Labsphere

advancing the technology of light

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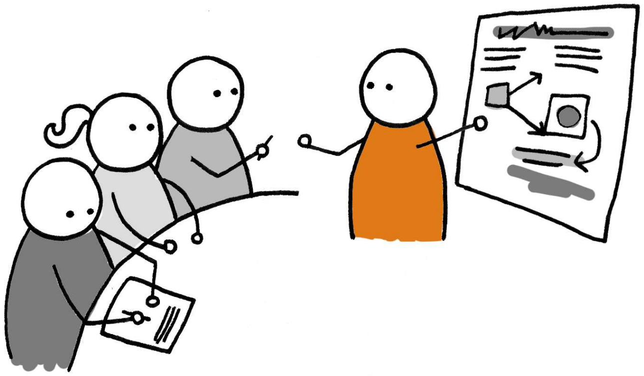
MEASURE
any light source

CREATE
any spectrum

REFLECT
any wavelength

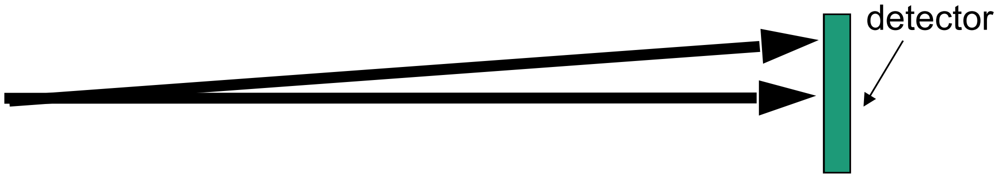
MEASURE

- Agenda
    - Spheres vs. Classic Laser Measurement Solutions
    - Temporal Issues with Spheres
    - Advantages/Disadvantages
    - Calibrating Spheres for Laser Power Measurements
    - Substitution Correction
- And…if there is time…
    - Spheres throughput with various devices
    - Laser Damage Thresholds
- (Not Covered) Product Slides & Supporting Information



Classic Laser Power Meter

Classic Laser Power Meter



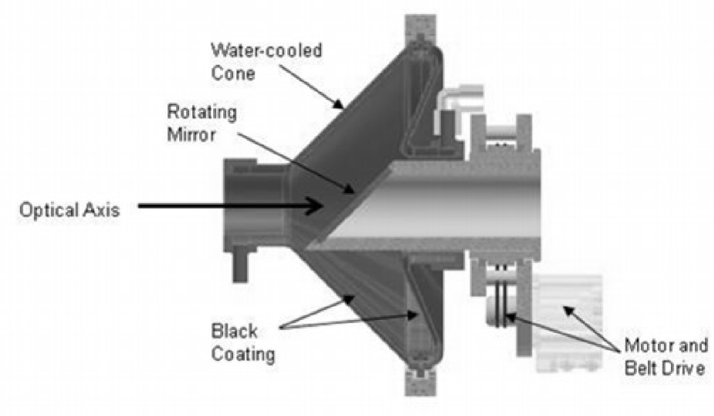
Thermopile, Absorber Cavities & Pyroelectric

PROS

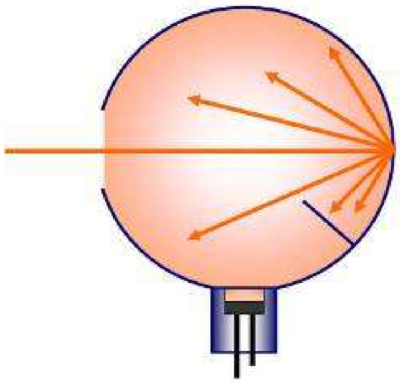
- Convert optical to thermal
- Can Very Accurate
- High damage thresholds
- Pyros can be very fast

CONS

- Thermos can be very slow
- Drift / Sensitive to Ambient changes
- Single wavelength at a time
- Can be angularly/spatially sensitive



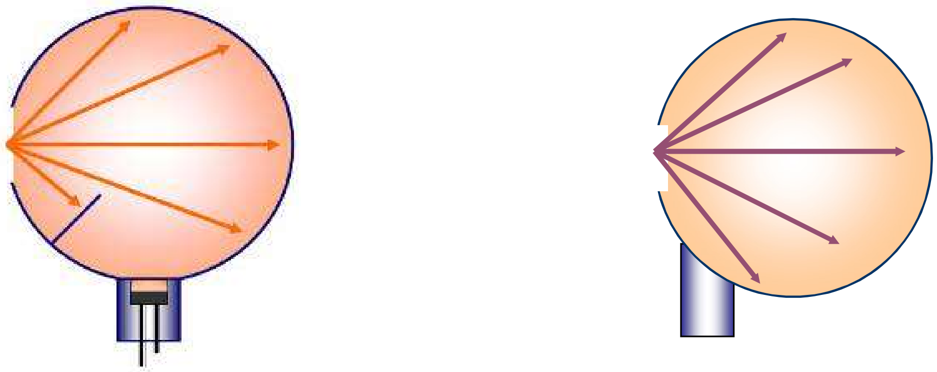
Spheres - Differentiating Collection Geometry



collimated beams

attenuation > 1000:1

baffle the “hotspot”



divergent, non-symmetrical beams

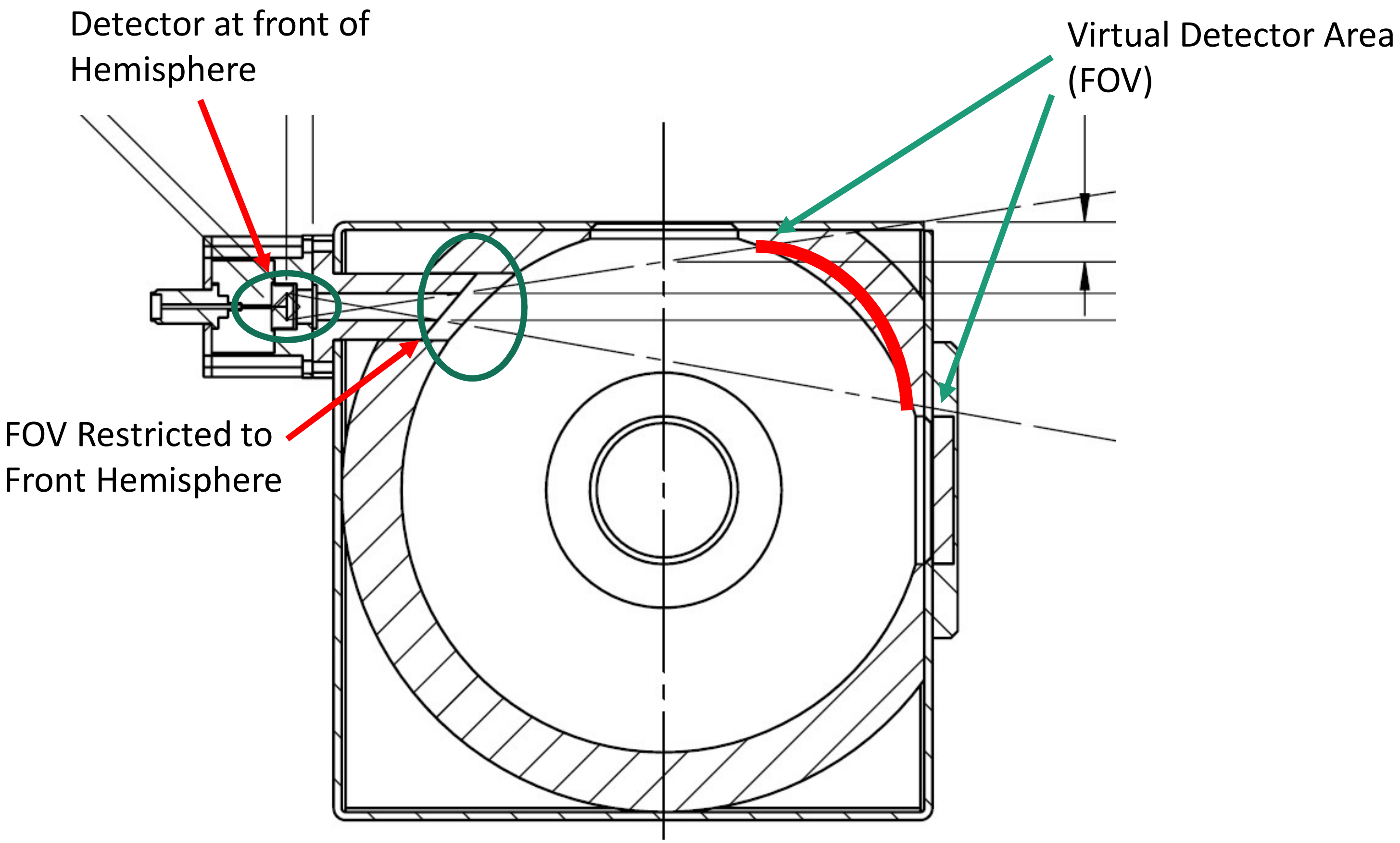
attenuation > 1000:1

total integration

FOV cannot overlap irradiation

attenuation > 10000:1

Cut Away of Off-Axis Sphere Design

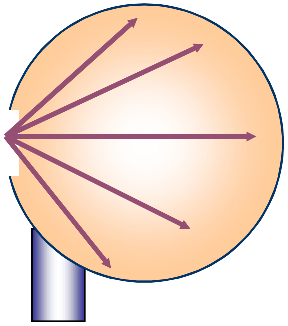


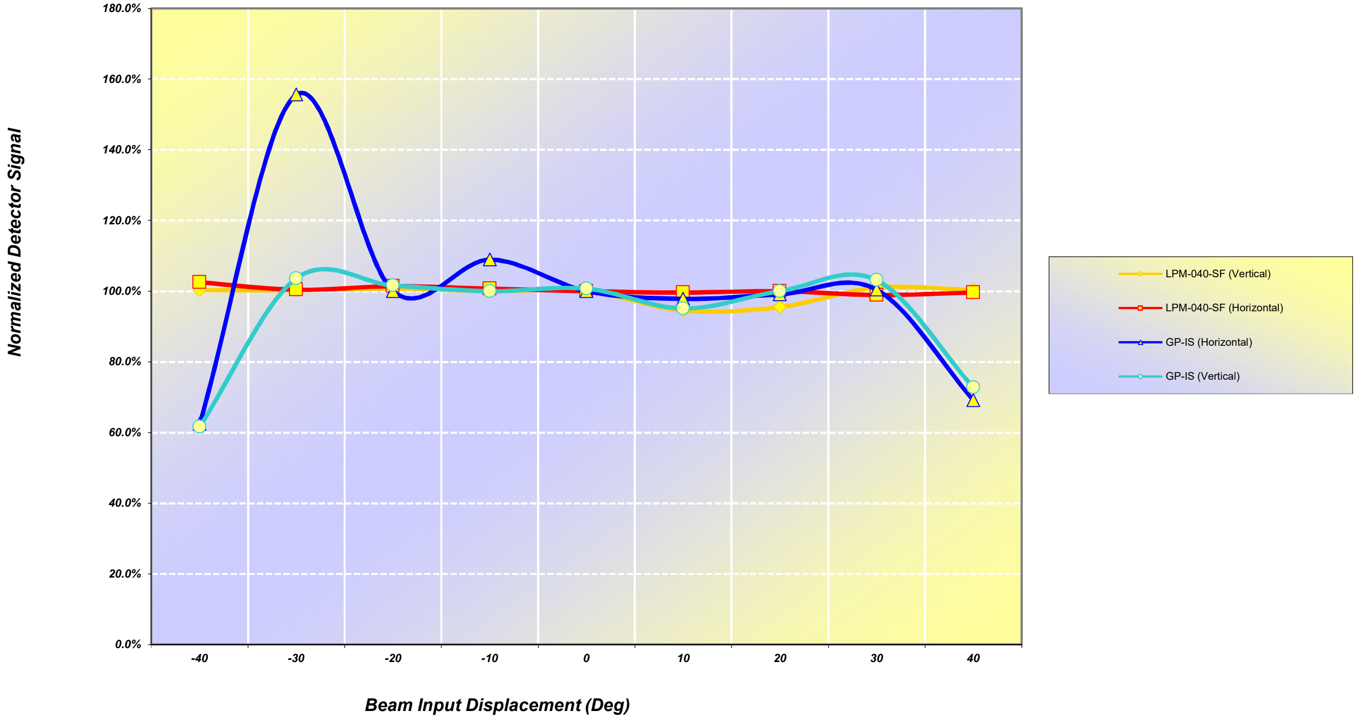
Detector at front of Hemisphere

Virtual Detector Area (FOV)

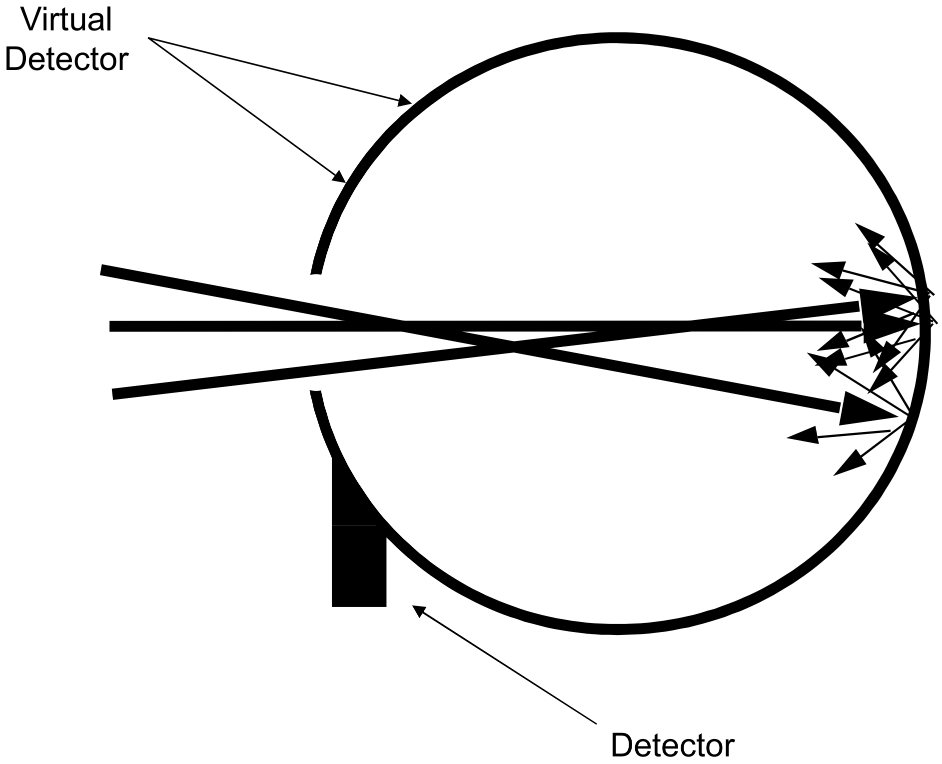
FOV Restricted to Front Hemisphere

Angular Sensitivity of Off-Axis Design





Sphere Laser Power Meter



Protected Aluminum
0.1-0.3um

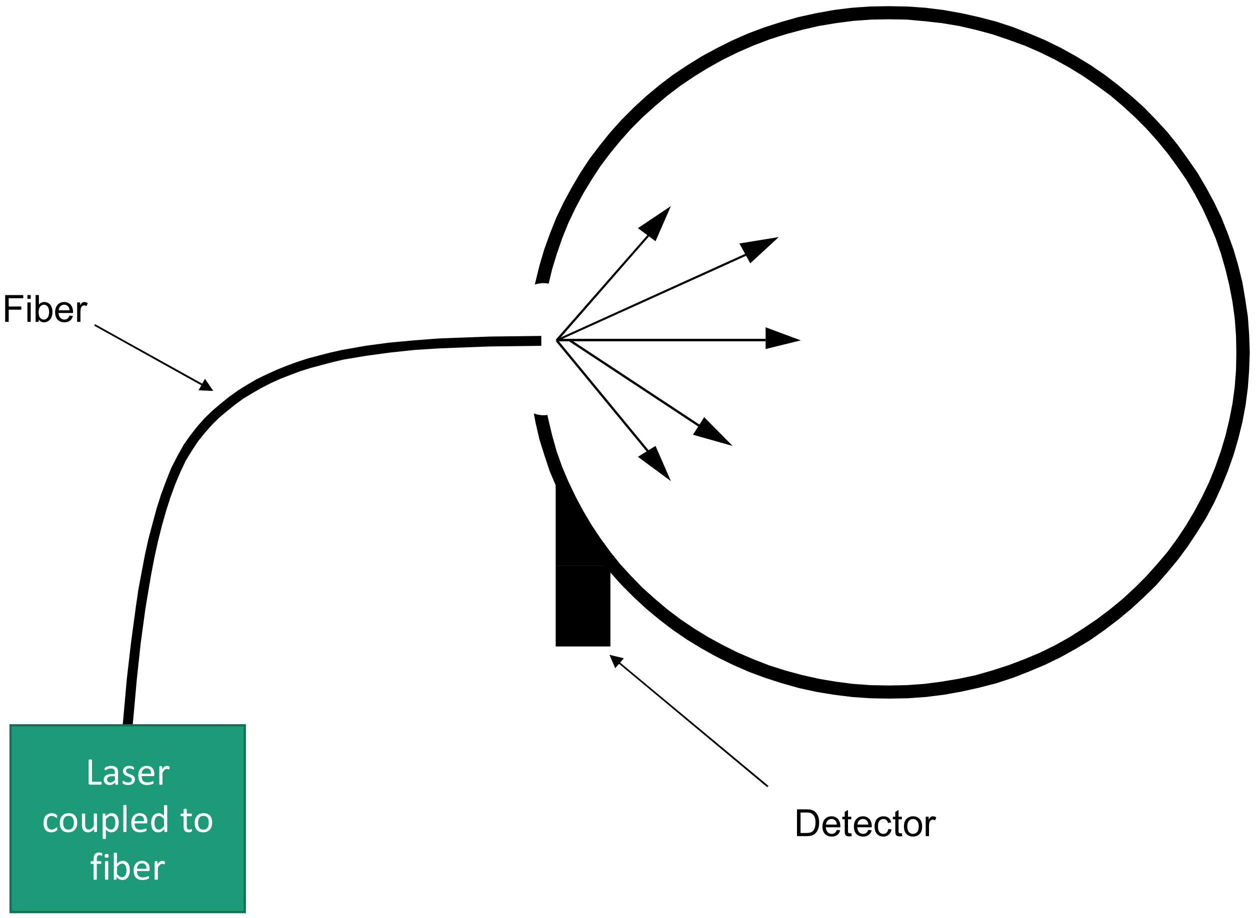
Spectralon (PTFE)
0.2-2.5um (even 3.0um)

Spectraflect (BaSO4)
0.4-1.3um (out to 2.5um).

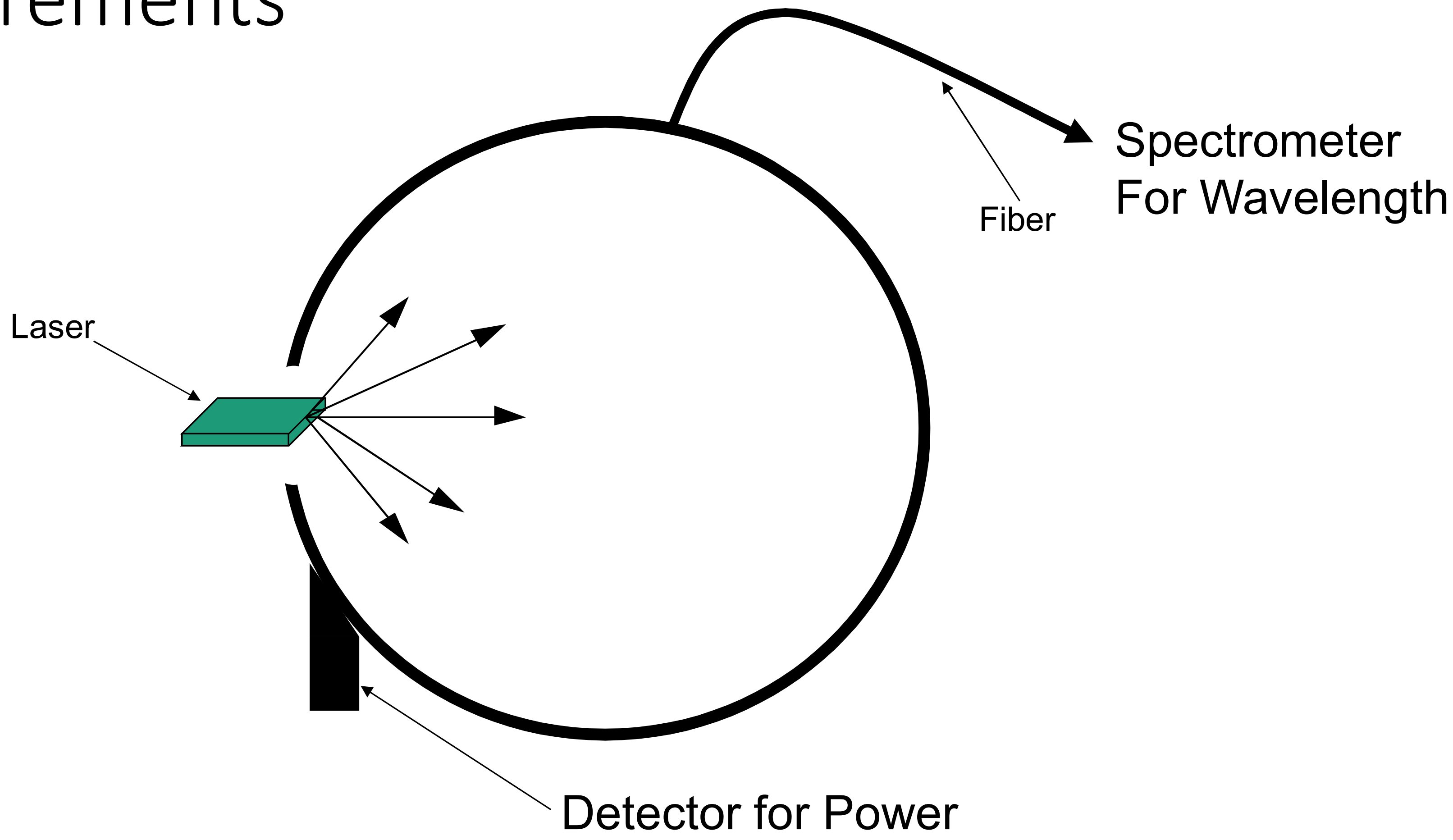
Protected Silver
0.3 to >12um

InfraGold
0.65 to >12um

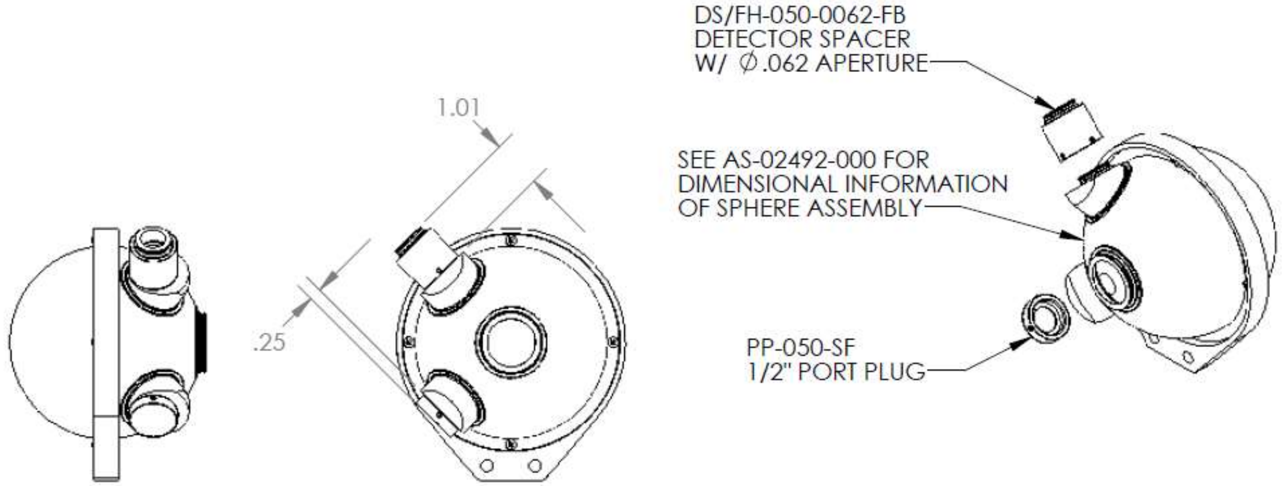
Diode Laser/Stack or Optical Fiber

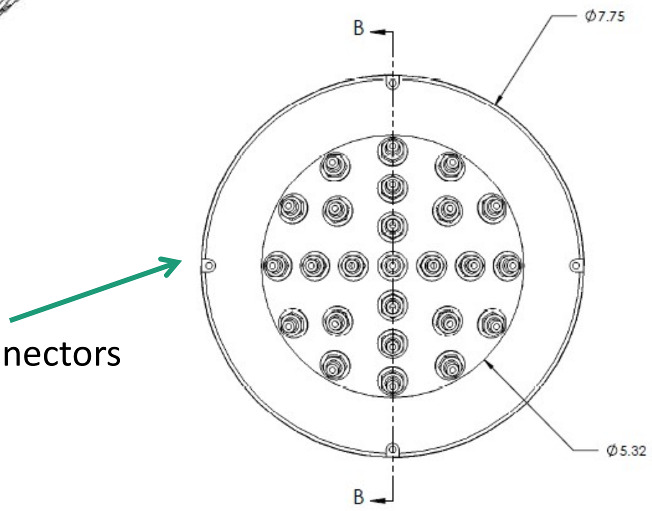


Wavelength and Power – Simultaneous Measurements



Multiple detectors on a sphere (Si, IGA, etc)





25 FC/PC Connectors

Temporal Issues with Spheres

Spheres and Speckle (Coherence)

- Spheres DO NOT Remove Coherence (unless very large diam.)
  - Speckle patterns can be readily observed at the output of spheres
  - Can be a problem for fiber coupling where core size is close to the speckle size (speckle/no speckle spots).

- Speckle can be “defeated” in some applications by simply “dithering” the laser or sphere physically.
  - Causes the speckle pattern to move spatially and randomly
  - If the frequency of the physical movement is faster than the scan rate of the sampling device the spatial field is averaged and appears uniform.

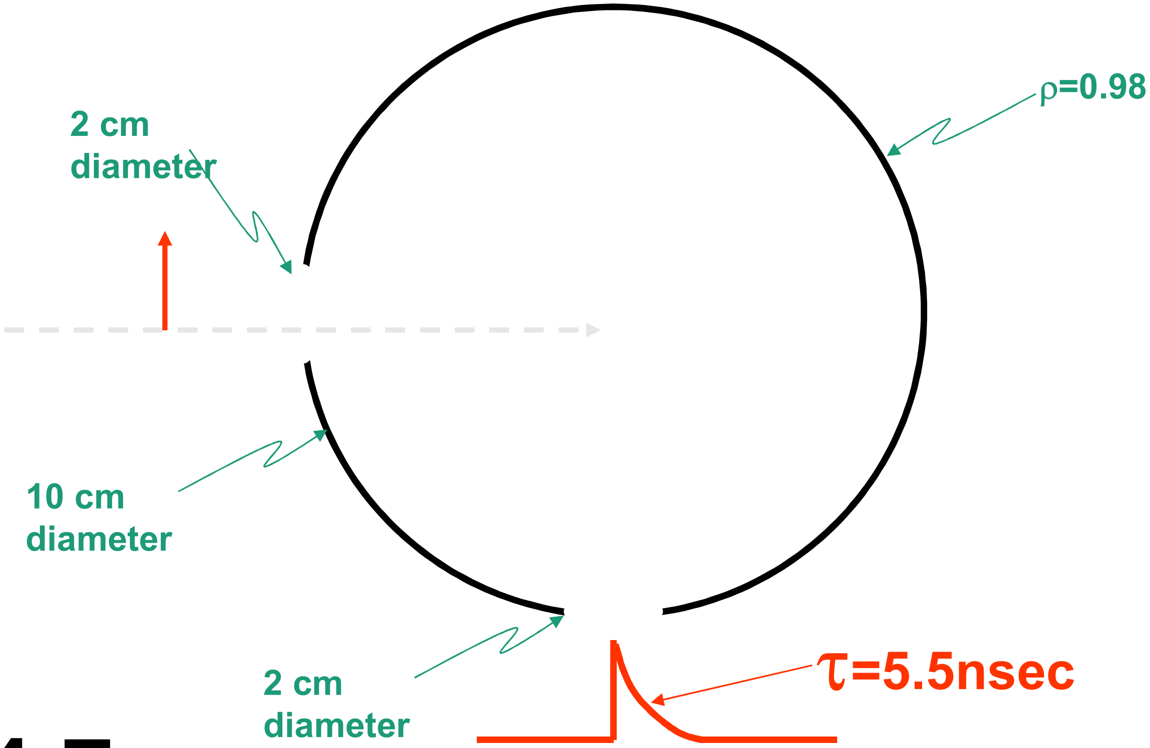
Sphere Time Constants

- Due to the multiple reflections in a sphere and the “random” path length of each photon, not all photons arrive at a designated point at the same time.
- A sphere acts very much like a “photon-capacitor” and has a time constant similar to this analogy.
- This Time Constant is driven by the D (diameter of the sphere), ρ_0 (the reflectance) and, c (the speed of light).

$$e^{-t/\tau} \quad \text{where} \quad \tau = -\frac{2}{3} \cdot \frac{D}{c} \cdot \frac{1}{\ln \rho_0}$$

- Typical time constants are 2-10ns.
- Problem can be a Solution in cases of very fast pulse where sphere time constant averages pulse

Sphere Time Constant Example



2 cm diameter

ρ=0.98

10 cm diameter

2 cm diameter

τ=5.5nsec

M=24.7

Sphere Advantages Summary

- Spatial
- Angular
- Robust, repeatable and easy measurement for most sources
- Use conventional detectors
- Wavelengths 0.1um to >12um (Sphere material dependant)
- Attenuation (SNR)
- Multipass chambers – path length = 10-30x Diameter.
- Polarization insensitive (removes polarization from inputs)
- Multiple Detectors can be employed
- Multiple Wavelengths at same time
- Real time detection (no thermal delay)
- Averaging of very fast pulses (time constant)
- Uniform coupling of light from one device to another (etendue)

Sphere Disadvantages Summary

- Throughput
- Time constants for high speed waveforms.
- SNR (Attenuation)
- Thermal limitations
- Multipass Chambers: Spheres are contamination sensitive (Humidity, Dust, Hydrocarbons, Air, etc)
  - Temporal stability depends on use
- Material Damage Thresholds
- Spectralon Sphere dimensions can change with temperature
- Uncertainty ~1.5-2.5% (k=2)
  - Si 450-850nm, InGaAs 1000-1700nm
- Uncertainty ~3-6% (k=2)
  - Si 300-450nm / 850-1050nm, InGaAs 900-1000nm / 1700-1800nm,
- Uncertainty Doesn’t scale well with power >1W due to calibration levels (10uW)
  - Opportunity to improve methods (here to learn)

Calibrating Spheres for Laser Power Measurements

Calibration Setup - Based on CIE 220:2011

- Features
  - Traceable to NIST
  - Automated to do scans and create calibrations with selected reference detector traceable to NIST
  - Creates Calibration Files readable by User Application

- Initial Setup
  - Set:

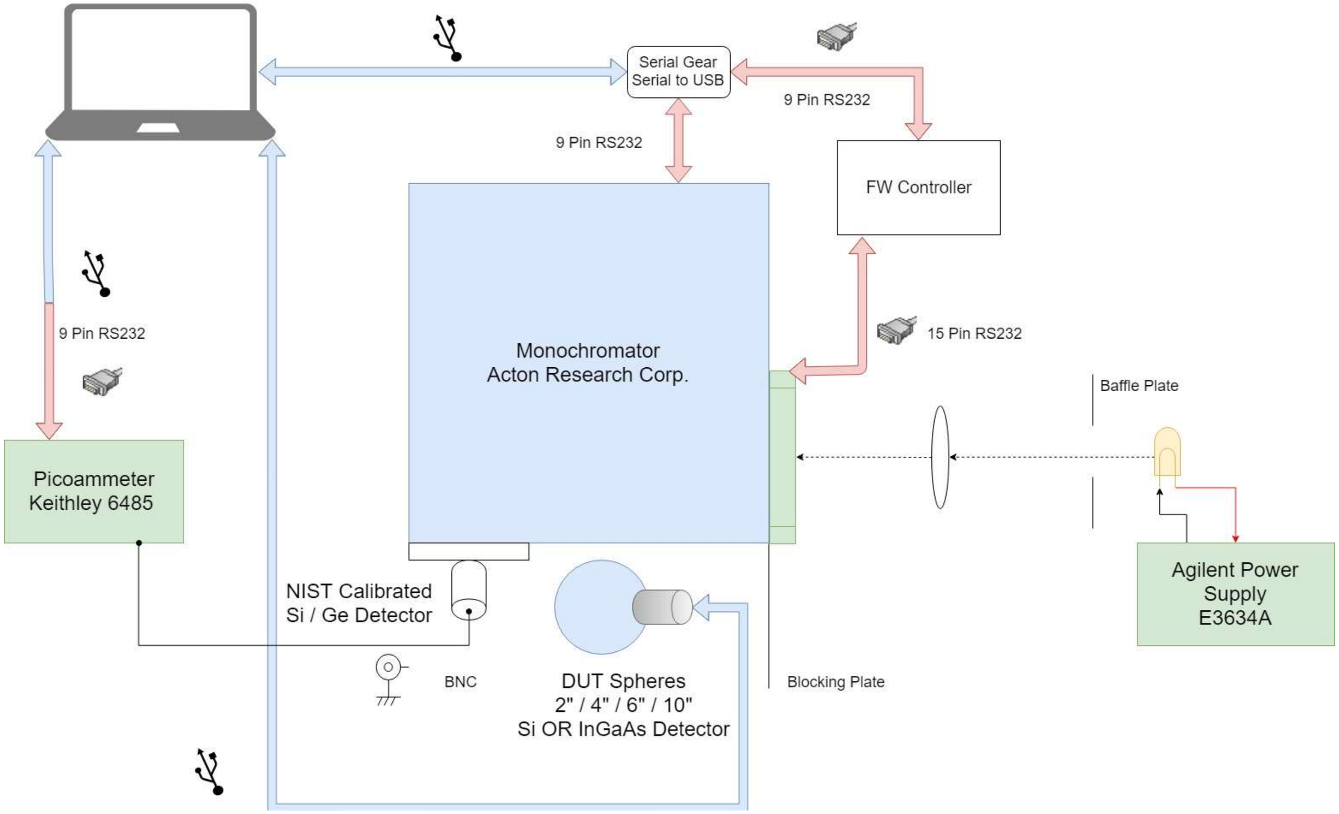
    Slit width at Entrance and Exit Ports
  - Setup:

    Reference Detector at Exit Port
  - Prepare:

    Mount DUT LPMS System on a suitable post for Exit Port

LPMS Calibration Setup

http://www.cie.co.at/publications/spectral-responsivity-measurement-detectors-radiometers-and-photometers



Process

Turn On and Stabilize	Light Source using Agilent Power Supply in Current Mode
Connect	Monochromator Filter Wheel Keithley6485 DUT LPMS Detector
Set	Averaging Period Scans to Average
Select	NIST Detector Calibration Type Calibration Slot Settings Calibration Wavelength Range and Interval
Start	
Preview Calcs	Preview Calibrations
Write	Raw Data Files (.csv) For Uncertainty Calcs Calibration File (.xml) For User Application

Applying Calibration Correction Multiplier

The power correction multiplier K_λ for the LPMS is defined as

$$K_\lambda = \frac{1}{R_{s\lambda}}$$

The radiant power ϕ_λ of the source is then calculated as:

$$\phi_\lambda = S_s K_\lambda$$

Where:

ϕ_λ = power of the of the laser, [W]
S_s = signal from the integrating sphere laser power meter, [A]
K_λ = power correction multiplier, [W/A]

Limitations

Wavelength Resolution	Lowest interval possible is 5 nm due to NIST Calibration
Time	Standard Calibration Wavelength Interval 10 nm As these are transient detectors, averaging is required, helps calibration and uncertainty evaluation If requested lower than 10 nm wavelength steps revisit calibration cost
Error	Silicon detector responsivity below 400 nm and above 1000 nm are low, measured power may have errors InGaAs detector responsivity below 800 nm and above 1650 nm are low, measured power may have errors
Measurement Uncertainty	Si detector NIST reported uncertainty below 400 nm and above 1000 nm are high, High Measurement Uncertainty Ge detector NIST reported uncertainty below 800 nm and above 1650 nm are high, High Measurement Uncertainty

Traceability

NIST Calibrated Detectors

- Si Detector calibrated from 350 nm - 1100 nm in 5 nm interval
- Ge Detector calibrated from 700 nm - 1800 nm in 5 nm interval

Detector Readout

- Keithley 6485 pico-ammeter calibrated by NVLAP Accredited Lab

Power Supply

- Agilent E3634A calibrated by NVLAP Accredited Lab

Monochromator

- Wavelength Accuracy reported by Manufacturer
- Stray Light Analysis Performed by Labsphere
- THL stability

LPMS

- Detector linearity
- Detector spectral thermal coefficient

Uncertainty

Analysis Environment

NIST/NPL Validated Computation Procedure

Modular and Scalable Architecture

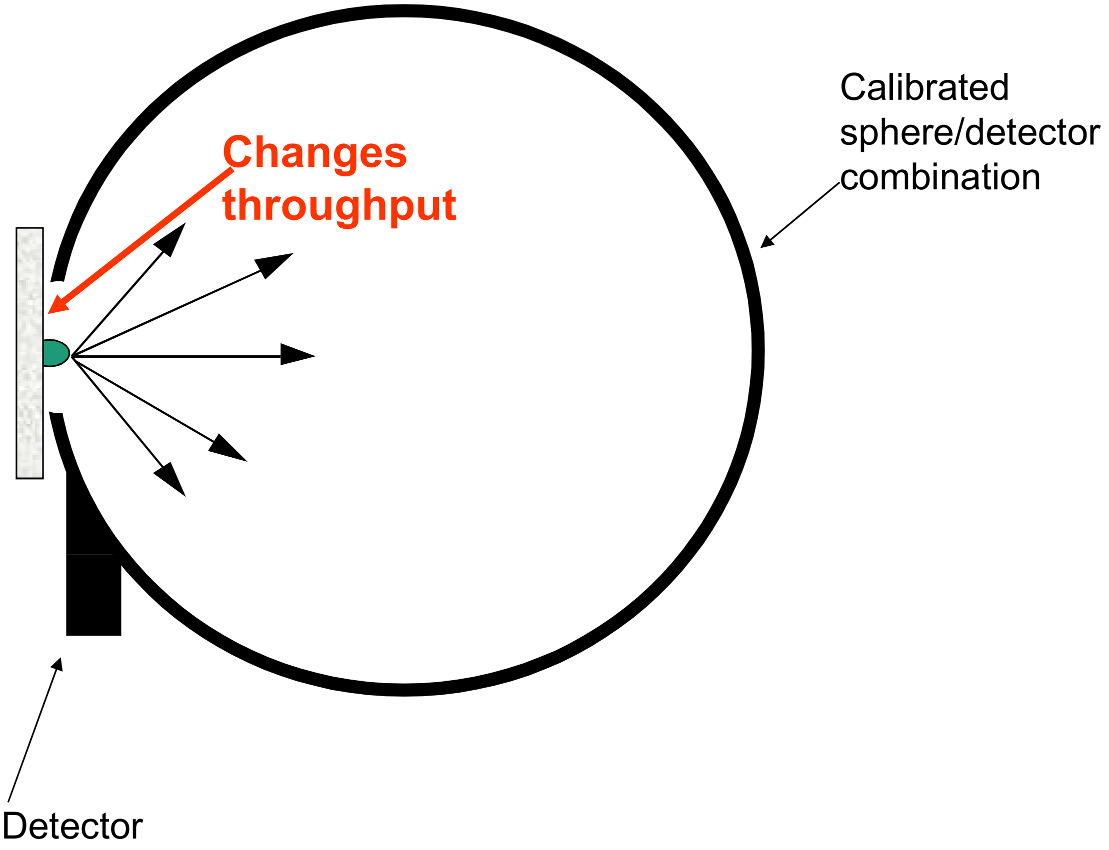
Expanded Uncertainty

Performed Pre-release analysis

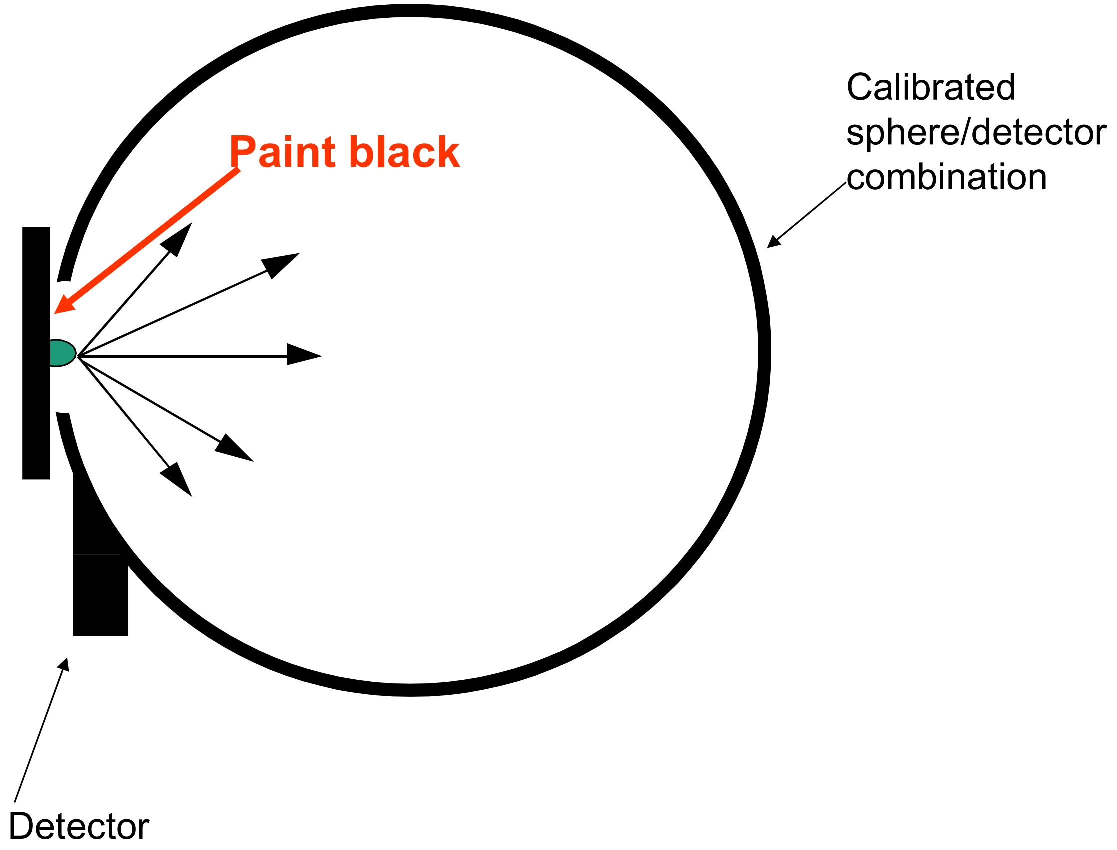
Can be reported with each calibrated unit

Substitution Correction for Sphere Calibrations

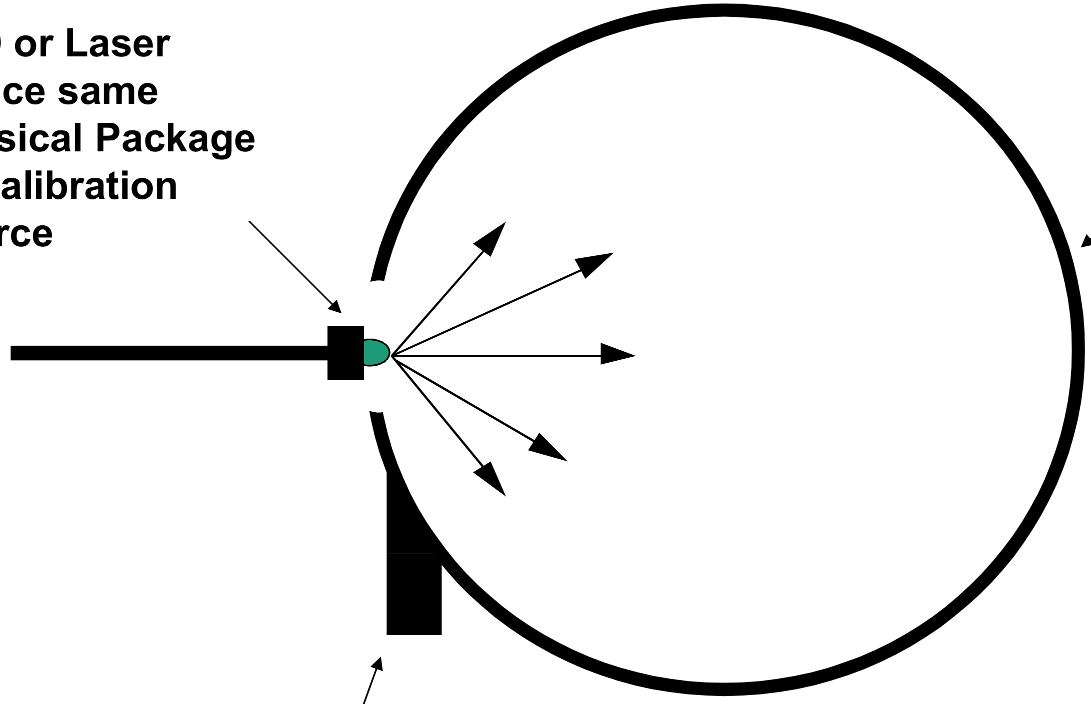
Substitution Error – Diode/LED



Substitution Error



Substitution Error – Use "Golden" Device

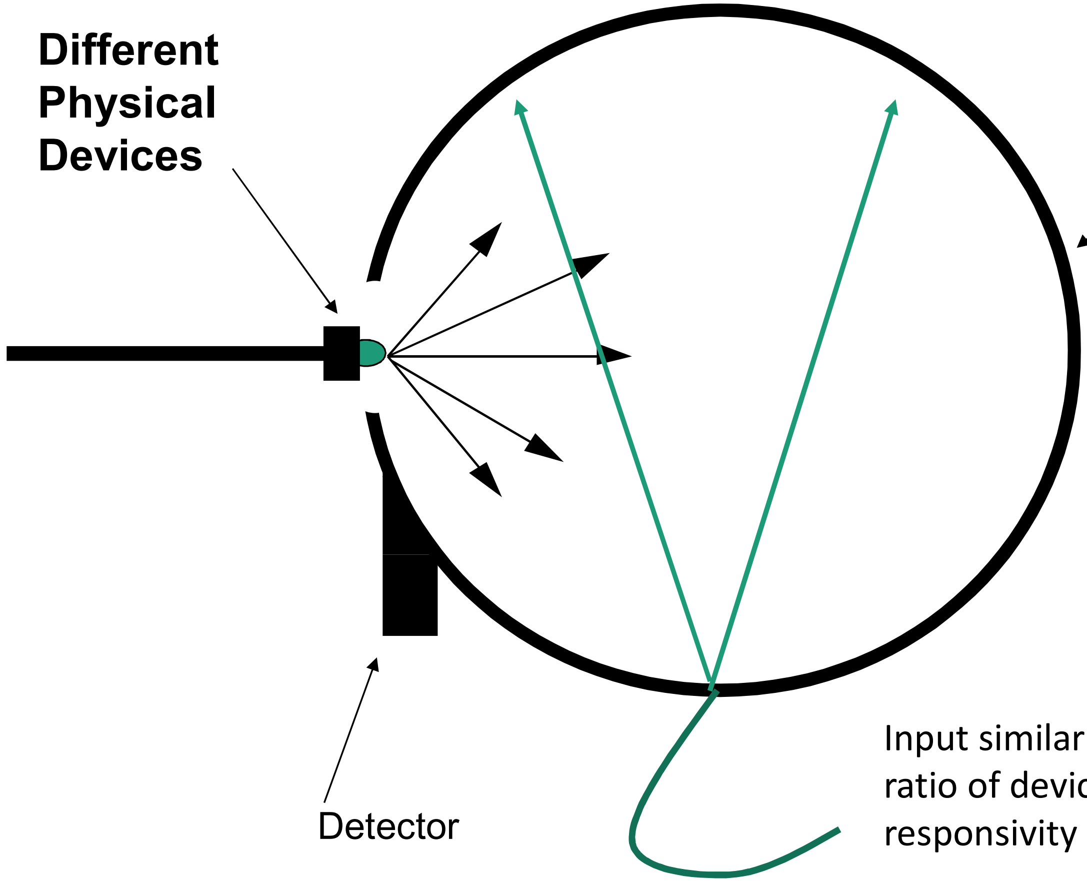


LED or Laser device same Physical Package as calibration source

Calibrated sphere/detector combination

Detector

Substitution Error – Use Auxilliary Source



Different Physical Devices

Calibrated sphere/detector combination

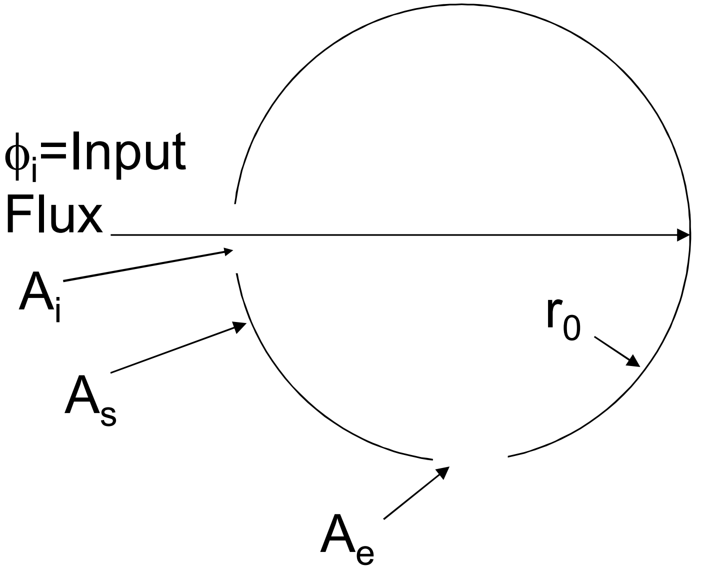
Detector

Input similar wavelength to sphere measure ratio of device/no device on sphere responsivity and develop Substitution Ratio(s)

Sphere Throughputs with Various Devices

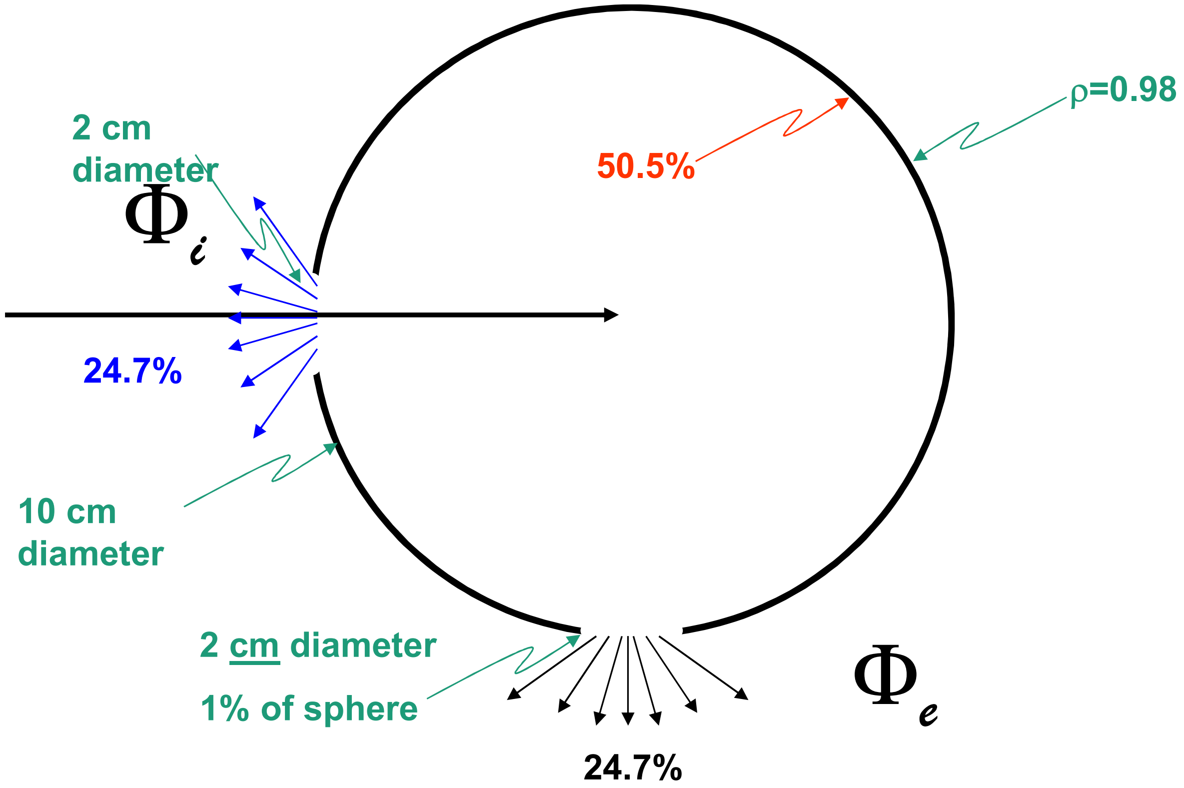
Throughput: Energy at a Port for a Sphere

- Energy at a port means we assume pi-steradian solid angle (drops pi from Sphere Radiance).
- Efficiency Calculation: 10cm sphere (98%) w/(2) 2cm ports = ~24.7% at the exit port.



$$Flux = \phi_i * \left(\frac{A_e}{A_s}\right) * \frac{\rho_0}{1-\rho_0(1-f)}$$

So…Where Does the Energy Go?



M=24.7

T=24.7%

Thoughtput Equation for a Detector

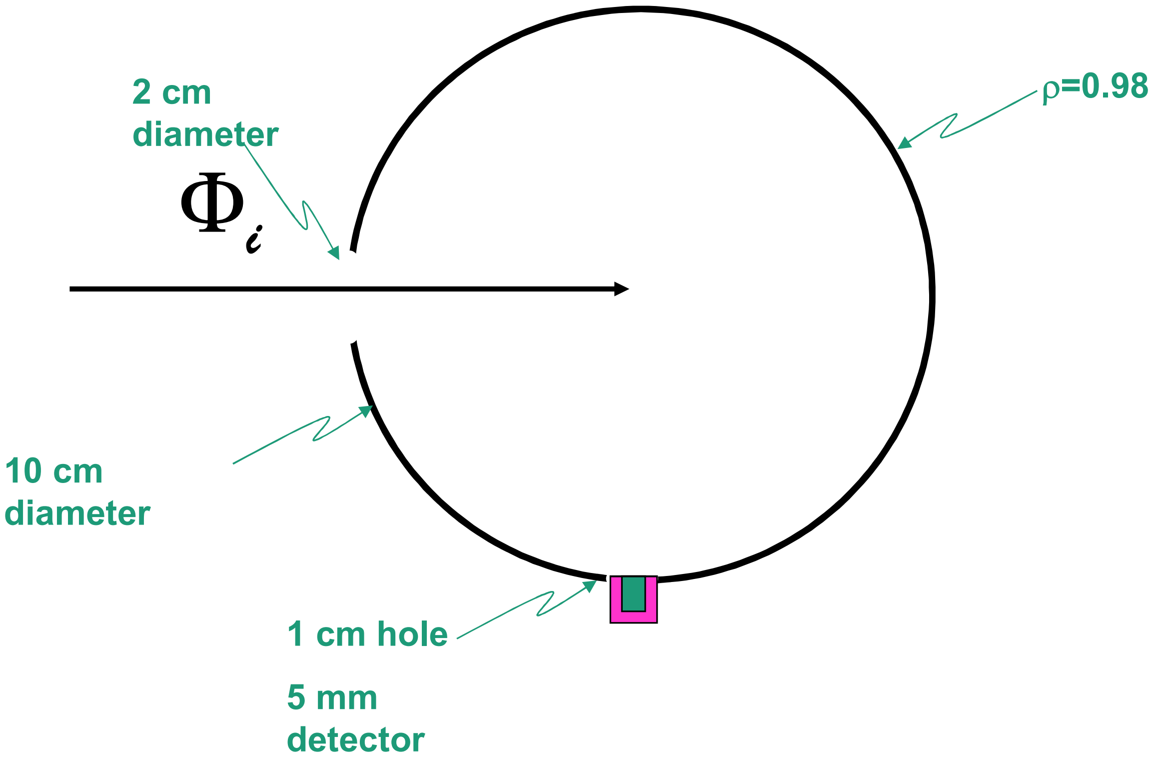
- Sphere Wall Radiance, L $= \frac{\phi_i}{\pi A_s} * \frac{\rho_0}{1-\rho_0(1-f)}$

- Throughput for Detector: $\boxed{T_{Detector} = \phi_i * \frac{1}{\pi A_s} * \frac{\rho_0}{1-\overline{\rho}} * A_d * \Omega}$

- L * Detector Area * Solid Angle

- Example: 0.5cm detector – 10cm Sphere
  - -15-20dB (NA 1.0)

Sphere and Detector Throughput Example



M=30.4 T=1.9% (-17.2dB)

Throughput Equation for a Fiber

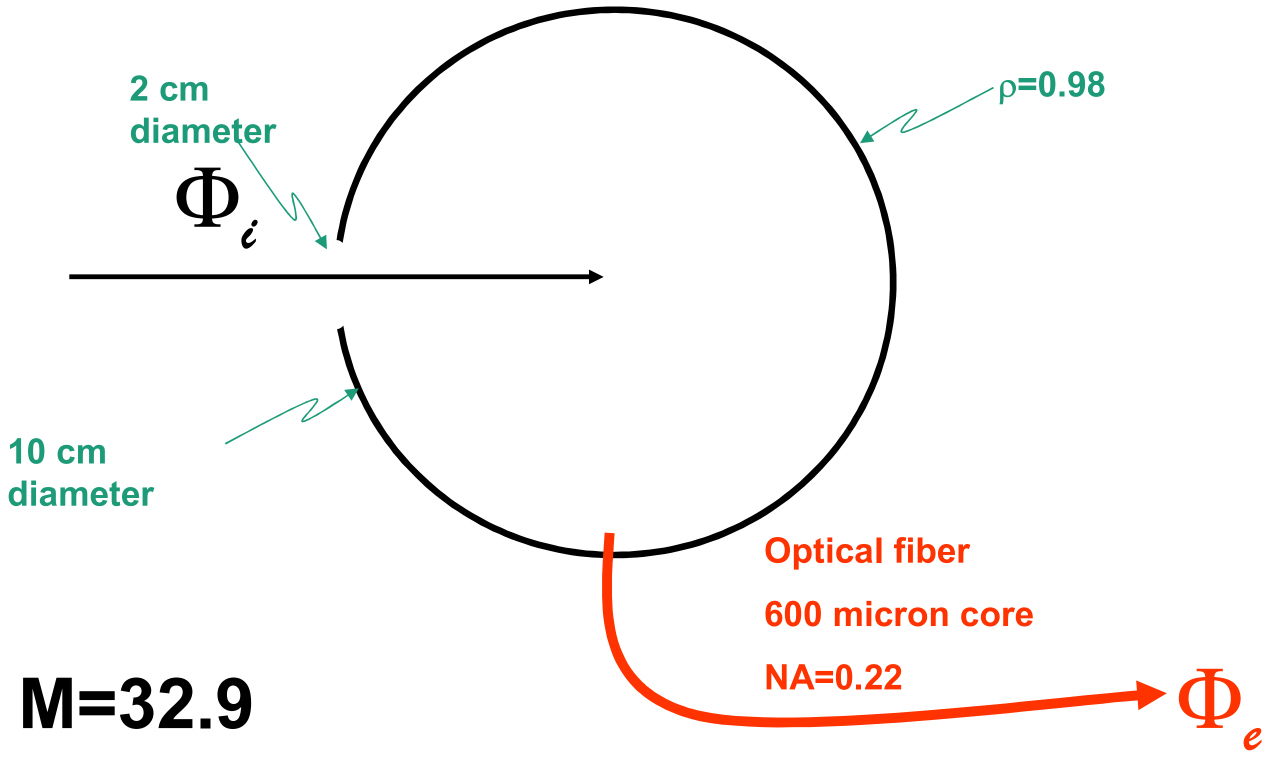
- Sphere Wall Radiance, L $= \frac{\phi_i}{\pi A_s} * \frac{\rho_0}{1-\rho_0(1-f)}$

- Throughput for Fiber: $\boxed{T_{Detector} = \phi_i * \frac{1}{\pi A_s} * \frac{\rho_0}{1-\bar{\rho}} * A_f * \Omega * (1-r)}$

- L * Fiber Core Area * NA (Field of View) * (1-Reflectance of Fiber Face)

- Example: Telecom Fiber (10cm Sphere, 98%):
  - 9um Fiber/NA 0.2 = (>-95dB!)

Sphere and Fiber Throughput Example



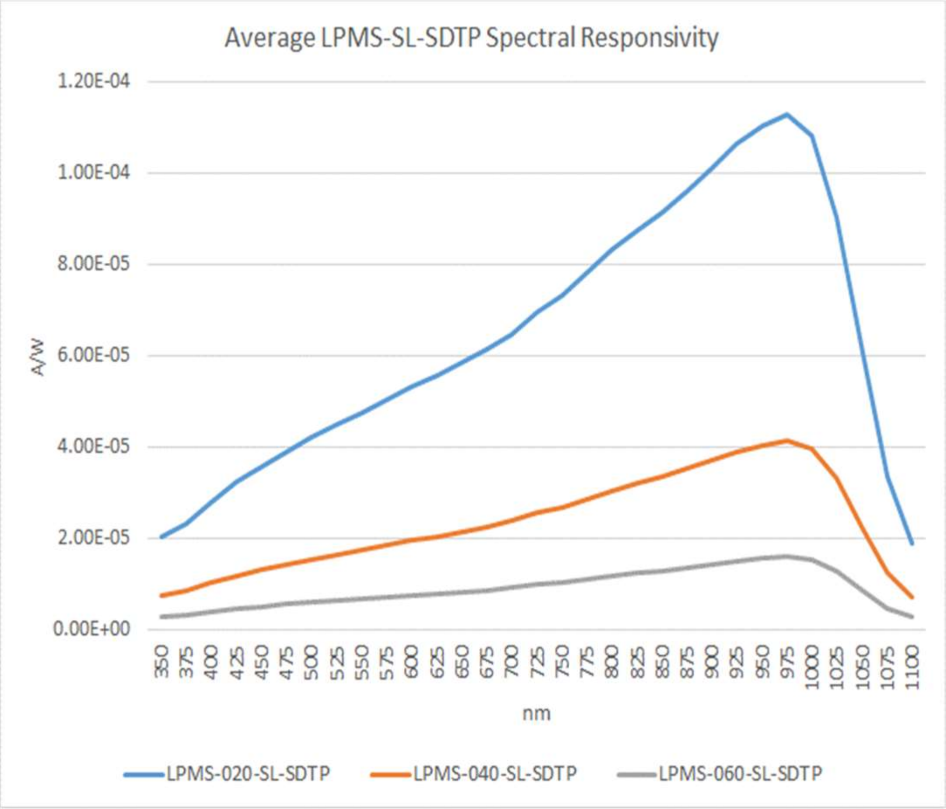
M=32.9

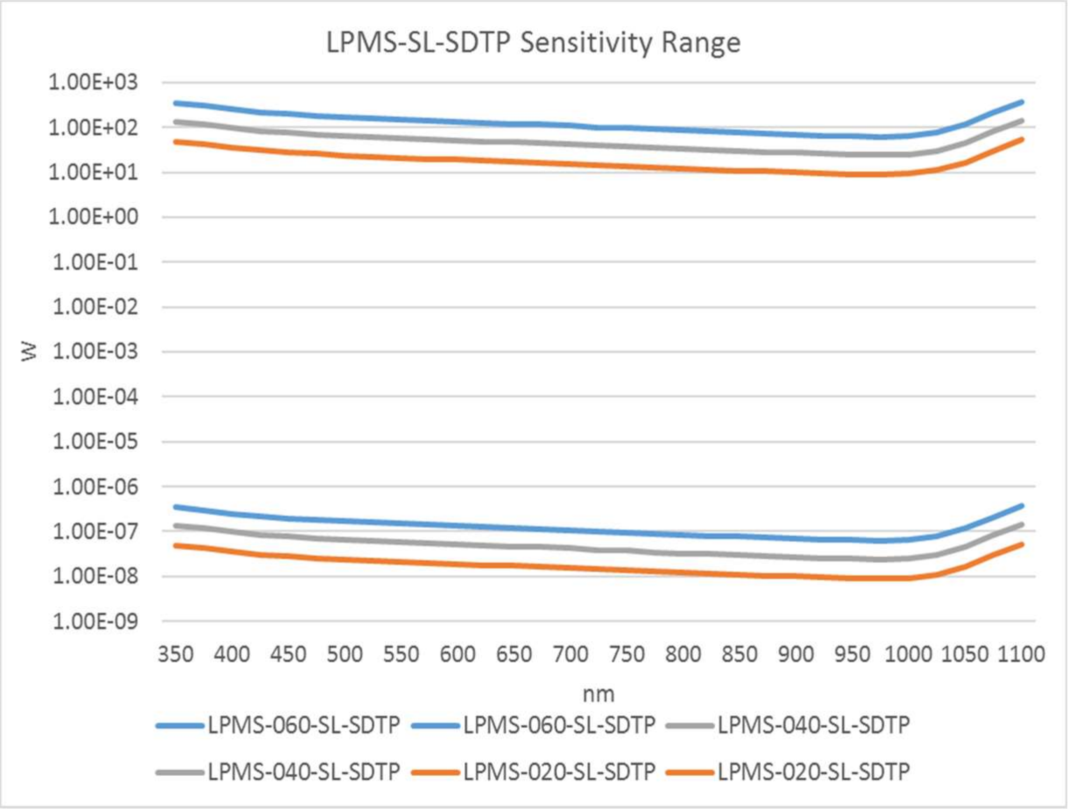
$T=1.4X10^{-5}$ =0.0014%= -48.5dB

10cm Sphere Throughput - Detectors & Fibers

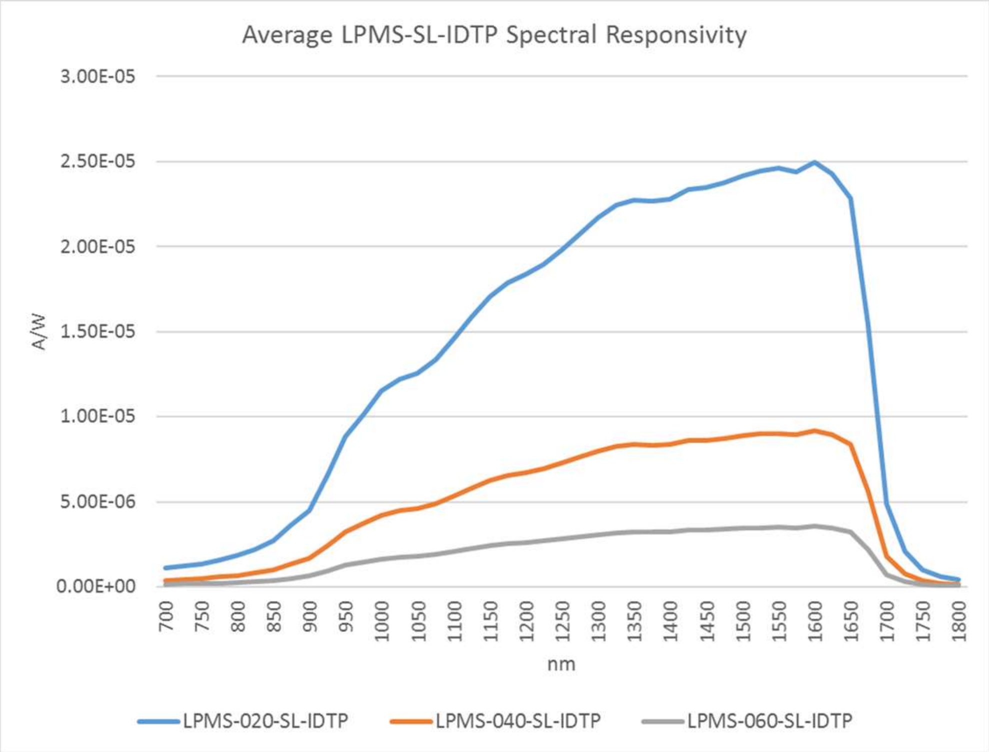
	dB to Detector								
		NA	0.018	0.126	0.178	0.399	0.691	1.000	
		Solid Ang.	0.001	0.05	0.1	0.5	1.5	3.142	
mm	Det. Active Area		sr	sr	sr	sr	sr	sr	
1	0.01	cm2	-67.73	-50.74	-47.73	-40.74	-35.97	-32.76	dB
2	0.04	cm2	-61.71	-44.72	-41.71	-34.72	-29.95	-26.74	dB
5	0.25	cm2	-53.75	-36.76	-33.75	-26.76	-21.99	-18.78	dB
7.5	0.5625	cm2	-50.23	-33.24	-30.23	-23.24	-18.47	-15.26	dB
10	1	cm2	-47.73	-30.74	-27.73	-20.74	-15.97	-12.76	dB
25.4	2.25	cm2	-44.21	-27.22	-24.21	-17.22	-12.45	-9.24	dB
	dB to Fiber								
		NA	0.12	0.2	0.3	0.4	0.6	1	
Refl Fiber	0.8	Sr	0.045	0.126	0.283	0.503	1.131	3.142	
um - diam	Fiber Area		sr	sr	sr	sr	sr	sr	
9	6.36E-07	cm2	-100.13	-95.69	-92.17	-89.67	-86.15	-81.71	dB
12	1.13E-06	cm2	-97.63	-93.19	-89.67	-87.17	-83.65	-79.22	dB
25	4.91E-06	cm2	-91.26	-86.82	-83.30	-80.80	-77.28	-72.84	dB
100	7.85E-05	cm2	-79.22	-74.78	-71.26	-68.76	-65.24	-60.80	dB
250	4.91E-04	cm2	-71.26	-66.82	-63.30	-60.80	-57.28	-52.84	dB
1000	7.85E-03	cm2	-59.22	-54.78	-51.26	-48.76	-45.24	-40.80	dB
5000	1.96E-01	cm2	-45.24	-40.80	-37.28	-34.78	-31.26	-26.82	dB

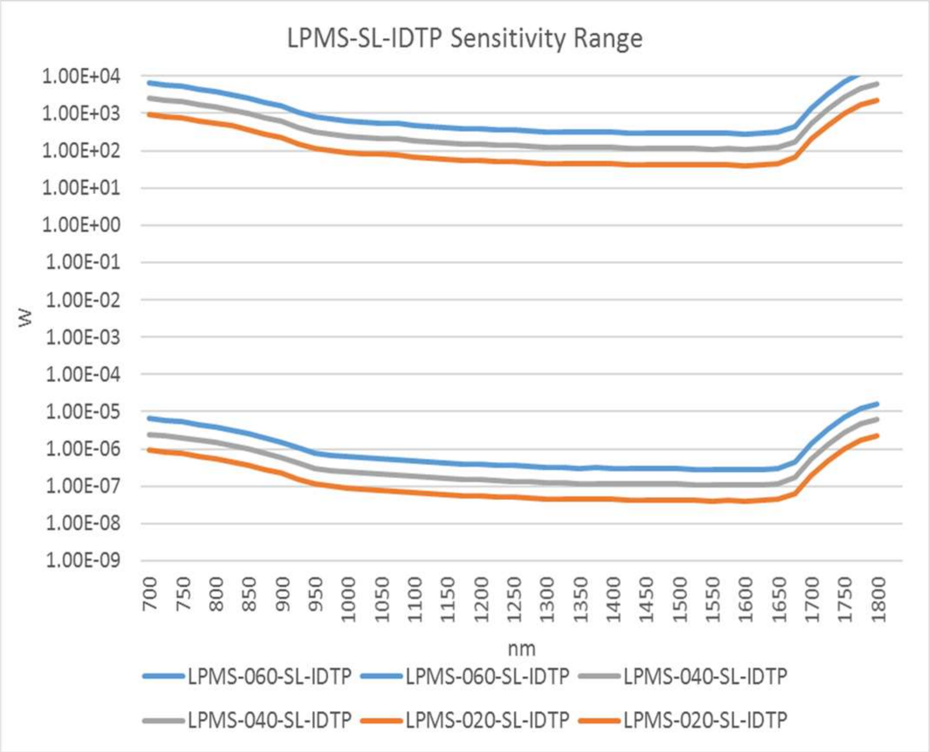
Silicon on SL: Spectral & Dynamic Range





InGaAs on SL: Spectral & Dynamic Range





Laser Power Damage Thresholds for Spheres

Laser Damage Threshold

Material	Max Temperature (°C)
Spectralon	400
Spectraflect	160
Permaflect	100
Infragold	n/a

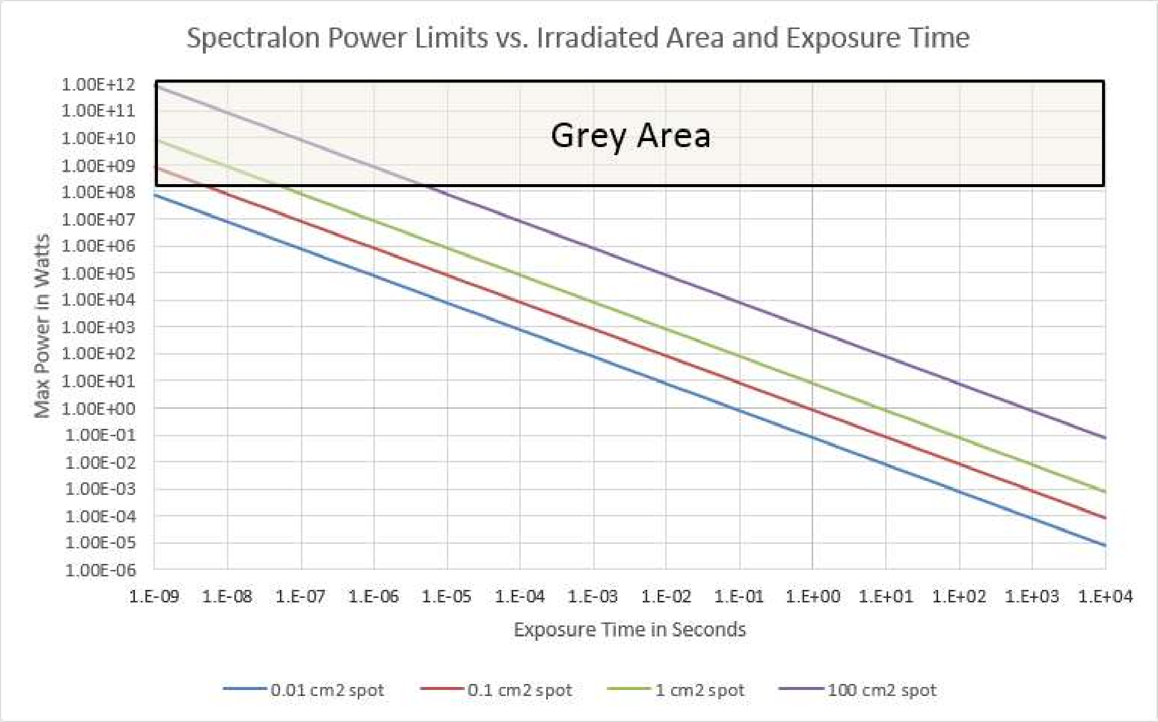
Damage threshold is the ability of the sensors or surface to survive the energy from an impinging beam. This depends on many factors including, but not limited to: pulse width, wavelength, irradiated area, exposure time, and the ability of the material to dissipate the energy.

Laser Damage Threshold

Material	Laser Type	Laser Wavelength	Energy Density	Power Density	Source
Spectralon	Pulsed (20ns, 20Hz)	1064nm	4 J/cm^2	160 MW/cm^2	Montana Laser Optics, Inc.
Spectraflect	Q-Switched YAG	532nm	1.7 J/cm2		Anecdotal
Spectraflect	Pulsed (20ns, 20Hz)	1064nm	0.7 J/cm^2	28 MW/cm^2	Big Sky Laser Technologies
Infragold	Pulsed (80ns, 20Hz)	10600nm	10.3 J/cm^2		Big Sky Laser Technologies
Infragold	[CO2]	10600nm	19.3 J/cm^2		Anecdotal

The typical laser damage threshold for some Labsphere optical materials is summarized above.

Laser Power Damage Thresholds



Graphical Example of Spectralon Sphere for quick reference

Thank You!

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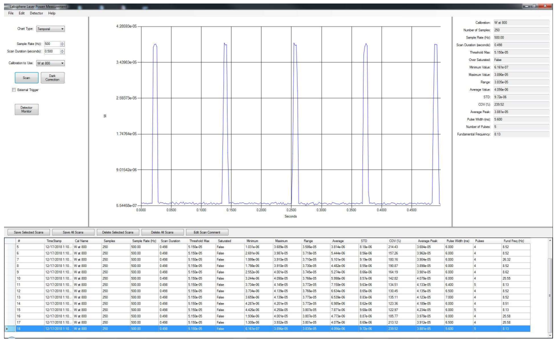
PRODUCT SLIDES
& SUPPORTING INFORMATION

Solution

+

+



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Detectors/Pre-Amp, Adaptor & Aperture

LPM Spheres

LPMS Software

LPMS Series

New Laser Power Systems

Pulsed Laser Power Measurement Systems

Accurate, reproducible method of determining total laser and laser diode power

https://www.labsphere.com/site/assets/files/2610/pb-13031rev03lpmsystems.pdf

Example of Labsphere's Laser Power Measurement Software

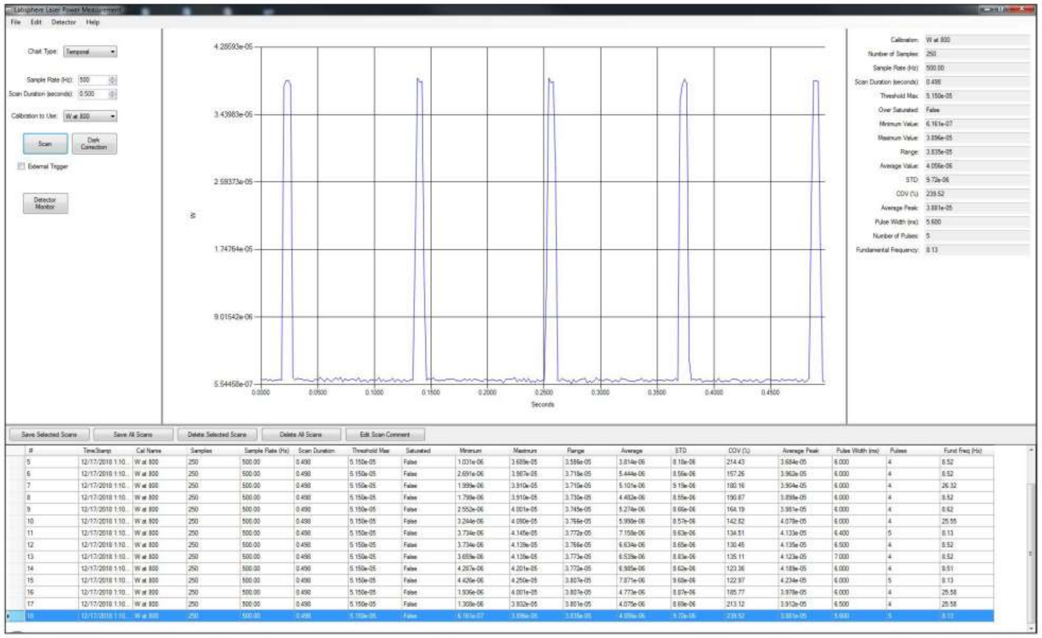


Chart Type: Temporal

Sample Rate (Hz): 500

Scan Duration (seconds): 0.500

Calibration to Use: W at 800

☐ External Trigger

Calibration: W at 800

Number of Samples: 250

Sample Rate (Hz): 500.00

Scan Duration (seconds): 0.498

Threshold Max: 5.150e-05

Over Saturated: False

Minimum Value: 6.161e-07

Maximum Value: 3.896e-05

Range: 3.835e-05

Average Value: 4.056e-06

STD: 9.72e-06

COV (%): 239.52

Average Peak: 3.881e-05

Pulse Width (ms): 5.600

Number of Pulses: 5

Fundamental Frequency: 8.13

#	TimeStamp	Cal Name	Samples	Sample Rate (Hz)	Scan Duration	Threshold Max	Saturated	Minimum	Maximum	Range	Average	STD	COV (%)	Average Peak	Pulse Width (ms)	Pulses	Fund Freq (Hz)
5	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.031e-06	3.689e-05	3.586e-05	3.814e-06	8.18e-06	214.43	3.684e-05	6.000	4	8.52
6	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	2.691e-06	3.987e-05	3.718e-05	5.444e-06	8.56e-06	157.26	3.962e-05	6.000	4	8.52
7	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.999e-06	3.910e-05	3.710e-05	5.101e-06	9.19e-06	180.16	3.904e-05	6.000	4	26.32
8	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.798e-06	3.910e-05	3.730e-05	4.482e-06	8.55e-06	190.87	3.898e-05	6.000	4	8.52
9	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	2.552e-06	4.001e-05	3.745e-05	5.274e-06	8.66e-06	164.19	3.981e-05	6.000	4	8.62
10	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.244e-06	4.080e-05	3.756e-05	5.998e-06	8.57e-06	142.82	4.079e-05	6.000	4	25.55
11	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.734e-06	4.145e-05	3.772e-05	7.158e-06	9.63e-06	134.51	4.133e-05	6.400	5	8.13
12	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.734e-06	4.139e-05	3.766e-05	6.634e-06	8.65e-06	130.45	4.135e-05	6.500	4	8.52
13	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.659e-06	4.135e-05	3.773e-05	6.539e-06	8.83e-06	135.11	4.123e-05	7.000	4	8.52
14	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	4.287e-06	4.201e-05	3.772e-05	6.985e-06	8.62e-06	123.36	4.189e-05	6.000	4	8.51
15	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	4.426e-06	4.250e-05	3.807e-05	7.871e-06	9.68e-06	122.97	4.234e-05	6.000	5	8.13
16	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.936e-06	4.001e-05	3.807e-05	4.773e-06	8.87e-06	185.77	3.978e-05	6.000	4	25.58
17	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.308e-06	3.932e-05	3.801e-05	4.075e-06	8.69e-06	213.12	3.912e-05	6.500	4	25.58
18	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	6.161e-07	3.896e-05	3.835e-05	4.056e-06	9.72e-06	239.52	3.881e-05	5.600	5	8.13

Liquid Cooled High Power Systems

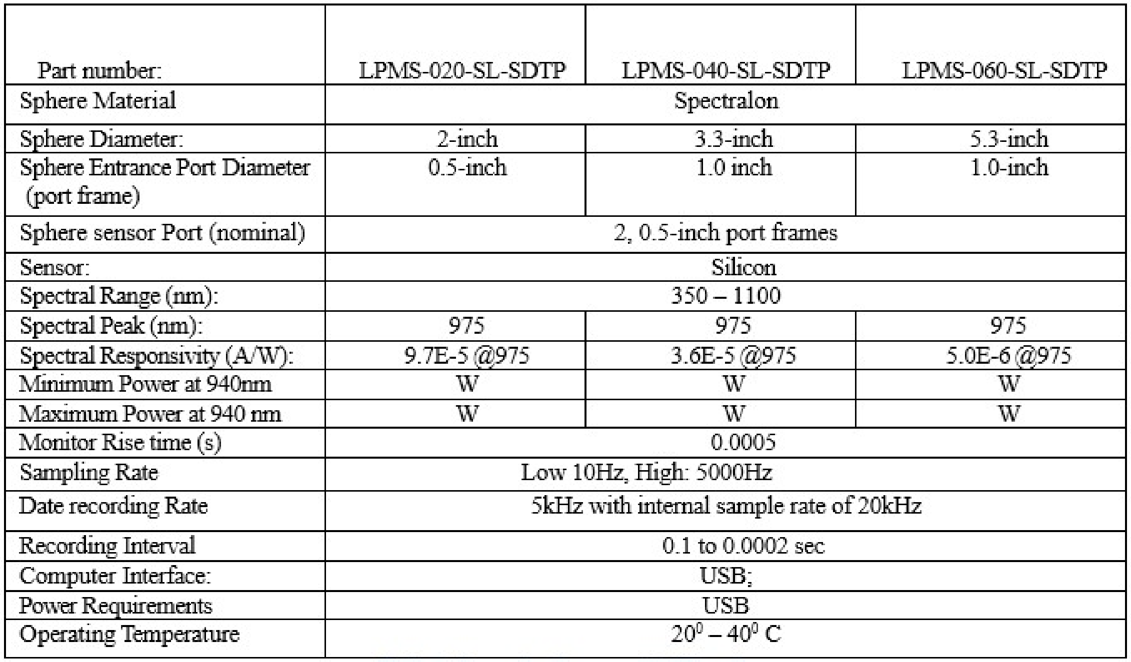
Solutions Matrix

Sphere	**Spectraflect**		**Spectralon**		**Infragold**
Applications/Detector	Si	InGaAs	Si	InGaAs	InGaAs
Low power VIS NIR lasers	✓				
Mid-power lasers in VIS NIR, more robust			✓		
Low power NIR lasers		✓			
Mid-power lasers in NIR, more robust				✓	
High-power lasers in NIR, higher heat threshold, robust					✓

Differentiating Measured and Reported Values

- Average Radiant Power at nth wavelength (CW)
- Average Peak Radiant Power at nth wavelength (pulsed)
- COV (CW)
- Detector sampling rate, Hz
- Detector scan interval, sec
- Laser Power Density: the instantaneous laser beam power per unit area. W/cm^2 with option to beam area in cm^2. Require input of beam area
- Max Power (CW)
- Min Power (CW)
- Overrange warning
- Peak Radiant Power (Pulsed)
- Pulse Width or interval of duration of a pulse
- Radiant power range (CW)
- Radiant Power. W
- Repetition Rate/frequency (Pulsed)
- Duty Cycle
- Standard deviation (CW)
- Threshold Max for given LPMS detector sensitivity range and system responsivity
- Threshold Min for given LMPS detector sensitivity range and system responsivity
- Total measurement time: not necessarily the same as the laser emission duration during the measurement, sec
- Total pulses.
- Wavelength (chosen by customer based on laser output and data table from calibration)

Specifications: (Mid Power VIS-NIR)



Part number:	LPMS-020-SL-SDTP	LPMS-040-SL-SDTP	LPMS-060-SL-SDTP
Sphere Material	Spectralon		
Sphere Diameter:	2-inch	3.3-inch	5.3-inch
Sphere Entrance Port Diameter (port frame)	0.5-inch	1.0 inch	1.0-inch
Sphere sensor Port (nominal)	2, 0.5-inch port frames		
Sensor:	Silicon		
Spectral Range (nm):	350 – 1100		
Spectral Peak (nm):	975	975	975
Spectral Responsivity (A/W):	9.7E-5 @975	3.6E-5 @975	5.0E-6 @975
Minimum Power at 940nm	W	W	W
Maximum Power at 940 nm	W	W	W
Monitor Rise time (s)	0.0005		
Sampling Rate	Low 10Hz, High: 5000Hz		
Date recording Rate	5kHz with internal sample rate of 20kHz		
Recording Interval	0.1 to 0.0002 sec		
Computer Interface:	USB;		
Power Requirements	USB		
Operating Temperature	20^0 – 40^0 C		

Hardware/Software Demo

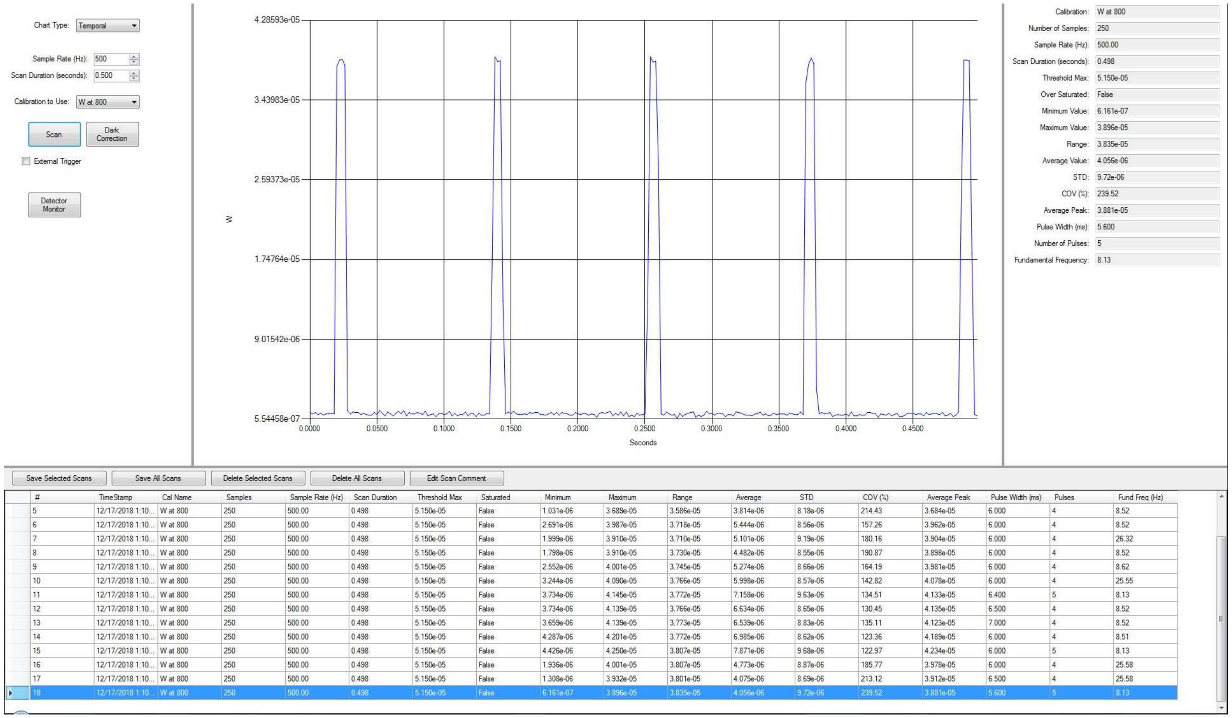


Chart Type: Temporal

Sample Rate (Hz): 500

Scan Duration (seconds): 0.500

Calibration to Use: W at 800

☐ External Trigger

Calibration:	W at 800
Number of Samples:	250
Sample Rate (Hz):	500.00
Scan Duration (seconds):	0.498
Threshold Max:	5.150e-05
Over Saturated:	False
Minimum Value:	6.161e-07
Maximum Value:	3.896e-05
Range:	3.835e-05
Average Value:	4.056e-06
STD:	9.72e-06
COV (%):	239.52
Average Peak:	3.881e-05
Pulse Width (ms):	5.600
Number of Pulses:	5
Fundamental Frequency:	8.13

#	TimeStamp	Cal Name	Samples	Sample Rate (Hz)	Scan Duration	Threshold Max	Saturated	Minimum	Maximum	Range	Average	STD	COV (%)	Average Peak	Pulse Width (ms)	Pulses	Fund Freq (Hz)
5	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.031e-06	3.689e-05	3.586e-05	3.814e-06	8.18e-06	214.43	3.684e-05	6.000	4	8.52
6	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	2.691e-06	3.987e-05	3.718e-05	5.444e-06	8.56e-06	157.26	3.962e-05	6.000	4	8.52
7	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.999e-06	3.910e-05	3.710e-05	5.101e-06	9.19e-06	180.16	3.904e-05	6.000	4	26.32
8	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.798e-06	3.910e-05	3.730e-05	4.482e-06	8.55e-06	190.87	3.898e-05	6.000	4	8.52
9	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	2.552e-06	4.001e-05	3.745e-05	5.274e-06	8.66e-06	164.19	3.981e-05	6.000	4	8.62
10	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.244e-06	4.090e-05	3.766e-05	5.998e-06	8.57e-06	142.82	4.078e-05	6.000	4	25.55
11	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.734e-06	4.145e-05	3.772e-05	7.158e-06	9.63e-06	134.51	4.133e-05	6.400	5	8.13
12	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.734e-06	4.139e-05	3.766e-05	6.634e-06	8.65e-06	130.45	4.135e-05	6.500	4	8.52
13	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	3.659e-06	4.139e-05	3.773e-05	6.539e-06	8.83e-06	135.11	4.123e-05	7.000	4	8.52
14	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	4.287e-06	4.201e-05	3.772e-05	6.985e-06	8.62e-06	123.36	4.189e-05	6.000	4	8.51
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16	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	1.936e-06	4.001e-05	3.807e-05	4.773e-06	8.87e-06	185.77	3.978e-05	6.000	4	25.58
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18	12/17/2018 1:10...	W at 800	250	500.00	0.498	5.150e-05	False	6.161e-07	3.896e-05	3.835e-05	4.056e-06	9.72e-06	239.52	3.881e-05	5.600	5	8.13

- Software Installation
- Calibration files location
- Making measurements
- Live demo of features
- Saving measurement
- Using Triggering function

Peak Power in a Pulse

Peak power is the product of the energy in the pulse, *Q*, and the pulse width (interval duration in time)

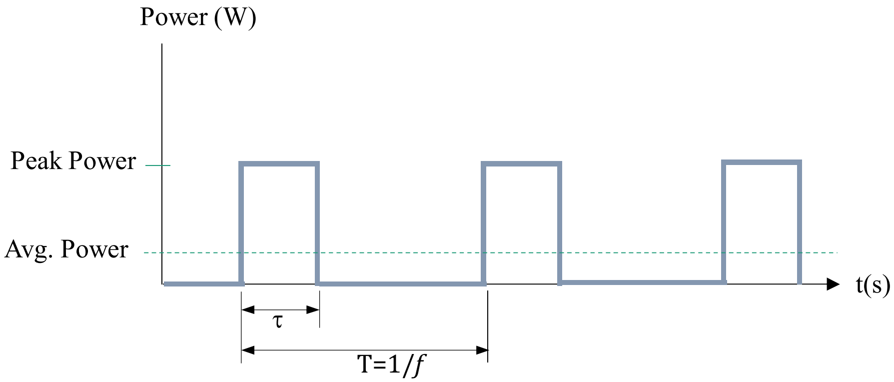
$$\phi_p = \frac{Q_\lambda}{\tau}$$

Average Peak power is calculated as the average of the power measurements within a pulse.

$$\bar{\phi}_{p\lambda} = \frac{\sum_i \phi_{p\lambda}}{n}$$

Average power in a pulsed laser

Consider a pulsed laser that has a constant power, ϕ_{peak}, over a pulse duration t, that repeats at a frequency f as shown below. The period of repetition is then $1/f$.



Average pulsed laser power :

$$\bar{\phi}_{pulse_{\lambda}} = \frac{1}{T}\int_0^T \phi(t)dt$$

Duty cycle, *D*:

$$D = \frac{\tau}{T}$$

Since there is no power after *t*=*t*, the integral above becomes:

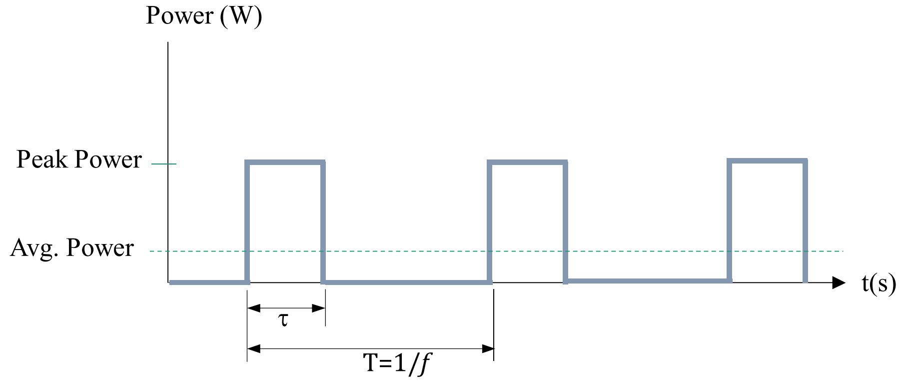
$$\bar{\phi}_{pulse_{\lambda}} = \frac{1}{T}\int_0^{\tau} \phi(t)dt = \frac{1}{T}\phi_{peak}\tau = D\phi_{peak}$$

The average pulse power is therefore equivalent to the average power over the course of one on/off cycle of the laser.

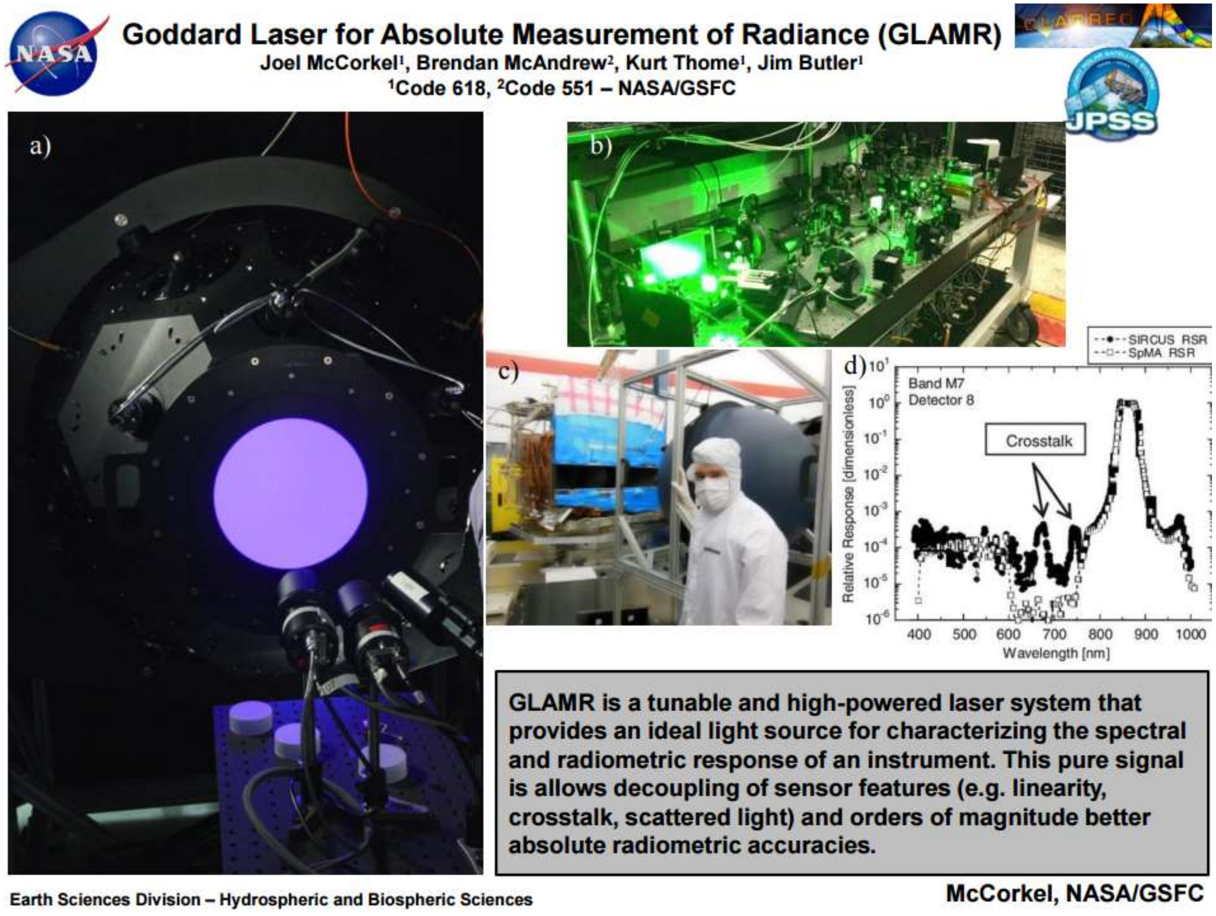
Peak Power from Average Peak Power

The peak power for a constant duty cycle and pulse width can be determined as:

$$\phi_{peak_\lambda} = \phi_{Avg_\lambda} \frac{T}{\tau}$$



NASA GLAMR Primary Calibrator (<0.3% k=2σ Uncert.).



Goddard Laser for Absolute Measurement of Radiance (GLAMR)

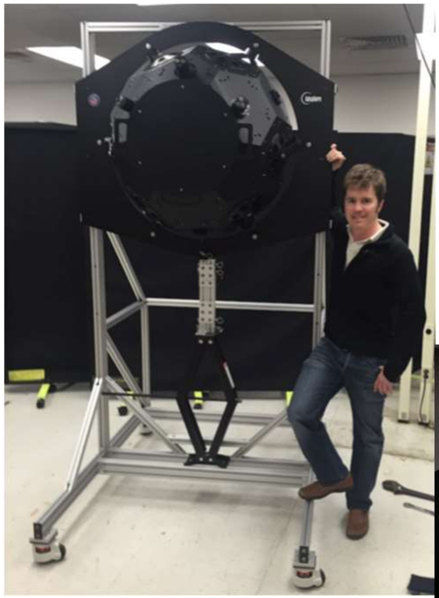
Joel McCorkel[1], Brendan McAndrew[2], Kurt Thome[1], Jim Butler[1]

[1]Code 618, [2]Code 551 – NASA/GSFC

GLAMR is a tunable and high-powered laser system that provides an ideal light source for characterizing the spectral and radiometric response of an instrument. This pure signal is allows decoupling of sensor features (e.g. linearity, crosstalk, scattered light) and orders of magnitude better absolute radiometric accuracies.

Earth Sciences Division – Hydrospheric and Biospheric Sciences

McCorkel, NASA/GSFC



Geodesic Design with seams <0.5mm