Tunable, Narrowband Filter for LWIR Hyperspectral Imaging

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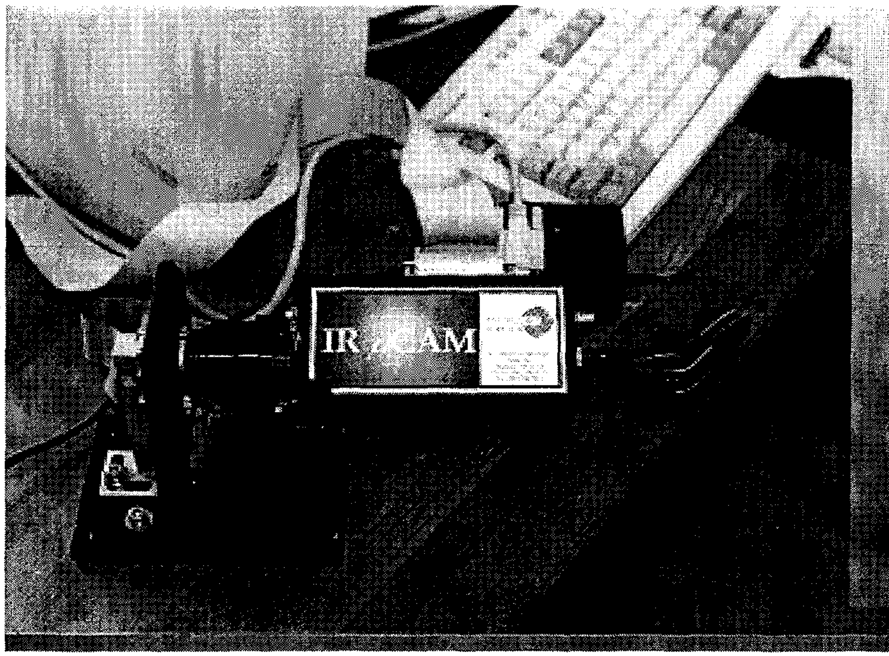
Program Objectives

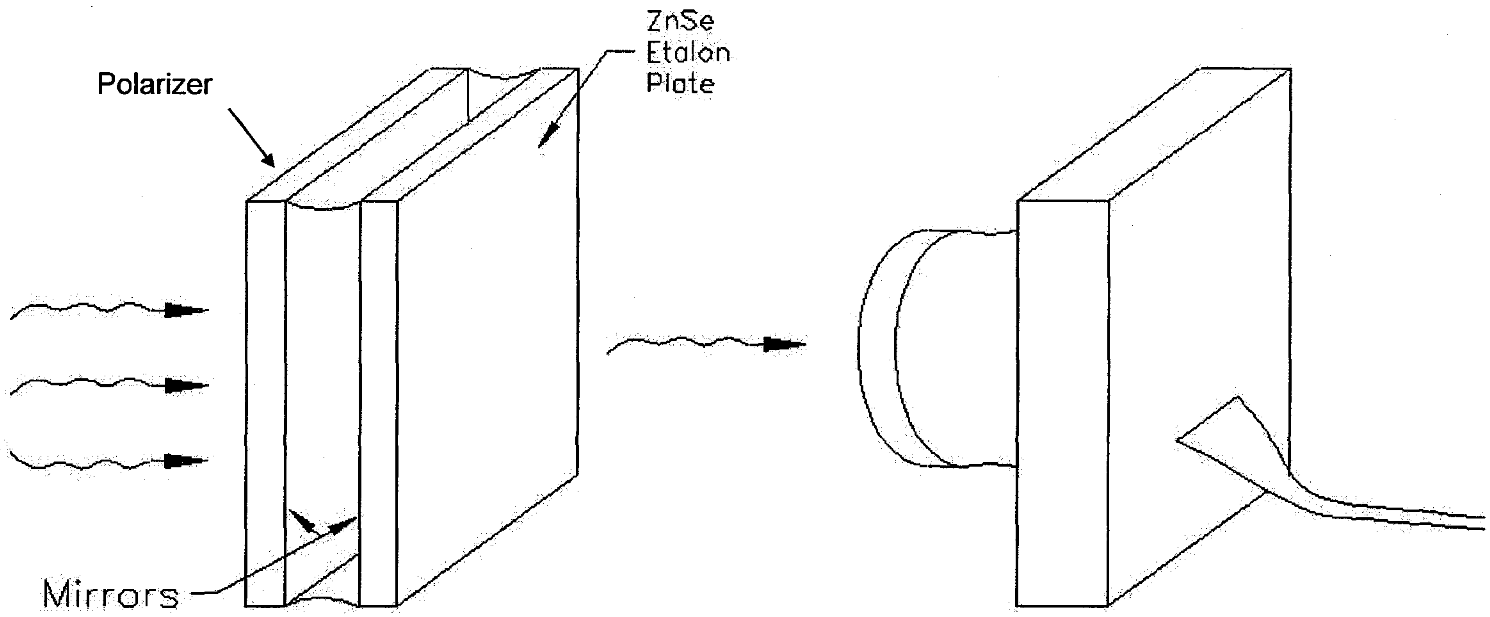
- ❑ Fabricate a prototype tunable filter based on liquid crystal-filled Fabry-Perot etalon (LCE).
- ❑ Enable voltage-controlled, tunable, narrow-band filtering at LWIR wavelengths
- ❑ Bandpass tunable at 60 Hz frame rates
- ❑ Enable rapid scene characterization for camouflaged target, or chemical identification
- ❑ Ability to build up Hyperspectral data cube with scanning software

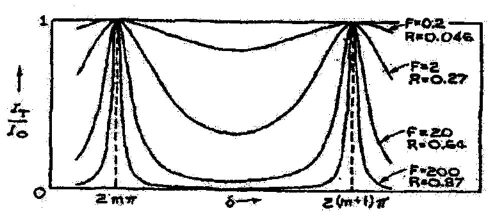
Digital IR Microcam Camera Set-up



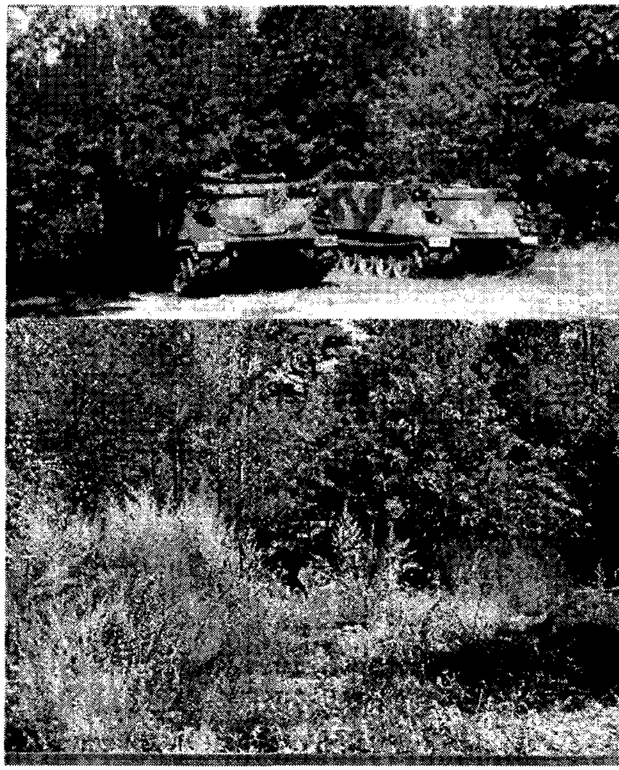
- Digital 8-12 micron IR Microcam Camera mated with a IR filter wheel holder.
- Using existing F1, 33°x25°field of view lens

Hyperspectral Liquid Crystal Etalon

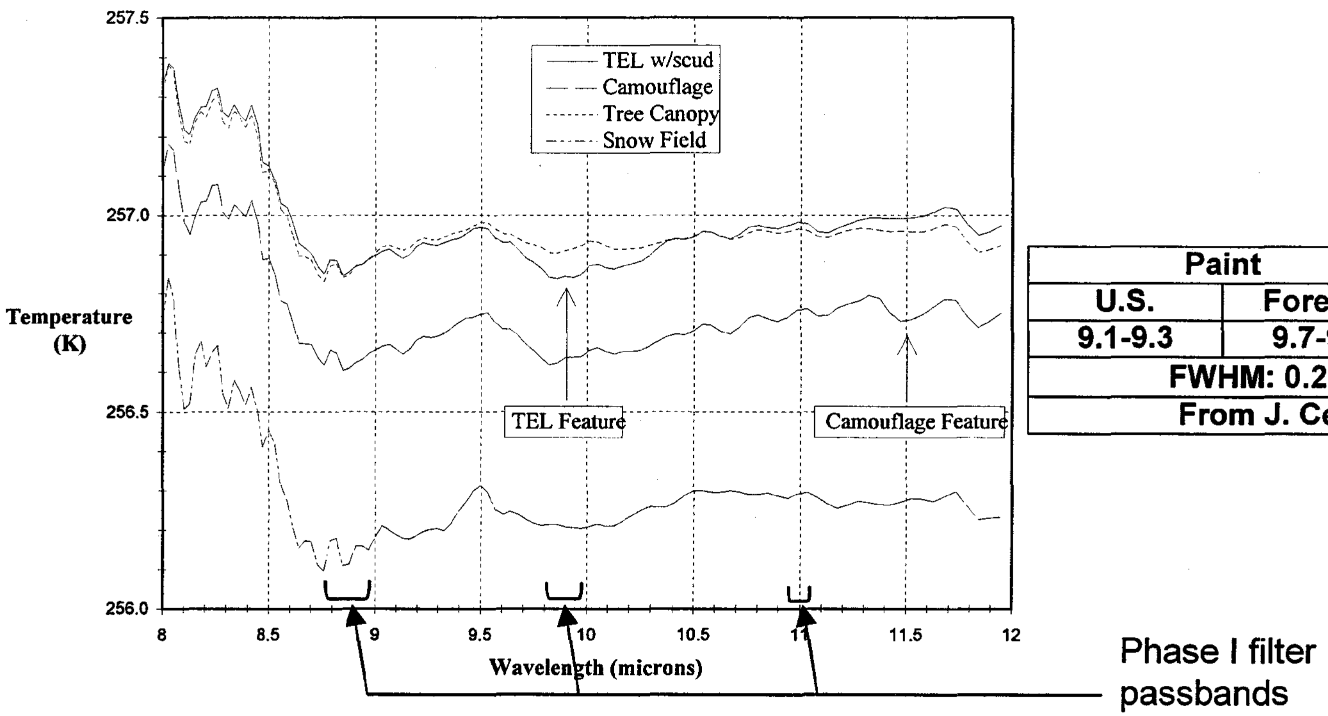




Potential Applications: Camouflage Penetration



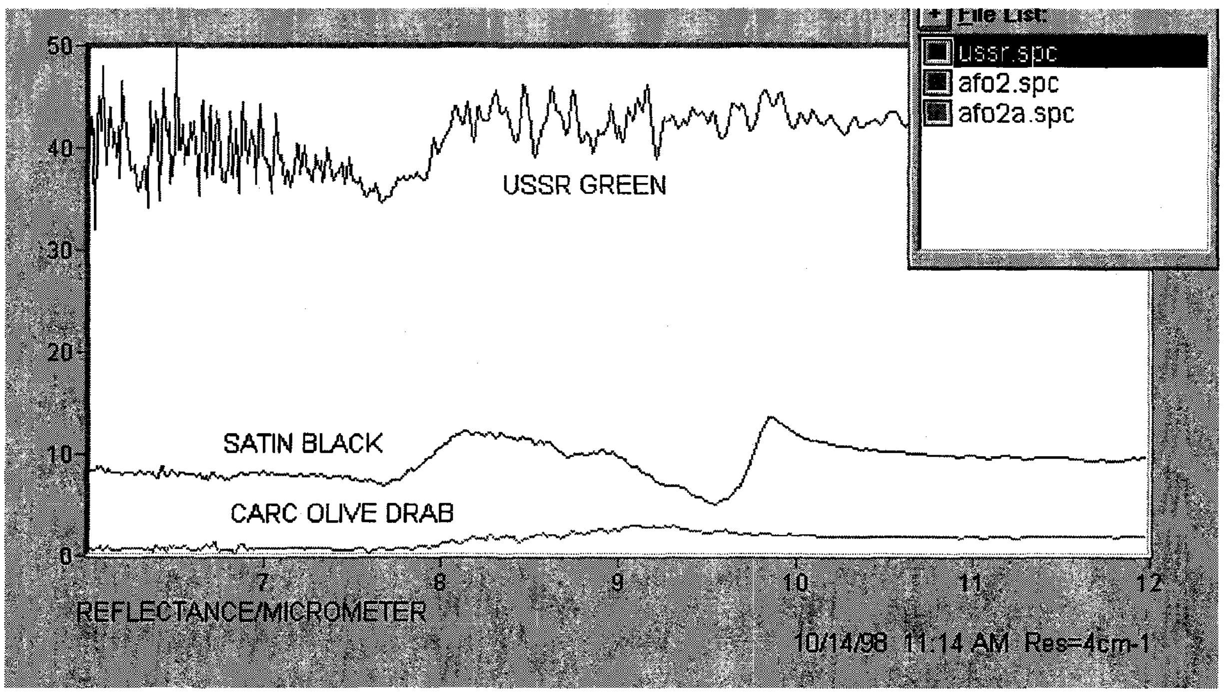
LWIR Comparison of Target & Background



Paint		Camo
U.S.	Foreign	Clutter
9.1-9.3	9.7-9.9	9.4-9.6
FWHM: 0.2 to 0.4 μm		
From J. Cedarquist		

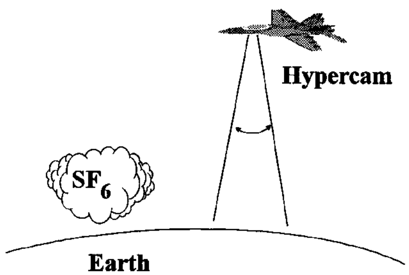
ERIM data shows typical paint, tree canopy and chamoflage spectra in the 8 to 12 um range. We selected filters to capture data around the SCUD spectral feature. This was compared to data from pictures on either side of the feature

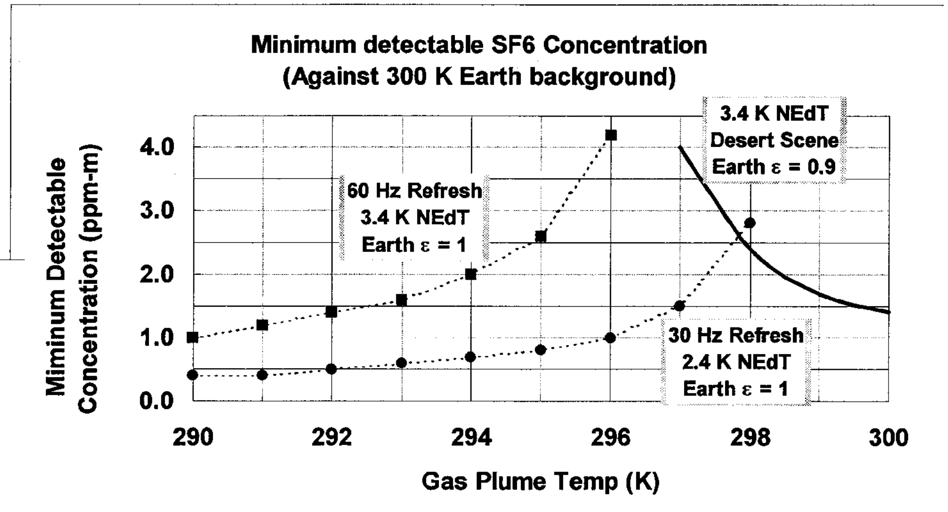
LWIR Comparison of Camouflage Paints

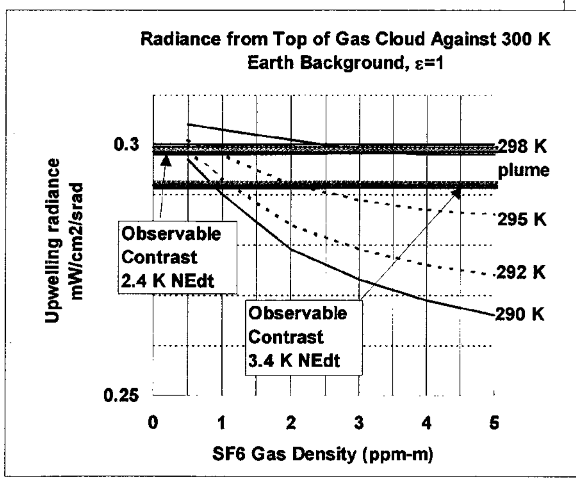


FTIR spectrum of camouflage paints. Our measured data of several paint samples shows that the spectral features are actually much larger then those provided by ERIM

Potential Applications: Standoff Plume Detection







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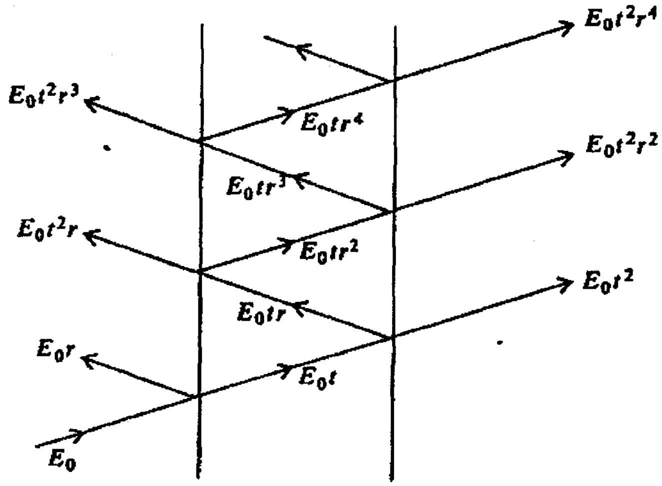
Fabry-Perot Etalon

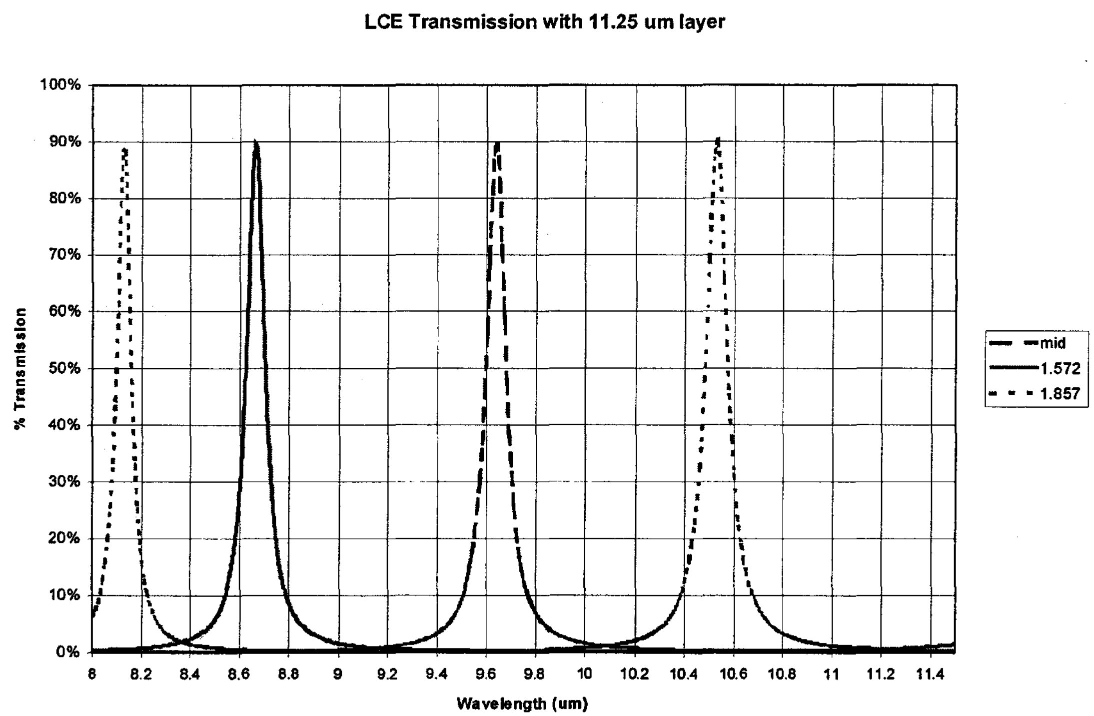


Phase difference between two successive rays is the optical path plus the phase shift from two reflections

$$Tx = \left[1 - \frac{A}{1-R}\right]^2 \cdot \left[\frac{1}{1 + \left[\frac{4 \cdot R}{(1-R)^2}\right] \cdot \sin\left(\frac{2 \cdot \pi \cdot n(v) \cdot d \cdot \cos(\theta)}{\lambda_0} + \delta(\lambda)\right)^2}\right]$$

Where:
A = mirror absorption
R = mirror reflectivity
$n(v)$ = LC index of refraction, and is a function of applied voltage
d = LC thickness
λ_0 = free space wavelength of incident light
$\delta(\lambda)$ = phase shift on reflection
θ = incident angle of rays entering LC

LCE Transmission Model



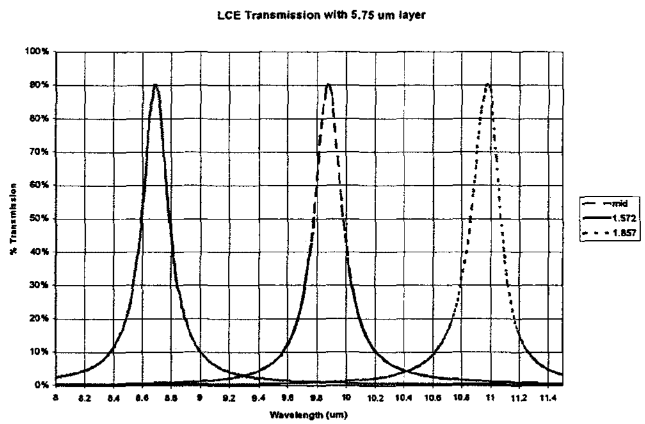
Three runs at n(v) = 1.572, mid, and 1.857

Transmission tuning range: 8.7 to 10.55 um

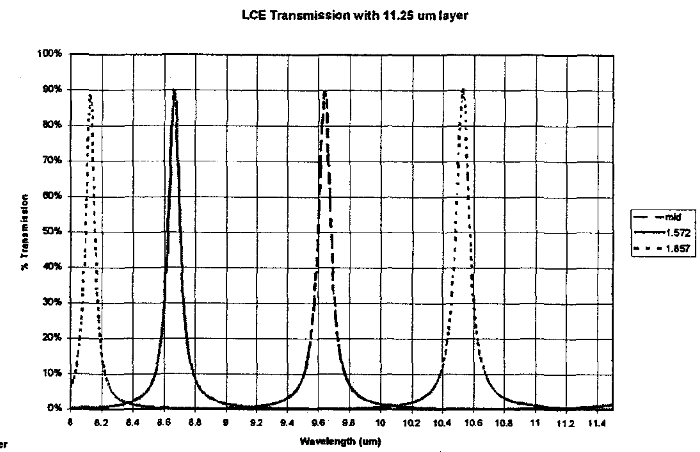
Bandpass: 0.1 um FWHM

Free Spectral Range: 2.4um

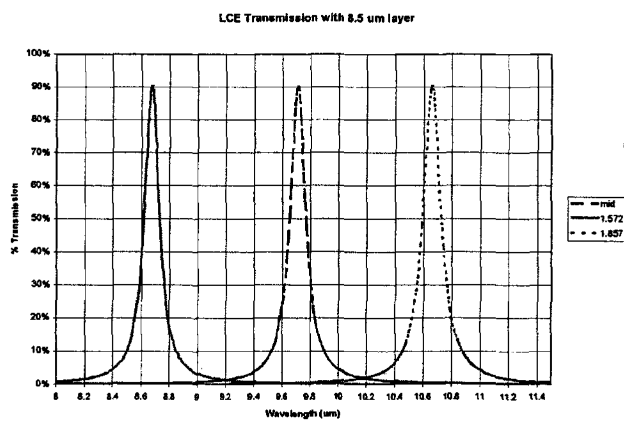
Changing Gap Changes Interference Order, Bandpass



5.75 um gap, 3rd order
0.22 um bandpass



11.25 um gap, 5th order
0.10 um bandpass



8.5 um gap, 4th order
0.13 um bandpass

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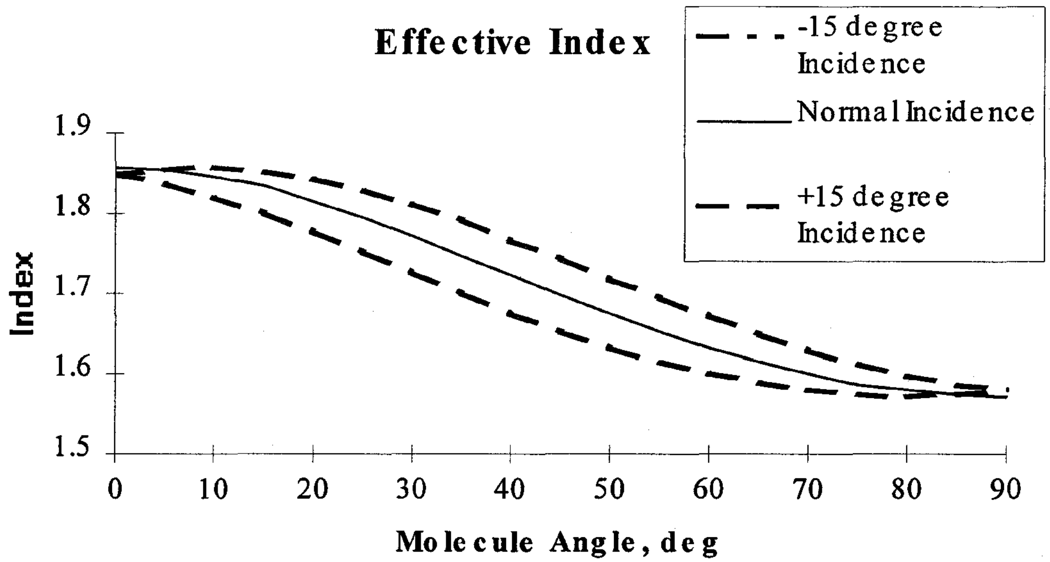
Reflection phase is critical to LCE gap size

Wavelength (um)	Phase shift (deg)	Wavelength (um)	Phase shift (deg)
8	150.8551	9.6	176.7255
8.1	153.7042	9.7	177.7442
8.2	156.2353	9.8	178.7416
8.3	158.5013	9.9	179.7212
8.4	160.5476	10	180.6861
8.5	162.4122	10.1	181.6394
8.6	164.1258	10.2	182.5835
8.7	165.7132	10.3	183.5211
8.8	167.1947	10.4	184.4543
8.9	168.5868	10.5	185.3855
9	169.903	10.6	186.3166
9.1	171.1545	10.7	187.2498
9.2	172.3507	10.8	188.1869
9.3	173.4996	10.9	189.1298
9.4	174.608	11	190.0805
9.5	175.6816		

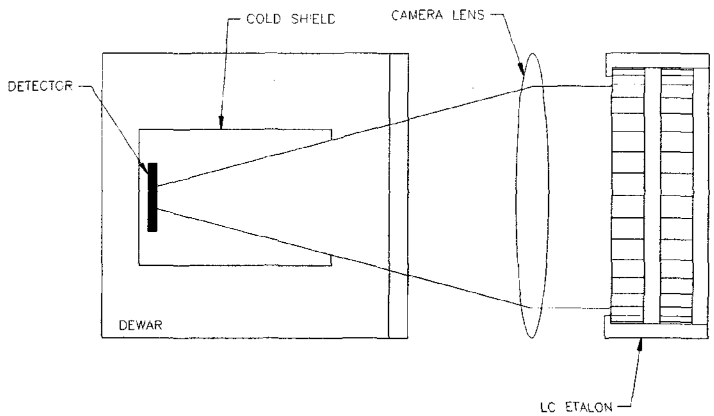
Calculated from thin film model of dielectric mirror. Phase shift is a function of wavelength.

Apparent Index Vs. Incidence Angle



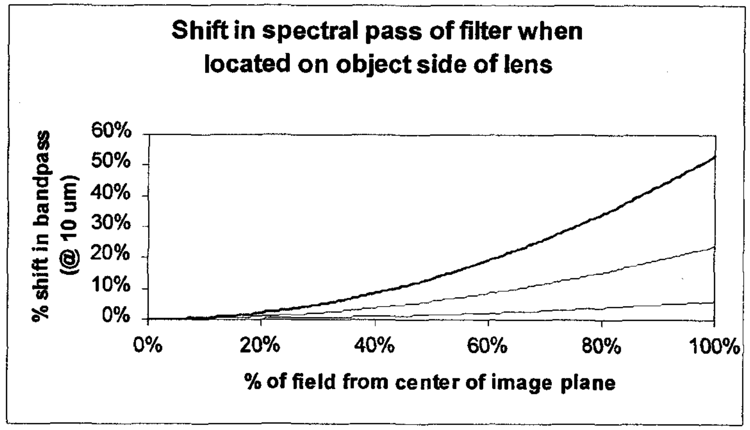
Plot of effective index of refraction of the LC, as the applied voltage causes the molecules to tilt. Note that the effective index also depends on the angle in which the light ray traverses the crystal.

System Issues

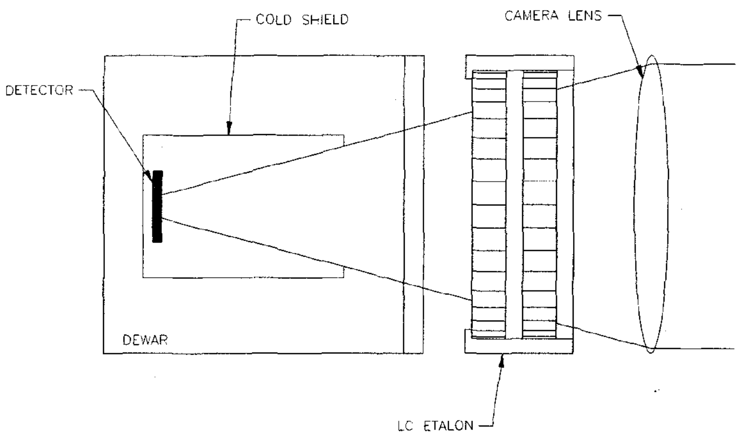


Filter before the lens

Bandpass peak shifts radial across FPA

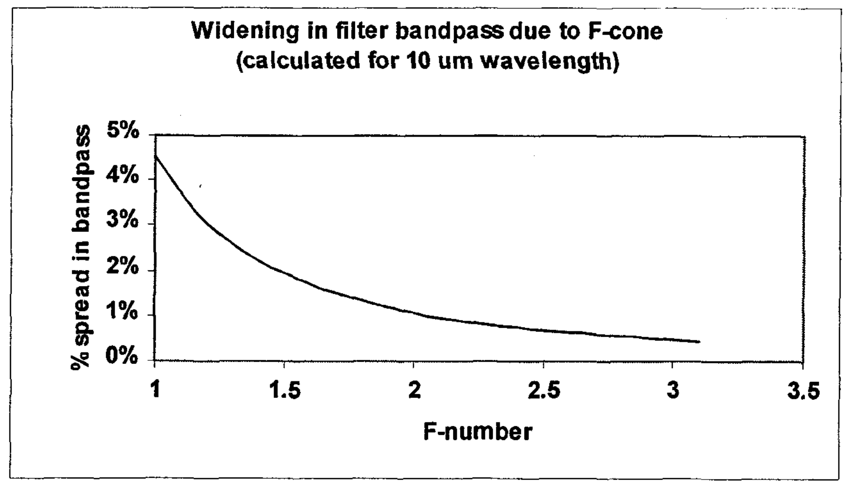


System Issues

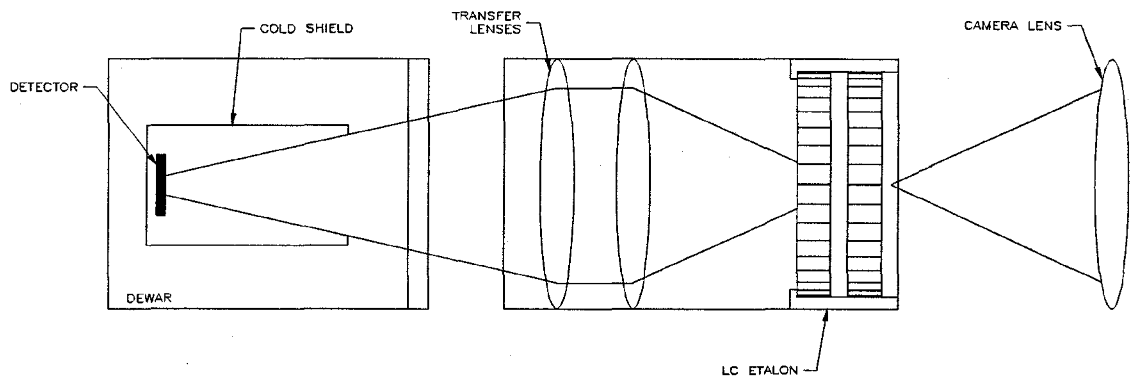


Filter after the lens

Bandpass widens depending on F#



System Design: Relay Reduces Stray Light



LCE/camera System Model

MS-DOS Prompt - DEARRAY

Receiver Parameters

300		Number of Pixels			
2.5	cm	Receiver aperture			
25	deg	Total FOV	264		δI/δT (µWatt/cm2 / K)
.9		Xmission thru rcvr optics	1.27		f/#
.9		Xmission through filter	3.18	cm	Focal Length
8	µm	Filter Cut-on Wavelength	3.49	in	Pixel Image at 200 feet
14	µm	Detector Cut-off	1.45	mrad	Pixel Field of view

System Parameters

301	K	Temperature of target	.001		Probabilty of false alarm
300	K	Temperature of background	.999		Probabilty of Detection
2	/Km	Atmospheric ext. coeff.			
.3		Target Emittance	DEARRAY		System Name

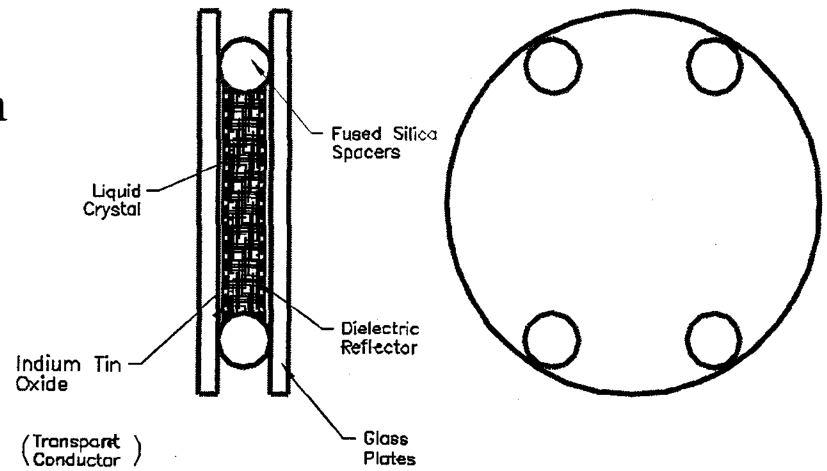
Detector Parameters

60	hz	Frame Rate	2		Read-out Noise Figure
50	%	Fill Factor	1E-7	W/K	Thermal Conductance
80	%	Absorptance	46.25	µm	Detector Side Dimension
90	%	Xmssion thru Window	.035	K	NETD

For Pfa = 0.001, Required TNR = 3.09 SNR at 0 ft Range = 8.57
For Pd = 0.999, Required SNR = 6.18 SNR at 200 ft Range = 7.59
Min DEL Temp to detect @ 200 ft = 0.81 K Maximum Detection Range = 537 ft
(R)eceiver (S)ystem (D)etector (Q)uit

Liquid Crystal Etalon

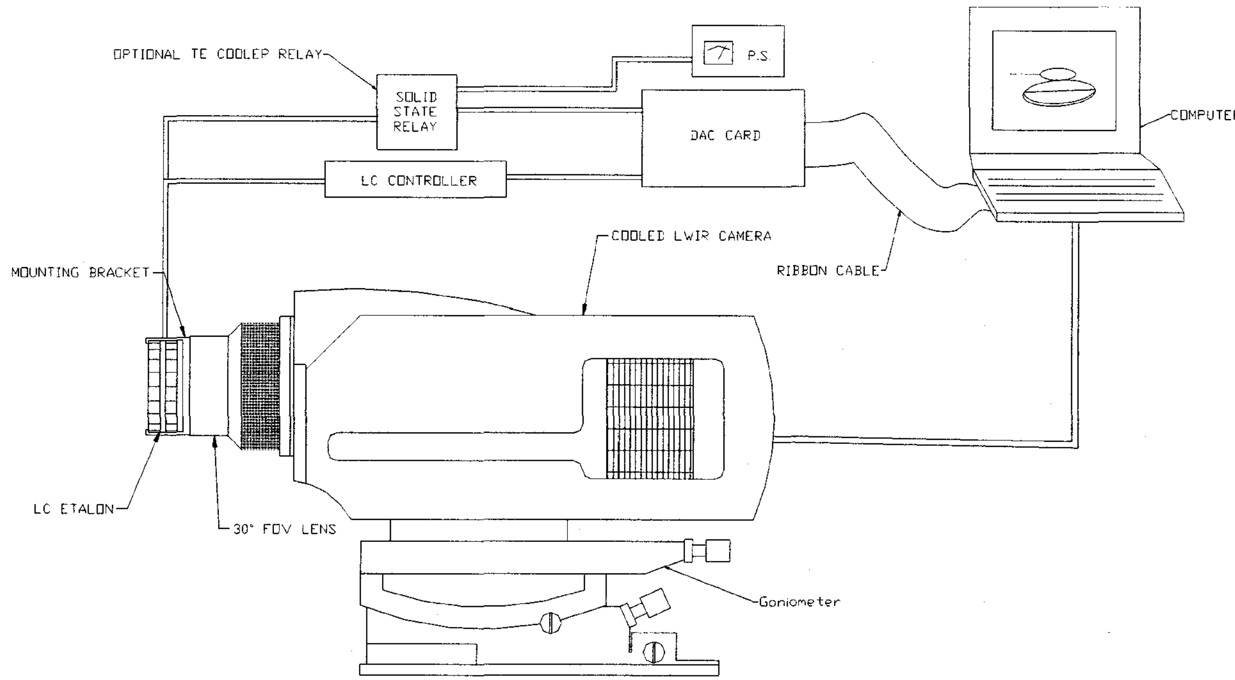
- Physical Diameter: 50.8 mm
- Clear Aperture: 45 mm
- Refractive Index: 1.57-1.86 µm
- Free Spectral Range: 2.4 µm
- Gap (LC thickness): 8.5µm
- Tuning range: 8.7 to 10.7 µm
- Bandpass FWHM: 0.13 µm
- Resolution: 1.3%
- Finesse ≥ 20
- Mirror material: ZnSe



Task 2: IR Camera Trade-off

- ***Model calculates MRTD at 200 ft. based on LCE properties and camera f#, FOV, spectral band pass, etc.***
- ***Must determine system limitations with best available cameras***
- ***Cameras to be considered: QWIP, HgCdTe, Microbolometer, BST***

LCE & Camera Test set-up



Conclusions

- ❑ ***Rapidly tunable narrow band LWIR filter***
- ❑ ***Convert LWIR camera to Hyperspectral imager***
- ❑ ***Create Hyper-data cube with scanning software***
- ❑ ***Applications include chemical and target identification***
- ❑ ***Suitable for terrestrial and space born applications***
- ❑ ***Prototypes available in 2000***