of the total propagation loss α. The experimental slope $A = 1.2$ (dB/μsec)/GHz falls between the two theoretical slopes shown in the figure and which are 0.8 and 2.5 (dB/μsec)/GHz for $\Delta H = 0.1$ and 0.3 oe., respectively. According to Vittoria and Wilsey[4] the high frequency slope A is given by Equation 1.

$$A = 4\pi(76.4)\lambda/\gamma^2 M \qquad (1)$$

with γ the gyromagnetic ratio, M the saturation magnetization and λ an empirical MSSW damping parameter which is independent of frequency. Using our data for the slope A we obtain, for YIG a value of 0.88×10^4 Hz for λ. This value compares favorably with a value of 1.163×10^4 Hz deduced by them on the basis of ferromagnetic linewidth alone.

The photographs in Figure 4 are of 4 GHz MSSW pulses on a YIG slab 22 x 5 x 1.2 mm chemically polished on one of the broad surfaces only. The first pulse is the EM direct leakage between input and output lines and the second is the delayed MSSW. In the first photograph there is no delayed pulse. The small pulse after the large one is due to leakage through the switch. For each succeeding photograph the input signal level has been increased in order to show more clearly the delayed pulse. Because only one side is chemically polished multiple echoes are not present. The fraction of energy from the first delayed pulse not picked up by the output line is absorbed on the opposite unpolished side of the YIG slab. When both sides are chemically polished multiple echoes, as shown in the last photo of Fig. 2, are observed. Dispersion is clearly evident for the longer delays. No attempt was made to reduce the dispersion on the delay lines reported here. Such dispersion can be reduced however by employing the techniques described by Bongianni[5].

In conclusion, we have shown that tunable delay lines between 3 and 12 GHz, with as much as 1.5 μsec delay, may be fabricated. Coupling losses are reducible to a few dB and propagation losses of less than 25 dB/μsec are possible. We have successfully related our experimental data with recent theory and shown the theory to be quite accurate.

References

1. J.B. Merry and J.C. Sethares, IEEE Trans.on Mag., Vol. MAG 9, No. 3, Sept. 1973, p. 527.

2. J.D. Adam, "Delay of MSSW in YIG," Electron.Lett., Vol. 6, p. 718 (1970).

3. W.L. Bongianni, D.M. Heinz, L. Needham, "Microwave Filters and Delay Lines," Tech. Report AFAL-TR-73-72, April 1973.

4. C. Vittoria and N.D. Wilsey, "Magnetostatic Wave Propagation Losses in an Anisotropic Insulating Medium," J.A.P., Vol. 45, p. 414, Jan 1974.

5. W.L. Bongianni, "Magnetostatic Propagation in a Dielectric Layered Structure," J.Appl.Phys., Vol. 43, No. 6, June 1972.

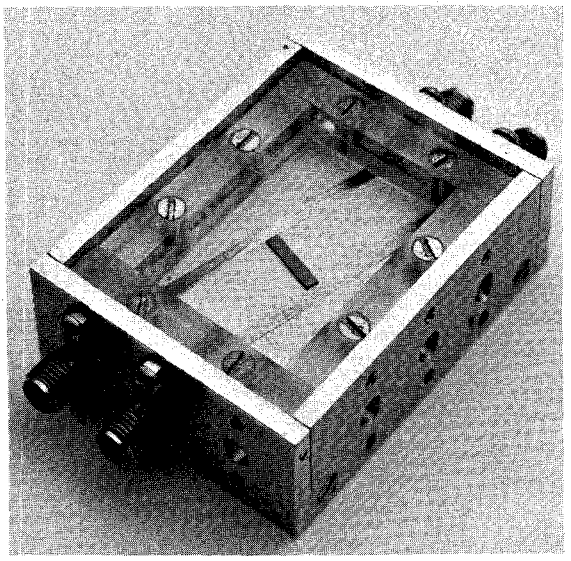

Figure 1 - Photograph of a variable microwave delay line. Overall dimensions are 2.25 x 1.75 x 0.75 inches

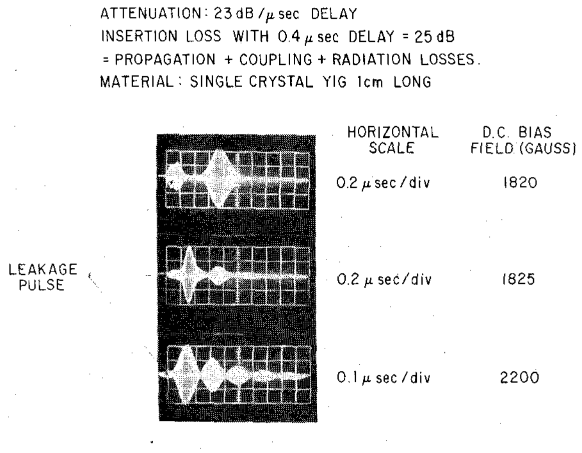

Figure 2 - Output signal of a 6.5 GHz MSSW delay line. Input pulse is 150 nsec in duration, and sample length 1 cm. Propagation loss is 23 dB/μsec and insertion loss, with a .4 μsec delay, is 25 dB.

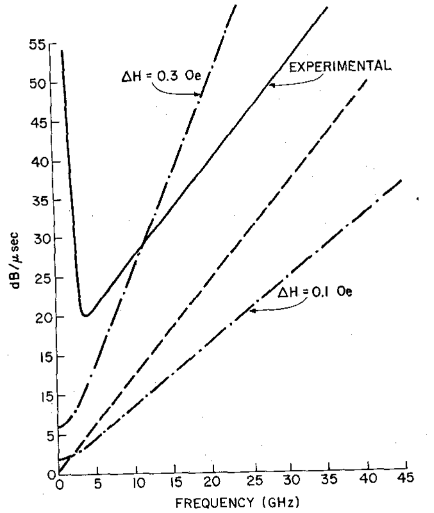

Figure 3 - Propagation loss versus frequency for MSSW's. The solid curve gives experimental values; the broken curves are theoretical. ΔH refers to intrinsic type Kasuya Le-Craw linewidths at X band.

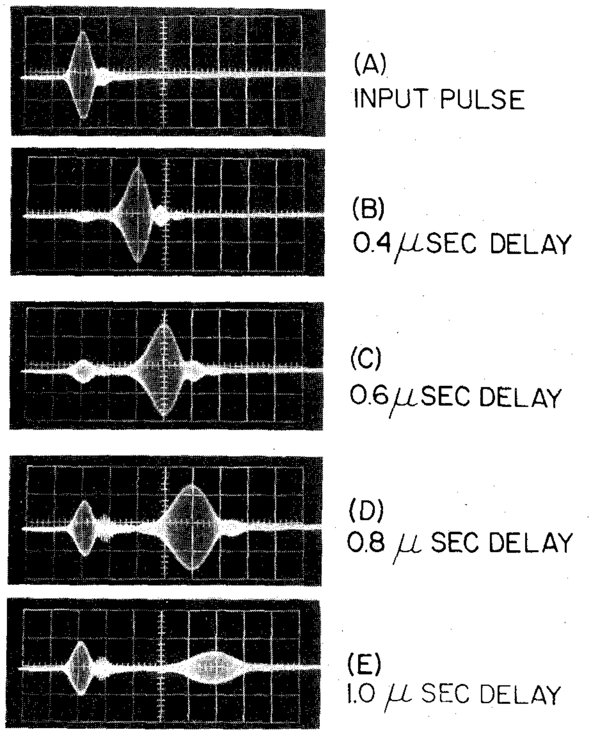

Figure 4 - Delay 4 GHz pulses at different biasing fields and delays. From top to bottom the respective field values are 880, 856, 848, 843 and 841 oersteds. Pulse spreading for the longer time delays is evident. The pulse width at 1 μsec delay is approximately twice the original pulse width.

NOTES