XII. MICROWAVE DEVICES EMPLOYING MAGNETIC WAVES

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1. MAGNETIC-GRADIENT LOCALIZED MAGNETOSTATIC RESONANCES

Joint Services Electronics Program (Contract DAAG29-78-C-0020)
National Science Foundation (Grant ENG76-18359)

Peter N. Horowitz, Frederic R. Morgenthaler, Robert L. Kyhl,
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We have previously discussed the conditions necessary to cause magnetostatic waves
to be bound or confined by dc magnetic-field gradients both in rectangular slabs and
solid or hollow cylinders when the wave propagation is parallel to the surfaces and per-
pendicular to the dc direction. Although special field profiles were discovered that
allow analytic treatment of particular waves, a more complete treatment of the eigen-
value problem has been desired.

We have now solved and presented in an invited paper,\(^1\) at the 1978 Intermag Con-
ference held in Florence, Italy during May 1978, the eigenvalue problem governing two-
dimensional magnetostatic mode propagation in thin ferrite disks when the dc magnetic
field, \(H_z\), is normal to the plane and varies radially as

\[ H_z(r) = A + Br^{2n}, \]

where \(n\) is an integer and \(B\) may be a positive or negative constant.

Although the approach taken produces a nonlinear differential equation with coef-
ficients that may have singularities, an appropriate transformation of variables leads
to a better behaved function that can be expanded without difficulty in terms of simple
analytic functions. As expected, modes are found that are bound to or guided by the
rim. These are similar to the surface modes found when \(B = 0\), and are termed
gradient-modified boundary modes. In contrast, when \(|B|\) is large enough, modes are
formed with peak response occurring at some interior radius. These boundary-modified
gradient modes are highly localized (radially) at a "virtual surface" of discontinuity
caused by the field gradient. It has been found for both types of mode that the velocity
of energy circulation around the track formed by the "virtual surface" can be controlled
by the magnitude of the dc gradient. All of the $B \neq 0$ modes have nonzero volume divergence of the small-signal RF magnetization. For the gradient-bound modes the divergence is very large at or near the track.

The effects of metallic boundaries placed in proximity to the ferrimagnetic disks have also been considered in the calculations. With simple modification, the theory is also applicable to disks transformed to annular rings by removal of their centers.

Experiments have been conducted on uniformly magnetized thin films of yttrium iron garnet (YIG) grown on substrates of gadolinium gallium garnet ($G^3$) by LPE techniques. Several such films approximately 5 microns in thickness have been very kindly supplied to us by Dr. Howard Glass of Rockwell International. They were grown under their Contract F44620-75-C-0045 with the Air Force Office of Scientific Research.

High-Q magnetic resonances have been observed in our preliminary experiments on these films, and magnetic pole pieces designed to generate the $A + Br^{2n}$ field profiles are under construction.

John J. Cooley completed his study of bound modes in thick single YIG disks, and on September 12, 1977 submitted a thesis entitled "Magnetostatic Modes Bound by dc H-Field Gradients" in partial fulfillment of the requirements for the degrees of Master of Science and Electrical Engineer. A summary of his thesis follows:

The study of high-Q microwave modes bound to an intentionally nonuniform dc magnetic field in a single crystal of yttrium iron garnet (YIG) was reported. The modes of a YIG disk, magnetized perpendicularly to its plane, and with internal dc field profiles either concave or convex were excited locally by fine-wire antenna structures. Modes with loaded Q's on the order of $10^3$ varied linearly with the externally applied bias field at a rate of 2.8 MHz/Oe over the frequency range 2.0 to 18.0 GHz. The internal field profiles resulted from placing the disk in either an initially uniform magnetic field (in which case the field was monotonic with the maximum at the disk edge), or a nonuniform external field shaped by high-permeability magnetic pole pieces (to approximate a parabolic internal field with the maximum at the center of the disk).

The crystal used had dimensions of 1.97 mm (radius) and 0.33 mm (thickness), was cut along the (110) plane, and had both plane faces polished to optical standards. Excitation was achieved via two separate coupling structures: one in which the YIG coupled two nominally uncoupled antennas. Experimental results for the uniform external-field configuration showed that two types of modes exist. There are well-coupled modes (10-20 dB insertion loss) which occur in a multiplet pattern (singlet, doublet, triplet, etc.) and there are poorly coupled modes (30-40 dB insertion loss) which do not follow this pattern. Experimental results for the shaped external-field configuration do not show clearly defined multiplets.

Subject to the simplifying assumptions that the variation of the dc and RF fields in the direction perpendicular to the plane of the disk may be ignored, a formalism for
finding the eigenmodes of a general circularly symmetric internal-field profile was discussed and a computer algorithm implemented. The computer-generated eigenmodes are $\phi$-directed and bound to circular tracks of constant radii. Families of eigenfrequencies which vary linearly with applied dc magnetic field at the rate of 2.8 MHz/Oe exhibit multiple degeneracies which suggests the possibility of multiplets. The widths of the experimentally observed modes spectra (approximately 1.5-2.0 GHz) agree qualitatively with computer-generated mode spectra.

References


2. MAGNETIC RESONANCE IN THIN FILMS CONTAINING MAGNETIC BUBBLES

Frederic R. Morgenthaler

The abstract of a paper presented at the 24th Conference on Magnetism and Magnetic Materials, Cleveland, Ohio, November 14-17, 1978 follows:

We have recently discussed magnetostatic modes in a normally magnetized, thin-film disk that are bound to "virtual-surfaces" created by the presence of a radial dc-field gradient; the frequency and polarization of such modes was found to be a sensitive function of the gradient. We now employ a similar method of analysis to study two-dimensional resonance modes in a thin film containing a single magnetic bubble. When the thickness of the bubble-domain wall is ignored, and there is no applied gradient, the spectrum, as expected, contains single-bubble resonances coupled to disk resonances. However, actual domain walls contain large anisotropy field gradients due to the often complex spin-reversal pattern. Such gradients will affect the mode polarization within the wall and the effective boundary conditions acting across the wall may be significantly altered for those resonances coupled to exchange modes within the domain wall. The related but simpler problem of RF exchange modes generated at a plane "virtual-surface" within a single-domain region is studied in detail.
References


3. OPTICAL DETECTION OF LOCALIZED MAGNETOSTATIC RESONANCES
   Joint Services Electronics Program (Contract DAAG29-78-C-0020)
   Nickolas P. Vlannes, Frederic R. Morgenthaler

   The doctoral thesis of Nickolas P. Vlannes, now in the initial phase, will deal with optical detection of localized magnetostatic resonances in thin LPE films of yttrium iron garnet (YIG).

   The experiments will make use of our existing Spectra Physics 125 laser tuned to 1.15 μm and new optical detectors capable of responding to approximately 2-GHz modulation rates. A new optical table has been installed and the microwave portions of the setup are currently being planned.

4. VARIABLE-SPEED MAGNETOSTATIC MODES IN UNIFORM OR NONUNIFORM DC H FIELDS
   Joint Services Electronics Program (Contract DAAG29-78-C-0020)
   National Science Foundation (Grant ENG76-18359)
   Peter N. Horowitz, Frederic R. Morgenthaler, Dale A. Zeskind

   The S. M. thesis of Peter N. Horowitz concerned the control of magnetostatic surface-wave group velocity on a sandwich structure composed of two ferrite rectangular slab crystals separated by an adjustable air gap. This geometry, suggested by Tsutsumi, is a valuable one in which to study fundamental wave properties and material constants. The thesis also contains preliminary results of magnetic wave propagation in thin films immersed in nonuniform magnetic fields. The abstract follows:

   Magnetostatic modes of bulk rectangular slabs and thin films of single-crystal yttrium iron garnet (YIG) are studied both theoretically and experimentally. Delay times of up to 300 nsec (a group velocity as slow as \(7.6 \times 10^{-4} \, c\)) are reported for magnetostatic surface waves propagating along a structure composed of two 1-mm × 5-mm × 7-mm slabs of YIG separated by an adjustable air gap (3 to 15 mils) between two of the 5-mm × 7-mm faces and magnetized normal to the 1-mm × 5-mm faces. High-quality thin films (5 microns thick) of YIG are transversely magnetized and
nonreciprocal magnetostatic surface waves with delay times of up to 280 nsec are observed with integrated-circuit microstripline antennas spaced 0.1 inch apart. The cutoff dc H fields of these modes are measured and found to be close to theoretical values. Surface modes for a transversely magnetized thin film are again shown to exist for only certain angles, \( \theta \leq \cos^{-1}\left(\frac{\omega}{(\omega_0 + \omega_M)^{1/2}}\right) \), between the plane of the film and the internal dc H field.

Two pole pieces were made to create a spatially nonuniform dc H field of the form A + Bx normal to the plane of the film. Gradients of from 110 to 145 Oe/mm were tried but only weak coupling resulted. With only the bottom pole piece in place (an in-plane component of the dc magnetization is expected), strong coupling was observed to nonreciprocal modes. Delay times of up to 320 nsec along 0.1 inch of YIG film are observed.

References


5. MAGNETOELASTIC YIG DELAY LINES

Joint Services Electronics Program (Contract DAAG29-78-C-0020)
National Science Foundation (Grant ENG76-18359)

Aryeh Platzker, Leslie M. Itano, Frederic R. Morgenthaler

An overview of our recent work\(^1\) on magnetic field synthesis procedures for magnetostatic and magnetoelastic devices was given in an invited paper at the 1978 International Symposium on Circuits and Systems in New York, May, 1978. The abstract follows:

Certain types of magnetostatic and/or magnetoelastic devices require nonuniform dc bias fields of sufficient strength to locally saturate the active ferrite element.

We here review a synthesis procedure for cylindrically symmetric geometries that allows prespecification of the field on the symmetry axis or on a plane perpendicular to it.

The method is then applied to the cases of both a thin-film disk magnetized normally to its plane and microwave magnetoelastic delay line designed for linear-frequency dispersion over wide bandwidths.

Finally, we report construction details and test data on an actual packaged device having greatly improved characteristics. Measured parameters for two-port operation at S-band over a 1-GHz bandwidth include a linear dispersion factor \( D = 0.3 \text{ nsec/MHz} \)
and an insertion loss (untuned) of 27-30 dB.

References


6. MAGNETOSTATIC ENERGY OF STRIPE DOMAIN PATTERNS

National Science Foundation (Grant ENG76-18359)

James H. Spreen, Frederic R. Morgenthaler

Results of the doctoral thesis\(^1\) research of James H. Spreen were presented at the 1977 Conference on Magnetism and Magnetic Materials in Minneapolis,\(^2\) and have been published in the Journal of Applied Physics (September 1978).\(^2\)

References
