

Computer-Based Frequency Drift Control of Multiple LASERs in Real-Time

Altaf H. Nizamani¹, Saeed A. Buzdar², Bilal Rasool³, Nek M. Shaikh¹, Hussain Saleem⁴

Abstract— This research presents a LASER locking scheme that provides considerably much higher stabilization of LASER frequency in real-time environment. The scheme is implemented using LabVIEW Software in Real-time Operating System (RTOS). The scheme allows stability of the LASERs within the line-width of the respective transitions. Using this scheme, the Extended Cavity Diode LASERs (ECDL) are locked to a saturated absorption curve of a reference LASER automatically. The system can remain locked for several hours. The scheme also provides a human friendly interface and allows access to tune the LASER frequencies.

Index Terms— Data, Frequency Drift, Frequency Locking, Imaging System, LabVIEW, LASER, Real-Time Operating System (RTOS)

1 INTRODUCTION

TRAPPING single atom is described as one of the most demanding experiments in atomic physics. Trapped and LASER-cooled ions are considered as most promising agents for the realization of an ion trap quantum computer [1],[2]. Ion trapping experiments require a number of LASERs operating at the required frequency to perform cooling and trapping of ions. The frequency of the cooling LASERs must be tuned very accurately relative to the transition frequencies of the trapped ions. The LASERs are frequency stabilized within the line-width of the respective transitions for efficient cooling and re-pumping requirement. In order to obtain flexibility and interactivity, the computer software-based graphical environment is developed using LabVIEW. The LabVIEW environment provides a robust control to the hardware used in frequency stabilization setups [3],[4],[5]. To ensure the deterministic behavior, the computer program is implemented on the Real-Time Operating System (RTOS) provided by National Instruments i.e. NI-RTOS. The key difference between RTOS and general computing operating systems (such as Windows, Linux, UNIX etc.) is the deterministic timing behavior which is the feature of RTOS. Deterministic timing means that the operating system consumes only known and expected amount of time. The RTOS operates in a controlled environment in which computer memory and processing power is limited. The RTOS controls the tasks execution on application software and provide their services within a strict time window to their users by running the tasks in a very timely and responsive way. The NI-RTOS installed computer (Target) used in our lab communicates with the personal computer (Host) via Ethernet network. The locking program runs on the target PC and its display and controls are monitored by using the host PC which runs with a Windows Operating System (Win/OS).

2 EXPERIMENTAL MODEL

A schematic diagram of our LASER frequency stabilisation setup is shown in Figure-1. There are three major parts of the scheme: (1) the stabilized LASER system, (2) the optical cavity and (3) computer controlled feedback based on synchronized scanning of the piezo-electric transducer (PZT) combined with data acquisition. Figure-1 also depict the LASER locking-scheme and alignment into the trap. The computer controlled program in LabVIEW real-time module simultaneously scans the cavities and generates error signal to control the drift in the LASER frequencies via feedback system.

2.1 LASER Setup

To ionise Yb (Ytterbium) and excite its internal energy states in an ion trap experiment, 369-nm, 399-nm, 638-nm and 935-nm coherent light sources are required. The External Cavity Diode LASERs (ECDL) are in common use in ion trapping and LASER cooling experiments. This flexibility of the ECDL makes them a primary choice for LASER systems for the experiments. ECDL frequency and output power can be varied by varying the current and the temperature of the diode along with the grating angle. To provide the first stage of the photo-ionization process for Yb atom, light at 399-nm is used to resonantly excite it from the $^1S_0 \rightarrow ^1P_1$ transition [6]. For the second stage, it is achieved by using light at 369-nm. It also cools the trapped ion immediately after ionization by exciting its $^2S_{1/2} \rightarrow ^2P_{1/2}$ dipole transition. The 369-nm light is generated by frequency doubling of light at 739-nm using a nonlinear crystal Lithium Triborate (LBO). The 739-nm light is generated by built-in ECDL setup. Light at 935-nm is used as a re-pump source to drive the $^2D_{5/2} \rightarrow ^3D[3/2]_{1/2}$ transition to prevent the ion being lost to the dark state $^2D_{5/2}$. The frequencies of the LASER diodes are strongly sensitive to temperature change, electric current and cavity length (acoustic oscillations). To avoid any drift in cooling LASER frequencies, it is necessary to lock the LASERs with a known frequency reference during the trapping and cooling experiments. Various electrical and optical methods have been experimented to improve the frequency stability of LASER diodes. The locking scheme in our lab is done by locking 739-nm and 935-nm LASERs to a passively stable reference cavity using an RF (Pound-Drever-Hall) lock.

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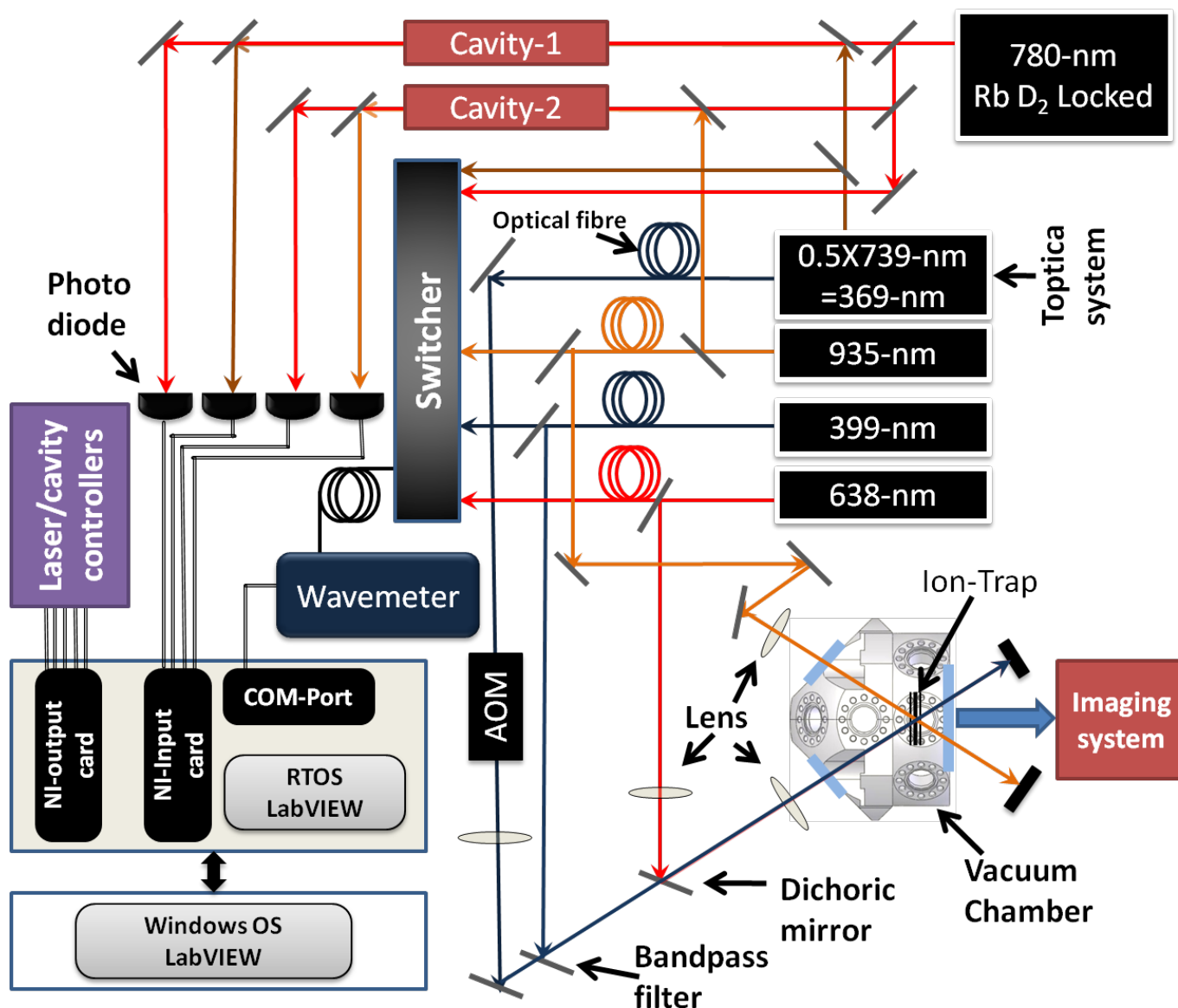


Fig-1: LASER locking-scheme and alignment into the trap. The computer control program in LabVIEW Real-Time module simultaneously scans the cavities and generates error signal to control the drift in the LASER frequencies.

2.2 Reference LASER

When the absolute LASER frequency stabilization is required, it is normal to lock the frequency of the LASER to an atomic standard using saturated absorption spectroscopy. Those frequency references which utilise the natural atomic transition lines, are in common use in LASER locking schemes. In order to keep the reference LASER locked with known standard wavelength, in our lab, Rb D₂ transition line with $\Gamma \sim 2\pi 6$ MHz is used as a frequency reference.

In order to provide a frequency reference, a 780-nm ECD LASER setup is constructed in the lab. The frequency of the 780-nm LASER is locked to one of the hyperfine atomic transitions of Rb. To access the hyperfine transition of Rb, a saturation absorption spectroscopy setup is constructed in lab [7],[8],[9].

Two counter-propagating overlapping pump and probe LASER beams, with 1.3 mW and 0.1 mW power respectively are crossed through a Rb cell. Figure 2(a) shows the saturation peaks with a Doppler background spectrum of Rb⁸⁷ and Rb⁸⁵ isotopes. The corresponding transitions are shown in Figure 2(b). The saturation peaks are obtained by scanning the LASER frequency around the resonance transition. By electronically differentiating the saturation peak signal using a Lock-in amplifier, a sharp zero crossing point at FWHM (full width at half-maximum) of the resonance corresponding to zero of the gradient is obtained. The feedback signal to stabilize the LASER around this zero crossing is then provided to the LASER controller using proportional integration (PI) controller. This locking scheme provides a stabilized frequency reference with an accuracy of less than 1MHz. This LASER is then used to lock the cooling LASERs by the transfer cavity lock method.

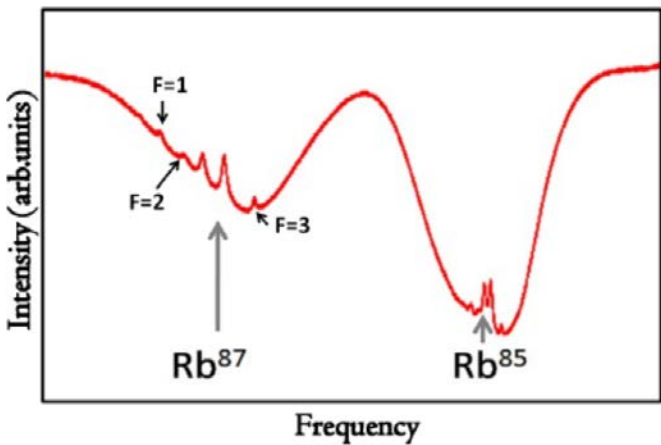


Fig-2(a): The saturation absorption spectroscopy signal obtained by scanning the LASER over the Rb⁸⁷ and Rb⁸⁵

2.3 Transfer Cavity Lock

There are two separate Fabry-Perot confocal cavities being used. A combined beam of stabilized 780-nm and 739-nm LASERs using a polarising beam splitter is aligned into one Fabry-Perot confocal cavity and 935-nm is combined with the 780-nm in the other cavity. In order to achieve the resonant peaks, the cavity is scanned at the speed of 50 to 70 Hz by applying a ramp voltage function to the piezo at the cavity. The output beam from the cavity is then split into its constituents using a second polarizing beam splitter and the intensities of two beams measured using photodiodes. The signal from the photodiodes is then read in computer controlled electronic analog to digital convertor (ADC) cards.

2.4 Wavemeter Lock

The absolute error on the wavemeter used in the lab is specified as ± 60 MHz and its relative uncertainty is ± 10 MHz. Therefore, the wavemeter can also be used to lock those LASERs where this level of accuracy is acceptable. Hence, the 399-nm ionisation LASER and 638-nm re-pumping LASERs are locked directly to the wavemeter. To achieve this, a LabVIEW program running on the wavemeter computer sends the frequency/wavelength values of the LASERs which has to be locked, to the RTOS computer, via the COM-Ports of both computers.

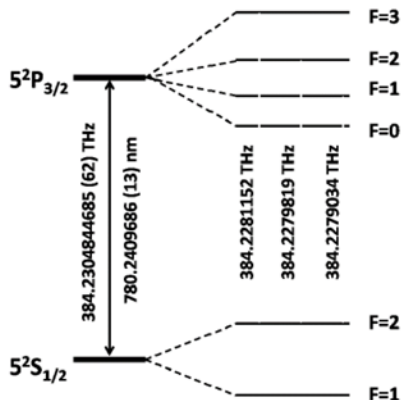


Fig-2(b): Hyperfine structure of Rb⁸⁷ D₂ line

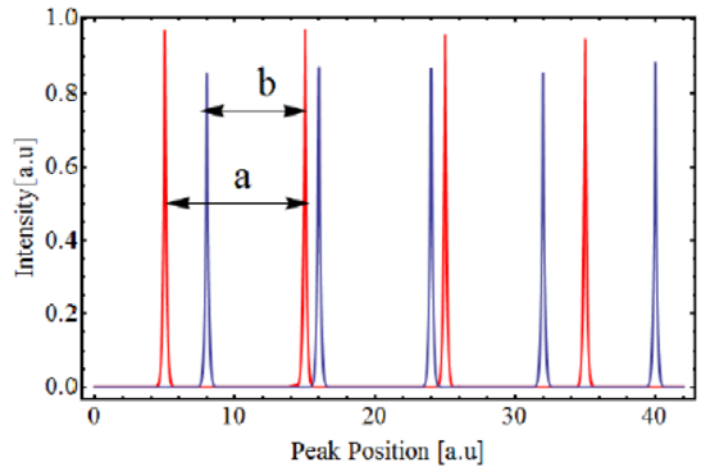


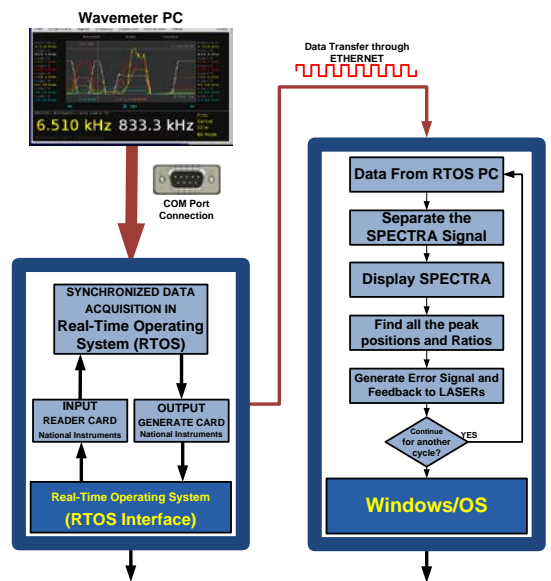
Fig-3: The distance between the two reference LASERs (780-nm) peaks is denoted as *a* and the separation between unstable LASER (739-nm or 935-nm) peak and the reference LASER peak is denoted as *b*.

3. SYNCHRONIZED LASER SCANNING AND FEEDBACK SYSTEM

In order to provide long-term stabilization to the LASERs used in our lab, a computer-based multifunctional data acquisition system scans the LASER cavities and synchronously reads the cavities spectra of the multiple LASERs. By comparing peak positions relative to the stabilized Rb-locked 780-nm LASER, the computer generates the error signal in real-time to control the long-term drift of the LASERs. The voltage signals from the photodiodes are read through the National Instruments (NI) Data Acquisition Card PCI-6143 S-series DAQ shown in Figure-4, which we have configured accordingly keeping in view electronic signal parameters.



Fig-4: National Instruments (NI) Data Acquisition Card PCI-6143 S-series DAQ, Input Read Card



Software Interface
LabVIEW User Friendly front panel of the Real-Time LASER Control Program



Fig-5: The Block Flow diagram of the Real-Time LASER locking program, which controls the cavity scan, data acquisition and LASERS parameters

The computer program written in the LabVIEW Real-Time module continuously displays the spectra of the fringes for all the LASERS which are sent through the cavities. The spectra fringes are obtained by scanning the lengths of the cavities with PZT. After each scan, the program calculates the fringe position of the reference LASER (Rb-locked 780-nm LASER) and the other LASERS and then corrects the drift in the LASER frequencies by adjusting the voltages that are sent to the controller of the grating of the LASERS. The error signals are generated by keeping the ratio of the positions of the spectra peaks of the LASERS a/b as constant value. The same technique is used in [10]. The position of the peaks is illustrated in Figure-3. The error signal is then translated into a voltage signal and generated at the analog output card (NI PCI-6722) for feedback to the LASER controllers.

The LASER locking program written in LabVIEW is illustrated in the block diagram shown in Figure-5. The

Software interface front panel of the LabVIEW program provides control boxes where the required wavelength can be typed-in. The program computes an error signal by comparing both the required and measured values. The calculated feedback is then sent to the LASER controller via the output card (PCI-6722).

4. CONCLUSION

We have successfully demonstrated a robust scheme for LASER frequency locking based on the real-time LabVIEW module implemented using commercially available NI-cards. The scheme provides a fast control over the LASER system. By using this locking-scheme the frequency of 739-nm and 935-nm LASERS are locked down to ~ 20 MHz. The 399-nm ionisation LASER and 638-nm re-pumping LASER are locked down to 60MHz. Furthermore, the scheme provides an easy access to tune the LASERS ranging in several hundred megahertz.

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REFERENCES

- [1] J. I. Cirac & P. Zoller, "Quantum Computations with Cold Trapped Ions", *Phys. Rev. Lett.*, 74, 4091, (1995).
- [2] C. Monroe, "Quantum Information Processing with Atoms and Photons", *Nature* 416, 238, (2002).
- [3] Canuto, Enrico, & A. Rolino, "Multi-Input Digital Frequency Stabilization of Monolithic LASERS", *Automatica* 40, 12, 2137-2145, (2004).
- [4] Liu, Dandan, et al., "Automatic Digital Frequency Locking System of Extended Cavity Diode LASER based on LabWindows/CVI", 2nd IEEE Intl. Conf. on Information Sc., & Engg., (ICISE), (2010).
- [5] J. A. Smith, et al., "LabVIEW-based LASER Frequency Stabilization System with Phase-Sensitive Detection Servo Loop for Doppler LIDAR Applications", *Optical Engineering*, Vol. 47, 1-9, (2008).
- [6] Tamm C., et al., "¹⁷¹Yb+ Single-Ion Optical Frequency Standard at 688 THz", *Instrumentation and Measurement, IEEE Transactions on*, Vol.56, No.2, 601-604, (2007).
- [7] James J. McLoughlin, Altaf H. Nizamani, James D. Siverns, Robin C. Sterling, "Versatile Ytterbium Ion Trap Experiment for Operation of Scalable Ion-Trap Chips with Motional Heating and Transition-Frequency Measurements", *Phys. Rev. A*, 83, 013406, (2011).
- [8] Altaf H. Nizamani, M.A. Rind, Nek M. Shaikh, A. H. Moghal & Hussain Saleem, "Versatile Ultra High Vacuum System for ION Trap Experiments: Design and Implementation", *Intl. Journal of Advancements in Research & Technology, USA*, Vol.2, Issue.5, (2013).
- [9] S.A. Buzdar, M. Afzal Khan, Aalia Nazir, M.A. Gadhi, Altaf H. Nizamani & Hussain Saleem, "Effect of Change in Orientation of Enhanced Dynamic Wedges on Radiotherapy Treatment Dose", *Intl. Journal of Advancements in Research & Technology, USA*, Vol.2, Issue.5, (2013).
- [10] Zhao, W. Z., et al., "A Computer-Based Digital Feedback Control of Frequency Drift of Multiple LASERS", *Review of scientific instruments*, Vol. 69.11, 3737-3740, (1998).



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