# DIRECT OBSERVATION OF SURFACE WAVE EXCITATIONS IN MAGNETOSTATIC WAVE DEVICES

G. Srinivasan and C. E. Patton


## ABSTRACT

The Brillouin light scattering (BLS) technique has been used for the direct detection of magnetostatic wave (MSW) excitations in a signal-to-noise enhancer MSW device structure. The device consists of a 23 μm wide microstrip transmission line in contact with a 26.6 μm thick single crystal yttrium iron garnet film on a gadolinium gallium garnet substrate, with the applied static magnetic field parallel to the stripline. By utilizing the wave vector- and frequency-selective capabilities of the BLS spectrometer, it was possible to determine the wave vector distributions of the MSW excitations at both low and high input microwave power levels. At low power levels, the spectra at 3.6 GHz consisted of magnetostatic surface wave excitations with wave number k from about 50 $cm^{-1}$ to 200 $cm^{-1}$ and propagation perpendicular to the field and microstrip line direction. At high power levels, parametric half-frequency excitations were observed with k-values greater than $10^4$ $cm^{-1}$.


## INTRODUCTION

A variety of devices, based on magnetostatic wave propagation in planar magnetic samples [1], have been designed for signal processing at microwave frequencies [2]. Device design, until now, has depended on the theoretical dispersive properties of magnetostatic wave (MSW) excitations. With the Brillouin light scattering (BLS) technique, it is now possible to detect directly MSW excitations and to measure the dispersion properties and energy flow profiles of these excitations in actual device configurations. The BLS spectrometer is frequency and wave vector selective [3], so that one can also determine the wave vector ($\vec{k}$) distributions of the MSW excitations. The purpose of this paper is to report the first such measurements on a microwave signal-to-noise enhancer MSW device structure [4,5]. The scattering intensity of surface magnons and parametric half-frequency magnons was measured as a function of applied field and input power level at frequencies from 2.8 to 4.0 GHz.

## EXPERIMENT

The signal-to-noise enhancer device [4,5] is shown schematically in Fig. 1(a). It consists of a 26.6 μm thick yttrium iron garnet (YIG) film on a gadolinium gallium garnet (GGG) substrate. The YIG film is in contact with a 23 μm wide microstrip line on an alumina ground plane. An external static magnetic field $\bar{H}$ is applied parallel to the stripline. A microwave signal in the microstrip line launches magnetostatic surface wave (MSSW) excitations in the YIG film. This, in turn, results in an attenuation of the microstrip signal. Since the power which can be pumped into the MSSW excitations is limited by spin wave instability processes for input power levels above some threshold power [6], the device has a large attenuation for small signals, such as noise, while large signals have a reduced attenuation.

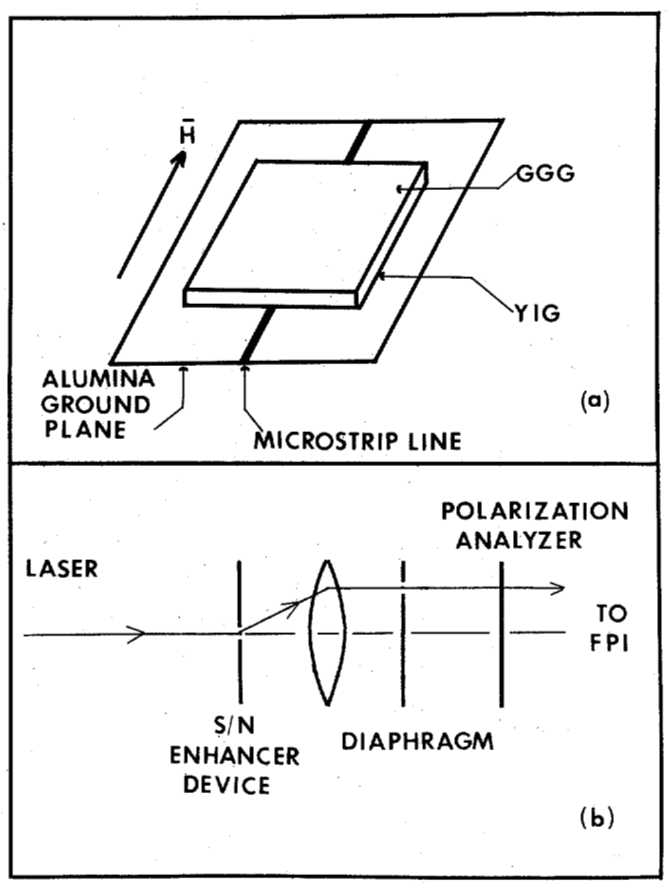


Fig. 1. Diagram showing: (a) signal-to-noise enhancer device, with the yttrium iron garnet (YIG) film, gadolinium gallium garnet (GGG) substrate, microstrip line and alumina ground plane; (b) the forward scattering geometry for the Brillouin light scattering detection of magnetostatic wave excitations in the device.

Manuscript received

This work was supported in part by the National Science Foundation, Grant DMR-8013727, the U. S. Air Force, Contract No. F-19628-83-K-0002, and a Faculty Development Grant from the Verbatim Corporation, Sunnyvale, California.

G. Srinivasan and C. E. Patton are with the Department of Physics, Colorado State University, Fort Collins, Colorado 80523.

0018-9464/85/0900-1797$01.00©1985 IEEE

The present series of experiments was performed to demonstrate the utility of the BLS technique to study MSW excitations in device structures. The forward scattering geometry is indicated schematically in Fig. 1(b). A small hole in the alumina ground plane away from the microstrip allowed access to the magnetic excitations in the YIG film.

The wave number k and in-plane propagation angle $\theta_k$ (angle between $\vec{k}$ and $\vec{H}$) of the specific MSSW excitation of interest was controlled by the position of the aperture in the diaphragm behind the collecting lens. The F1.4 aperture and 50 mm focal length of the collecting lens allowed access to wave numbers from essentially zero (direct forward scattering) to about $4 \times 10^4$ cm$^{-1}$. The scattered light was analyzed with a high contrast multipass-tandem Fabry-Perot interferometer, indicated by "to FPI" in the figure. For all of the results presented below, the drive frequency was 3.6 GHz. Theoretical values of k and $\theta_k$ in the discussion to follow were based on well known magnon dispersion equations for MSSW excitations and spin waves, and values of 1750 G and 2.8 GHz/kG for the saturation induction and g-value, respectively, of YIG.

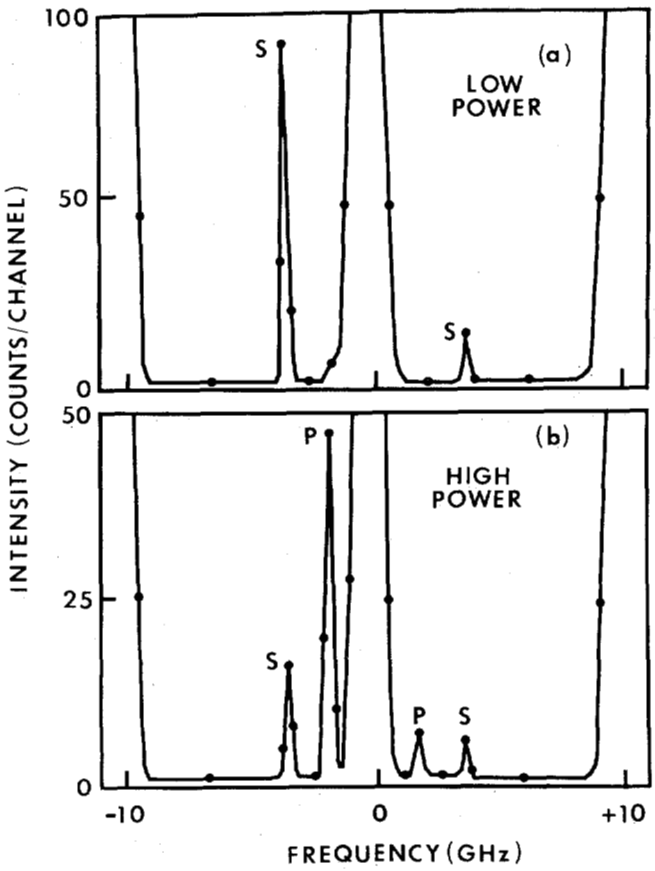


Fig. 2. Brillouin light scattering spectra for magnetostatic wave excitations in a signal-to-noise enhancer device for an excitation frequency of 3.6 GHz, a static field of 570 Oe parallel to the microstrip line, and an input power of 0.6 mW for (a) and 40 mW for (b).

BLS data were obtained for power levels from about 0.5 mW to 40 mW (the maximum output of the signal generator) at 3.6 GHz. Representative spectra for H = 570 Oe and no collection aperture are shown in Fig. 2. For this field and frequency, the theoretical MSSW k-value for propagation away from the microstrip line ($\theta_k = 90°$) is about $10^2$ cm$^{-1}$, well within the accessibility limit of $4 \times 10^4$ cm$^{-1}$ discussed above. Figure 2(a) is for 0.6 mW sweep generator output power. The spectra show peaks corresponding to magnetostatic surface waves at ±3.6 GHz, labeled "S" in the figure. The propagation of surface magnons is nonreciprocal and a MSSW peak should appear only on one side of the central Rayleigh peak. The weaker peak to the right of the central peak is probably due to an oppositely traveling MSSW excitation which is excited on the GGG side of the YIG film by the leakage microwave field of the microstrip.

For no aperture, the interferometer "sees" all accessible MSSW excitations below $|\vec{k}| = 4 \times 10^4$ cm$^{-1}$. Various apertures in the diaphragm of Fig. 1 were used to map out the k- and $\theta_k$ distributions of the excitations which contribute to the S-peaks in Fig. 2(a). The k-distribution was found to be centered at the expected theoretical value ($\sim 1 \times 10^2$ cm$^{-1}$) and had an aperture-size limited width of about 50 cm$^{-1}$. The propagation angle was found to be 90° ± 10°.

The spectra shown in Fig. 2(b) are for the same excitation frequency, bias field and scattering geometry, but for an input power level of 40 mW. In addition to the MSSW scattering peaks at ±3.6 GHz, additional magnon peaks at ±1.8 GHz are observed. These correspond to paramagnetic half-frequency magnons which are excited in the YIG film for high input microwave power levels due to spin-wave instability processes [6]. The $\vec{k}$-values for these "P" magnons were also determined by placing appropriate apertures in the diaphragm of Fig. 1. Wave numbers from $1 \times 10^4$ cm$^{-1}$ to $4 \times 10^4$ cm$^{-1}$ (the limit of the collecting lens) were observed, with an in-plane propagation angle of about 5°.

One important question for MSW devices concerns the range of k-values which are excited for a given stripline geometry in a specific device structure. In order to address this question, intensity data were also obtained as a function of applied field with no selective aperture in place, so that the entire range of accessible wave numbers (0 - $4 \times 10^4$ cm$^{-1}$) could be detected. Intensity vs. field profiles for an excitation frequency of 3.6 GHz are shown in Fig. 3. The data in Fig. 3(a) are for an input power of 0.6 mW, for which no half-frequency magnons are generated. The intensity of the MSSW S-peaks is relatively large over the field interval 520-620 Oe. As the dc field is changed over this interval, the theoretical MSSW wavenumber at 3.6 GHz ranges from 50 cm$^{-1}$ (at 620 Oe) to 200 cm$^{-1}$ (520 Oe). The experimental k-values were checked at selected field points (as discussed above) and found to agree with theory. A k-value of 200 cm$^{-1}$ corresponds to a wavelength of about 300 μm, so that the 23 μm stripline is mainly generating MSSW excitations of wavelength greater than 300 μm.

The low power profile was found to change dramatically under high power conditions which give rise to the P-peaks discussed above. Such profiles are shown in Fig. 3(b) for both the MSSW S-peaks and the P-magnons. These results show that the excitation of

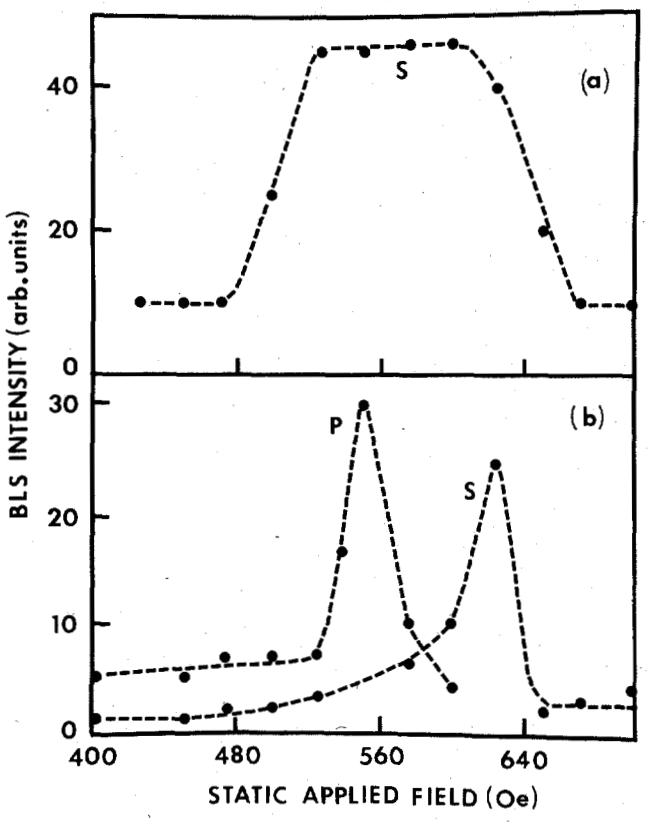


Fig. 3. Variation in the light scattering intensity of magnetostatic surface waves (S) and half-frequency magnon (P) peaks with applied field at 3.6 GHz for an input power of 0.6 mW for (a) and 40 mW for (b).

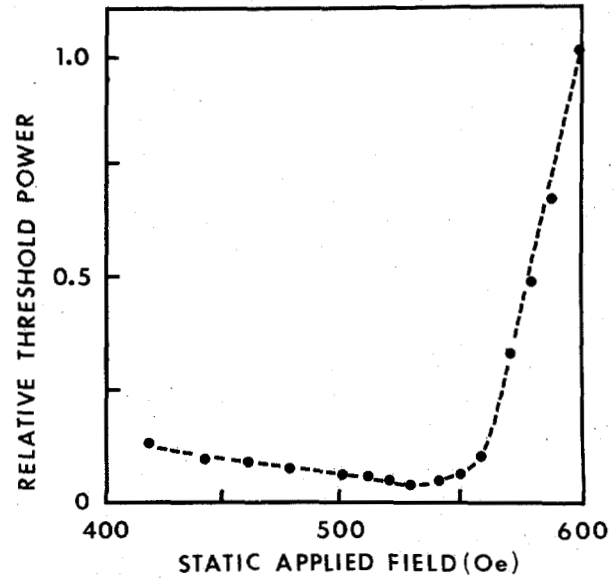


Fig. 4. Relative threshold microwave power required for excitation of half-frequency magnons as a function of static field for an excitation frequency of 3.6 GHz.

P-magnons occurs only over a portion of the total field interval for which S-magnons are found under low power drive levels. The occurrence of P-magnons causes the population of the S-magnons or MSSW excitation to decrease. The high field portion of the MSSW profile is unaffected.

For a signal-to-noise enhancer, data on the threshold power required for the excitation of half-frequency magnons are important from a device point of view. Figure 4 shows the variation of the relative threshold microwave power for the observation of P-magnons as a function of applied field at 3.6 GHz. These determinations were based on spectra obtained with no aperture. The results indicate that the threshold decreases slowly with increasing field to a minimum at $H_{min}$ = 525 Oe, and increases sharply at higher fields. According to theoretical calculations, P-magnons propagate in a plane almost perpendicular to the surface wave wave-vector, not in the film plane, and at an angle $\theta_k$ of about 22° [8]. A more involved light scattering geometry would be needed to accurately determine this angle experimentally. We do find maximum scattering intensity for an in-plane angle of about 4°, more-or-less consistent with ref. 8. The data in Fig. 4 correspond to a butterfly curve for a subsidiary absorption type of spin wave instability process, but obtained by a new technique in an actual device configuration.

## ACKNOWLEDGEMENTS

The authors are grateful to Drs. J. D. Adam and P. R. Emtage, Westinghouse Research and Development Center, Pittsburgh, for providing the signal-to-noise enhancer device used in these experiments and for helpful discussions on the nature of magnetic excitations in such device structures.

## REFERENCES

1. R. W. Damon and J. R. Eshbach, J. Phys. Chem. Solids 19, 308 (1961)
2. J. C. Sethares, Proc. 1981 RADC Microwave Magnetics Technology Workshop, June 10-11 (1981), RADC-TR-83-15, Jan., 1983
3. W. D. Wilber, W. Wettling, P. Kabos, C. E. Patton and W. Jantz, J. Appl. Phys. 55, 2533 (1984)
4. J. D. Adam, IEEE Trans. Magnetics MAG 16, 1168 (1980)
5. J. D. Adam and S. N. Stitzer, Appl. Phys. Lett. 36, 485 (1980)
6. H. J. Suhl, J. Phys. Chem. Solids 1, 209 (1957)
7. W. Wettling, W. D. Wilber, P. Kabos and C. E. Patton, Phys. Rev. Lett. 51, 1680 (1983)
8. S. N. Stitzer and P. R. Emtage, Circuits, Systems, and Signal Processing (To be published)