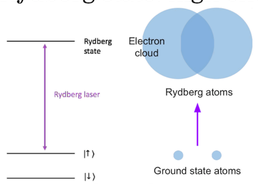
Developing a power stabilization lockbox for precise control of atomic interactions

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Introduction

- Atoms have discrete energy levels
- Can excite to specific energy levels with laser pulses
- Rydberg state: high energy state



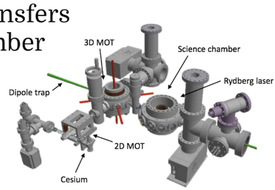
  - Outer electrons highly excited and far from nucleus
  - Interactions on μm scale
- Potential applications
  - Quantum metrology: precise measurements
  - Quantum simulation: study many-body physics with cold atoms

Experiment

- Dipole trap
  - Tightly focused laser applies dipole force to atoms and traps them in 50 μm waist beam
  - Trap depth and number of atoms trapped correlate with beam intensity
  - Focus tunable lens transfers atoms to science chamber



- Rydberg laser
  - Applies multiple short UV pulses to excite atoms to Rydberg state



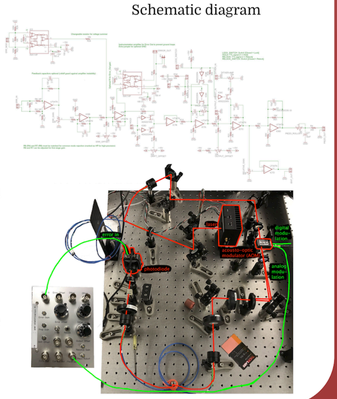
Project goals

- Goal: Optimize power stabilization lockbox to meet experimental set up requirements
  - Dipole trap
    1. **Stable signal**
  - Rydberg laser
    2. **~1 MHz bandwidth**
    3. **Control pulse height**
    4. **Turn on quickly and controllably**

Lockbox

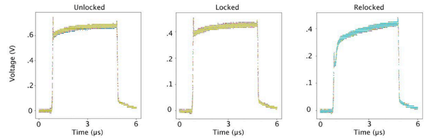
Error in: photodiode signal
Output offset: set unlocked signal
Lockbox out: signal fed back to AOM
Relock: locked when signal low, unlocked when signal high
Error offset: set lockpoint
Error out: difference between photodiode signal and lockpoint

Schematic diagram



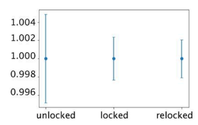
1. Signal stability

- Turned AOM on and off to mimic UV pulses and took 10 traces



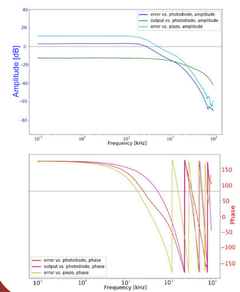
  - Unlocked
  - Locked
  - Relocked: AOM on = locked, AOM off = unlocked
- Integrate to find pulse area, normalize by mean
  - Locking reduced standard deviation of pulse areas
  - Relocking and locking with comparable stability

Standard deviations



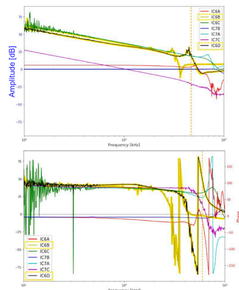
2. Improving bandwidth

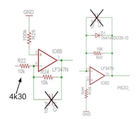
Breaking up bandwidth limitations between AOM and circuit



- Measuring bandwidth: inject noise of varying frequency and observe amplitude and phase response of components
- Comparing contributions of lockbox and AOM to the overall bandwidth
- Lockbox is the limiting component

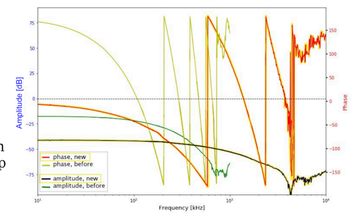
Isolating op-amp contributions to bandwidth





- Measure bandwidth across individual op amps in lockbox circuit
- IC6B, IC6D (left of dashed line, shown above) are slowest
- Change input impedances to improve bandwidth

Optimizing AOM bandwidth



- Add additional fiber to improve shape of beam, and lens telescope to focus beam in AOM
- Bandwidth improved by few 100 kHz

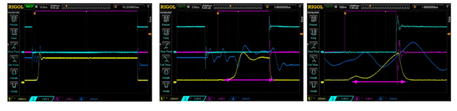
Stabilizing short pulses

3. Change error offset to change pulse height



- Can lock over full range of AOM

Shortening pulses

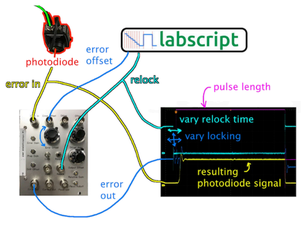


4. Turn on quickly and controllably



Trade start time for sharpness





- Send signals from computer to lockbox, using python script and labscript program
- Amplitude and timing precisely controlled

Next Steps

- Continue improving sharpness of pulse
  - Trade time delay for pulse sharpness
  - Improve bandwidth more
- Implement lockbox in experimental setup
  - Start with 1064 nm dipole trap
  - Improve sharpness for UV laser

Conclusion

- Stable laser power required for better control of atomic interactions
- Bandwidth reached few hundred kHz, can handle 2.5 μs laser pulses
- Can stabilize signal and adjust pulse height
- Lockbox can be implemented for 1064 nm dipole trap,
- Bandwidth should be improved for Rydberg laser

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