12. Microwave and Quantum Magnetics

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Objective

Our objective is to develop an understanding of magnetostatic and magnetoelastic wave phenomena and to employ them to create novel device concepts useful for microwave signal-processing applications.

One of the primary motivations for exploring the use of magnetostatic waves (MSW) in microwave signal-processing devices arises from the fact that MSW operation at rf frequencies is possible in the range of 1-10 GHz and beyond. This is in marked contrast to the situation with surface acoustic wave (SAW) devices that usually operate on the if signal.

The basic difference between the frequency dispersion of SAW and MSW is depicted in Fig. 12-1 which illustrates the reduction of the elastic wavelength for increasing frequency. Because the Rayleigh wave velocity, V, is on the order of 3×10^5 cm/sec, the wavelengths shrink to submicron size for S-band frequencies and above. This makes fabrication of interdigital transducers with half-wavelength spacing progressively more difficult; moreover, since the wave penetration into the substrate is on the order of λ, imperfections can cause catastrophic deterioration of SAW device performance - even beyond the increased insertion loss expected due to bulk attenuation.

Although the situation is alleviated somewhat by employing a "fast" substrate for which v (and therefore λ) is larger, other material properties may have to be sacrificed and, in any event, piezoelectric materials providing very large increases in v are not available.

In contrast, frequency dispersion of MSW modes of a thin ferrite film can have the form shown in Fig. 12-1, with the intercept $\omega(o) > 0$ tunable by means of a DC magnetic bias. This implies that λ can be adjusted to any convenient value so long as it is small enough to provide magnetostatic slow wave character. The result is that the same MSW transducer can be magnetically tuned to operate at a variety of frequencies in the GHz range.

It should be emphasized that MSW and SAW are complementary rather than competitive technologies. For the former, time delays are typically in the tens to hundreds of nanoseconds but are achievable over gigahertz bandwidths.

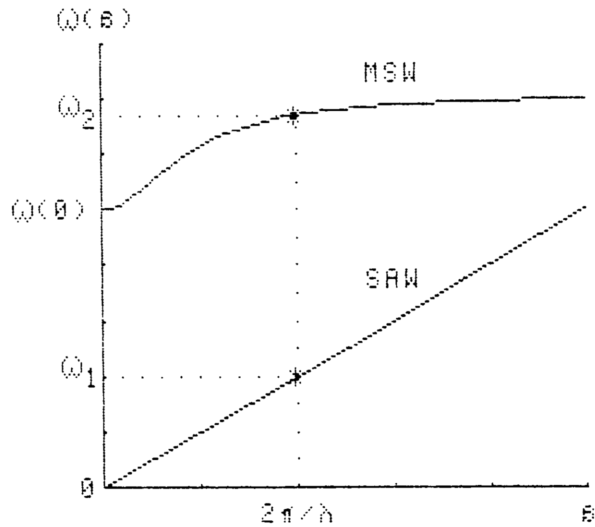

Figure 12-1: Comparison between SAW and MSW normalized frequency dispersion. For a given wavelength λ, the MSW frequency ω_2 can be much higher than the SAW frequency ω_1. Moreover, since $\omega(0)$ depends upon the dc bias, ω is magnetically tunable.

Because of the number of equivalent arithmetic operations per second that a digital computer must perform to match the analog signal-processing capability of a device with bandwidth B and differential delay τ is 40 B $\log_2$ (8Bτ), it follows that MSW and magnetoelastic wave processors can have very high rates. Fig. 12-2 is taken from Sethares' recent overview and makes this point dramatically.[1] The point marked Time Prism Filter represents the performance of a linearly dispersive magnetoelastic wave-delay line that was developed by Morgenthaler and Platzker.[2] The research discussed in Section 12.11 of this report is an outgrowth of that earlier work.

References

1. J.C. Sethares, "Magnetostatic Wave Devices and Applications," 27th Annual Conference on Magnetism and Magnetic Materials, Atlanta, Georgia, November 10-13, 1981, (to be published in JAP March 1982).
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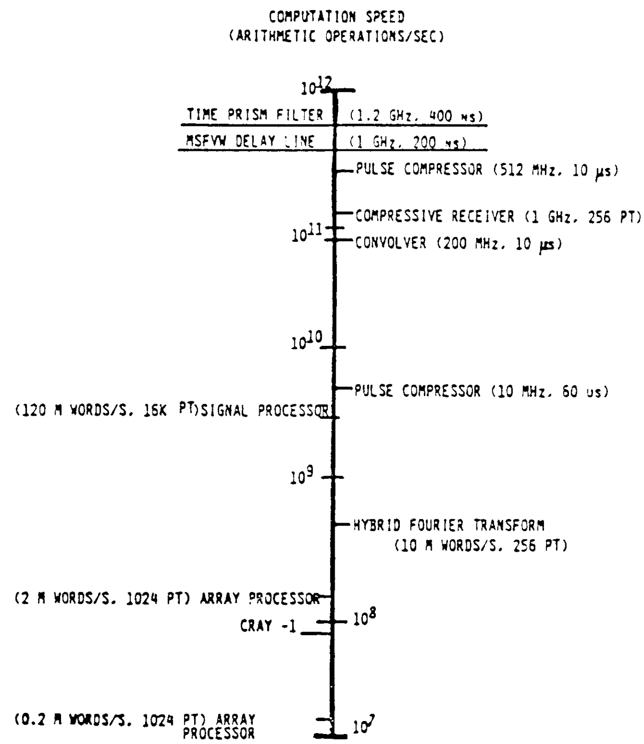

Figure 12-2: Equivalent arithmetic operations provided by various analog signal-processing devices.

12.1 Tutorial Review of MSW

In this tutorial section, we first review magnetostatic plane waves propagating along a ferrite thin film in the shape of a rectangular strip surrounded by air and placed between parallel perfectly conducting ground planes.

In the absence of an applied magnetic field, a ferrite specimen will subdivide into many small domains in which the direction of the moments alternates. The transition regions between oppositely magnetized domains can oscillate at microwave frequencies thereby absorbing power. Such losses can be prevented by applying a DC magnetic field strong enough to wipe out the domain pattern and we assume this has been done. In the magnetically saturated sample, the magnitude of $\bar{M}$ (and hence also the angular momentum density, $\bar{J} = M/\gamma$ [where γ is the gyromagnetic ratio]) is a constant at every point within the material.

The basic equation of motion governing the magnetization in a saturated ferrite is Newton's Law $d\bar{J}/dt = \bar{\tau}$ where $\bar{\tau}$ is the total torque density composed of the electromagnetic part $\tau_{em} = \mu_o \bar{M} \times H$ and a material part τ_m arising from interactions between the magnetic moments (exchange) as well as those involving the lattice (anisotropy, and magnetic loss). Since the spacing between moments is fixed and only the spin direction can change, $\bar{\tau}_m$ can be written as $\mu_o \bar{M} \times \bar{H}^m$ and with $\bar{H}^E - \bar{H} + \bar{H}^m$,

$$\frac{\partial \overline{M}}{\partial \tau} = \gamma \mu_o \overline{M} x \overline{H}^E \tag{1}$$

In the following, we set $\overline{\tau}_m = 0$ for simplicity. This is a valid approximation when the magnetic losses and anisotropy are small and the perturbation from equilibrium are waves for which exchange effects are negligible. The fields are described by Eq. I together with Maxwell's equations.

The DC magnetic field within the ferrite is assumed to be $\overline{H}_o = \overline{i}_z H_z$; the magnetization vector in static equilibrium $\overline{M}_o = \overline{i}_z M$. When deviations from equilibrium occur, there exist in addition small-signal fields $\overline{m}, \overline{h}, \overline{e}$.

Substitution into Eq. I and the neglect of m x h yields

$$\frac{\partial m}{\partial t} = \overline{i}_z \; x \; (\omega_z \overline{m} - \omega_M \overline{h}) \tag{2}$$

where $\omega_z = -\gamma \mu_o H_z > 0$ and $\omega_M = -\gamma \mu_o M > 0$.

Notice that if $\overline{h} = 0$ (no electromagnetic coupling), Eq. 2 has the simple solution

$$\overline{m} = m_o[i_x \cos(\omega_z t + \phi) + \overline{i}_y \sin(\omega_z t + \phi)] \tag{3}$$

where ϕ can be an arbitrary function of position. Because of the characteristic precession frequency, one might expect a resonant response from the material whenever an applied rf excitation occurs at the frequency ω_z. The actual situation is more complicated because an applied $\overline{h}$ field in general causes the material to produce a reaction field that shifts the resonance frequency. However, to a first approximation, such responses depend only weakly upon wave length but strongly on both the value of the dc bias field and direction of propagation. The value of ω_z corresponds to a frequency of 2.8 MHz/Oe.

Equation 2 implies that circularly-polarized components of $\overline{m}$ and $\overline{h}$ are linearly related by scaler magnetic susceptibilities $m^+ = \chi^{\pm} h^{\pm}$ where

$$m^{\pm} = \frac{1}{2}(m_x \pm j m_y), \qquad h^{\pm} = \frac{1}{2}(h_x \pm j h_y), \qquad \chi^{\pm} = \frac{1}{Z \pm \Omega},$$

and we have defined dimensionless quantities $Z = \omega_z/\omega_M$ and $\Omega = \omega/\omega_M$.

It is often convenient to utilize two alternate susceptibilities, χ and κ, defined by $\chi = 1/2 \; (\chi^+ + \chi^-)$ and $\kappa = 1/2 \; (\chi^+ - \chi^-)$.

Whenever the propagation constant $\overline{\gamma}$ of a plane wave at frequency ω satisfies either $|\overline{\gamma} \cdot \overline{\gamma}| \gg \omega^2 \varepsilon \mu_o$ or $\ll \omega^2 \varepsilon \omega_o$, $\nabla \; x \; h = \omega^2 \varepsilon \mu_o (\overline{\gamma} x \overline{m})/(\overline{\gamma} \cdot \overline{\gamma} + \omega^2 \varepsilon \mu_o)$ is small. The magnetostatic approximation defined by setting $\nabla x h = 0$, is then valid and $\overline{h} \simeq -\nabla \psi$ where ψ is the rf magnetostatic potential. Although the electric field energy contribution $(1/2 \; \varepsilon |\overline{e}|^2)$ to the wave energy density is negligible, it should be recognized that the wave power flux remains given by $\overline{e} \times \overline{h}$

and is in general nonzero.

For a uniform dc bias field along z, the magnetostatic potential ψ satisfies Walker's Equation,

$$(1+X)\left(\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}\right)+\frac{\partial^2\psi}{\partial z^2}=0 \tag{4}$$

In the air regions immediately outside the ferrite, $\chi = 0$ and Eq. 4 reduces to Laplace's Equation.

From Eq. 4 [which reduces to $(1+X)(\gamma_x^2+\gamma_y^2)+\gamma_z^2-0$] the normalized frequency of a single magnetostatic wave is therefore

$$\Omega^2 = Z^2 + Z\frac{\gamma_x^2+\gamma_y^2}{\gamma_x^2+\gamma_y^2+\gamma_z^2} \tag{5}$$

For a uniform plane wave. $\bar{\gamma} = j\bar{\beta}$ and Eq. 5 can be expressed as $\Omega = Z^2 + Z\sin^2\theta$ where θ is the angle between $\bar{\beta}$ and the z-axis. The normalized frequency is therefore strongly dependent upon the direction of propagation but not upon the magnitude of $\bar{\beta}$. We next consider the effect of transverse boundary conditions on MSW propagation.[1]

Magnetostatic Forward Volume Waves (MSFVW)

For the Fig. 12.3 geometries (with $x_1 = x, x_2 = y, x_3 = z$) and neglecting width variations

$\gamma_x = 0, \quad \gamma_y = j\beta, \quad \gamma_z = \pm jk_z.$

Therefore from Eq. 5,

$$\Omega^2 = Z^2 + Z\frac{\beta^2}{\beta^2+k_z^2}. \tag{6}$$

A pair of such propagating waves with opposite values of k_z creates a standing wave along z that satisfies the boundary condition at the film surfaces $z = +d/2$, provided

$$\beta \tanh \beta D = k_z \begin{cases} \tan\frac{k_z d}{2} & \text{(even)} \\ -\cot\frac{k_z d}{2} & \text{(even)} \end{cases} \tag{7}$$

The potential is either an even or odd function of z. When $D = 0$, $k_z = p\pi/d$ with $p = 0, 1, 2, \ldots$.

These modes (shown plotted in Fig. 12-4a for the case $D = \infty$, $Z = 1$) are termed forward volume waves because they all have positive group velocities, trigonometric thickness variations and lie within the volume wave manifold

$$Z \leq \Omega \leq \sqrt{Z(Z+1)}.$$

For the lowest order even mode without ground planes, the dispersion for $\beta d \ll 1$ is approximately $\Omega \simeq 1/4 \ \beta d$. Therefore the group velocity is given by $v_g = \omega_M \frac{\partial \Omega}{\partial \beta} \simeq \frac{1}{4}\omega M d$

and is controlled by the product of saturation magnetization and film thickness. (For a 10 μm YIG film, $v_g \simeq 8 \times 10^6$ cm/sec).

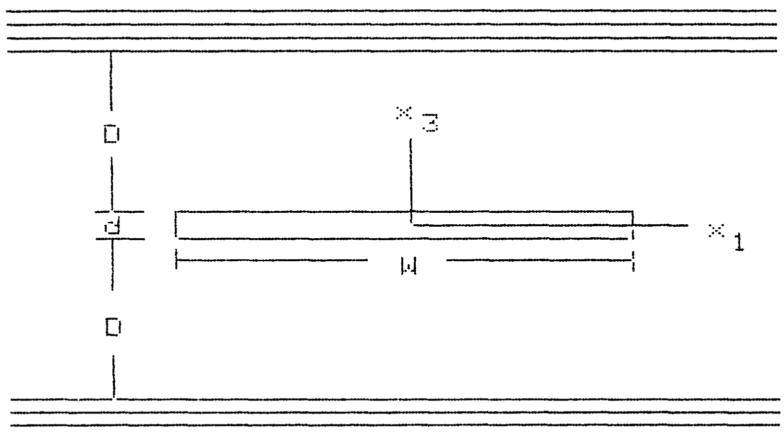

Figure 12-3: Transverse section of a thin ferrite strip placed between ground planes. Longitudinal propagation of MSFVW, MSBVW, and MSSW results when, respectively, the dc bias is parallel to the x_3, x_2, x_1 axis.

Magnetostatic Backward Volume Waves (MSBVW)

For the Fig. 12-3 geometry (with $x_1 = x$, $x_2 = -z$, $x_3 = y$), again neglecting width variations

$$\gamma_x = 0, \qquad \gamma_y = \pm j k_y, \qquad \gamma_z = j\beta.$$

Therefore, from Eq. 5,

$$\Omega^2 = Z^2 + Z \frac{k_y^2}{k_y^2 + \beta^2} \tag{8}$$

A pair of waves propagating with opposite values of k_y creates a standing wave along y that satisfies the boundary conditions at the film surfaces, $y = \pm d/2$, provided

$$\beta \tanh \beta D = k_y \begin{cases} -\cot\left(\frac{k_y d}{2}\right) & \text{even} \\ \tan\left(\frac{k_y d}{2}\right) & \text{odd} \end{cases} \tag{9}$$

The potential is either an even or odd function of z. When D = 0, $k_z = p\pi/d$ with p = 0, 1, 2, ...

The modes shown plotted in Fig. 12-4b for the case D = ∞ , Z = 1, are termed backward volume waves because they have negative group velocities, trigonometric thickness variations and lie within the volume wave manifold.

Magnetostatic Surface Waves (MSSW)

For the Fig. 12-3 geometry (with $x_1 = z$, $x_2 = y$, $x_3 = -x$) and still neglecting width variations, $\gamma_z = 0$ and $\gamma_y = j\beta$.

From Eq. 5, it appears that $\Omega^2 = Z(Z+1)$ independent of γ_x and β. For volume waves this is true because $\gamma_x = jk_x$ and $-\gamma_x^2+\beta^2 > 0$. However, for nonuniform plane waves satisfying $\gamma_x = \beta$, Eq. 5 is indeterminate, and we must proceed differently.

The result is surface wave propagation at the normalized frequency.

$$\Omega^2 = Z^2 + \frac{2Z(1+\tanh|\beta|D)+1-[2Z(1-\tanh|\beta|D)+1]e^{-2|\beta|d}}{(1+\tanh|\beta|D)^2-(1-\tanh|\beta|D)^2 e^{-Z|\beta|d}} \quad (10)$$

For D = ∞, Eq. 10 reduces to

$$\Omega = \sqrt{\left(Z+\frac{1}{2}\right)^2 - \frac{1}{4}e^{-2|\beta|d}} \quad (11)$$

The MSSW dispersion is shown plotted in Fig. 12-4c for the case d/D = 0, Z = 1.

For $|\beta|d \ll 1$, the frequency is approximately $\Omega \sim \sqrt{Z(Z+1)}$ and the mode is uniformly distributed over the film thickness. For increasing $|\beta|$d, the frequency rises and the mode becomes increasingly localized on one of the two surfaces; the left most one for $\beta < 0$, the right most for $\beta > 0$. When $|\beta|d \ll 1$, the mode frequency approaches the value Z + 1/2 which implies $\mu^+ = -\mu_0$. For D = 0, the rf flux normal to the film is excluded ($\bar{h} = -\bar{m}$), and $\Omega = Z + 1$.

The MSSW mode potentials for the case D = ∞ are sketched in Fig. 12-5 for opposite directions of propagation. The localization, which is stronger for increasing $|\beta|$ d, occurs on the surface for which the mode has the largest positive-circularly-polarized component. Such field displacement nonreciprocity provides the underlying basis for many nonreciprocal devices, including Y-circulators. These cases can be shown to be closely related to mode resonances propagating circumferentially around a spheroid which may take the limiting shapes of cylinder, a thin film disk. This connection between MSSW propagation in a rectangular thin film and magnetic resonance in a small cylinder or sphere is emphasized because it provides a key to understanding the manner in which nonuniform bias fields can alter and hence control the frequency dispersion of MSW.[2]

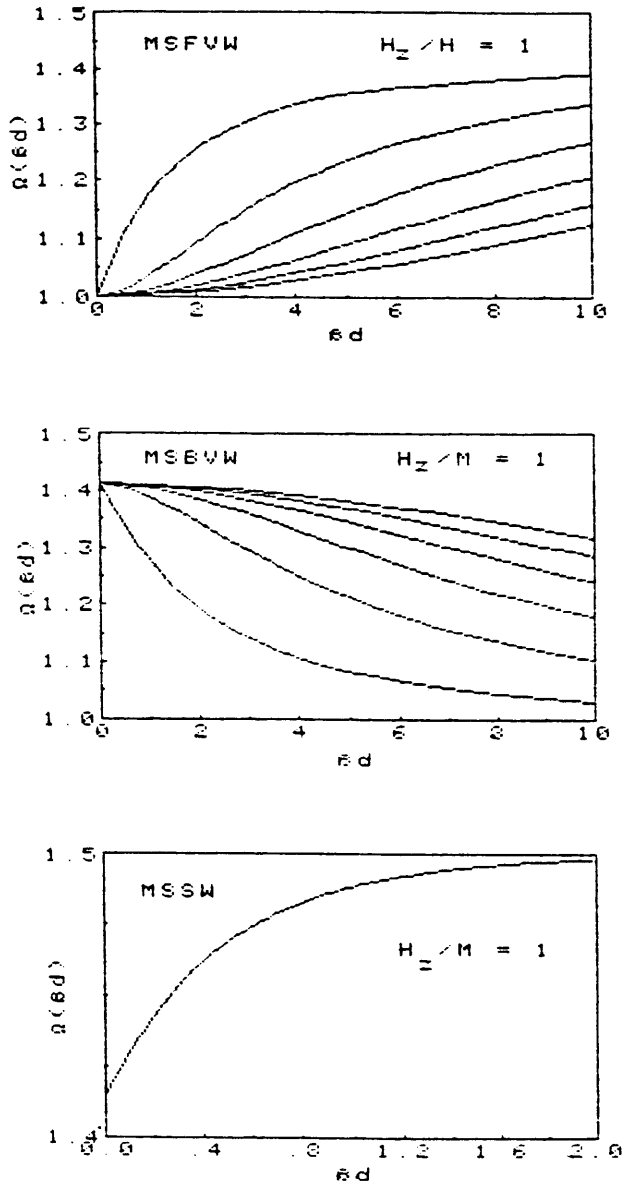

Figure 12-4: Normalized MSW$_l$ frequency dispersion for the geometry of Figure 12.2 when the dc magnetic bias is oriented parallel to (a) x_3, (b) x_2, and (c)x_1 axis. The respective modes are termed MSFVW, MSBVW, and MSSW.

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1. R.W. Damon and H. van der Vaart, "Propagation of Magnetostatic Spinwaves at Microwave Frequencies in a Normally-Magnetized Disk," J. Appl. Phys. 36, 34-53 (1965).
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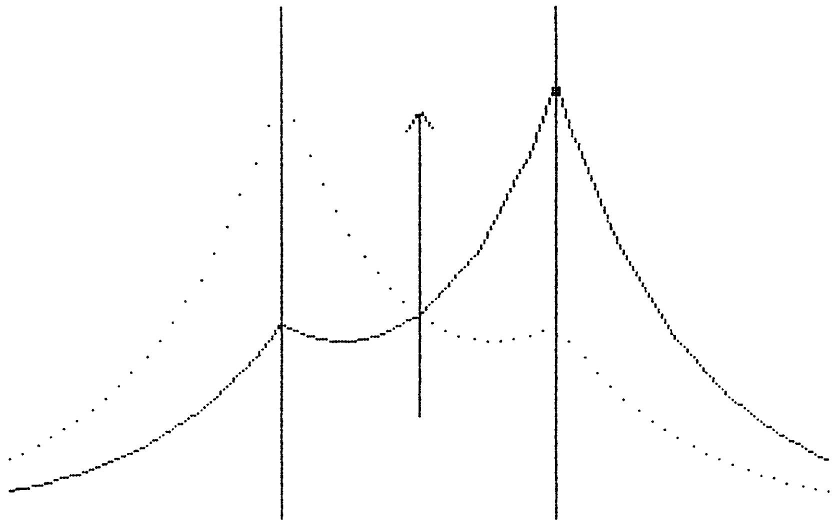

Figure 12-5: MSSW mode potentials of a finite slab for opposite directions of propagation. Localization occures near the surface for which the mode is more nearly positive-circularly polarized and is termed field-displacement nonreciprocity. The solid curve is for β out of the paper.

12.2 Magnetostatic Modes Bound by DC Field Gradients

Joint Services Electronics Program (Contract DAAG29-80-C-0104)
National Science Foundation (Grant 8008628-DAR)
Frederic R. Morgenthaler, Robert L. Kyhl, Tushar Bhattacharjee, Dale Zeskind, Daniel D. Stancil

The Ph.D. Thesis of Daniel Stancil titled "Effects of Nonuniform Fields on Magnetostatic Waves in Ferrite Thin films," has been completed. The abstract follows:

Magnetostatic waves in thin ferrite films have been studied extensively in recent years because of the possibility of their use in a new class of microwave signal processing devices. In this thesis, we concentrate primarily on the effects of nonuniform fields on magnetostatic wave propagation.

First, the effects of the quantum mechanical exchange interaction in a nonuniformly magnetized film between conducting plates is studied. The bias field is taken to be normal to the film plane. A mathematical method is described which, under certain circumstances, permits closed form solutions including both exchange and dipolar interactions to be found. These are believed to be the first exact, closed form solutions including both interactions to be reported.

Second, the effects of nonuniform in-plane fields on surface waves are studied both theoretically and experimentally. Experiments are reported which investigate the effects of nonuniform in-plane fields on the dispersion of surface waves propagating along straight paths. In addition, experiments are described in which gradients are used to guide surface waves through a turn of 160°. This is the first time the ability to guide surface waves through large angles has been demonstrated.

Finally, the first theoretical and experimental discussions of magnetostatic wave precursors in thin films are presented. The theory is general enough to describe single mode transients in both uniform and nonuniform fields, if the dispersion relation is known.

Guiding a magnetostatic surface wave (MSSW) around a bend is complicated when the in-plane bias is uniform and is complicated by mode conversion to backward volume waves, but it has proved possible to overcome this difficulty by employing gradients that arise from a change in the direction of the bias field.[1,2]

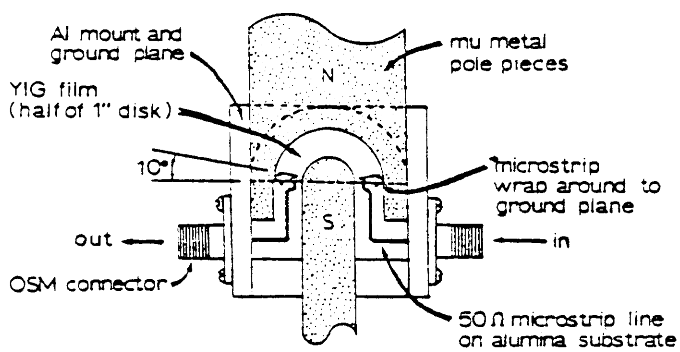

Figure 12-6: Geometry of curved-path experiment

The geometry used to investigate guiding a surface wave through a turn of 160° is shown in Fig. 12-6. The 4.5 μmeter thick YIG film is in the shape of a half disk one inch in diameter.

The inner radius of the channel of ~.4 cm and the outer radius is ~.9 cm resulting in a channel width of ~.5 cm, and a mean radius of ~.6 cm. The mean circumferential path between antennas is ~1.8 cm.

The transmission characteristics are shown in Fig. 12-7. Since the YIG exists beneath the mu-metal as well as in the channel, other propagation paths than the channel are conceivable, though unlikely, due to the change in field direction. In order to verify that the signal was indeed propagating around the curved path, the wave was probed using a small induction loop at several points along the path. In addition to verifying the presence of the wave at various points along the path, the loop was used to determine the local direction of the k vector. This was done by making use of the fact that the loop is most sensitive to k vectors directed normal to its plane; hence the direction of k-can be approximately determined by rotating the loop. The results of these measurements strongly support the waveguide interpretation. The curved path experiment is believed to be the first demonstration of the ability to guide MSSW's.

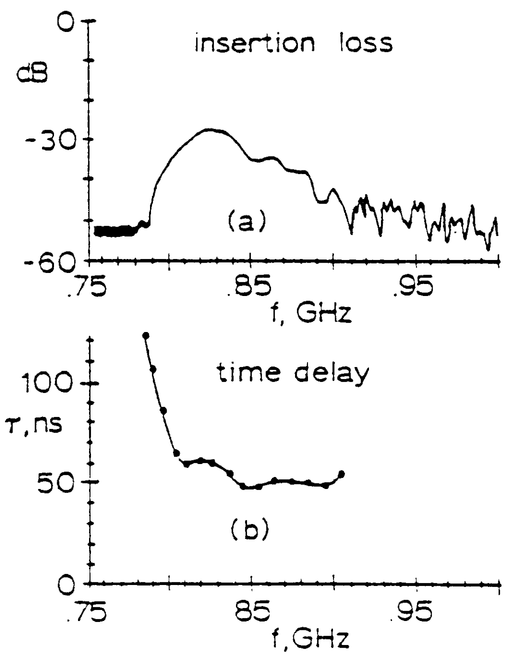

Figure 12-7: Transmission characteristics of curved-path delay line

References

1. D.D. Stancil and F.R. Morgenthaler, "Guiding Magnetostatic Surface Waves With Nonuniform In-plane Fields," Microwave Magnetics Technology Workshop, Hanscom Air Force Base, Bedford, Massachusetts, June 1981.
2. F.R. Morgenthaler, "Field Gradient Control of Magnetostatic Waves for Microwave Signal Processing Applications," Microwave Magnetics Technology Workshop, Hanscom Air Force Base, Bedford, Massachusetts, June 1981.

12.3 Optical and Inductive Probing of Magnetostatic Resonances

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

Nickolas P. Vlannes, Frederic R. Morgenthaler

The doctoral thesis of N.P. Vlannes will attempt optical detection of localized magnetostatic resonances in thin LPE films of YIG. At infrared frequencies, the magneto-optical response of YIG can be modeled by a dielectric tensor that is dependent upon magnetization; thus one can probe for the characteristics of the magnetization.

A magnetic induction probe is also being developed to examine magnetostatic wave characteristics propagating in ferrite materials. The probe senses the rf magnetic field of a magnetostatic wave that fringes from the surface of the material that supports the magnetostatic wave. The probe consists of a metal loop made either manually from 25 μm diameter gold wire, Fig. 12-8a, or photolithographically from aluminum deposited on glass, Fig. 12-8b.

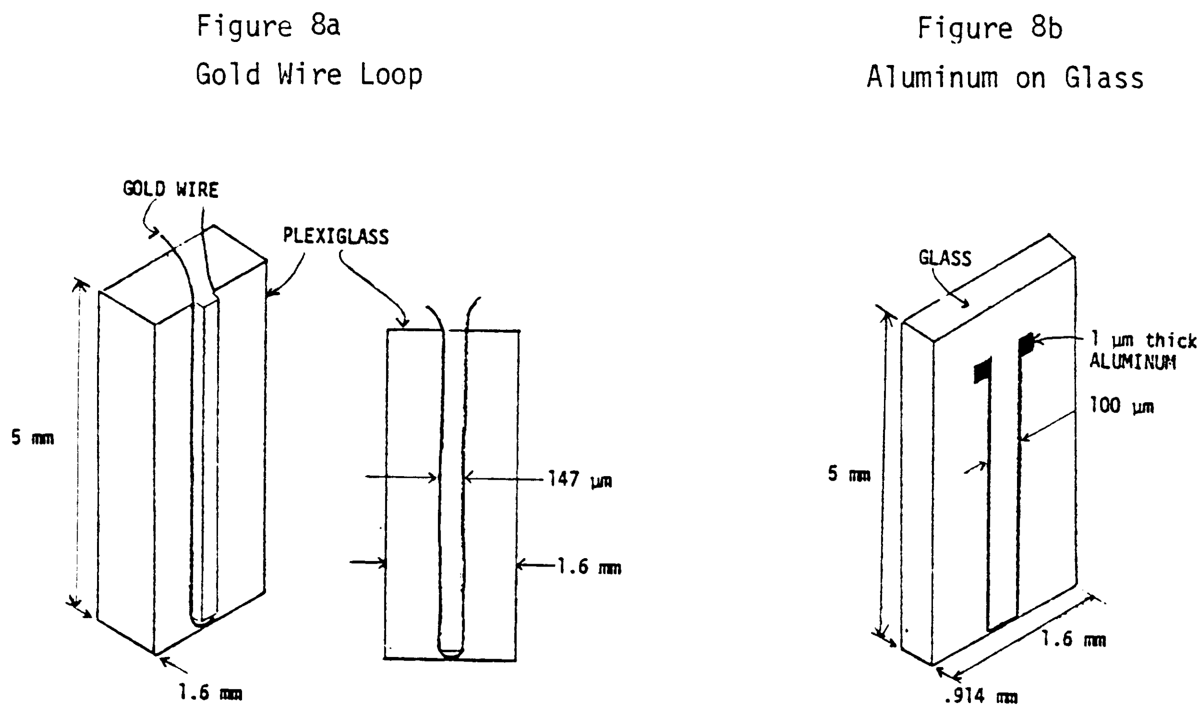

Figure 12-8: Probe tips of induction probe

Loop sizes of 147 μm width were made using the gold wire, and 100 μm to 25 μm width using the photolithography. Figure 12-8 illustrates the loop designs of the two methods. The loop and its supporting structure are referred to as the probe tip. The loop is attached to a semi-rigid coaxial cable which is then connected to external signal processing equipment. Rotation and translation stages are used to properly position the probe on the surface of the sample to be examined. A schematic of the probe is illustrated in Fig. 12-9. One prototype probe has been built to investigate the feasibility of the induction probe, and then to examine the profiles of magnetostatic surface waves (MSSW) in LPE-YIG thin films, Fig. 12-10. Measurements were conducted using pulsed microwave signals in order to differentiate between electromagnetic feedthrough from the launching antenna and the MSSW signal. Figure 12-11 illustrates the profile of an MSSW as viewed looking in the direction of propagation. Early work with the prototype probe demonstrated the general probe concept and provided experience in using the probe. Presently under construction is a more accurate probe to be used in examining magnetostatic wave propagation in uniform and nonuniform bias fields.

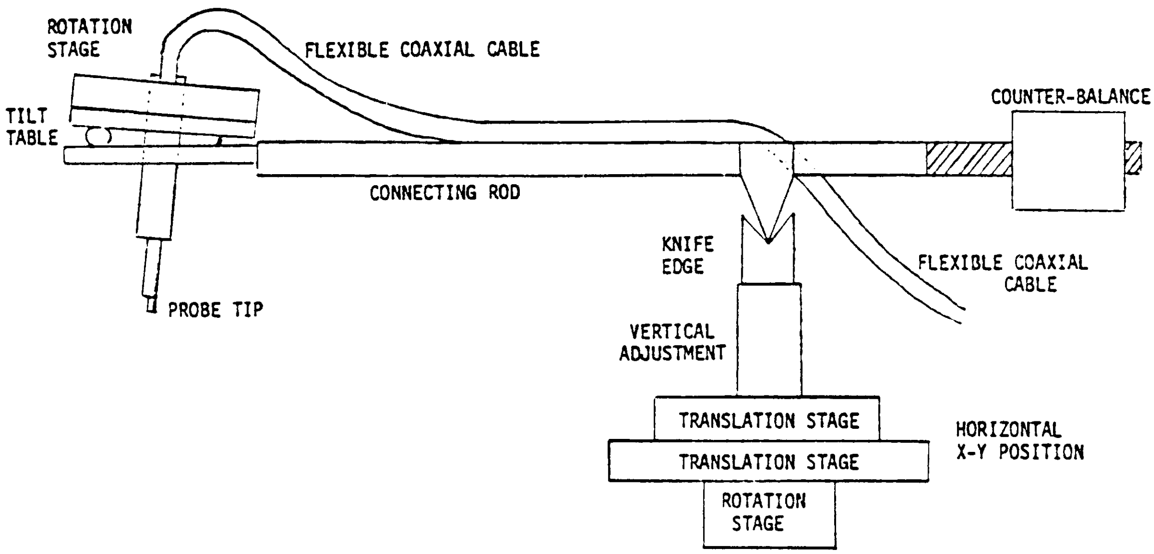

Figure 12-9: Schematic of Induction Probe

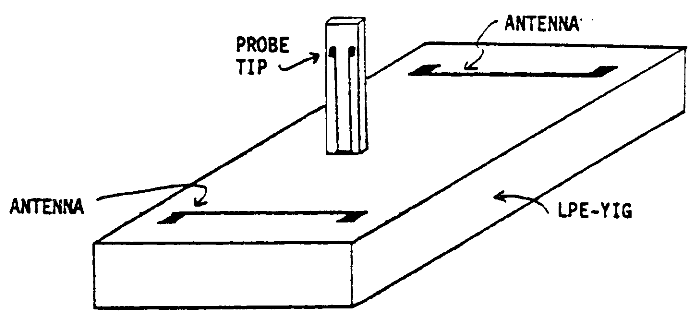

Figure 12-10: Probe tip on LPE-YIG thin film

12.4 Mode Synthesis

National Science Foundation (Grant 8008628-DAR)
U.S. Army (Contract DAAG29-8l-K-0l26)
Frederic R. Morgenthaler

Nonuniform magnetic bias field can control magnetostatic waves and modes in ferrite thin films.[1,2] Gradients in either the field magnitude, direction or both can be employed to synthesize wave or mode spectra to prespecified characteristics.

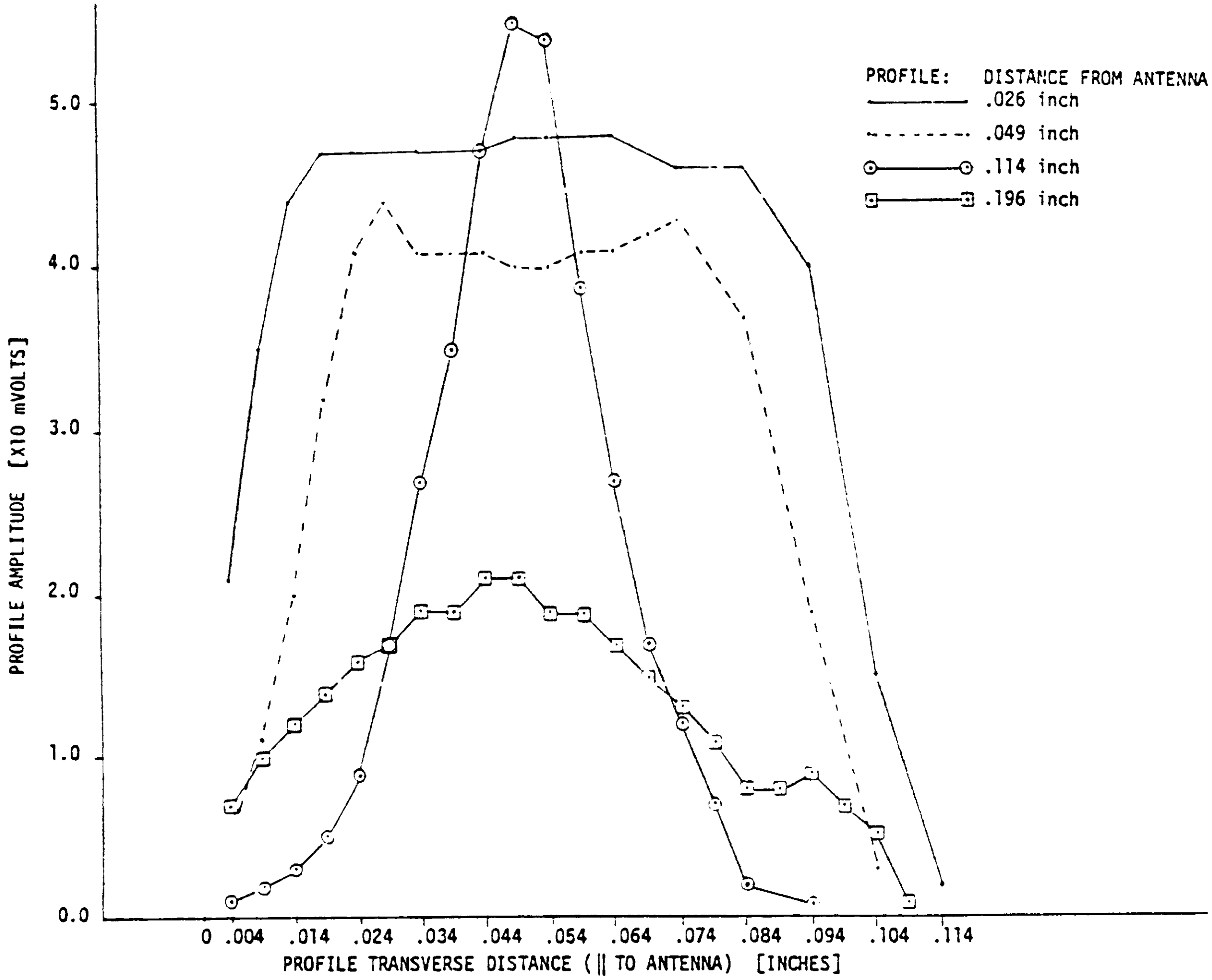

Figure 12-11: MSSW profiles

Parameters affected include frequency, rf energy distribution, impedance, velocity of energy circulation, and the threshold governing the onset of nonlinear effects due to parametrically unstable spin waves.

Morgenthaler has recently reported a synthesis procedure for forcing MSFVW dispersion to assume prespecified values over a finite bandwidth.

The abstract of a paper titled "Nondispersive Magnetostatic Forward Volume Waves under Field Gradient Control," presented at the 1981 Conference on Magnetism and Magnetic Materials[3] follows:

The magnetostatic dispersion relation for a single ferrite strip of width W and thickness d, placed between arbitrarily spaced parallel ground planes, is derived under the assumption that the dc magnetic bias is normal to the plane of the strip but a general polynomial function of the transverse coordinate.

Edge wave and volume wave modes are considered separately and both types are found to be susceptible to field gradient control. Assuming N-field gradient coefficients are available for dispersion control, a least-squares procedure can be employed to find that set which best approximates nondispersive (or other desired) propagation over a prescribed bandwidth. As expected, control is best achieved with moderately long magnetostatic wavelengths.

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12.5 New Techniques to Guide and Control Magnetostatic Waves

National Science Foundation (Grant 8008628-DAR)
Joint Services Electronics Program (Contract DAAG29-80-C-0104)
U.S. Army (Contract DAAG29-81-K-0126)
Daniel Stancil, Frederic R. Morgenthaler, Dale A. Zeskind

The prospect of guiding magnetostatic waves is of considerable interest because of possible device applications.[1] Such guided waves might be used to increase the delay time realizable on a given-size sample by meandering the path, or to make a resonator by guiding the waves along a closed loop. In addition, controlling the coupling between adjacent waveguides could make possible signal-routing devices such as directional couplers and diplexers.[2]

Stancil has developed a novel technique for an MSW diplexer that is described in the Microwave and Quantum Magnetics Group Technical Memorandum No. 6; the memorandum follows:

In a tangentially magnetized thin film, surface waves propagate for $k \perp \bar{H}_{dc}$ and $\omega > \sqrt{\omega_H(\omega_H + \omega_M)}$ while backward volume waves propagate for $k \parallel H_{dc}$ and $\omega < \sqrt{\omega_H(\omega_H + \omega_M)}$, where $\omega_H = \gamma H_{dc}$, $\omega_M = \gamma 4\pi M_S$ and $\gamma = 1.759(10^7)\ s^{-1}Oe^{-1}$. This suggests that a simple diplexer could be constructed using the transducer geometry indicated in Fig. 12-12.

Such a geometry has been constructed and is shown in Fig. 12-13. Measurements were made by simply placing a 1" diameter 7 μm film on top of the transducers. Some difficulty was encountered, however, due to radiation from the back sides of the transducers causing significant "cross-talk"

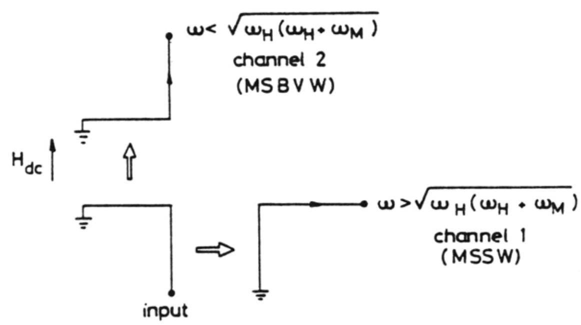

Figure 12-12: Schematic Diagram of microstrip transducer geometry

between the channels. This was possible because of the permissible cone of angles for surface wave and backward volume wave propagation. In particular, backward volume waves can propagate within the angles of $\pm \tan^{-1} z^{1/2}$ relative to the bias field direction,[1] and surface waves travel over the complement of angles. For the present geometry, this crosstalk is minimized for $z \simeq 1$, or $\tan^{-1} z^{1/2} = 45^{\circ}$. This occurs within the frequency range of 6-7 GHz. It should be possible to eliminate this difficulty by using two separate samples. This would make it possible to physically remove the path for coupling between the channels due to radiation from the undesired portion of the antenna.

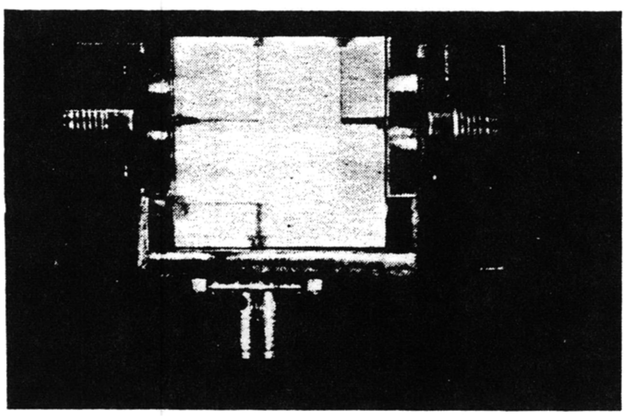

Figure 12-13: Experimental diplexer with YIG film removed

The passband characteristics of this device are shown in Fig. 12-14. It was found that the precise passband shapes depended strongly on sample orientation and placement. A significant factor in this behavior was probably edge reflections. The sample used has crystal axis reference flats cut on two edges which would be expected to enhance coherent edge reflections in certain orientations. In an actual device, care would need to be taken to minimize these reflections.

The results in Fig. 12-14 clearly demonstrate the feasibility of constructing a diplexer based on this principle.

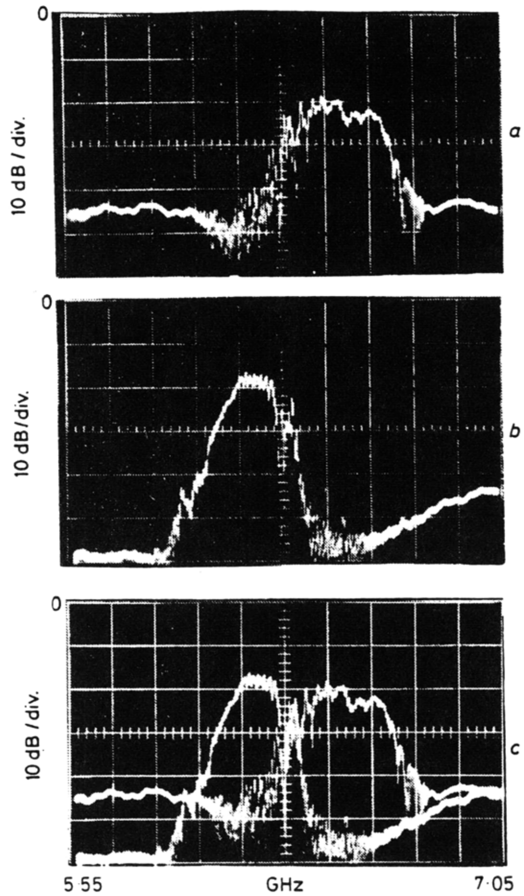

Figure 12-14: Diplexer Characteristics, Hdc = 1460 Oe
a. Channel 1, MSSW
b. Channel 2, MSBVW
c. Composite

References

1. D.D. Stancil, "Effects of Nonuniform Fields on Magnetostatic Waves in Ferrite Thin Films," M.I.T. Department of Electrical Engineering and Computer Science, Ph.D. Thesis, August 1981.
2. D.D. Stancil, "A Microwave Diplexer Using Magnetostatic Surface and Backward Volume Waves," M.I.T. Microwave and Quantum Magnetics Group Technical Memorandum No. 6, August 1981.

12.6 Magnetostatic Wave Dispersion Theory

U.S. Air Force (Contract F19628-79-C-0047)

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

Frederic R. Morgenthaler, Tushar Bhattacharjee, Daniel D. Stancil

In our prior analyses of nonuniform magnetostatic modes in thin films, the bias field was assumed to be directed normal to the plane and the modes considered were quasi-two-dimensional in that thickness variations of the rf magnetization were ignored. We have developed a general theory,[1] based upon coupled-integral equations. that can deal with surfacelike modes in one or more thin-film sections when the bias and any material nonuniformities (such as variation of the saturation magnetization) are purely transverse. The boundary conditions required at the film surfaces are built directly into these equations: the transverse conditions enter through the components of the Polder susceptibility tensor.

The equations govern a very wide range of physical situations. For example, coupling between modes circulating on two rectangular strips spaced by an air gap can be handled so as to model MSW directional couplers, etc.

Computer algorithms for numerical solutions of this class of eigen frequency problem continue to be developed. A version suitable for solving a single uniformly biased rectangular strip is currently operating.

References

1. F.R. Morgenthaler, "Magnetostatic Surface Modes in Nonuniform Thin Films with In-plane Bias Fields," J. Appl. Phys. 52, 3, Part II, 2267-2269.

12.7 Velocity of Energy Circulation of Magnetostatic Modes

National Science Foundation (Grant 8008628-DAR)
Daniel Fishman, Frederic R. Morgenthaler

The S.M. thesis of D.A. Fishman titled "Investigation of the Velocity of Energy Circulation of Magnetostatic Modes in YIG," has been completed; the abstract follows:

The velocity of energy circulation associated with the uniform precession mode in a ferrite is studied. It is shown theoretically (following Morgenthaler), and then proven experimentally, that this velocity can be altered by changing the specific electromagnetic boundary conditions of the magnetostatic fields. The situation where this boundary condition is of the form of a concentric conducting spherical shell is studied for the uniform precession magnetic resonance mode. Theoretical analyses indicate that there is a critical ratio, between the radius of the ferrite sphere and the conducting cavity, where the energy-velocity will approach zero. A consequence of the lowering of such a velocity is an increase of the energy density, per unit power flow, in the uniform precession mode. The onset of spin wave instabilities, due to the nonlinear coupling of the uniform precession to spin wave excitations, is brought on by the rf-energy density inside the ferrite exceeding a certain value. Thus a decrease in the energy velocity is expected to decrease the amount of incident power required to obtain this critical energy density.

We report that such decreases in the Suhl first order spin wave instability have been observed, as a function of the cavity radius. The experimental cavity was comprised of two conducting planes, one on each side of the spherical ferrite sample.

References

1. Daniel Fishman, "Investigation of the Velocity of Energy Circulation of Magnetostatic Modes in YIG," M.I.T. Department of Electrical Engineering and Computer Science S.M. Thesis, August 1981.

12.8 Magnetoelastic Waves and Devices

Joint Services Electronics Program (Contract DAAG29-80-C-0104)
National Science Foundation (Grant 8008628DAR)
Leslie Itano, Frederic R. Morgenthaler, Alan Wadsworth

A microwave yttrium-iron-garnet (YIG) delay line can be made to provide linearly dispersive delay with instantaneous bandwidth in excess of 1 GHz in S band. The dispersion of the device is based on the properties of spin and elastic waves in magnetically biased YIG, a ferrimagnetic material. In particular, linear dispersion can be achieved by first specifying a particular DC magnetic field profile along the axis of a YIG rod and then designing the necessary pole pieces with the aid of a computer. The isolation and coupling of the delay line is controlled by the input/output antennae design. Thin flexible wire loops have been used previously but have proven to be problematic. New thin film antennae were developed by Leslie Itano in her S.M. thesis[1] to provide more reproducible and reliable coupling. In addition a new delay line fixture was built that allows the interchange of both pole pieces and antennae, opening the way for future series of experiments to maximize power handling capabilities, minimize attenuation and maximize antenna isolation and coupling.

Alan Wadsworth is currently making use of these antennas and fixtures in the course of his S.M. thesis. This research centers on the design and evaluation of field profiles that should provide nearly constant focusing of the magnetoelastic wave as a function of frequency during those portions of its transist when it has only magnetic character.

References

1. Leslie Itano, "Microwave Delay Line with Thin Film Antennae," Department of Electrical Engineering and Computer Science, S.M. Thesis, August 1981.

12.9 Short Millimeter Wave Magnetics

U.S. Army (Contract DAAG29-81-K-0126)

Frederic R. Morgenthaler, Robert L. Kyhl, Dale A. Zeskind, Tushar Bhattacharjee

A new research program has begun that is aimed at providing novel signal processing of microwave signals that modulate short millimeter wave carriers and nonreciprocal ferrite devices for the carrier frequencies themselves.

Laboratory equipment at 94 GHz is being ordered. Low field, below resonance interactions will be studied using quasi-optical techniques.