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Designing a Repump Beam Path for an Optical $^{171}Yb^{+}$ Ion Clock

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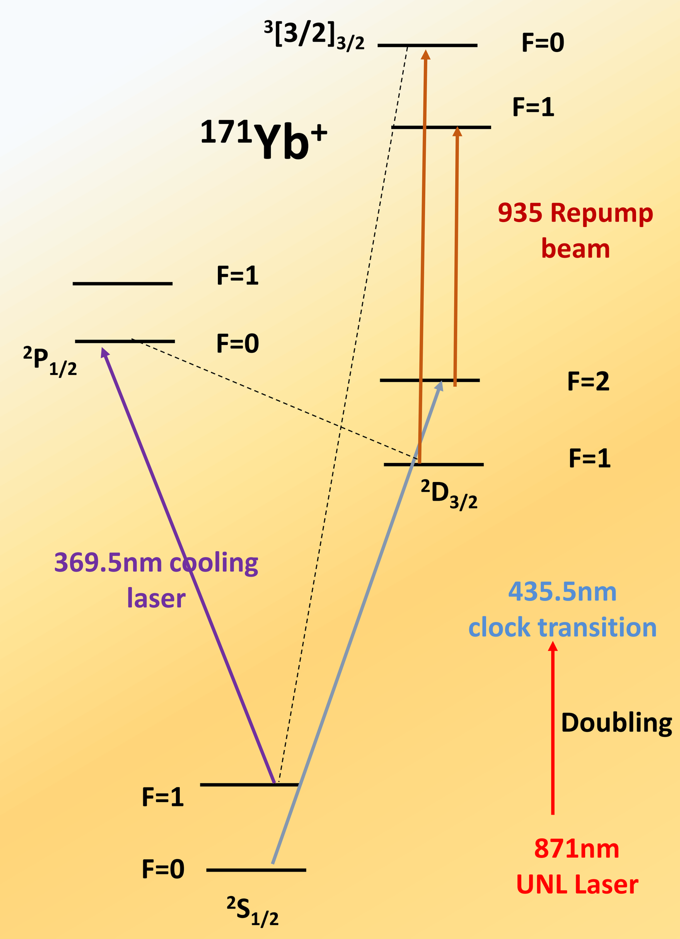
Abstract: We designed a 935 nm repump beam path for use in a Ytterbium ion based optical clock. This state of the art clock work makes use multiple ensembles of ions trapped in separate RF potentials. Separate beams are amplified for coupling into the chip's integrated waveguides for precision pumping of ions out of dark states.

The board acts as both a switch and modulation board. The pump beam is frequency locked to a wavemeter. Two beams are amplified and coupled into the integrated waveguides. The other two beams will be used for free space light delivery.

Optical Atomic Clocks: Current atomic cesium clocks count in the range of microwave frequencies with uncertainties approaching 10^{-16}[1]. Optical atomic clocks based on ultra-stable laser addressing of narrow atomic linewidths achieve frequency uncertainties of ~10^{-18}[2]. These advanced clocks will impact technologies which rely on precision time keeping such as GPS, computing, and communication.

Repump Beam Design Objective

- Design a compact modulation board for delivering light to the ensemble of ions in the testing apparatus
- Fit all the components of the switch board on a 18 x 24 breadboard
- Design parameters
  - 1 beam to frequency lock
  - 2 beams to be amplified for coupling into waveguides
  - 2 beams to address ensembles through free space
- *935 nm beam addresses dark states which can occur during cooling*

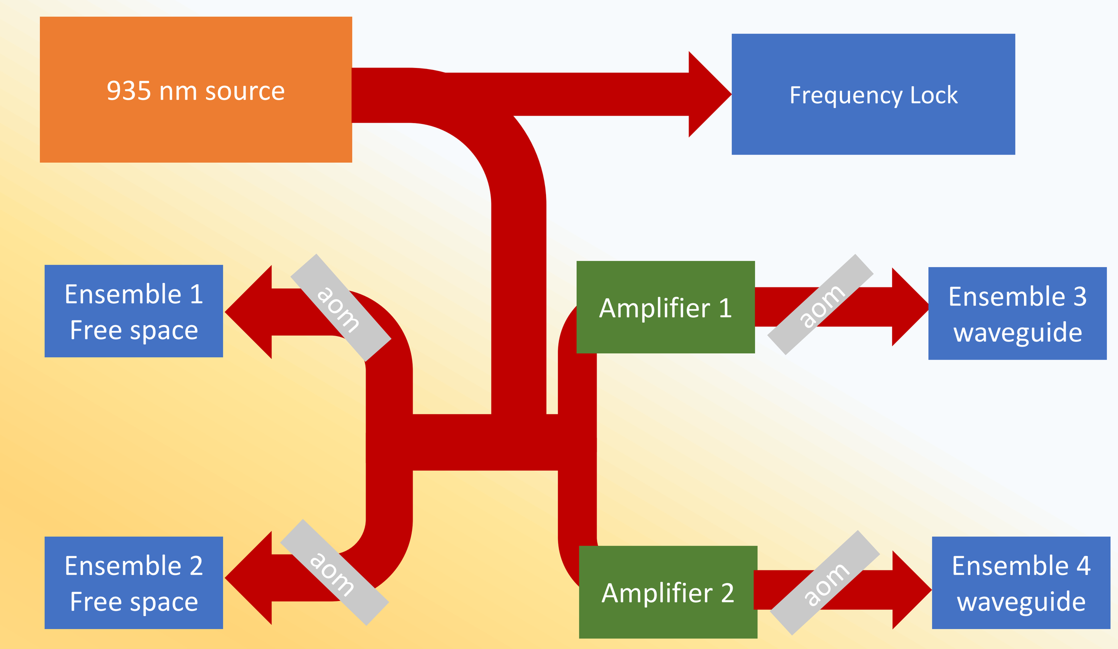


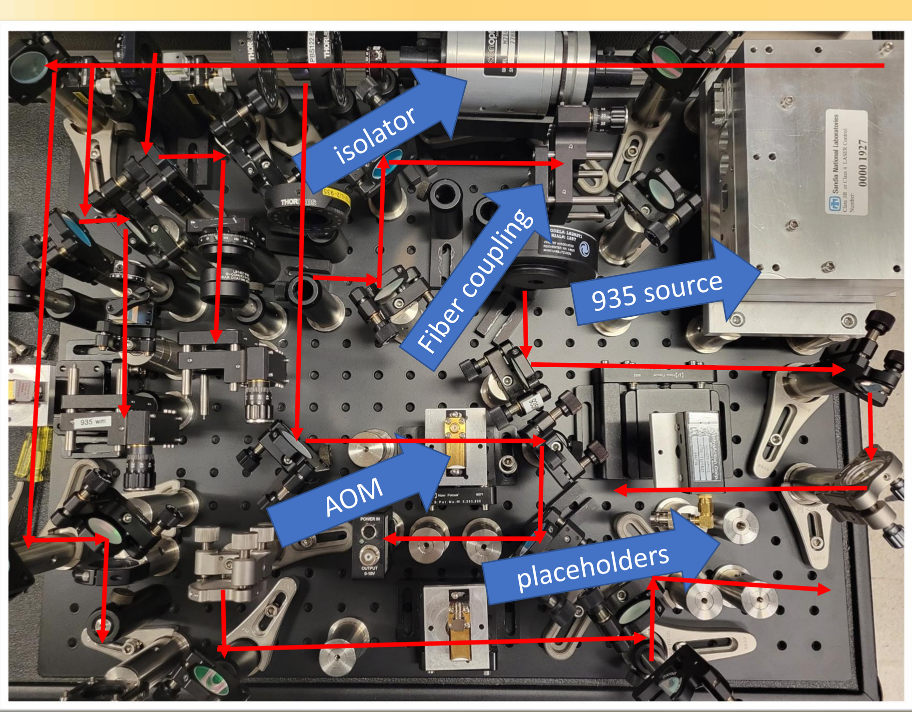
Optical Sources

- *Clock transition beam:* 871 nm diode laser is doubled to 435.5 nm
- *Repump beam:* using custom 935 nm laser
  - Used to address dark states
- *Cooling beam:* 369.5 nm laser used for doppler cooling

General Design

- Simplified beam path diagram
- Depicts the overall design parameters
- Redesign fulfills need for addressing more ensembles



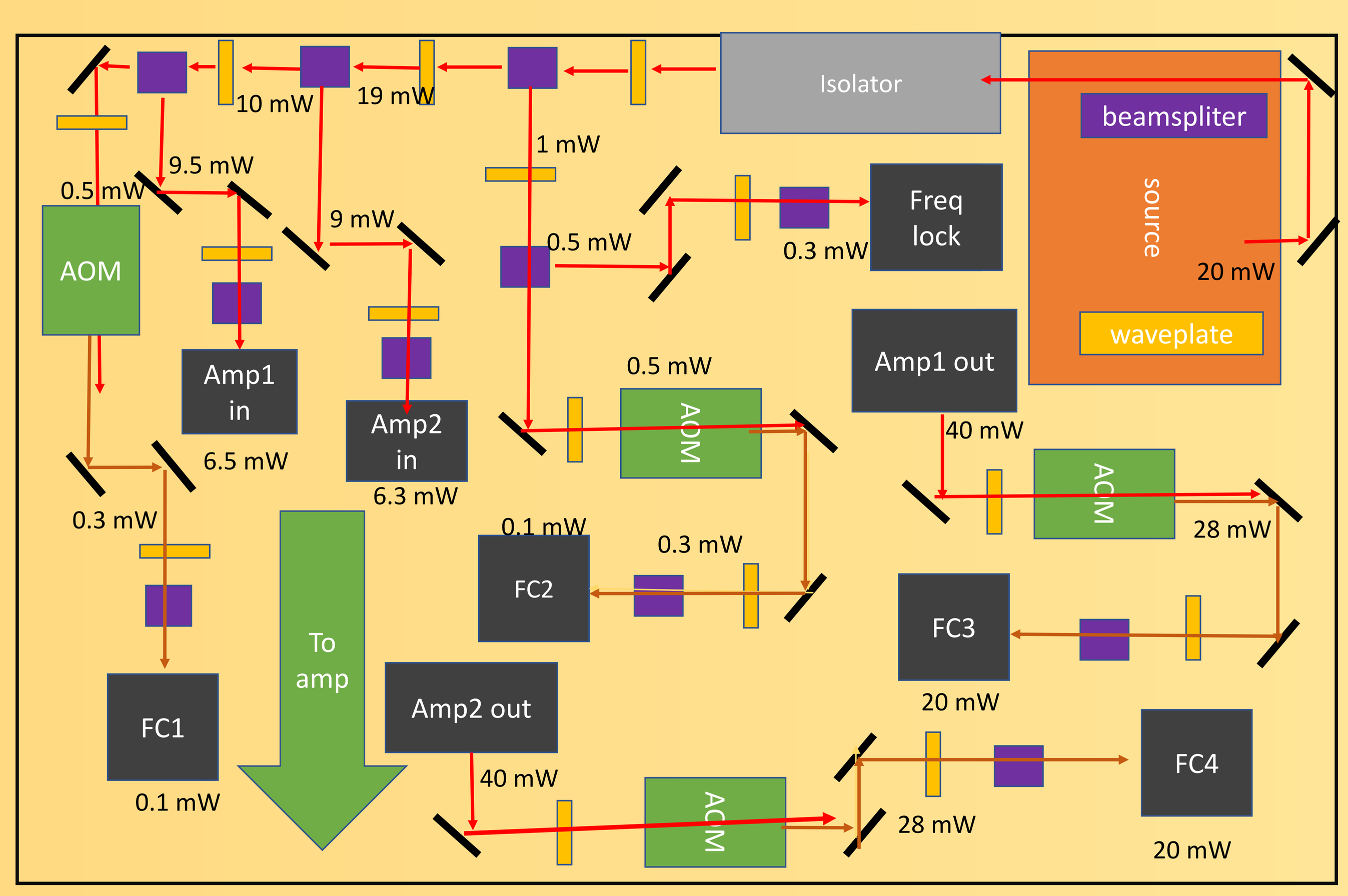


Challenges in implementation

- Source power input is on same side as the beam output
- 18"x24" is very small for this many components
- 9 total fiber coupling assemblies are bulky and require space for fibers
  - 7 input and 2 outputs
- AOMs are bulky and require precise alignment

Repump beam switchboard design parameters

- Address 4 different ensembles
- Acousto-optical modulators used for switching
- Fiber coupled amplifiers require polarization matching
  - ~0.1 mW power for free space addressing
  - ~20 mW power for integrated waveguides due to loss
- Fit all components on 18"x24" optical breadboard



Robust Optical Clock Network (ROCkN) Size, Weight, and Power (SWaP)

- *200 L* total package – including:
  - Optics
  - Ion pump
  - Technology on chip
  - Ultra-high vacuum chamber

Performance

- Clock instability of $\leq 10^{-15}/\sqrt{\tau}$

Clock Instability Equation

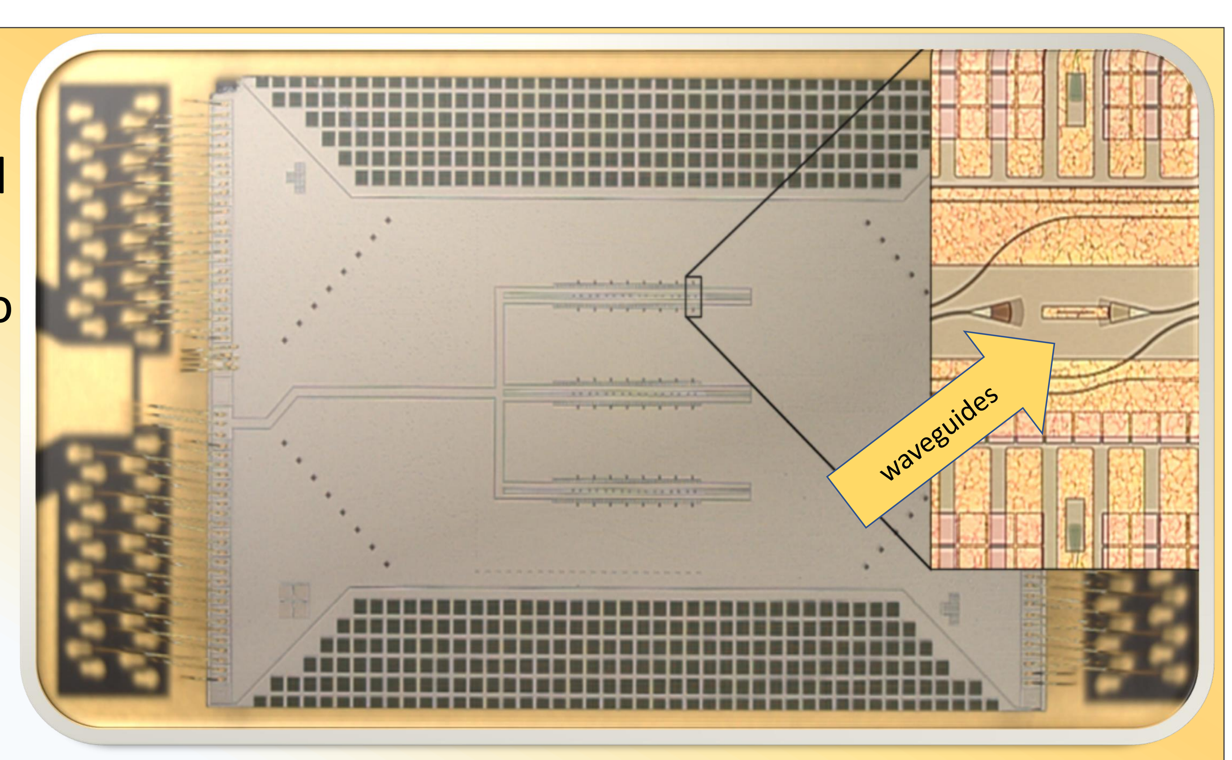
$$\sigma_y(t) \approx \frac{\Delta\nu}{\nu_0\sqrt{N^m}}\sqrt{\frac{T_c}{\tau_m}}$$

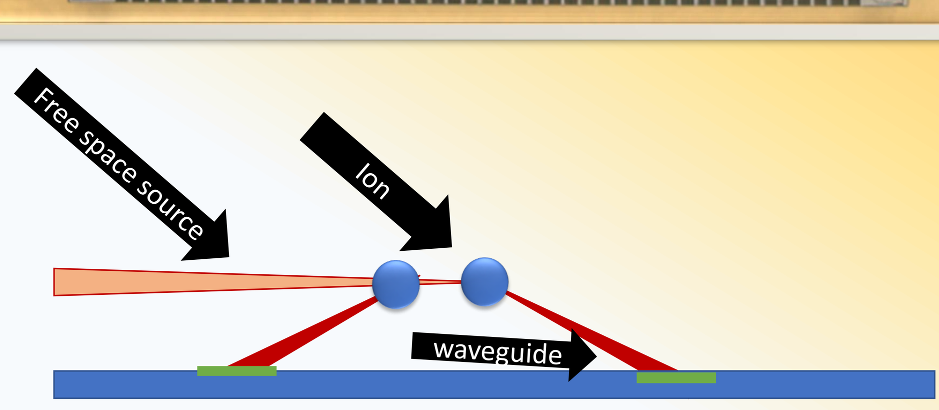
N = # of ions,
T_C = cycle time,
τ = interrogation time,
Δν = transition linewidth,
ν0 = transition frequency,
m = ensembles

Frequency Instability	
State of the Art Optical Clocks	~10^{-18}
CSAC	~10^{-10}
Volume	
State of the Art in Lab	11,000 L
CSAC	0.017 L

Ion Surface Traps

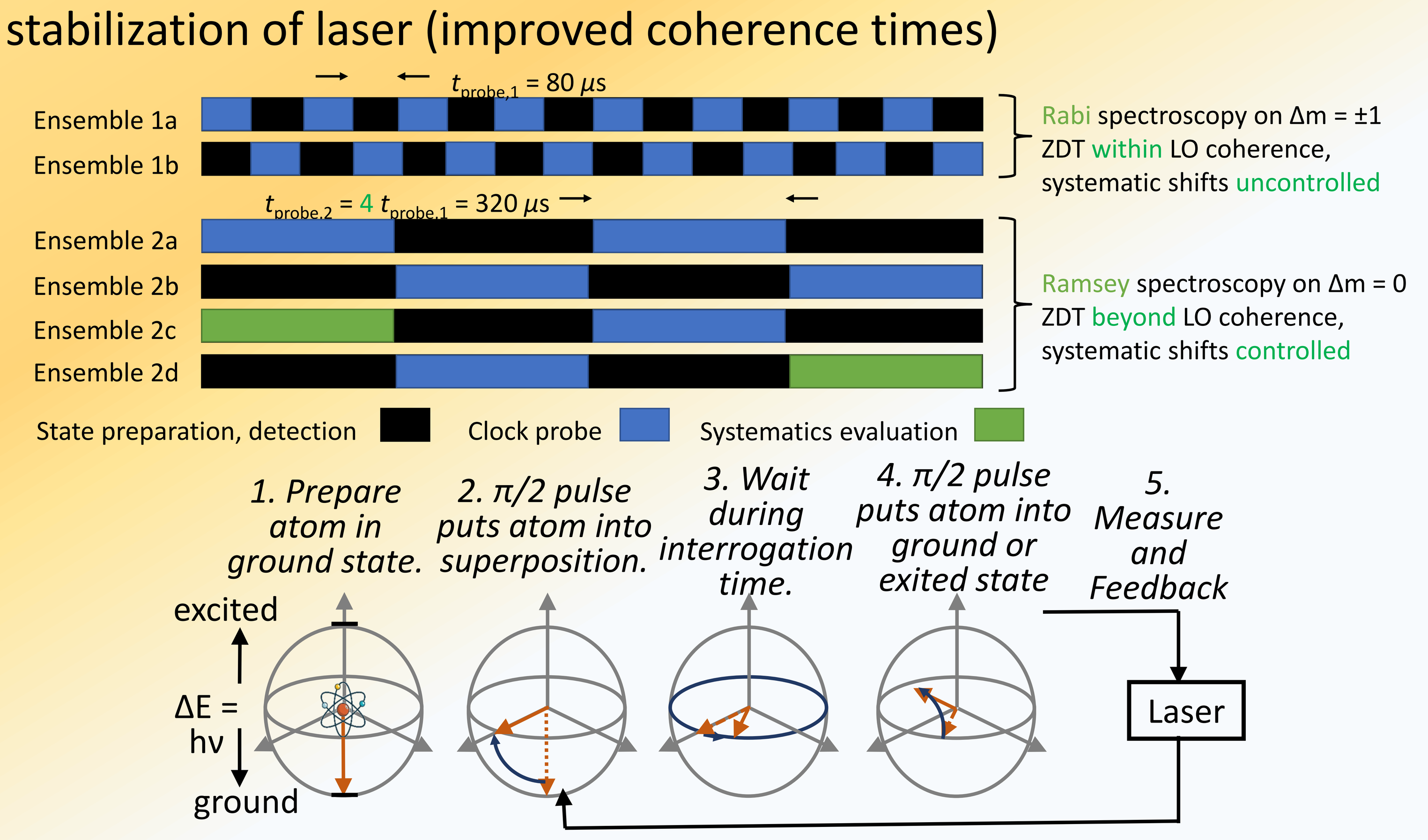
- Atomic ion's are trapped in RF potentials can be swapped and shuttled to precise locations.
  - Fabricated at Sandia's MESA facility
- *Integrated Alumina and SiN waveguides* allow delivery of light to the ions [3]
  - Delivered light is used for cooling, clock interrogation & repump





Multi-ensemble interrogation scheme

- Clocks with less than 1 ns per year error
- Multi-ensemble approach reduces dead time and the need for cavity stabilization of laser (improved coherence times)



References

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[2]S. M. Brewer et al., "$^{27}Al^{+}$ quantum-logic clock with systematic uncertainty below 10^{-18}", Phys. Rev. Lett. 123, 033201 (2019)

[3]M.K. Ivory et al., "Integrated optical addressing of a trapped ytterbium ion", submitted to Phys. Rev. X

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LAB

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