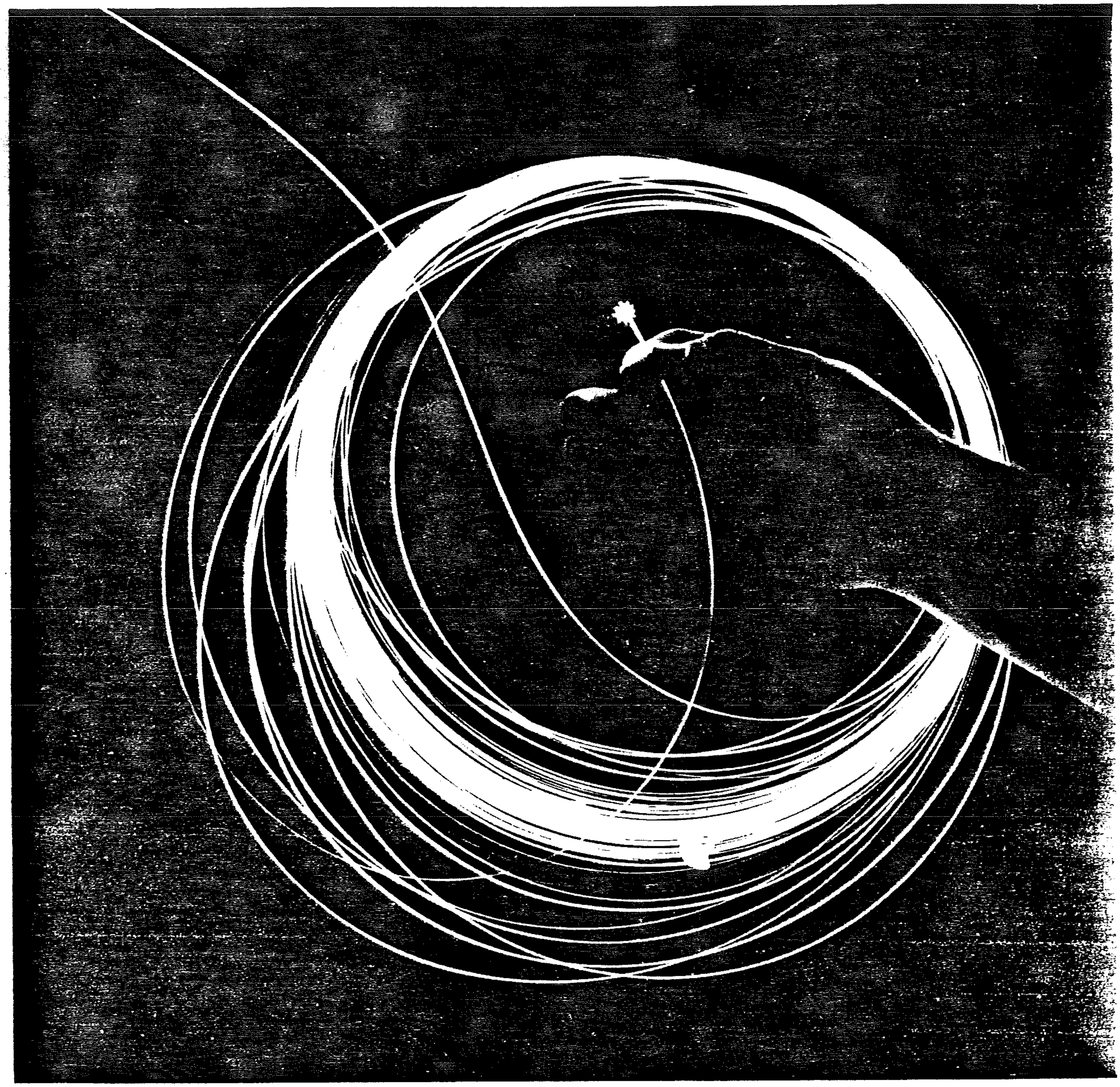
PROCEEDINGS



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High Speed Magnetic Field Sensors Based on Iron Garnets

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1. INTRODUCTION

Optical fiber sensors employing the Faraday effect are now being used in many electric current and magnetic field sensing applications.[1] These sensors typically use diamagnetic materials, such as bulk glass or optical fiber, as the sensing elements, although other materials, such as iron garnets, offer potentially higher sensitivity.[2] Based on the results reported here, we believe that iron garnets are well-suited for many magnetic field sensing applications, particularly when sensitivity and bandwidth are key issues.

2. SENSITIVITY

The dependence of Faraday rotation angle on applied magnetic field for a typical sample of YIG (yttrium iron garnet, $Y_3Fe_5O_{12}$), a commercially available material, is shown in Fig. 1. The data were taken with a laser diode at 1.3 μm. The response is very linear until saturation, which occurs near 80 mT. The sensitivity, defined as the ratio of the saturation Faraday rotation angle to the saturation field, is approximately 0.84 deg/mT for this sample.

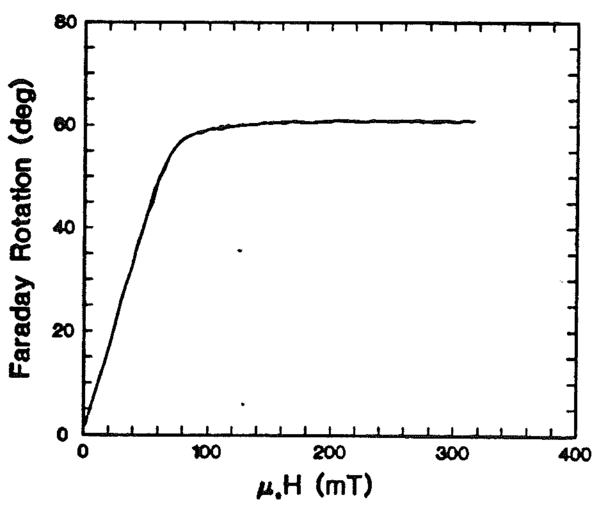

Fig. 1. Faraday rotation versus applied field for YIG sample 5 mm diameter by 3 mm length.

To determine the minimum detectable magnetic field, the setup of Fig. 2 was used. In this experiment, an oscillating magnetic field of 10^{-4} T (1 G) was applied to the sample with Helmholtz coils, and the output of a differential detection system was fed to a signal analyzer. The results, shown in Fig. 3, exhibit a minimum detectable field of approximately 10 nT/$\sqrt{\text{Hz}}$ at 80 Hz.

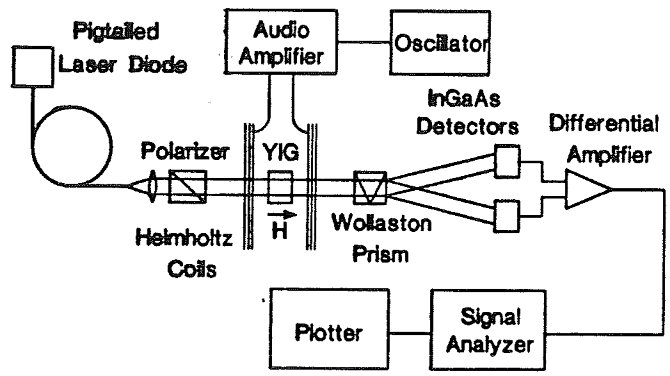

Fig. 2. Apparatus for determining sensitivity of YIG sensor.

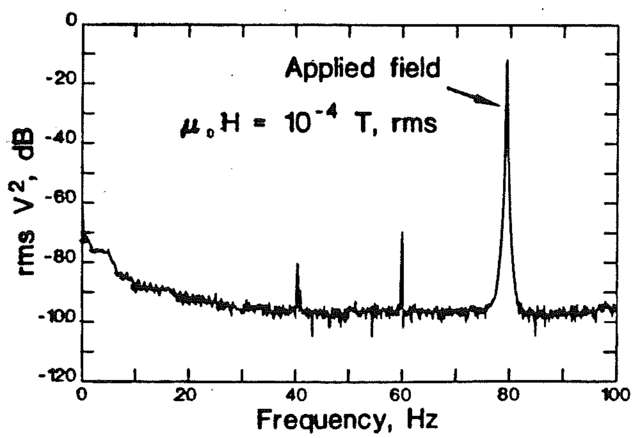

Fig. 3. Noise spectra obtained with apparatus of Fig. 2. Noise bandwidth is 0.187 Hz. The noise-equivalent magnetic field is -10 nT/$\sqrt{\text{Hz}}$.

3. FREQUENCY RESPONSE

The response of a YIG sample was measured at discrete frequencies from 1 MHz to 1 GHz and is plotted in Fig. 4. The field amplitude remained constant throughout the measurements at -0.5 μT. The response appears to be independent of frequency below 500 MHz and has a -3 dB rolloff near 700 MHz, making it suitable for high-speed applications.

4. SUBSTITUTED IRON GARNETS

The magnetic and magneto-optical properties of iron garnets are both extremely dependent on composition and can thus be tailored to improve sensitivity. For example, bismuth-substituted iron garnets exhibit values of saturation Faraday rotation an order of magnitude greater than those of YIG.[3]

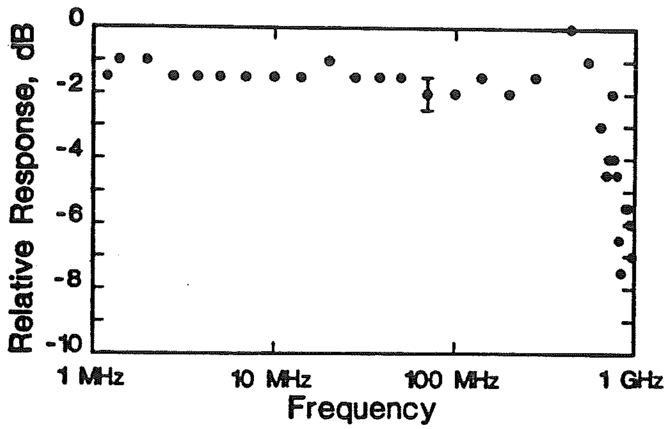

Fig. 4. YIG frequency response.

Alternatively, the sensitivity may also be increased by simply reducing the saturation field, which is done by reducing the saturation magnetization. Substituting small amounts of gallium into iron sites in YIG produces this effect yet does not significantly affect the saturation Faraday rotation angle.[4]

5. CONCLUSION

Iron garnets are attractive materials for use in Faraday-effect magnetic field sensors in terms of both their sensitivity and available bandwidth. Measurements on YIG demonstrated minimum detectable fields of 10 nT/√Hz and a bandwidth of 700 MHz. Other garnet compositions should be substantially more sensitive than YIG.

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