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# Imaging Spectrometry Using Liquid Crystal Tunable Filters

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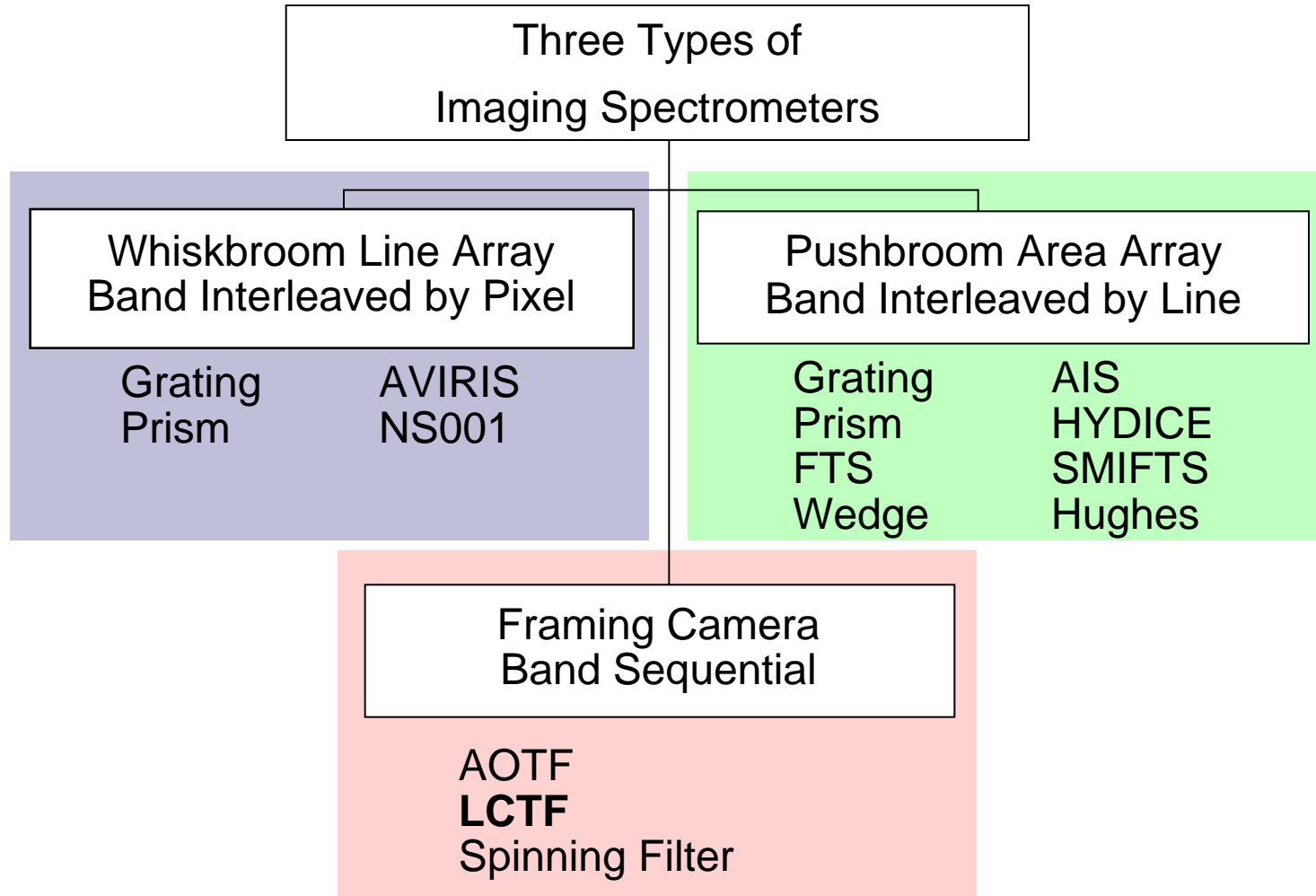
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## OVERVIEW

1. Introduction
2. How Liquid Crystal Tunable Filters Work
3. JPL Prototype LCTF Imaging Spectrometer
4. Balloon Experiment Results
5. System Modelling Effort
6. Summary

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## What is a Liquid Crystal Tunable Filter?

Consider Video Camera With Filter Wheel

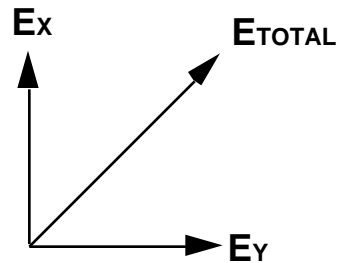
- Large aperture
- Large field of view
- Good optical quality
- Mechanical wheel selects filters
- Limited number of filters fit on wheel
- ~Seconds required to step filters in set sequence
- Band shape characteristics tailored for each filter

Now Consider a LCTF Solid State Optical Filter

- Large aperture
- Large field of view
- Good optical quality
- Pass Band is Electronically Tunable
- Can select any wavelength over wide range
- ~Milliseconds required to step wavelength, random access
- Bandwidth is constant in frequency space (  $\lambda / \nu = \text{constant}$  )

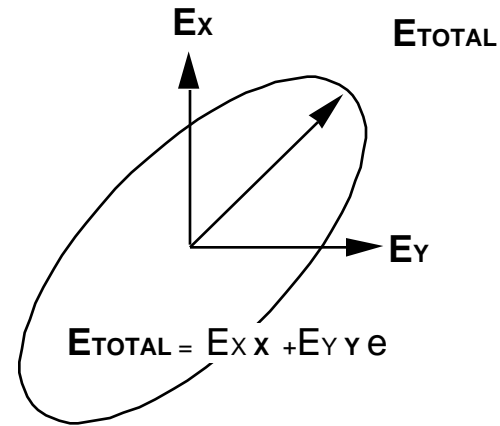
### Polarized Light

The E-field of linearly polarized light can be broken into X and Y components  
Both components are in phase

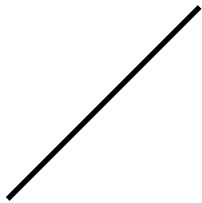


$$E_{TOTAL} = E_x x + E_y y$$

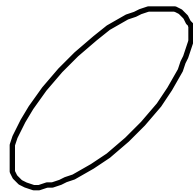
The E-field of elliptically polarized light can be broken into X and Y components  
with phase delay  $\delta$



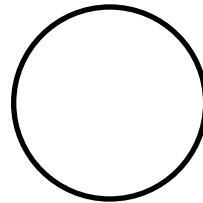
$$E_{TOTAL} = E_x x + E_y y e^{i\delta}$$



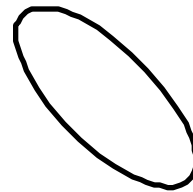
$$= 0$$



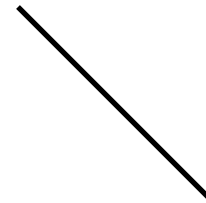
$$= \pi/4$$



$$= \pi/2$$

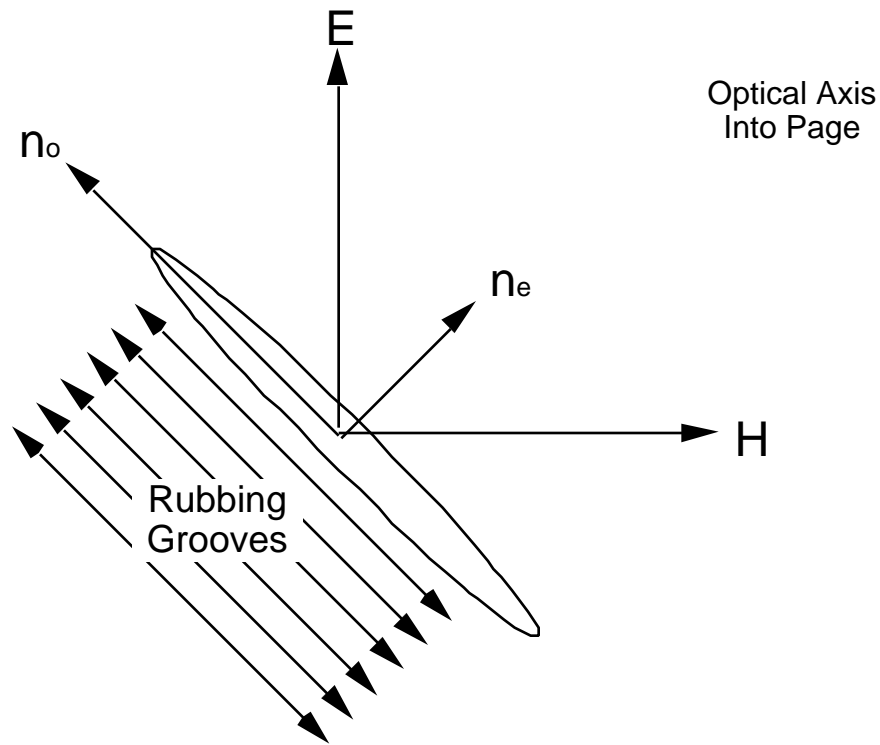


$$= 3\pi/4$$

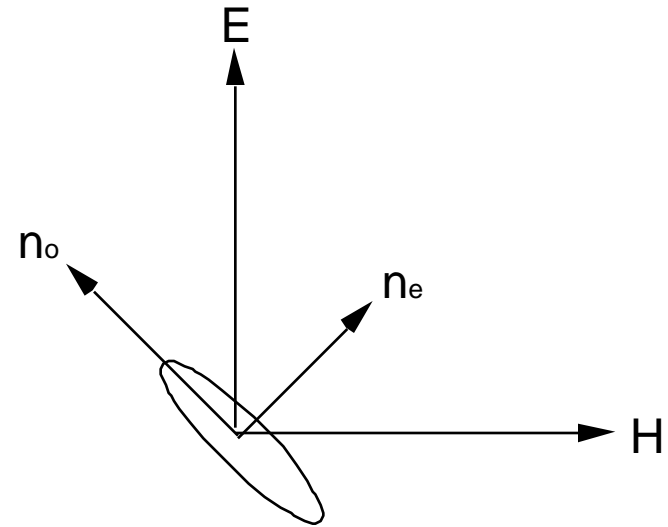


$$= \pi$$

## Liquid Crystal Cells Are Variable Retarders



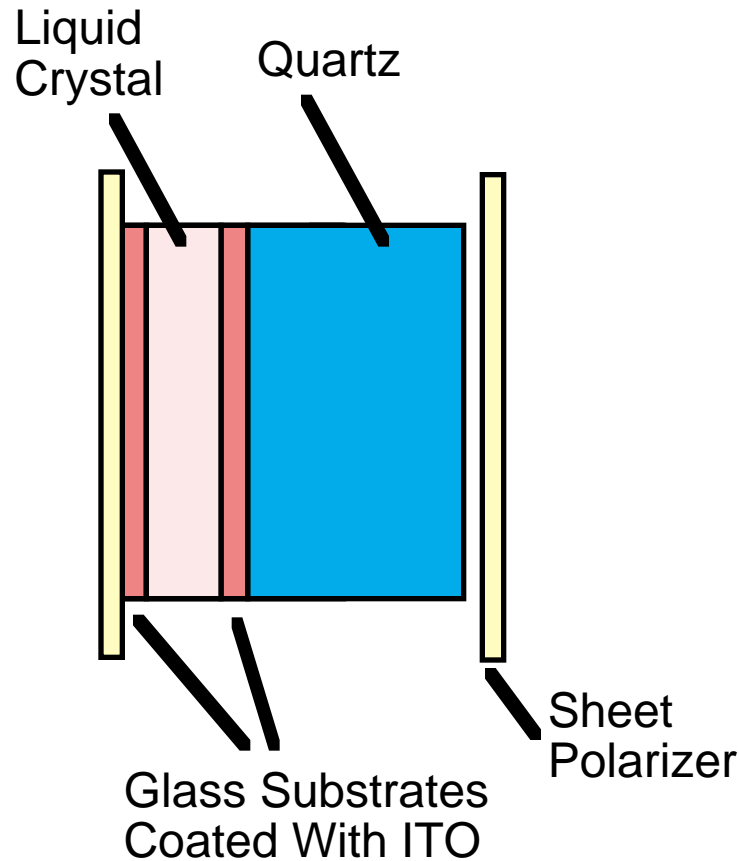
With no voltage applied, liquid crystal aligns with grooves in cell walls



Applied voltage causes liquid crystals to twist downtrack, aligning with E-field

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A Single Lyot Stage Consists of Birefringent Material  
Between Linear Polarizers



$$\Delta n = n_e - n_o \quad \text{Birefringence}$$

$$\Delta = d \Delta n \quad \text{Retardance}$$

$$\Delta_{\text{Total}} = \Delta_{\text{LC}} + \Delta_{\text{Quartz}}$$

$$\Delta_{\text{Total}} = 2 \Delta_{\text{Total}} / \lambda \quad \text{Phase delay}$$

$$T(\theta) = \cos^2 \theta$$

$$T(\theta) = \cos^2 (2 \Delta_{\text{Total}} / \lambda)$$

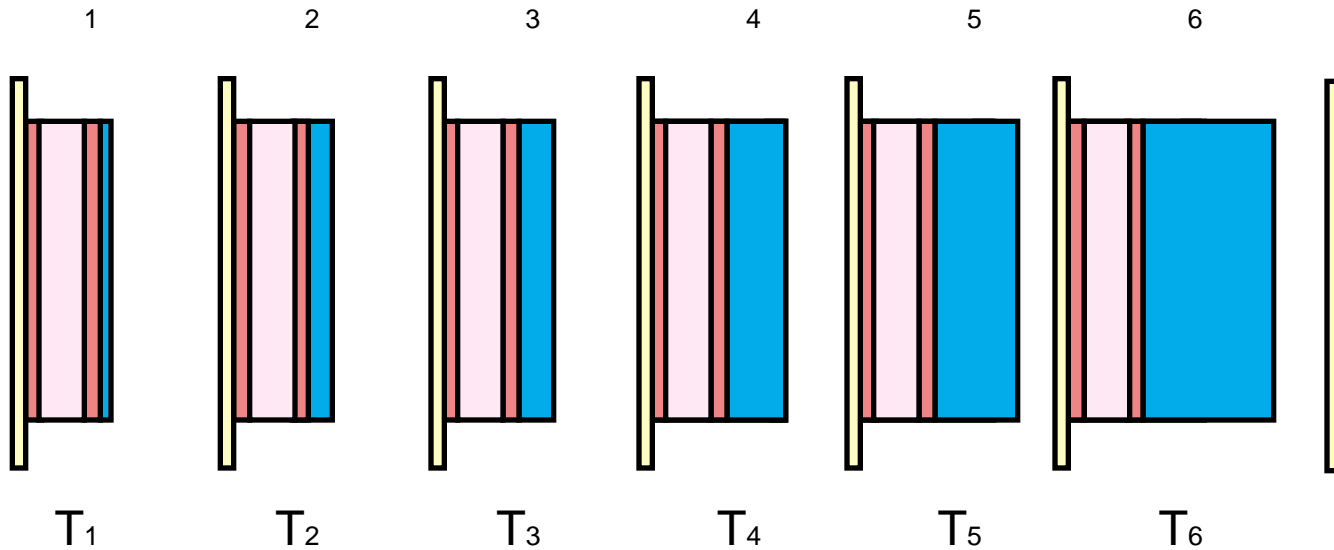
$$T = 1; \quad m \Delta_{\text{Total}} = d \Delta n$$

for integer m

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Lyot Filter Consists of Multiple Cells of Increasing Retardance

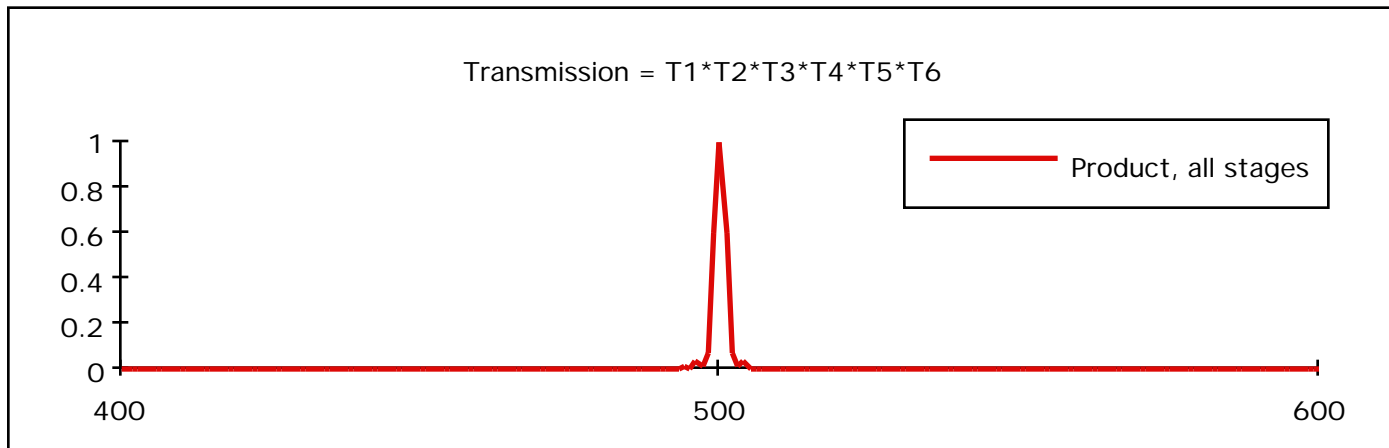
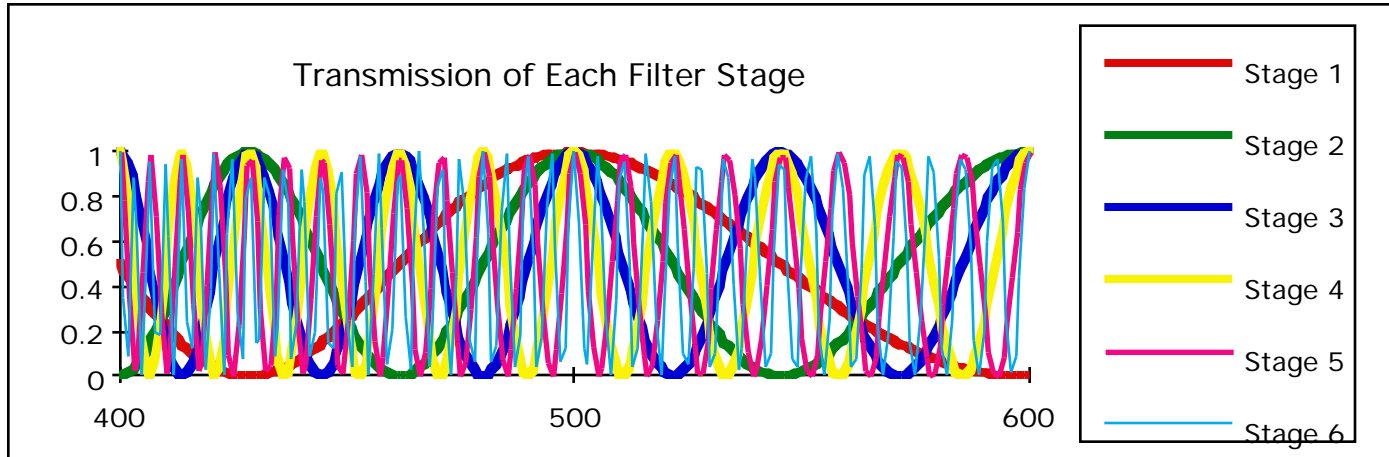
$$n+1 = 2 n$$



$$T_{\text{Total}} = T_1 * T_2 * T_3 * T_4 * T_5 * T_6$$

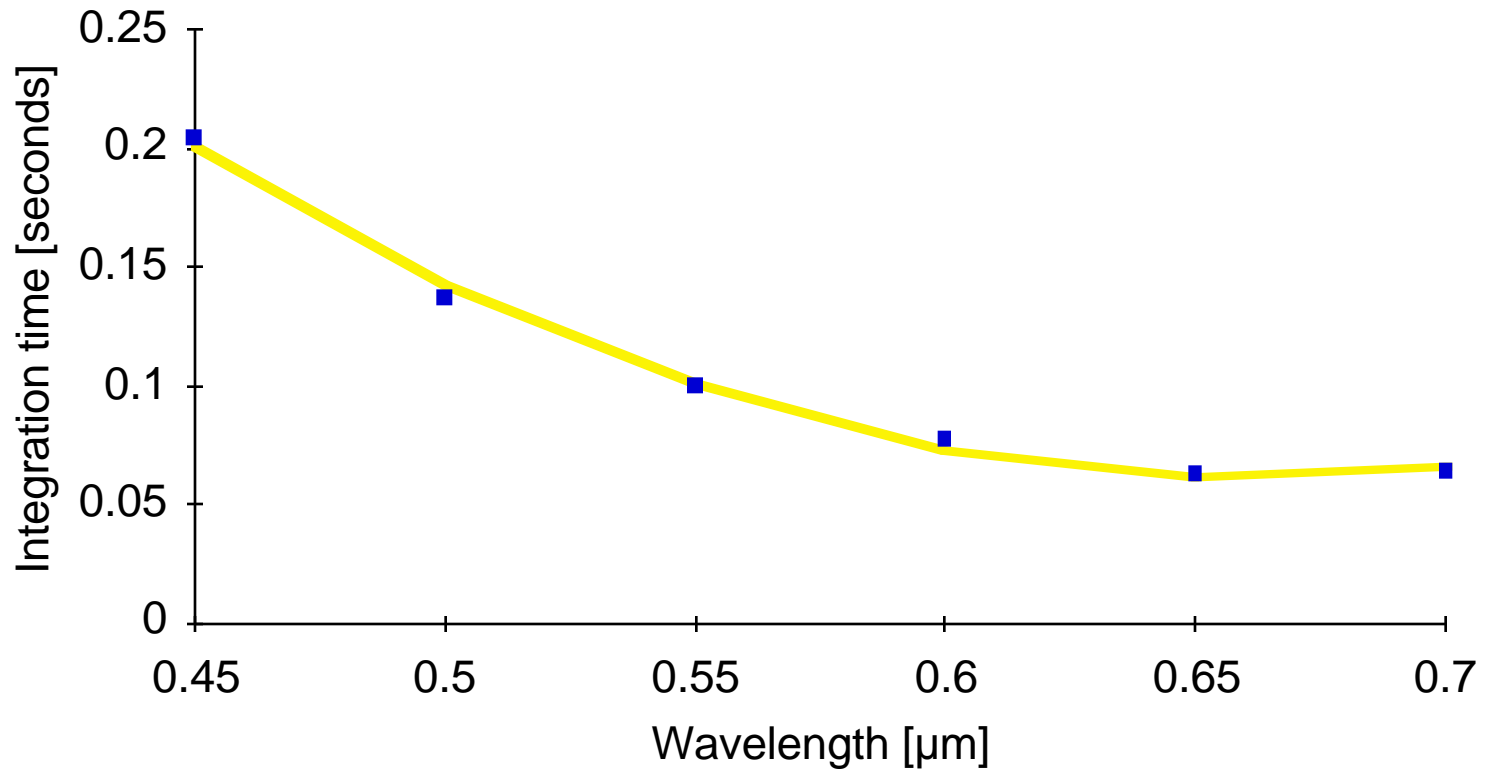
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## Lyot Filter Transmission Versus Wavelength



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### Transmission of 6 stage LCTF Filter



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## Summary

- Liquid Crystal Tunable Filters Imaging Spectrometers Are Feasible
- They Are Compact, Light Weight, And Use Little Power
- LCTF Imaging Spectrometer Data Can Be Calibrated To Reflectance
- Coregistration Is Feasible For Moving Platforms
- High SNR Is Possible Using Commercially Available Components
- Time Varying Integration Enables Constant SNR Across Spectrum