Laser power stabilization using acousto-optic modulator and feedback control circuit

Author : Thanarat Phitlam

Advisors: Asst.Prof.Dr. Waranont Anukool

Dr. Parinya Udommai, Ms. Phatwarach Siriworakoonchai

Department of Physics, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

This work presents a laser power stabilization system using an Acousto-Optic Modulator (AOM) integrated with a PID-controlled feedback loop for high-precision quantum research. The system effectively minimizes light intensity fluctuations, which are critical for stable atomic energy level manipulation. Experimental results demonstrate that the power fluctuations were reduced from 3.57% to 1.61% compared to the unstabilized laser, at an average optical power of 190 μW, maintaining stable operation for over 5 hours. Furthermore, the implemented system supports flexible amplitude modulation via arbitrary waveform signals, enhancing its versatility for diverse experimental applications.

Introduction

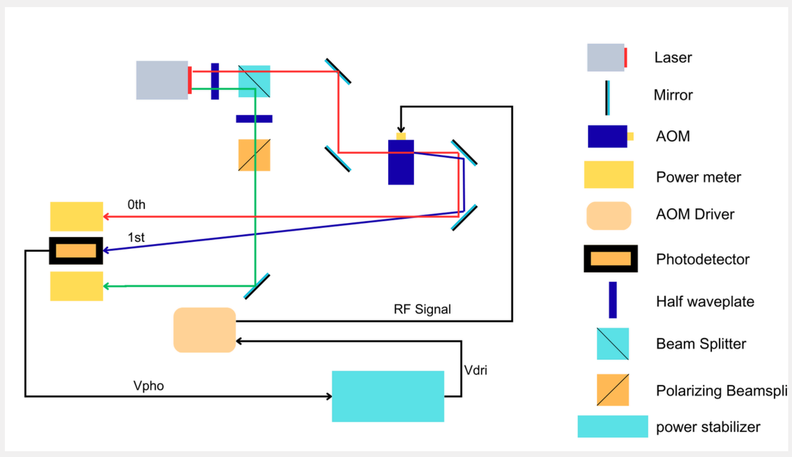
Precise quantum experiments require highly stable laser power, since intensity fluctuations degrade atomic transitions and reduce SNR. In this work, an AOM with PID feedback is used to stabilize laser intensity without direct current modulation, enabling fast, flexible, and robust optical power control.

Experiments

Experimental Setup and System Implementation.



(a) Experimental setup.



(b) System block diagram.

Figure 1: (a) Experimental setup and (b) system block diagram of the Laser power stabilization system using an AOM. A portion of the laser beam is detected by a photodetector to monitor the optical power. The detected signal is compared with a reference value to generate an error signal, which is processed by the PID controller and fed back to adjust the modulation voltage of the AOM driver, thereby stabilizing the laser intensity.

Results

1. Optical Power of 0th and 1st Orders vs. Modulation Voltage (Vmod).

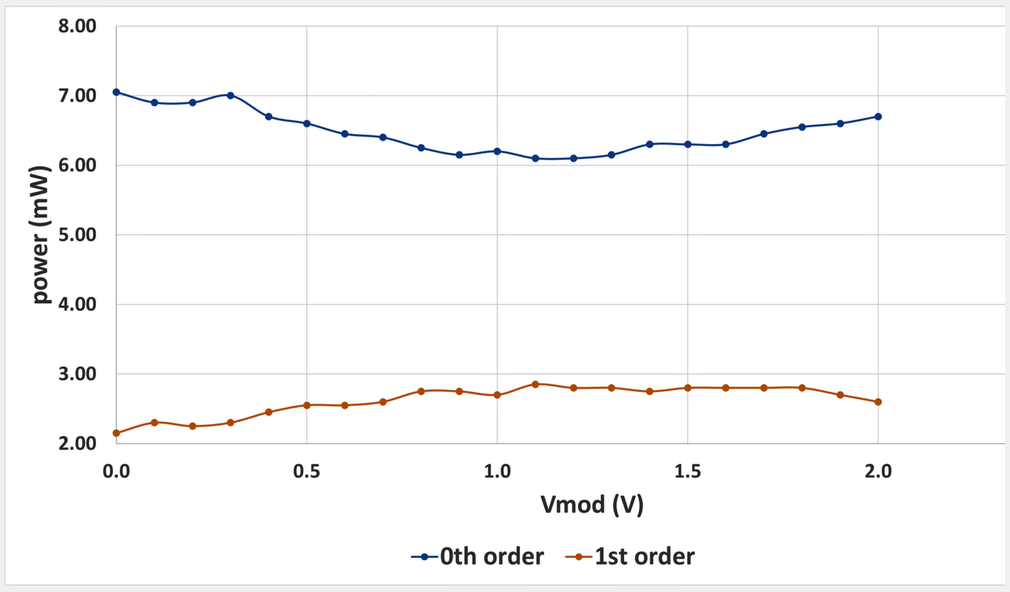


Figure 2: Optical power of the 0th and 1st diffraction orders versus modulation voltage (Vmod). Increasing Vmod increases the diffraction efficiency of the AOM, resulting in higher optical power in the 1st-order beam and a corresponding decrease in the 0th-order beam.

2. Laser Stability Comparison: Before vs. After AOM Stabilization.

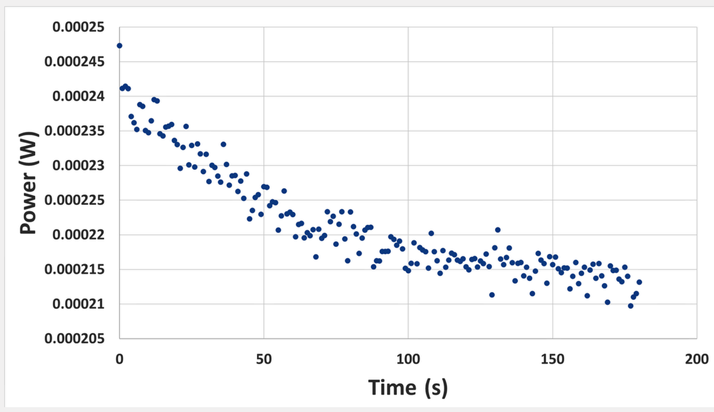


Figure 3: Laser power before AOM stabilization. The laser intensity exhibits noticeable fluctuations over time.

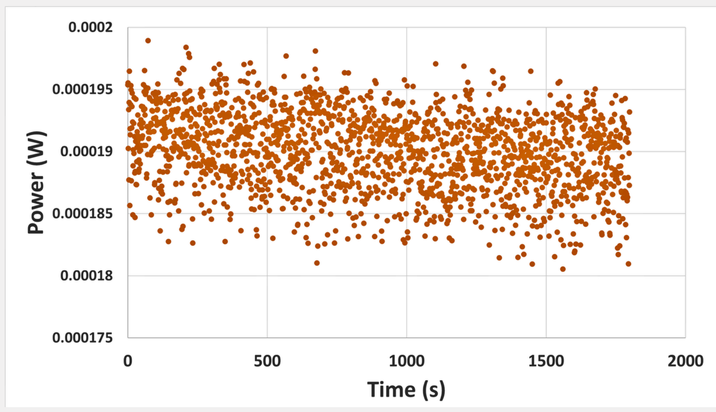


Figure 4: Laser power after AOM stabilization. The fluctuations are significantly reduced due to the PID feedback control.

Before Stabilization	
Power Standard Deviation (%)	3.57%
Average power	221.4 μW
Stability time	5 hours

Table 1: Laser stability parameters before AOM stabilization.

After Stabilization	
Power Standard Deviation (%)	1.61%
Average power	193.2 μW
Stability time	5 hours

Table 2: Laser stability parameters after AOM stabilization.

Conclusions

- A laser power stabilization system using an AOM with PID feedback control was successfully implemented.
- The system reduced laser intensity fluctuations from 3.57% to 1.61%.
- The stabilized laser maintained stable operation for more than 5 hours.
- The results demonstrate effective suppression of laser intensity noise, suitable for precision optical and quantum experiments.

References

[1] A. Korpel, Acousto-Optics, Marcel Dekker, 1988.
[2] K. J. Åström and R. M. Murray, Feedback Systems: An Introduction for Scientists and Engineers, Princeton University Press, 2008.
[3] B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 2nd ed., Wiley, 2007.