

# Assembly of a Faraday modulator for polarimetric measurements

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**Abstract.** We present the construction of a Faraday modulator for use in a polarimeter set up for quartz control plates optical rotation calibration. The choice of a glass type and relevant parameters for modulation are shown as well as initial test results.

## 1. Introduction

Industrial polarimeters and saccharimeters are calibrated by using quartz control plates as standards to ensure traceability. It was built at the Optical Metrology Division (Diopt) – Inmetro a high resolution polarimeter for calibration of quartz control plates by measuring its optical rotation by the polarimetric method [1]. The actual method using a rotating analyzer is detailed at [1, 2]. In this paper we show a Faraday modulator assembly, which will be part of a new set up of the polarimeter [3] with the purpose of comparing the results obtained by two different methods.

## 2. Lock-in modulation

A Faraday modulator consists of a solenoid containing a glass rod inside and an AC power supply wick output is modulated by a lock-in amplifier. The alternated magnetic field inside the solenoid causes the polarization plane of the He-Ne laser radiation to be rotated and modulated as it passes through the glass rod. The radiation is detected at the silicon photodetector connected to the lock-in. The lock-in recovers the modulated signal at the chosen frequency and thus very weak signals can be discriminated against large background noise.

### 2.1. Signal noise

The radiation at the photodetector generates an electrical signal as shown below:

$$V_{\text{signal}}(t) = V_0 + V_{\text{noise}} \quad (1)$$

where  $V_0$  is the signal of interest. It is observed that the noise frequency is proportional to  $1/f$  where  $f$  is the signal frequency. In very low measurements this noise is accepted as a common characteristic called flicker noise (that can be lessened) to the electronic systems caused by several factors. Incident photons in a photodetector is a random quantity that generates other noise source, shot or quantum noise, as known. In the equation (1),  $V_{\text{noise}}$  noise shot and Johnson noise are taken into account among others, and are the photodetector offset. In very low signal measurements, this total noise has great influence in the result of the measurement.



## 2.2. Operation

Basically, lock-in amplifier works in the following way: a sinusoidal signal is generated with the following form:

$$V(t) = V_0 \cos(\omega t) \quad (2)$$

where  $V_0$  is amplitude (voltage) of the signal and other sinusoidal signal, called reference signal (generated by the lock-in itself) at the same frequency  $\omega = 2\pi f$ , but with different angles  $\theta$  (detuned) which reference signal is described as below:

$$V_R(t) = V_{0R} \cos(\omega t + \theta) \quad (3)$$

where  $V_{0R}$  is amplitude (voltage) of the sinusoidal reference signal. The product  $V(t)V_R(t)$  of these two signals is:

$$V(t)V_R(t) = \frac{V_0 V_{0R}}{2} \cos\theta + \frac{V_0 V_{0R}}{2} \cos(2\omega t + \theta) \quad (4)$$

The averaged value of  $V(t)V_R(t)$  gives the resulting low noise exit signal.

## 2.3. Modulation method with Faraday Effect applied in the polarimeter

In the Faraday Effect the radiation linear polarization axis rotates as it passes through a medium immersed in a magnetic field by an angle that is proportional to the Verdet constant of the material. In the modulator an AC current generates an alternating magnetic field. Verdet constant is expressed in International System of Quantities as  $[rad/T \cdot m]$  and frequently encountered expressed in  $[min/G \cdot cm]$ . For assembling the modulator we started from an existing hollow solenoid and we did a study in order to specify the glass rod type and size and later we made the characterization of the solenoid plus glass assembly.

## 2.4. Modulator characterization study

The most important characteristic for the glass rod inside the solenoid is the generation the largest rotation of the linear polarization axis with the smallest attainable magnetic field, in order to keep the solenoid body temperature as low as possible. The best choice was a SF4 glass with Verdet constant of  $0.061 \text{ min/G} \cdot \text{cm}$ . The Verdet constant is defined as the rotation per unit path per unit field strength.

$$B(G) = 3.39654 + 348.4039I(A) \quad (8)$$

And so, a current ( $I$ ) =  $0.15 \text{ A}$  generates a magnetic field ( $B$ ) =  $55.66 \text{ G}$  or  $0.006 \text{ T}$  approximately. And for the proportionality relationship among field, Verdet constant and length of the glass:

$$\theta = VBl \quad (9)$$

where  $\theta$  is the polarization rotation angle in degrees and  $V$  is the Verdet constant value,  $B$  is the magnetic induction and  $l$  is the length of the medium. The generated field results approximately  $0.29^\circ$  ( $0.005 \text{ rad}$ ) or  $\approx 17 \text{ min}$ , enough for the modulating signal necessary for the lock-in amplifier operation. The study showed that a glass rod of  $5 \text{ cm}$  length positioned in the center of the solenoid would provide the ideal rotation for radiation modulation. The glass Verdet constant was recalculated again after measurements of its optical rotation in the polarimeter resulting a value of  $\approx 0.062 \text{ min/G} \cdot \text{cm}$  in agreement with the manufacturer's declared value.

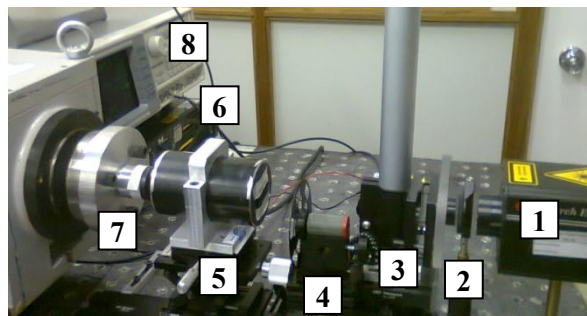
Another accomplished study was the temperature increasing due to the current applied in the solenoid as a function of time and for a given current, with sensors positioned in the solenoid body and in the air at  $1 \text{ cm}$  away from it. We concluded that a current close to  $0.15 \text{ A}$  causes a very small temperature increase in the air around the Faraday modulator and that will not affect the temperature of the quartz control plates because they are isolated inside a thermalization chamber [1].

## 2.5. Test of the modulation system assembly

In the solenoid, an AC current generates an oscillating magnetic field through the glass rod, which causes the rotation of the radiation polarization axis to oscillate at the same applied AC current

frequency. The solenoid is positioned between two linear polarizers and the laser radiation passes through them and is detected by the photodetector and so the input modulating signal for the lock-in amplifier is obtained. To provide the current for the coil, the lock-in amplifier generates a sinusoidal reference signal adjusted in its internal oscillator that feeds in an external amplifier that drives the solenoid.

Figure 1 presents the Faraday modulator experimental test set-up detailed. (1) He-Ne laser; (2) linear polarizer; (3) neutral density filter; (4) chopper (to compare the solenoid modulation – it will not use in final set-up); (5) solenoid; (6) power amplifier; (7) rotating linear polarizer (analyzer); (8) lock-in amplifier.



**Figure 1.** Faraday modulator experimental set-up.

With the assembled system we defined the lock-in reference signal voltage  $(0.500 \pm 0.001) V$ , the frequencies (commons  $50 Hz$  and  $60 Hz$  harmonics free) which we used  $(177.05 \pm 0.05) Hz$ ,  $(137.05 \pm 0.05) Hz$ , and  $(380.05 \pm 0.05) Hz$ , and thus with this parameters the power amplifier provided the expected and necessary current to the system modulation. Table 1 shows a resulting gain in accuracy measurement when using the lock-in amplifier instead of just the voltmeter.

**Table 1.** Voltmeter – lock-in comparative.

Measurement	Voltmeter ( $V$ ) ( $\times 10^{-5}$ )	Lock-in ( $V$ ) ( $\times 10^{-5}$ )	Accuracy increase %
1	2.9	2.583	12.8
2	2.4	2.135	13.0
3	2.1	1.853	13.6
4	1.7	1.509	13.4
5	1.6	1.379	12.5
6	1.5	1.370	11.5
7	1.5	1.314	14.5
8	7.5	6.439	16.7
9	5.6	4.874	14.5

### 3. Acquisition system and first results

The lock-in amplifier was connected in a PC with GPIB interface, and a LabView lock-in control system program was developed to set the parameters, acquire and record the data measurements. With the assembled Faraday modulator the first evaluation measurements were realized. It was studied the signal obtained in the configuration where polarizer and analyzer had their polarization axis at  $90$  degrees, a situation of minimum irradiance reaching the detector. The modulator was able to recover approximately 88% of the signal without noise.

#### 4. Conclusions

Preliminary tests of a Faraday modulator built in the laboratory for polarimetric measurements presented satisfactory results as a considerable attenuation in the noise at low radiation level was reached. In next steps the modulator will be assembled inside the polarimetry system described in [1] to compare both methodologies and realize a complete metrological characterization of all system.

#### Aknowlwdgements

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