RF over Fiber
Optical Fiber Thermal Compensation for Femtosecond Timing

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Define the Problem

At SLAC, we use an RFOF timing system for the synchronization of the experiment lasers to the X-ray beam. The RFOF fiber is run ~5km from the injector to the NEH, with a portion of the fiber running through the Klystron Gallery. This fiber sees significant changes in temperature which affect the index of refraction of the fiber, thus affecting the timing. Natural variations in temperature cause phase changes, allowing the timing to drift. The timing must be accurate within a few femtoseconds, so we must control the temperature of the fiber optic to control the timing drift.

Fig 1: Klystron Gallery

Research and Design Concepts

Temperature can be controlled using a solid, liquid, or gaseous interface. The most effective method of temperature control is through liquid. A liquid temperature control system can either be open (cheap and simple) or closed (better performance). Our initial design concept was to have the fiber optic spool sit in a bath of water, pumping water in and out from our chiller unit to the bucket. I designed a feed-through so the water and fiber lines could enter a sealed bucket.

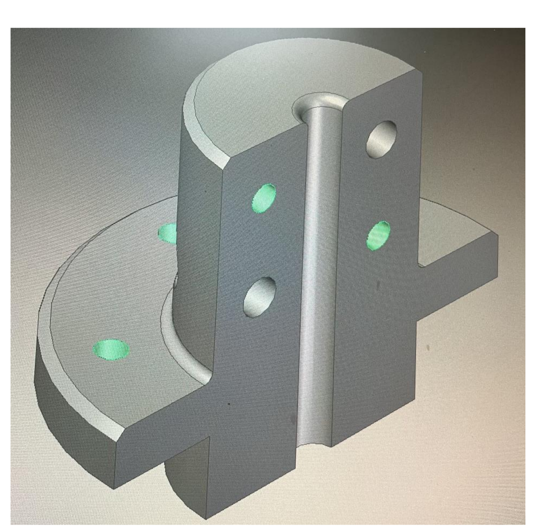


Fig 2: Bucket lid with feedthroughs installed (Right)
Fig 3: CAD model of clamshell waterline feedthrough (Left)

Prototype

An Ultimaker 3 was used to fuse PLA layer by layer into the shape of the feed-throughs. I drilled holes in the bucket lid and tapped threads into the feedthrough. I then put two feedthrough pieces around a ¼" water line and secured the feedthrough to the bucket. I used a ¼" Swagelok fitting to hold down the water line and used a ¼" Swagelok to 3/8" NPT fitting to attach the water lines to the chiller. Running the water lines straight into the bucket did not work because there was not enough pressure building up to push water back into the chiller. I then transition the setup to a closed loop of copper tubing. The chiller ran in this state without starving the water reservoir in the chiller.

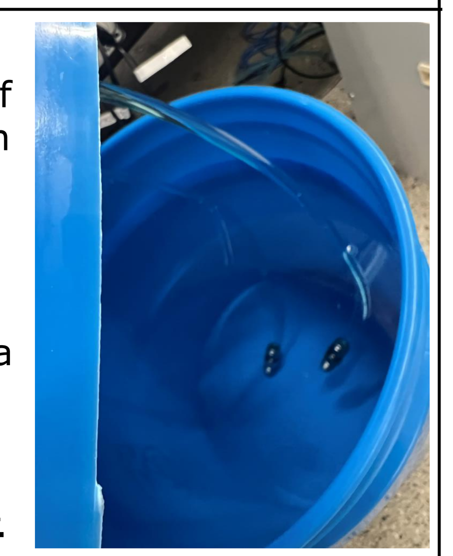
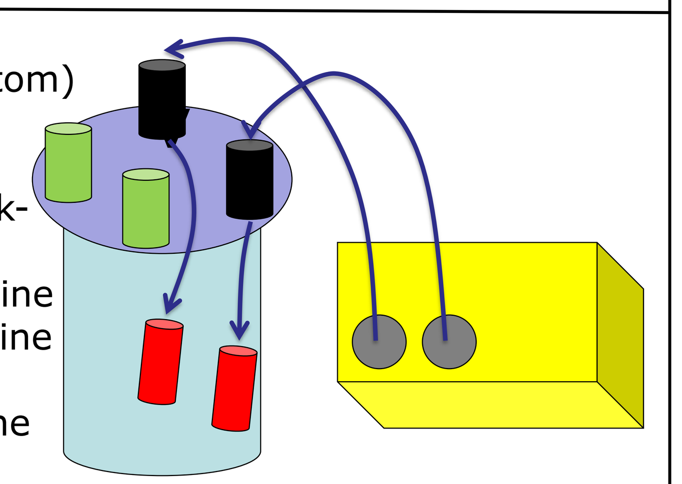
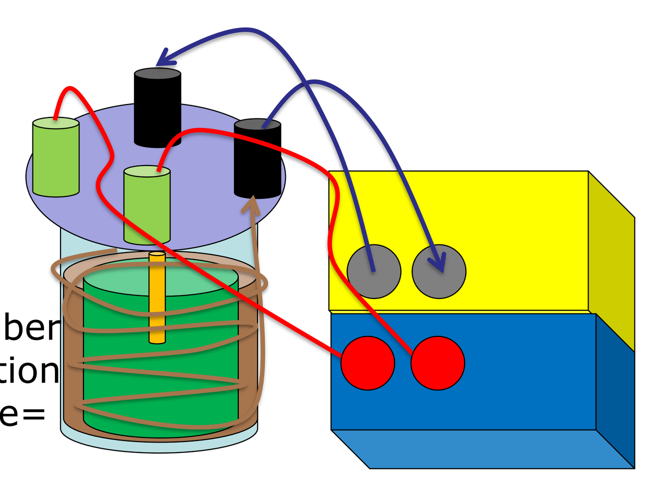


Fig 4: Open lines pour in the bucket (Top)
Fig 5: Closed copper coil loop (Bottom)

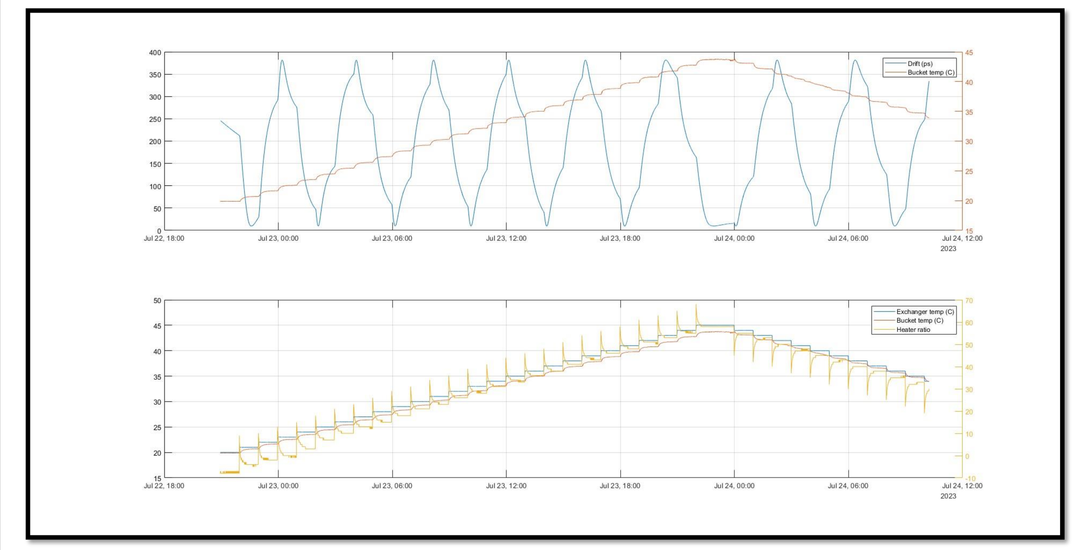
Fig 6: Prototype (Top)
Fig 7: Test setup (Bottom)
Key-
yellow box= chiller
gray circles= Swagelok-NPT fitting
blue lines= ¼" water line
black cylinder= waterline feedthrough
red cylinder= water line weight
light blue cylinder= bucket
purple circle= lid
orange cylinder= thermocouple
dark green cylinder= fiber spool
red lines and circle= fiber optic line and termination
brown cylinder and line= copper coil
blue box= phase detector





Test and Refine

Fig 8: Test results from the test setup.



With the chiller running, it was possible to collect data about the performance of the setup. Heat transfer through copper created a significant delay in changes in temperature. The bucket took about 45 minutes to match the temperature of the water running through the chiller. Temperatures cause changes to the refractive index of a fiber optic cable creating drift. Drift makes the timing unpredictable. The performance of the setup showed that the chiller water needs to run directly to the fiber spool to allow for accurate timing at the femtosecond level. With the data collected, I modeled a water bath set up to meet all the parameters to achieve the desired performance. With a clear vision in mind, manufacturing is the next step. The model below would take over a month to fabricate.

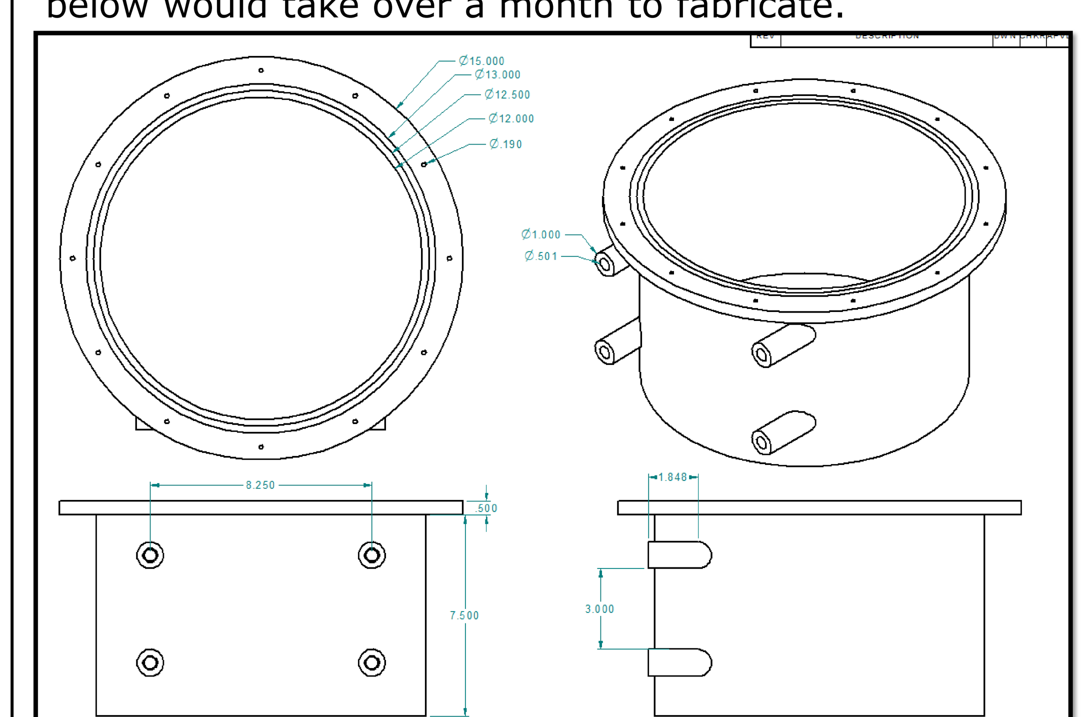


Fig 9: Refined design for a closed system drawing

Final Design

To cut back the fabrication time as the project is on a deadline, the design must use off the shelf parts. The final design uses a PVC pipe with flanges and caps on the end to seal the pipe and build pressure. The inlet and outlet for the water lines will be on either end of the pipe. A custom spool is designed for the pipe to fit perfectly and increase fiber surface area. The fiber will be run through holes filled with silicon and the water lines will attach with Swagelok and bulkhead fittings.

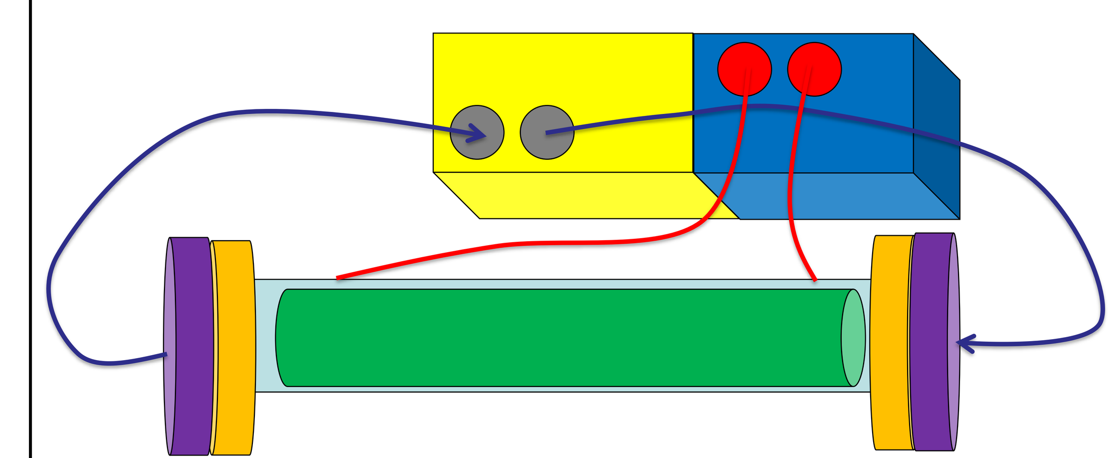


Fig 10: Final design
Key-
yellow box= chiller
gray circles= Swagelok-NPT fitting
blue lines= ¼" water line
purple cylinder= solid cap
orange cylinder= flange
green cylinder= custom fiber spool
blue cylinder= 8" PVC pipe
red lines and circle= fiber optic line and termination

Conclusion and Communication

In order to successfully synchronize experiment lasers to the X-ray beam, we must control the fiber's drift. Drift is caused by temperature changes, so a consistent temperature means predictable drift. The temperature of a spool of optical fiber can be held at a consistent temperature if the temperature control system is a closed loop allowing the chiller to cycle and cycle the water from the chiller directly on the fiber. The timing of the project does not allow for long machining times so off the shelf parts were configured that can satisfy all requirements.

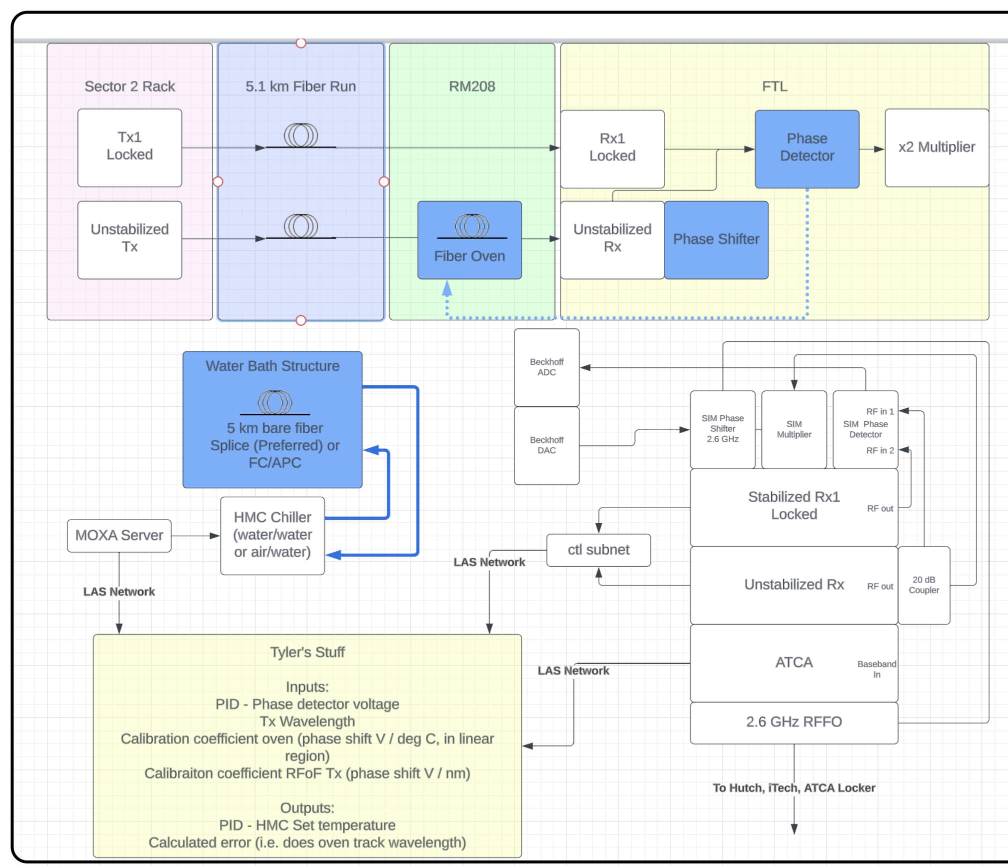


Fig 11: General Block Diagram

Block Diagram

The block diagram to the left is an overview of the system. This explains the whole process from receiving data to acting on that data to allow for the correct compensation of the fiber. To the left is a block diagram localized to focus on my project. The RFOF connects to the phase detector. The phase detector connects to the chiller, and as drift occurs the phase detector compensates by sending a signal to the chiller to inverse the natural temperature of the RFOF fiber. The chiller controls the water temperature which then controls the temperature of the fiber spool. That fiber spool connects to the phase detector allowing drift to be balanced. This will give better accuracy in within the timing system.

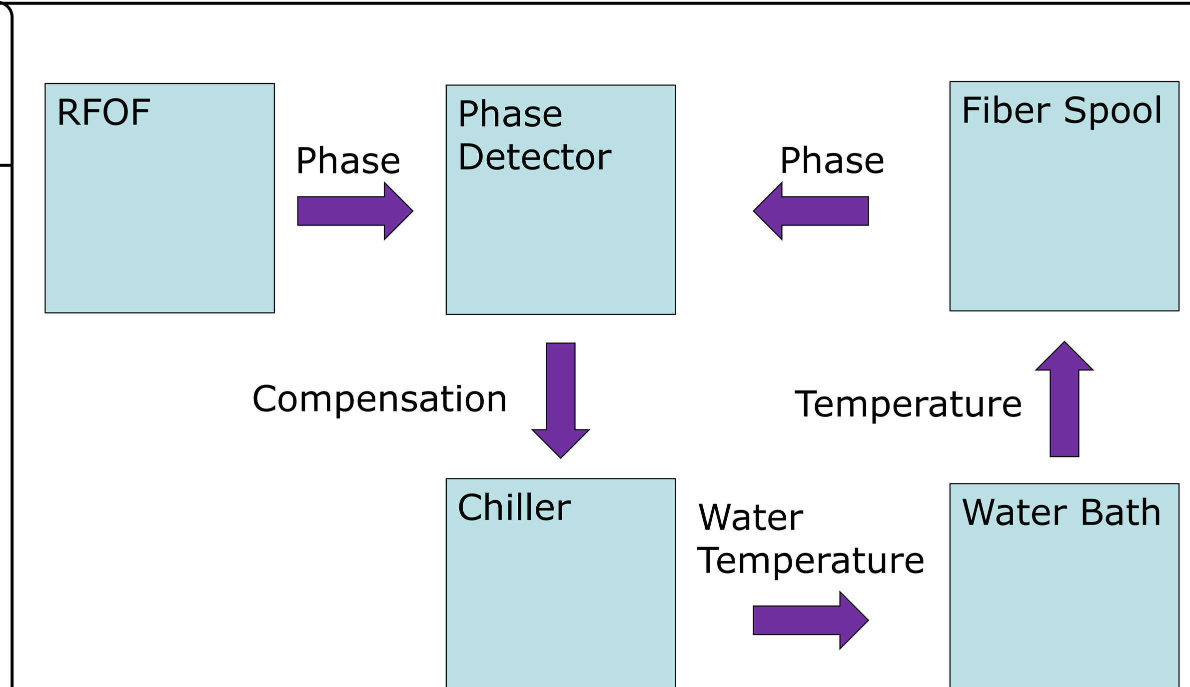


Fig 12: Localized Block Diagram

Acknowledgments

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