Electro-Optical Lyot Filter Automation

Lyot Filter Demonstration Instrument (LFDI) – HESTO

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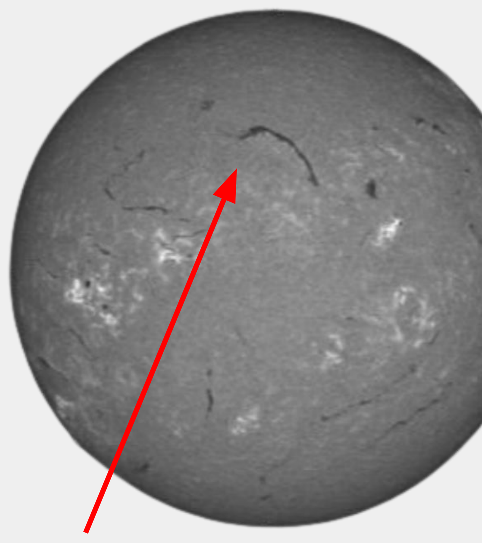
Lyot Type Filters and LFDI Background

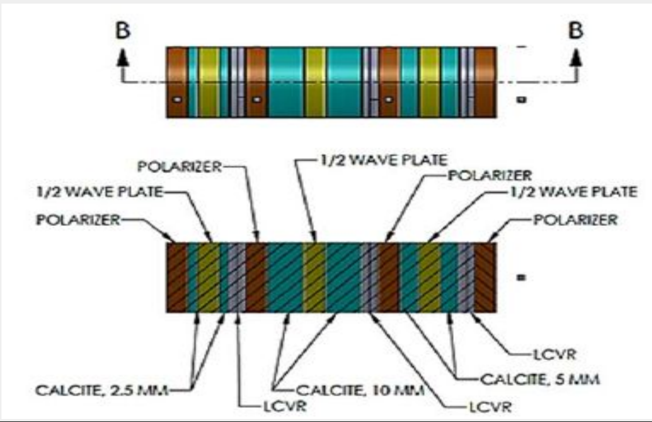


Filaments are one type of phenomena solar astronomers are interested in observing, as CMEs tend to be associated with these structures.

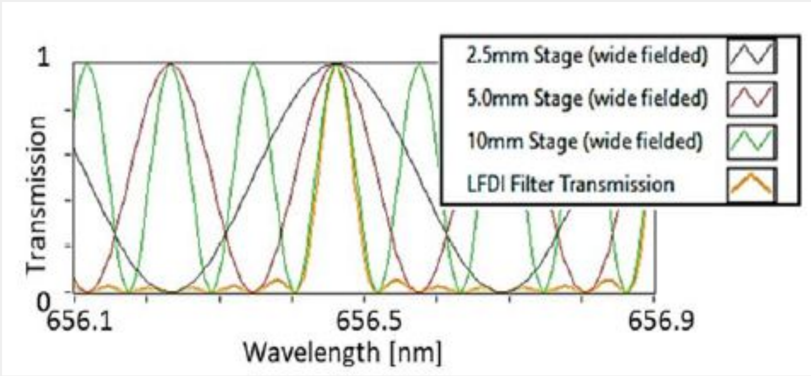
Lyot filters offer solar physicists the advantage of full-disk imagery combined with spectropolarimetry, enabling the observation and analysis of solar activity in detail. This technology not only captures physical interactions on the sun's surface but also provides mapping of spectral characteristics such as Doppler shifts. This capability, along with the extended observational periods afforded by space-based operations, drives the development of the Lyot Filter Demonstration Instrument (LFDI) at NSF-NCAR's High Altitude Observatory.

A typical Lyot filter consists of several stages, each comprising at least two polarizers and a wave plate. Despite the variations in Lyot filter designs, they all function by interfering with polarized light, transmitting narrow wavelength passbands. For LFDI, the filter design aims to provide spectrometry for imaging payloads, in line with HAO's goals. The three filter stages each include two polarizers, two calcite waveplates, a ½ waveplate, and a Liquid Crystal Variable Retarder (LCVR). The calcite waveplates set the Free Spectral Range (FSR) and Full Width Half Max (FWHM) of the transmission peaks, while the LCVR is crucial for the filter's tunability.

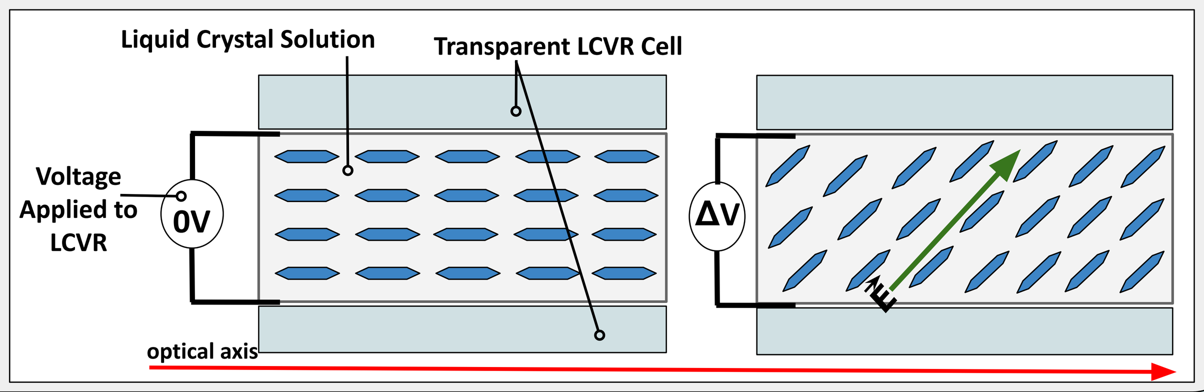
LCVRs consist of a transparent cell filled with a liquid crystal solution that acts as a waveplate. When voltage is applied, the liquid crystals align with the electric field, altering the polarization state of the light and therefore the transmission pattern, a phenomenon known as retardance. Similarly the polarization state changes as the LCVR is subjected to temperature changes. The LFDI design leverages this electro-optical tuning to overcome thermal and tuning challenges faced by previous Lyot filters. Calibrating the LCVRs' retardance is essential for optimal performance of each stage. A significant advancement in the LFDI project is the development of software to automate this calibration process via the Tuning Control Board (TCB). Once calibrated, the Lyot filter can be controlled, to tune to user defined wavelength and to compensate for temperature variations during operation.



Complete stack of LFDI Filter components (left), which is made up of the 3 different stages.Each stage has a different thickness which when combined transmits at the central wavelength of 656.46 nm commonly known as Hα (right).

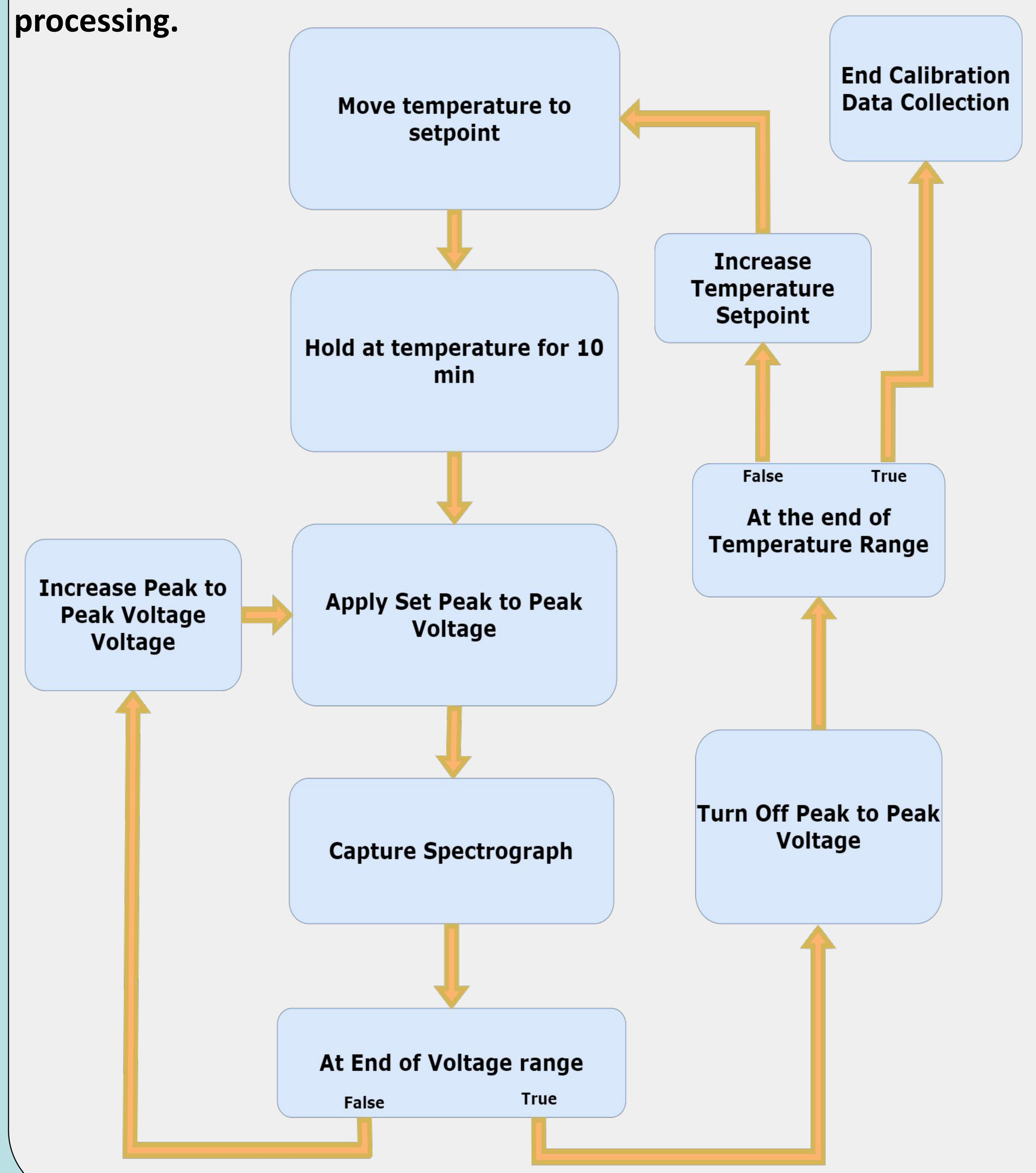


Orientation of Liquid Crystals as voltage is applied. When there is no electric field the crystal alignment is dependent on the alignment layer which is determined during manufacturing. As the peak voltage changes the crystals align with the electric field that is induced, giving a level of retardance (right)



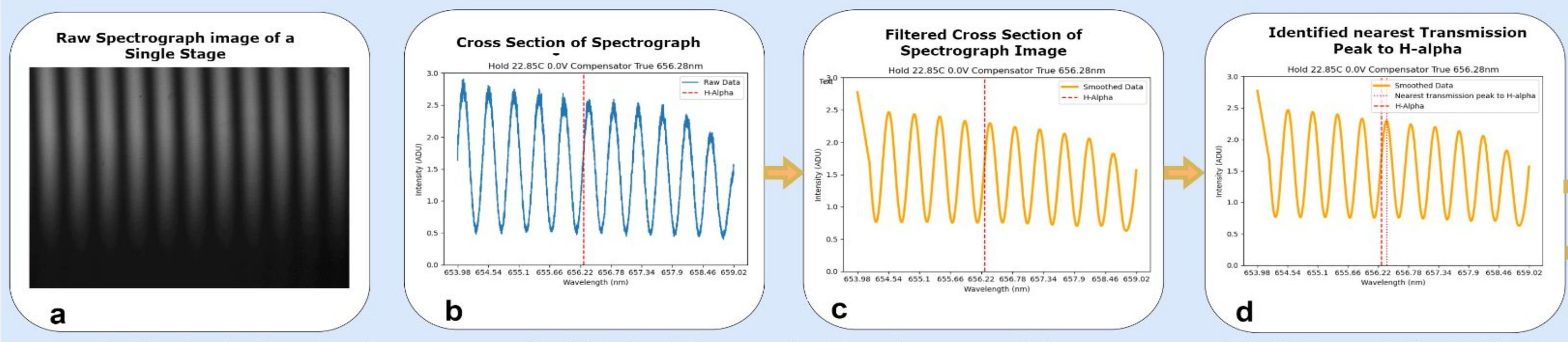
Calibration Data Collection

To tune a Lyot filter, the characteristics of each stage—dependent on calcite thickness, LCVR temperature, and voltage—must be identified. This is done by placing a single stage in front of a spectrometer, warming it to a set temperature, applying a square wave to the LCVR, and capturing images at different voltage-temperature pairs for processing.



Calibration Data Processing Pipeline

Calibration Scan

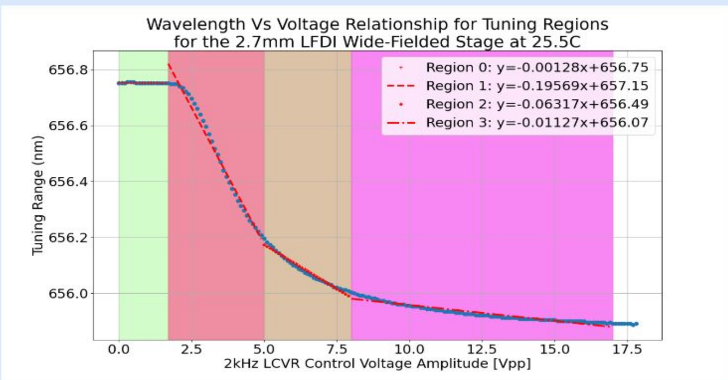


1. Pipeline begins by extracting a cross section (b) of each image taken from the output of the spectrometer (a). The transmission peaks closest to H-alpha are identified(c & d), then plotted as 2 separate plots; Transmission Peak Vs Voltage at constant temperature and Transmission Peak Vs Temperature at a constant voltage.

Identifying Voltage Dependent Retardance Curve

Filter For Scans all at the same Temperature

Retardance Curve

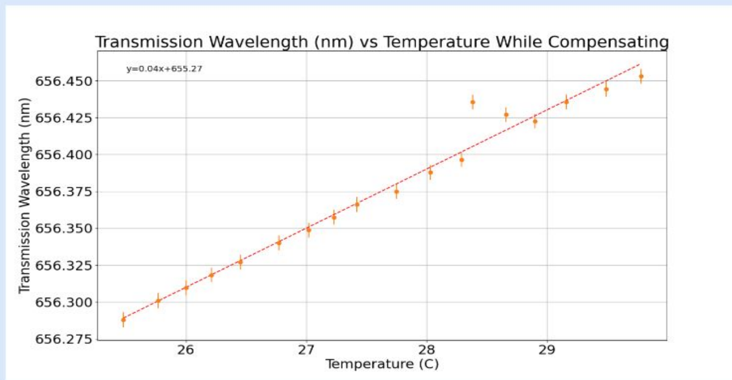


2a. retardance curve shows a nonlinear relationship between applied voltage and wavelength transmission. This plot is used to create a lookup table (LUT) of voltages to apply to achieve specific wavelength at a known temperature.

Identifying Temperature Drift Constant Linear Function

Filter For Scans all at the same Voltage

Temperature Dependent Wavelength Drift



2b. The plot of temperature vs transmission peak is used to find the linear relationship of the between temperature and the transmitted wavelength. the linear equation found from this plot will be used to adjust the wavelength used to index the LUT.

Data Products

LUT of Modeled Retardance Curve

(Values representing millivolts indexed by wavelength)

```
uint16_t lookup27[1000] = {5800, 5811, 5822, 5833, 5844, 5856, 5867, 5878, 5889,
5900, 5911, 5922, 5933, 5944, 5956, 5967, 5978, 5989, 6000, 6025, 6050, 6075, 6100,
6111, 6122, 6133, 6144, 6156, 6167, 6178, 6189, 6200, 6225, 6250, 6275, 6300, 6311,
6322, 6333, 6344, 6356, 6367, 6378, 6389, 6400, 6425, 6450, 6475, 6500, 6520, 6540,
6560, 6580, 6600, 6611, 6622, 6633, 6644, 6656, 6667, 6678, 6689, 6700, 6725, 6750,
6775, 6800, 6825, 6850, 6875, 6900, 6920, 6940, 6960, 6980, 7000, 7025, 7050, 7075,
7100, 7125, 7150, 7175, 7200, 7220, 7240, 7260, 7280, 7300, 7325, 7350, 7375, 7400,
7425, 7450, 7475, 7500, 7520, 7540, 7560, 7580, 7600};
```

Temperature Drift Linear Equation

Wavelength Drift = 0.04*(Current Temperature) + 655.22nm

3. The modeled retardance curve (represented by the LUT) and the temperature dependence represented by the (linear equation) modeled by the previous step. are uploaded to the embedded system and used to dynamically tune to user set wavelengths.

In-Flight Tuning Determination System

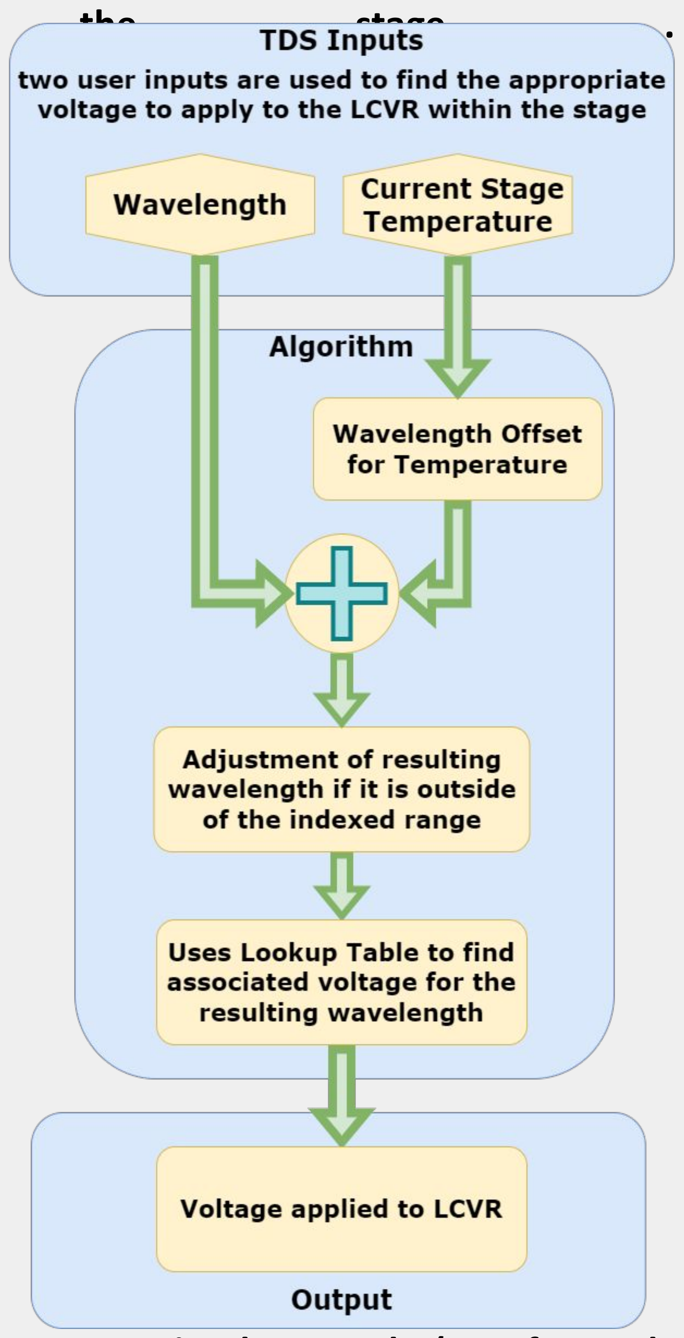
During the operation of the Lyot Filter Demonstration Instrument (LFDI) a tuning determination system is used to find the appropriate voltage to apply to the LCVR to achieve a desired wavelength at the current temperature of the stage.

1. Wavelength defined by user which the Lyot filter will be tuned for. The current stage temperature is measured on the outside of the stage with a (TMP117) digital temperature sensor.

2. a)The TDS uses the current temperature to calculate the wavelength offset, which is then added to the desired wavelength to get an adjusted wavelength.

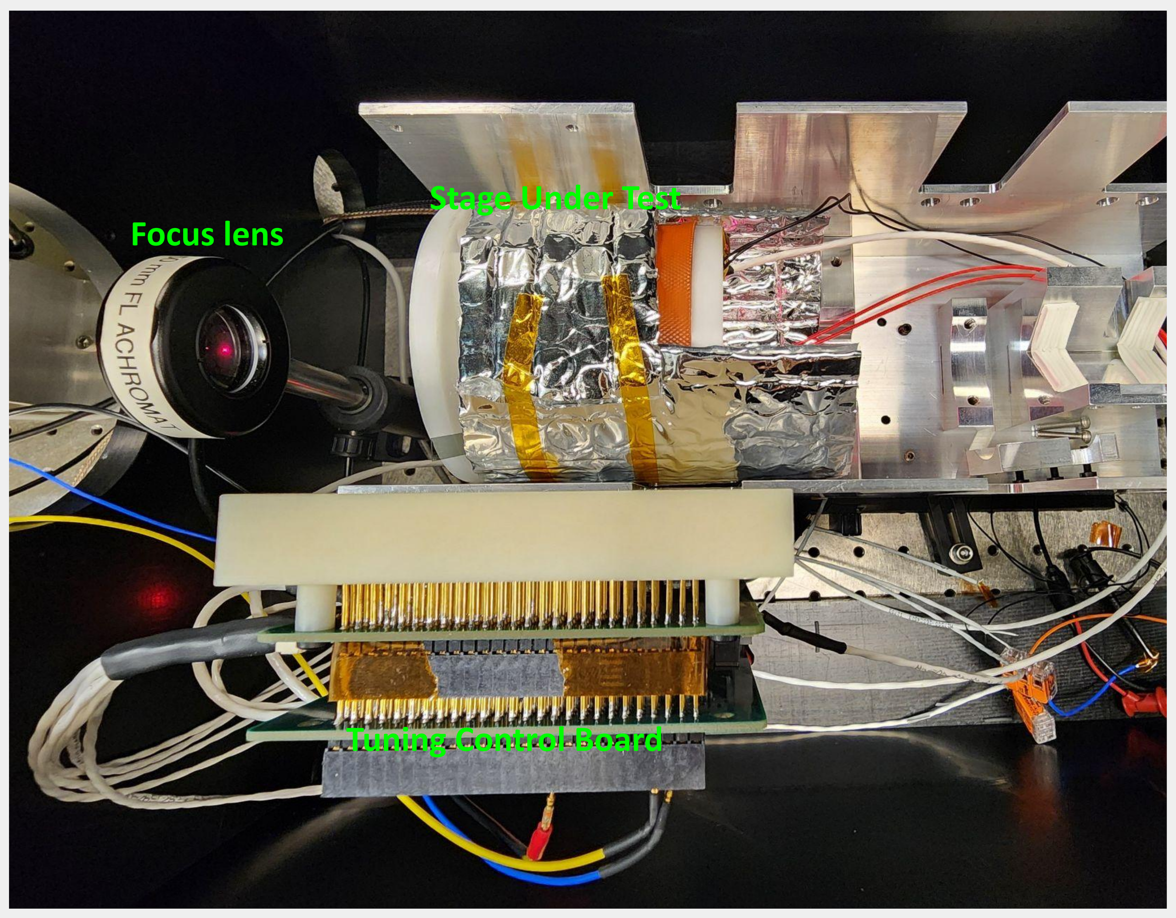
   b.) The adjusted wavelength is used to index the LUT finding the correct voltage to apply to the LCVR to generate the desired wavelength.

3. The associated voltage is applied to the LCVR for tuning.

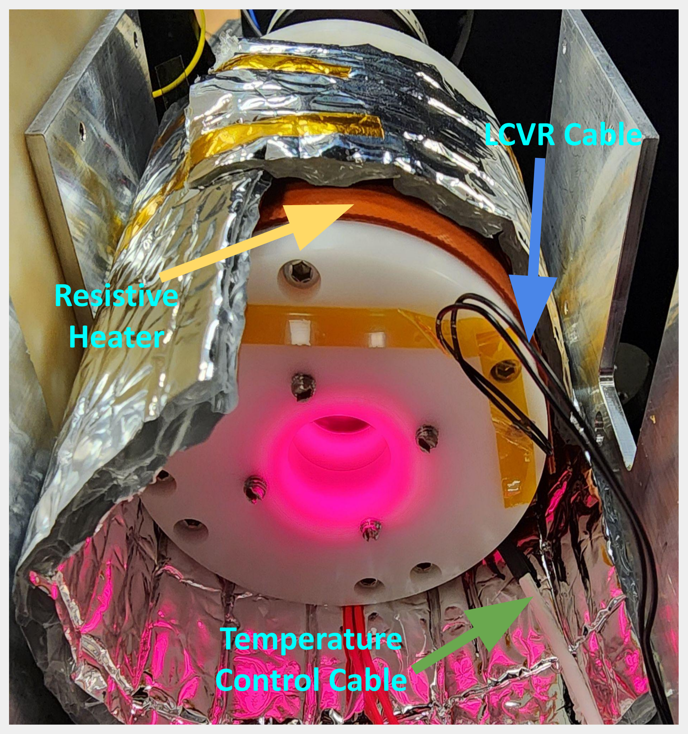


For LFDI three instances of the TDS are ran simultaneously (one for each stage) to achieve full tuning of the assembly.

Lab setup for the calibration of each LFDI stage



Lyot Filter Stage



Acknowledgements

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Scan QR code to access open source embedded software, calibration pipeline printed circuit board files.

Results

Using the calibration process outlined in this poster the system is able to maintain a tuning stability of +/- 0.01nm RMS over a temperature delta of 10C.