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Radiometric Calibration Transfer Chain from Primary Standards to End-to-End Sensor Characterization

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Session I - Assessment of Absolute Radiometry for Remote Sensing

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Introduction

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A primary absolute radiometric scale of irradiance has been realized at TRW in support of the Hyperion sensor calibration.

The Hyperion sensor has been integrated with the Earth Observing Spacecraft (EO-1) as part of the New Millennium Program.

This irradiance scale has been transferred to a secondary standard of radiance radiometric calibration of Hyperion responsivity and transfer to the on-board calibration radiance source.

This irradiance scale is an internally cross-calibrated set of four standards, three of which are directly traceable to NIST physical standards.

The calibration plan incorporates the desire to have absolute standards directly, physically located within the sensor calibration environment and cycle; this hopefully limits the transfer errors in the train of calibration traceably.

Primary Standards

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HQE Si pn Photodiode Trap Detector - QED-150 (Graseby Optronics)

EG&G UV444B Si Photodiodes

HQE Si pn Photodiode Trap Detector - SPR-73 (Cambridge Research and Inst.)

Hamamatsu S1337-1010 Si Photodiodes

LaserProbe RS-5900 (ECPR)

Electrically Calibrated Pyroelectric Radiometer (ECPR) (Laser Precision Corp)

The Sylvania FEL 1000 Watt QTH Lamp (Optronic Labs, Inc.)

High Quantum Efficiency Silicon Photodiode Trap Detector

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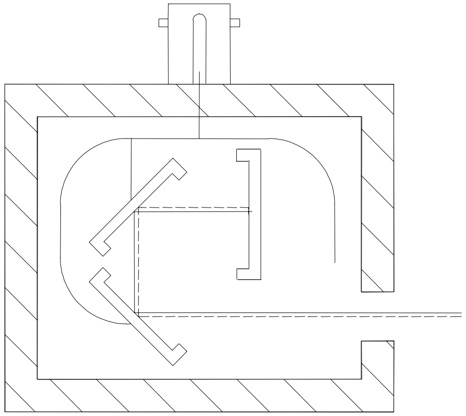
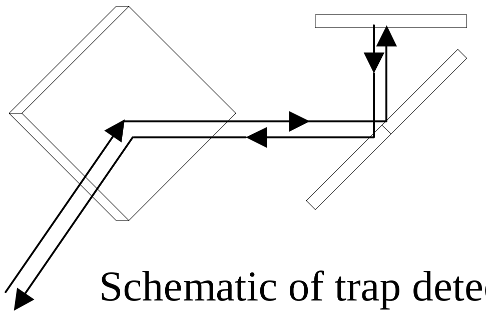
- Detector performance traceable to fundamental solid state physics in which each incoming photon is converted to an electron which provides a current in an external circuit
- Silicon inversion layer pn photodiode detectors have internal quantum efficiencies better than 99.9 % across the visible spectrum
- Literature spans 20 years on study of photon absorption physics
- Reflection losses at the silicon surface are minimized by using three detectors arranged in the classic trap configuration providing 5 reflections.





Schematic of trap detector using 3 photodiodes Detectors lie in different planes

Electrically Calibrated Pyroelectric Detector (ECPR)

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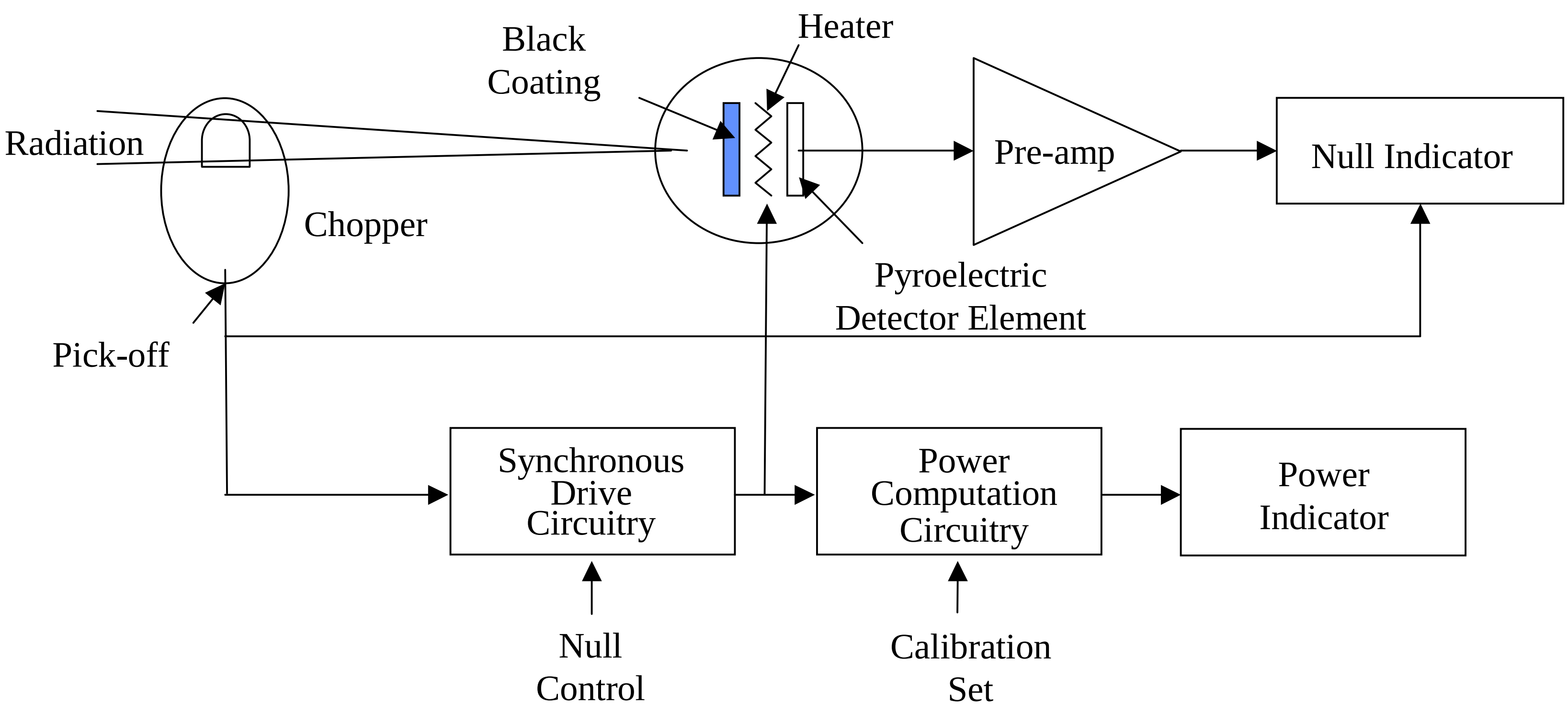
- Lithium Tantalate Pyroelectric Crystal Detector with thin film heater deposited on surface
  - with black gold absorbing layer
- CTX-515 fixed speed (5Hz) Chopper
- Tuned lock-in voltmeter serves as a null detector
- Power computation circuitry and indicator



Overview of Process

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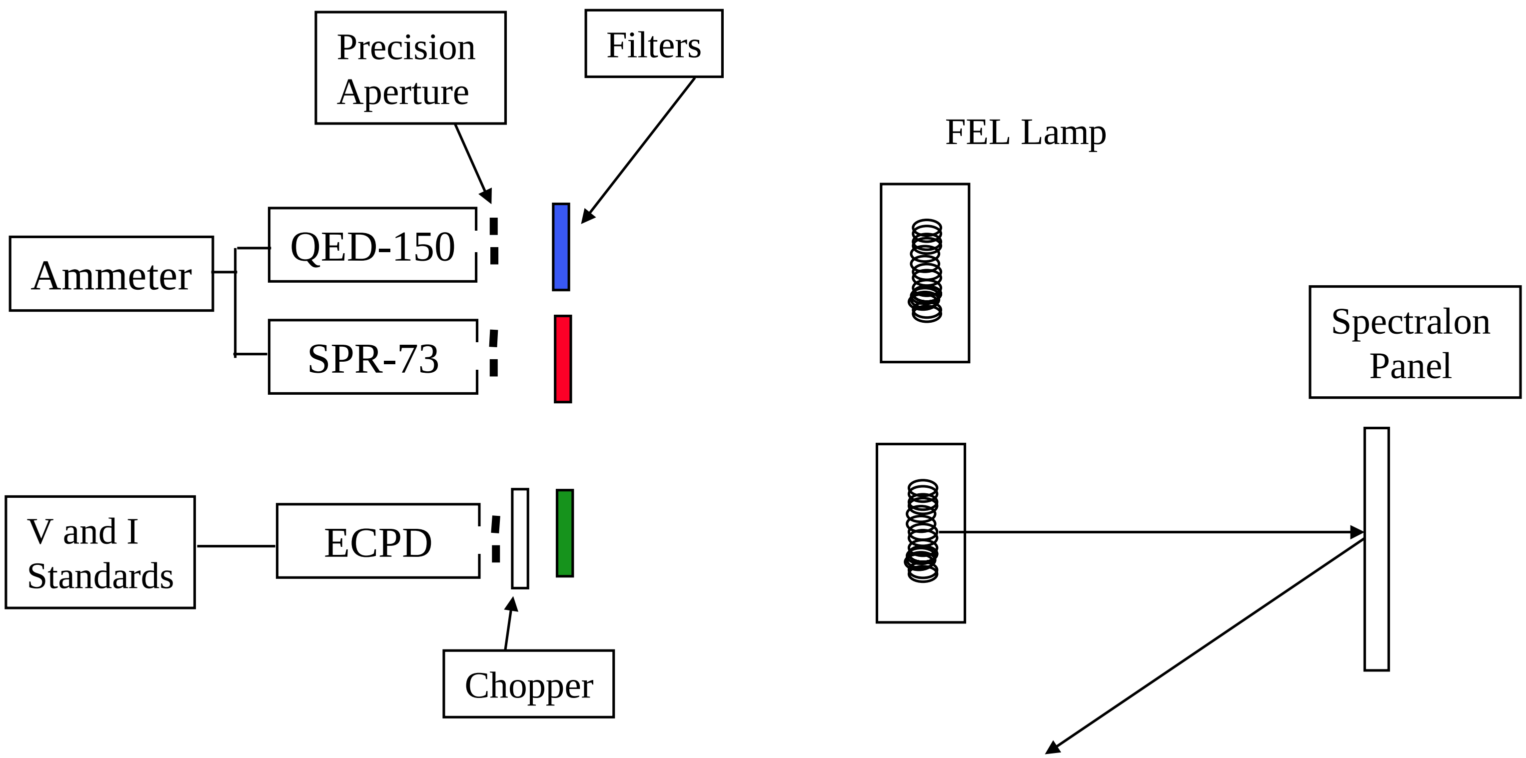

Bandpass Filters Employed

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Reflectance of filters measured with Cary 5 Spectrometer

Linearity of Cary 5 checked at 0.6328 HeNe line using a trap detector as reference and was found to be 1.39 % low

Left set of 10 filters used with trap detectors plus ECPR

ECPR uses 19 in list on right for extension of scale out to 2500 nm

Effective Wavelength [nm]	Effective Bandwidth [nm]	Effective Wavelength [nm]	Effective Bandwidth [nm]
402.3	2.41	999.9	5.69
450.9	5.66	1052.5	5.72
502.2	6.50	1099.5	4.42
549.4	4.16	1199.6	3.16
601.6	5.92	1298.6	4.08
651.6	6.74	1388.3	3.05
698.4	5.29	1499.7	4.02
751.9	5.24	1552.7	6.75
800.5	5.61	1600.8	5.30
901.7	7.74	1648.2	4.86
		1701.1	4.68
		1794.1	5.19
		1899.8	6.15
		1999.6	6.58
		2095.8	4.87
		2193.1	2.85
		2297.0	5.51
		2400.2	7.51
		2498.1	3.74

Comparison of Primary Detectors

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HeNe 0.6328 µm Laser Line Comparison Eliminates Aperture and Filter Errors

Using 9 spectral filters from 450 to 900 nm:

- Comparisons made with different trap detectors and same apertures and;
- Comparisons made with same trap detectors and different apertures
- Comparisons made with trap detector and ECPD

HeNe Laser Line Comparison					
	Gain	Error	Offset	Error	Levels
QED vs ECPR	0.99981	0.0011	-0.017	0.012	8
QED vs SPR	1.00080	0.00033	0.0046	0.0089	12

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		Gain	Error	Offset	Error	Levels
QED	Different Apertures	1.0087*	0.0038	-0.053	0.061	9
SPR	Different Apertures	1.014*	0.0045	-0.053	0.068	8 **
QED vs SPR	SPR Aperture	0.9912	0.0027	0.026	0.043	8 **
QED vs SPR	QED Aperture	1.0034	0.0019	-0.079	0.031	9
QED vs SPR	Measurements one day apart	0.9836	0.0051	0.029	0.081	9
QED vs SPR	"own aperture"	0.9881	0.0011	0.0017	0.017	9
QED vs ECPR		0.9960	0.0058	-0.10	0.091	9
* QED Aperture / SPR Aperture appears about 1 % QED Aperture Diameter = 0.3197 cm; SPR Aperture Diameter = 0.5065 cm						
** One 4 sigma data point thrown out						

Spectral Irradiance Curve

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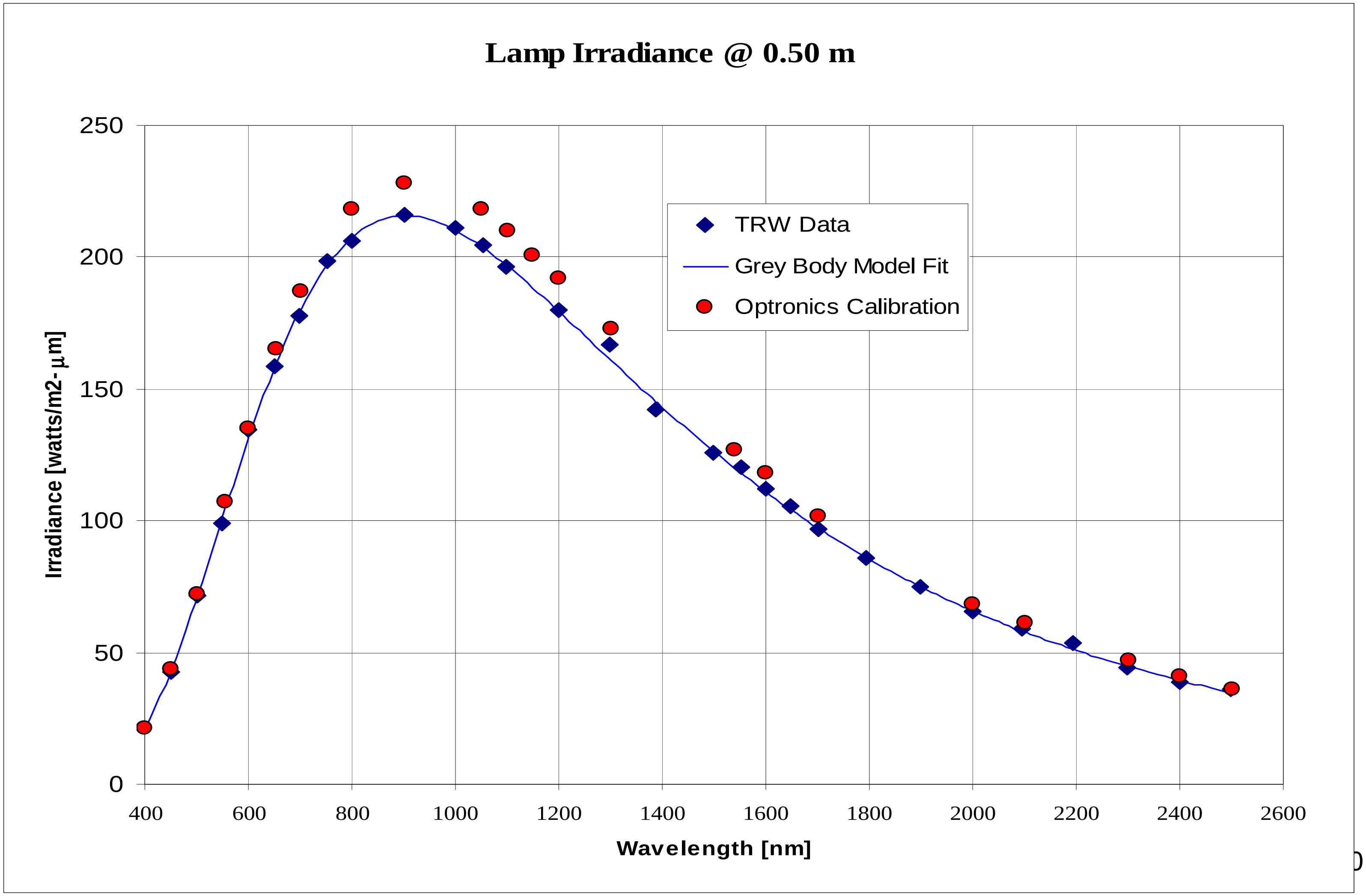

Interpolation Model

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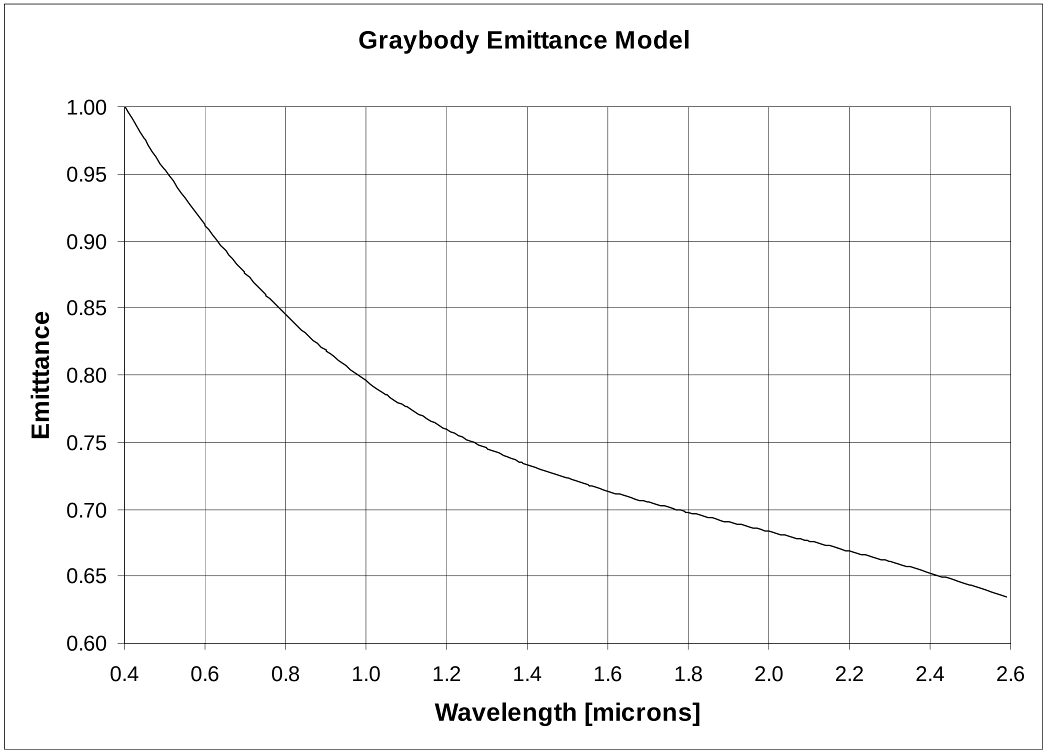
A 3100 Kelvins Graybody function with the emittance curve at right was used to smoothly interpolated the data points

RMS of variation about spectral irradiance curve is 1.19 %



Conversion to Radiance

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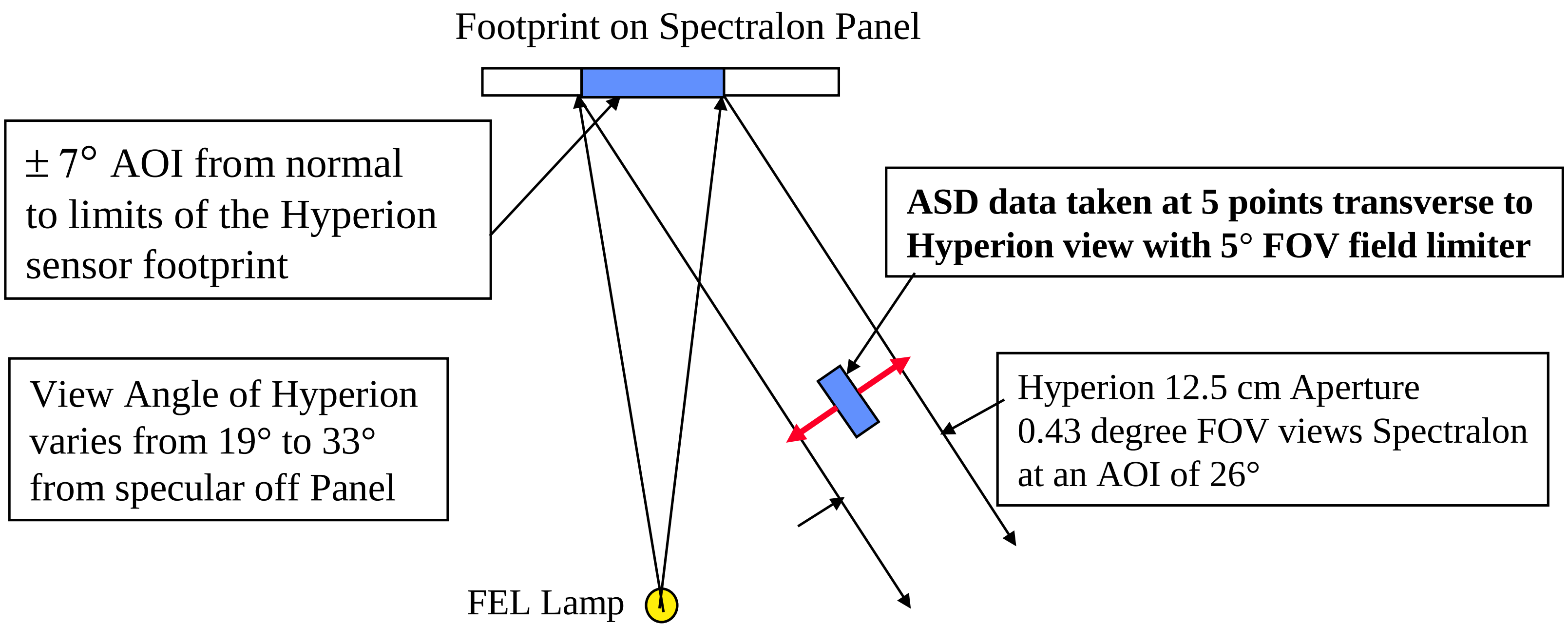

FEL Incident Irradiance falls as $\cos^3$ of the AOI which is a 2.5 % falloff in Irradiance

The BRDF characteristics of the Panel are critical in converting FEL Irradiance incident on the Panel to Radiance. The assumption that the BRDF is flat from 19° to 33° based on vendor data was tested using an ASD Field Spec as shown. ASD data matched the 2.5 % falloff to ± 0.3 %

Transfer Radiometer Components

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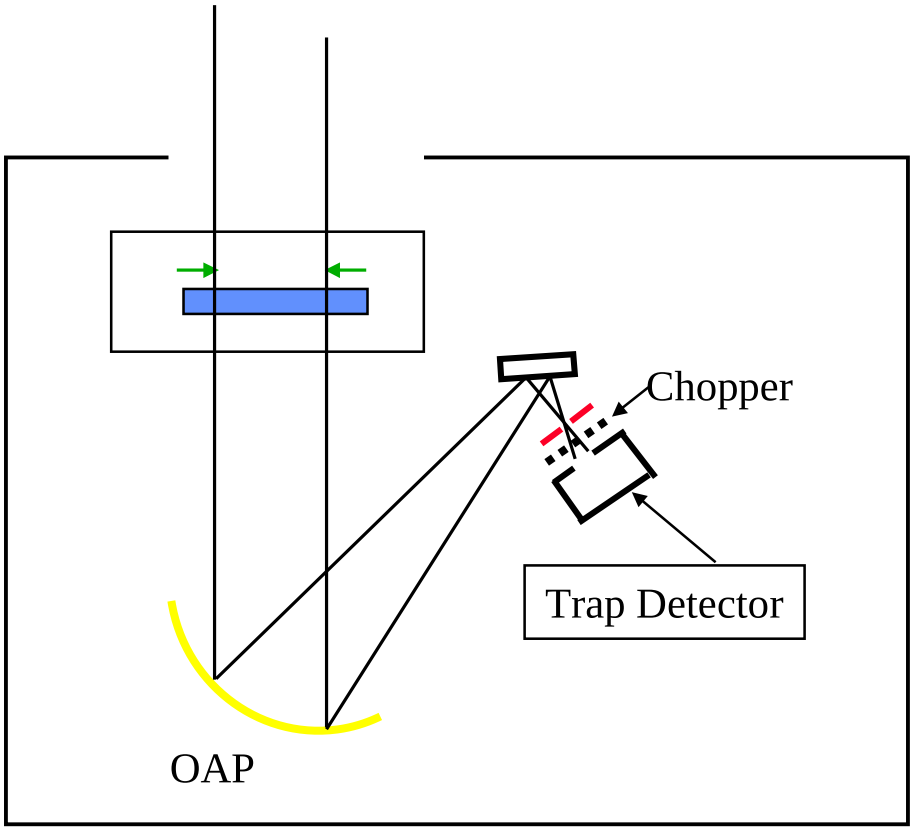

Entrance Aperture - 22.2 mm
0.7 - 0.9 µm Bandpass Filter
Off-Axis Parabola OAP
Field Stop
Chopper
Si Photodiode Trap Detector

Spectralon Panel Assembly (SPA) Validation

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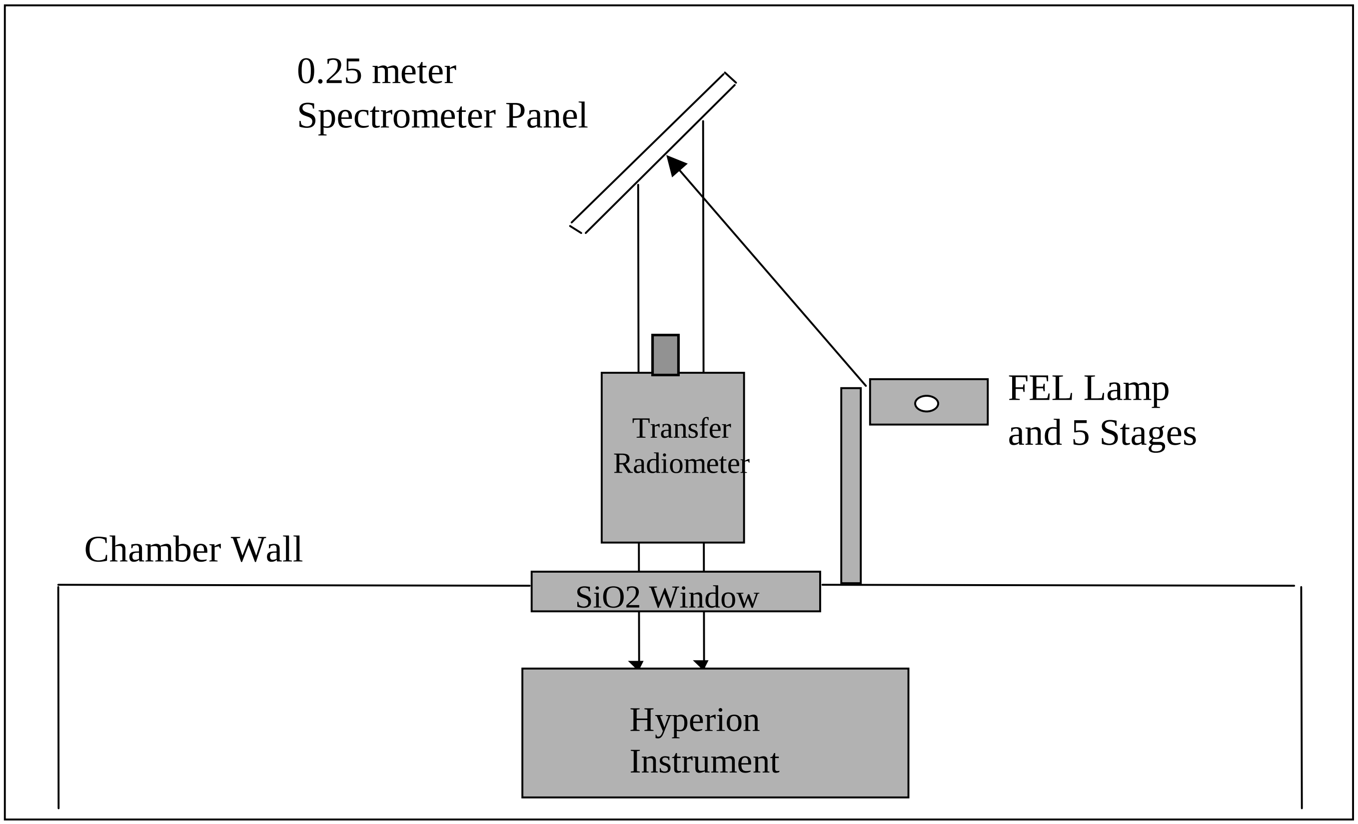

Spectralon Panel Assembly Installed

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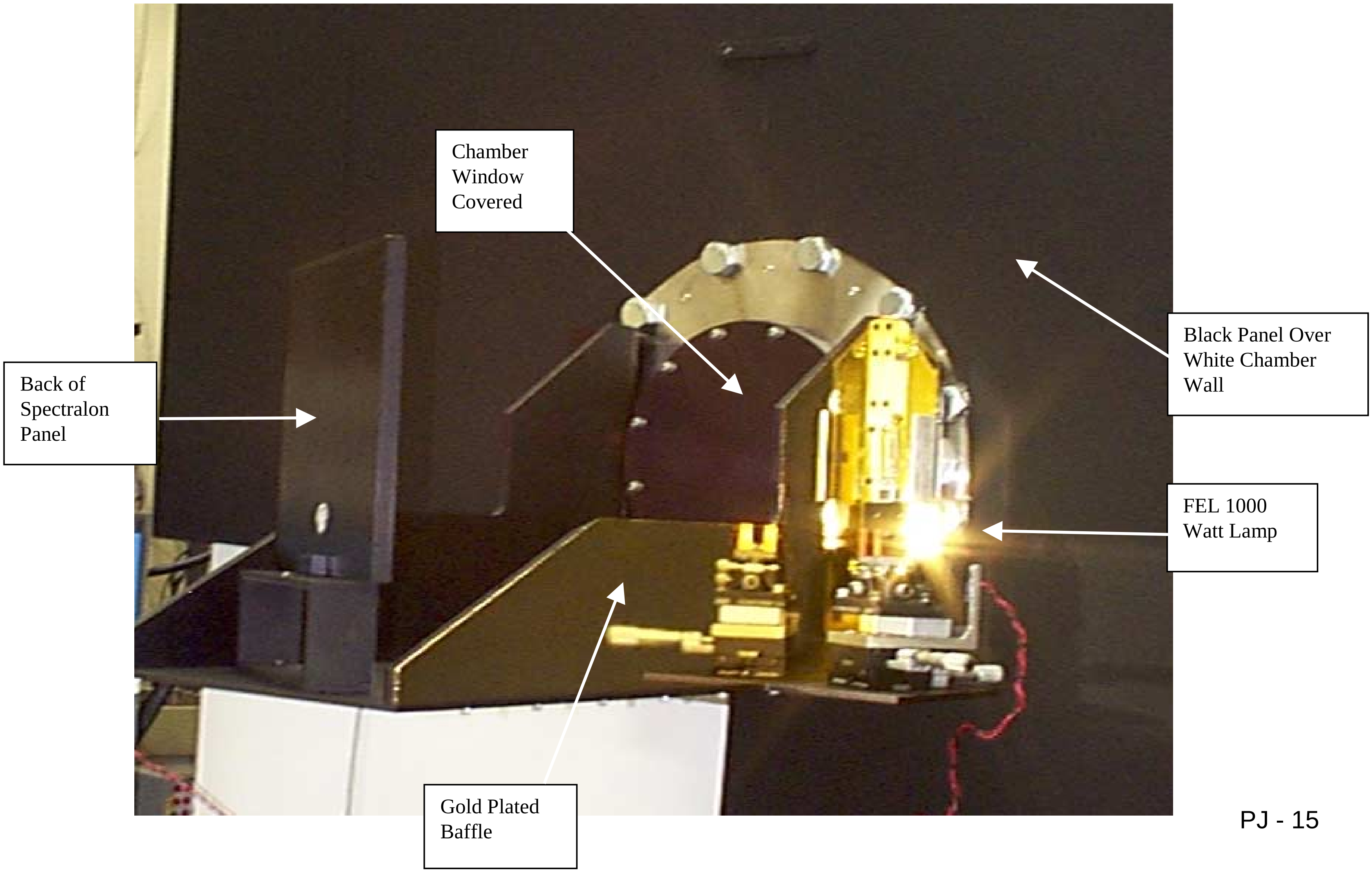

Transfer Radiometer History

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The Radiance of the Spectralon Panel is calculated by the Ratio of the incident FEL lamp Irradiance and the BRDF of the Spectralon (including the Reflectance of the Spectralon taken from vendor specifications).

The expected Current Signal from the Si Photodiode Trap Detector is calculated from the throughput of the Transfer Radiometer including the optical AΩ, the effective filter Transmittance and the Reflectance of two silver mirrors
- note the responsivity of the trap detector cancels out.

Date	Configuration	Lamp Age [Hours]	Expected Signal [μA]	Measured Signal [μA]	Relative Difference [%]
5/6/99	Panel on open bench	25.4	0.3487	0.3502	0.41
5/6/99	Panel mounted in assembly on bench	30.1	0.3487	0.3527	1.13
6/8/99	Panel assembly mounted on Vacuum chamber	39.4	0.3487	0.3505	0.51
7/2/99	Panel assembly mounted on Vacuum chamber	68.6	0.3487	0.3509	0.61

Error Budget for the Two Validation Paths for Irradiance to Radiance Conversion

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Radiance Error from Assumed Spectralon Properties	
Error Term	**Error [%]**
Reflectance at 26^{o} Angle of Incidence	1.0
Scatter Uniformity with Angle	0.5
Stray Light	0.5
Total Error	**1.2**

Radiance Error from Calculated Transfer Radiometer Throughput	
Error Term	**Error [%]**
Entrance Aperture Area	0.2
Field Stop Area	0.2
OAP Focal Length	0.5
Effective Filter Transmittance	1.5
Silver Mirror Reflectance	0.7
Total Error	**1.8**

SPA Error Budget Summary

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Lamp Irradiance		
Primary Standards		0.29
Agreement	0.1	
Trap Detector Ammeter Calibration	0.3	
HQE Correction	0.1	
Lamp-Trap Detector Distance		0.5
Precision Aperture Area		0.5
Filament Alignment Repeatability		0.3
Lamp Current Repeatability		0.1
Filter Effective Bandwidth		1.0
Interpolation Between Band Data Points		0.5
Sub-Total Lamp Irradiance		**1.39**
Conversion to Radiance		1.0
Stray Light Contamination		0.5
SiO_2 Window Transmittance		0.5
Total Error (1 sigma)		1.85