Variations in autooscillation frequency at the main resonance in rectangular yttrium–iron–garnet films

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Variations in auto-oscillation frequency at the main resonance in rectangular yttrium–iron–garnet films

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High power microwave experiments conducted on a rectangular yttrium-iron-garnet (YIG) film indicate a parabolic dependence of the square of the frequency of auto-oscillations on microwave signal amplitudes, an observation that is qualitatively consistent with prior theoretical predictions. Forward volume magnetostatic waves were excited using a microstrip transducer kept in contact with a YIG film placed in a constant external magnetic field (H_{dc}=3.48 kG). Variations in the input microwave power (10 dBm$<P<$25 dBm) and frequency (5.1 GHz$<f<$5.7 GHz) were used to locate and study auto-oscillations close to the Suhl instability at the main resonance. A novel method of viewing changes in the microwave passband using density plots enables us to study variations in the dipole gaps in the passband near the Suhl instability. A broadening of dipole gaps into fingerlike regions of weak transmission marks the onset of auto-oscillations beyond the instability threshold. These regions are associated with a variety of spin-wave dynamics ranging from simple auto-oscillations to auto-oscillations with period doubling and in some cases an abrupt transition to a turbulent wide-band power spectrum. The parabolic dependence of the auto-oscillation frequency persists despite a period-doubling bifurcation.
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I. INTRODUCTION

Modulational instabilities at high microwave power levels have been previously studied in thin yttrium-iron-garnet (YIG) films[1] and in YIG spheres.[2,3] These studies indicate that the frequency of auto-oscillation (AO) increases monotonically with an increase in the amplitude of the microwave signal. Using the center-manifold theory on the entire degenerate spin-wave manifold, Zhang and Suhl[4] calculated the frequency of the limit cycle associated with the AO and predicted that the square of the frequency would vary in a parabolic manner with an increase in the microwave signal amplitude. Our experimental observations on a rectangular YIG film are qualitatively consistent with these predictions. Careful measurements taken at the main resonance, close to the second Suhl instability (SI) threshold, reveal that the parabolic behavior persists even when the system undergoes a period-doubling bifurcation. However, as also noted by various authors,[2–5] depending on the exact input parameters it is possible to follow a route to chaos where the frequency of AO appears to merely increase monotonically and the spin-wave manifold undergoes an abrupt transition to turbulence without observing the parabolic behavior predicted theoretically.

The ferromagnetic resonance (FMR) measurements by McMichael and Wigen on circular YIG films[6] indicate the existence of fingerlike regions of AO associated with the standing wave magnetostatic modes in low-power FMR spectra. In our experiments on propagating waves in rectangular YIG films at high power, we observed the emergence of similarly shaped fingers that corresponded to regions of weak transmission. A wide variety of chaotic dynamics, including AO, were visible in the fingerlike regions. By monitoring the changes in the microwave passband with increases in microwave power, we note that the fingers are associated with the broadening and shifting of the dipole gaps in the passband. The use of density plots to display the data enables us to map the regions of weak transmission over a wide range of input parameters (10 dBm$<P<$25 dBm and 5.1 GHz$<f<$5.7 GHz).

II. EXPERIMENTAL RESULTS

Our experiments were carried out on a rectangular YIG film (5 mm×10 mm×7.4 μm). Separate low power FMR measurements on the film indicate a linewidth of 0.9 Oe at 9.2 GHz suggesting a decay rate of 1.27 cm^{-1}. A constant magnetic field, H_{dc}=3.48 kG, was applied perpendicular to the film plane and spin-waves were excited using a microstrip transducer in contact with the film. A second transducer, 3 mm from the first, picks up the output signal from the device and feeds it to a spectrum analyzer where the AO appear as secondary peaks surrounding the primary input frequency. The frequency of AO is calculated as the average separation between adjacent peaks in the output spectrum. Figure 1 shows the variation of the AO frequency as a function of input signal amplitude both with and without a period doubling bifurcation. The signal amplitude was calculated at the input terminals of the device after accounting for cable losses and the reflected power. The parabolic nature of the variation in frequency is qualitatively consistent with the theoretical predictions by Zhang and Suhl.[4,7] A quantitative comparison of the experimental and theoretical results would involve (a) estimating the decay constants and coupling coefficients associated with interacting modes, (b) modeling the microstrip geometry to calculate the amplitude of the rf field and (c) reformulating the center-manifold theory to in-

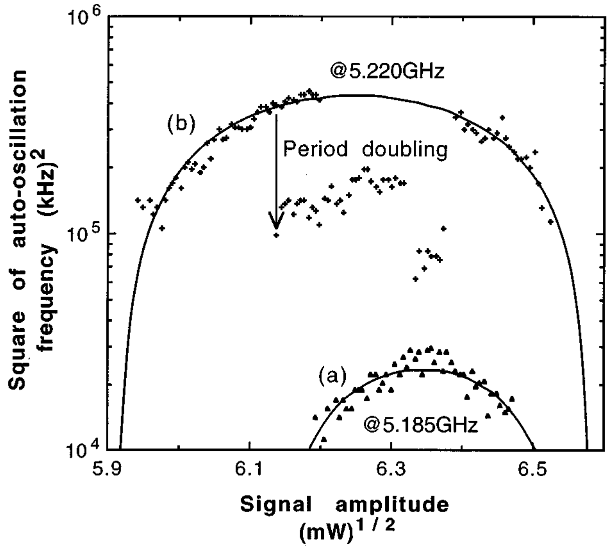

FIG. 1. Variations in the square of AO frequency with increasing microwave signal amplitudes. (a) Simple parabolic dependence and (b) parabolic dependence with a period doubling bifurcation. Both sets of data have been fit to binomial expressions to facilitate comparisons.

clude the dependence of the coupling coefficients and decay constants on the mode number, tasks that are beyond the scope of this article.

We observe a wide range of AO frequencies depending on the location of the input signal frequency in the microwave passband. As one approaches the top of the parabola, the spin-wave system attempts to follow one of various competing routes to chaos. While this attempt manifests itself as a small deviation from the parabolic behavior in the curve of Fig. 1(a), the curve of Fig. 1(b) demonstrates a case of period doubling with the formation of a limit-two cycle, where the system returns to its original limit cycle after further increases in signal amplitude. Very often, as we increase the input power, we see an abrupt transition to turbulence near the top of the parabola. Such behavior is reminiscent of attractor destruction when, as the power reaches a critical value P_c, the attractor collides with the stable manifold of an unstable periodic orbit (boundary crisis). Carroll, Pecora and Rachford[5] have reported similar observations in their experiments on YIG spheres near the first Suhl instability. They also provide a description of the overlapping basins of attraction for chaotic and nonchaotic attractors in the spin-wave system that can explain the deviations from the parabolic dependence that we sometimes observe.

A typical microwave passband measurement using a network analyzer with a device input power of −24 dBm is shown in Fig. 2. The dipole gaps in the passband are due to the pinning of spin-waves on the surfaces of the film.[8,9] Figure 2 also shows the location in the passband where the measurements in Fig. 1 were made. By replacing the network

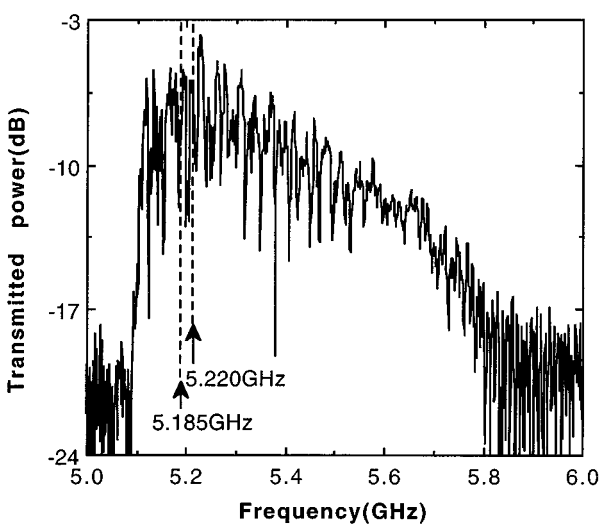

FIG. 2. Transmission characteristics of the YIG film. The passband was obtained with a device input power of −24 dBm in the presence of an external field H_{dc}=3.48 kG. The arrows mark the frequencies at which the two sets of data in Fig. 1 were taken.

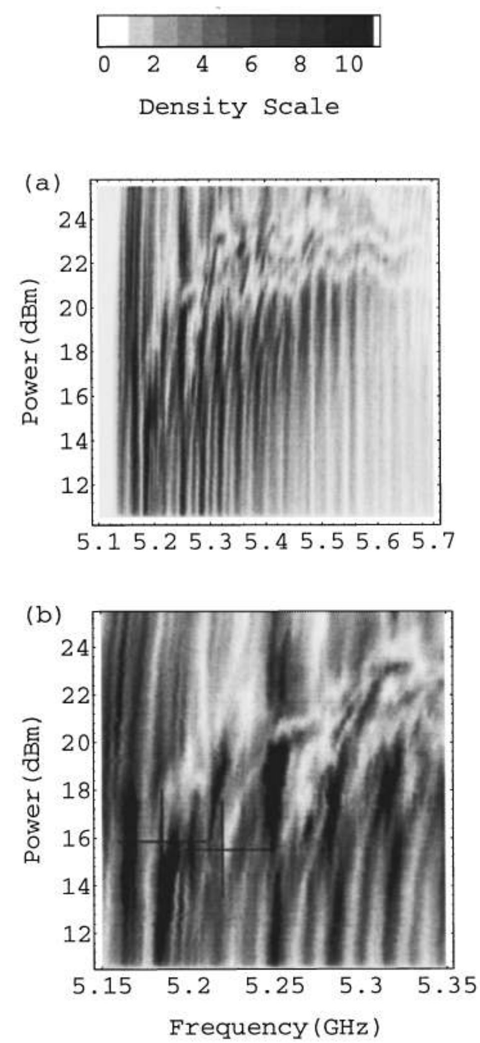

FIG. 3. (a) Density plot of the passband obtained by stepping the input power between 10 and 25 dBm in steps of 0.2 dBm. The frequency scale is accurate to within 1.2 MHz. The white areas correspond to regions of weak transmission. The density is proportional to $P_{transmitted}/P_{incident}$, normalized on a scale of 0 to 10. (b) An inset that shows the emergence of global patterns associated with weak transmission (patterns similar to the fingers of AO). The cross-hairs mark the regions where the data in Fig. 1 were obtained.

analyzer with an amplifier and a diode detector, and sending the output to a digital oscilloscope, we observe changes in the passband at much higher power levels (10 dBm $>P>25$ dBm). Figure 3 is a density plot of the passband over a region of frequency-power phase space. The density is linearly proportional to transmitted power divided by power incident on the device, with black corresponding to maximum transmission. The y-scale shows the raw incident power at the device and has not been corrected for any reflections from the input port. The dipole gaps in the passband, which at low power appear as thin white lines, eventually broaden into wider regions with weak transmission characteristics. These broad white regions reveal very complex routes to chaos while their edges approximately mark the onset of AO. Similar contiguous regions of AO have previously been referred to in the literature as fingers of AO.[6] Although the orientation of the regions of weak transmission in Fig. 3 appears to be different from that of the fingers of AO reported by McMichael and Wigen,[6] when we keep H_{dc} constant and sweep the frequency, we are actually mapping regions in phase space similar to theirs. The measurements of the AO frequency were made at the edges of the white regions, presumably in areas having fewer interacting spin-wave modes. The cross-hairs in Fig. 3(b) reveal the exact locations in phase space where the AO measurements were taken. The marked difference in the parabolic dependence seen in Fig. 1 appears to be a result of experiments conducted at different locations in parameter space, possibly in different fingers of AO. There is a shift in the bottom of the passband ($\approx$10 MHz) similar to the frequency shift observed in experiments on magnetostatic wave delay lines.[10,11] Measurements of the reflected power indicate that the waviness in the white pattern visible at high frequencies is due to reflections from the input port of the device. These reflections cause variations in the actual power coupled into the spin system. However, the broadening of dipole gaps that leads to the formation of regions of instability is a nonlinear phenomenon that does not appear in a density plot of the reflected power. The various features that appear in the density plots for transmitted power (Fig. 3) and reflected power are currently under investigation.

III. CONCLUSIONS

The onset of AO at the main resonance was observed experimentally. The square of the frequency of AO followed a parabolic dependence on the input signal amplitude in a manner consistent with theoretical predictions. The exact location in frequency-power phase space where the measurements were possible was determined using density plots of the microwave passband. It was found that the dipole gaps in the passband broaden out and shift toward higher frequencies, eventually forming wide regions of weak transmission. Since these regions are fairly rich in a variety of routes to chaos, the measurements on AO frequency were made at their edges. The parabolic dependence is observed even when the spin-wave system undergoes a period doubling bifurcation. The exact nature of the dependence varies with the location in parameter space.

The density plots of the transmitted power have revealed a global absorption pattern similar to the fingers of AO. There is also a frequency shift in the entire passband that could be a combination of thermal and nonlinear effects.

ACKNOWLEDGMENTS

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[1] B. A. Kalinikos, N. G. Kovshikov, and N. Slavin, JETP Lett. **10**, 392 (1984).
[2] P. H. Bryant and C. D. Jefferies, Phys. Rev. A **38**, 4223 (1988).
[3] F. M. Aguiar, A. Azevedo, and S. M. Rezende, J. Appl. Phys. **73**, 6825 (1993).
[4] X. Y. Zhang and H. Suhl, Phys. Rev. B **38**, 4893 (1988).
[5] T. L. Carroll, L. M. Pecora, and F. J. Rachford, Phys. Rev. Lett. **59**, 2891 (1987).
[6] R. D. McMichael and P. E. Wigen, Phys. Rev. Lett. **64**, 64 (1990).
[7] H. Suhl and X. Y. Zhang, Phys. Rev. Lett. **57**, 1480 (1986).
[8] J. D. Adam, T. W. O'Keefe, and R. W. Patterson, J. Appl. Phys. **50**, 2446 (1979).
[9] B. A. Kalinikos, N. G. Kovshikov, and A. N. Slavin, JETP **38**, 413 (1983).
[10] M. A. Tsankov, M. Chen, and C. E. Patton, HE-10, Sixth Joint MMM-Intermag Conference, Alberquerque, NM (June 1994).
[11] A. F. Cash and D. D. Stancil, HE-11, Sixth Joint MMM-Intermag Conference, Alberquerque, NM, June 1994 [IEEE Trans. Magn. (to be published)].