Noise Properties of the Faraday Effect Measurement Systems

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Abstract. Nowadays, nanomagnetic devices have a main role in computer industries. To observe magnetic features of the nanomagnetic device, Magneto-optical effects such as Kerr effect and Faraday effect can be used. We report the fabrication of the Faraday effect measurement setup for characterization of nanomagnetic elements. With achievement of low noise measurement configuration by precision electronic measurements, Faraday effect was observed. The essence of the experiment is to measure a light intensity that is transmitted from the transparent magnetic material. Light intensity is measured by a photodiode detector (Hamamatsu S5870) which produced the laser-induced photocurrent. Using transimpedance amplifier, the signal is converted to the voltage which is measured by the lock in amplifier (Stanford Research SR810). By performing the measurement at different lock-in frequencies and different analyzer angles, we systematically analyzed various random noise sources and their effect to the signal to noise ratio. The interestingly, the noise characteristics of the measured photocurrent exhibit a 1/f noise behavior with a scaling exponent practically 1.

1. Introduction
Spintronics is a multidisciplinary field which has a main role in computer industry nowadays. Mainly, related to speed of data processing and capacity of data storage. Spin term, in this case, according to spin of single electron $s$ which can be detected by its magnetic moment $-g\mu Bs$ ($\mu B$ is the Bohr magneton and $g$ is the electron g factor) or average spin of a group of electrons, expressed by its magnetization [1]. The main goal of spintronics research is to understand interaction between spin particles with its solid state environment and then to get a useful device from this information.

Kerr effect or Faraday effect is the most famous method to explore the spintronics behavior [2, 3]. The first magneto-optic Kerr effect (MOKE) was founded by John Kerr in 1877. He did it while he was investigating the polarization of light reflected by refined electromagnetic rod. This experiment is a simple experiment but very effective to explore spin behavior in a material. It is presently described full information in the context of macroscopic dielectric theory or microscopic theory.

In this work, we describe very basically Faraday experiment setup. In this setup, we explored a noise which is produced by the instrumentation setup, depend on frequency and power of laser. In the measurement system setup, there are several types of noise like, Johnson noise, Shot noise and 1/f noise [4-8]. It becomes important to know the noise behavior before the experiment setup is completed.
2. Experimental scheme

2.1. Faraday effect noise measurement setup

The Faraday effect noise measurement setup is shown in Fig. 1. In this experiment, we used green laser, 532 nm wavelength, 30 mWatt maximum power, as a light source. This light then is chopped by chopper equipment. The chopper is SR540 by Stanford Research System. Its frequency can be controlled until 4 kHz and has several type of reference mode. In a Faraday effect measurement, light as a measuring signal, should be in polarization condition. In this experiment, we used beam splitter polarizer by Newport as a polarizer. Entering a simple configuration optics device, then the laser will be lain on photodiode sensor. The photodiode sensor is S5870 from Hamamatsu which has 5-10 nA dark current. Current signal from photodiode is converted into voltage using transimpedance amplifier. As a measurement voltage signal tool, we used lock in amplifier SR810 by Stanford Research System. The experiments consisted of measuring the noise as a function of frequency and power of laser.

![Figure 1. Faraday effect noise measurement setup.](image)

2.2. Transimpedance amplifier

The circuit that we used to measure the photodiode noise current spectral density is shown in Fig. 2. This is feedback negative circuit amplifier that a resistor as a feedback. The photodiode noise current is amplified by this low-noise transimpedance amplifier. The amplifier and setup are considered to ensure that the total noise, measured at the amplifier output, is dominated by the contribution of the photodiode. The reverse bias current of the diode is supplied by the amplifier via the feedback resistor, connected in a negative feedback loop. Cf is a feedback capacitor that the value is same with the total capacitance parallel to the input port of the amplifier caused by stray capacitance and terminal capacitance of photodiode. The noise of the feedback resistor is modelled by thermal noise with voltage spectral density of $V_{\text{noise(rms)}} = \frac{1}{2}(4kTR_f\Delta f)$, where k is Boltzmann’s constant, T is the absolute temperature, $R_f$ is feedback resistor and $\Delta f$ is bandwidth in Hz. The amount of noise measured by the lock-in is determined by the measurement bandwidth. The lock-in does not narrow its detection bandwidth until after the phase sensitive detectors. In a lock-in, the equivalent noise bandwidth (ENBW) of the low pass filter (time constant) sets the detection bandwidth.
3. Results and discussion

3.1. Frequency effect
The noise from setup instrumentation was measured as a function of frequency. On the log-log scale, the noise behavior of Faraday rotation was divided into 2 part, low and high frequency as illustrated in Fig. 3. For low frequency, the noise response is shown in the first part of Fig. 3, in this term is referred to 45-200 Hz chopper frequency and we used 5f chopper configuration as a frequency reference. At this measurement, the lock in amplifier configures in small frequency reference, such as; synchronous filter slope as of low pass filter and properly time constant. According to this figure, we can see that the noise response decrease as a frequency increase and close to high frequency, it became flat-band and stable.

For high frequency, 400 – 3600 Hz chopper frequency, the noise response is shown in the last part of Fig. 3. At this measurement, the slope of low pass filter of lock in amplifier is 6dB/oct and 3ms time constant. According to this figure, the noise response decrease as a frequency increase and start to be stable at frequency 1000 Hz and absolutely stable over 2400 Hz.

According to this figure, we can see that the noise response has an exponential dependent to frequency. This characteristic is in a good agreement with 1/f noise theory. It makes measurements at low frequencies more difficult.
3.2. Power of laser effect
We also measured the noise response as a function of power of laser. In several constant frequencies, we demonstrated that noise response depends on power of laser. This behavior is shown in Fig. 4. For a high frequency (1000 – 3000 Hz), this dependency is quiet small. Different behavior appears for a low frequency (100 Hz), noise response increase smoothly at one point as power of laser increase.

![Figure 4. Noise response as a power of laser measurement.](image)

4. Conclusions
The general purpose of this experiment is to setup a Kerr effect experiment. At the first study we find out the noise characteristic of this instrumentation. The noise response for this experiment has two behaviors, stable at high frequencies, more than 1000 Hz and unstable at low frequencies, less than 1000 Hz. For this setup, the maximum signal to noise ratio is about $1.572 \times 10^8$. For stability and easily measurement, frequencies chopper should be more than 2400 Hz.

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