The 11th International Conference on New
Developments and Applications in Optical Radiometry
September 19-23, 2011, Maui, Hawaii, USA

New Method for Spectral Irradiance and Radiance Responsivity Calibration using Pulsed Tunable Lasers

Yuqin Zong
Steven Brown, George Eppeldauer, Keith Lykke, and Yoshi Ohno

National Institute of Standards and Technology
Gaithersburg, Maryland
USA

Continuous wave (CW) tunable lasers

- high power,
- narrow bandwidth,
- Being used for calibrations of primary detectors and remote sensing instruments

Shortcomings:

- bulky
- expensive
- interference fringes
- hard to operate and maintain

Pulsed tunable lasers

- Fully automated
- Large tunable range
- Finite bandwidth, no or less interference fringes
- portable,
- affordable.

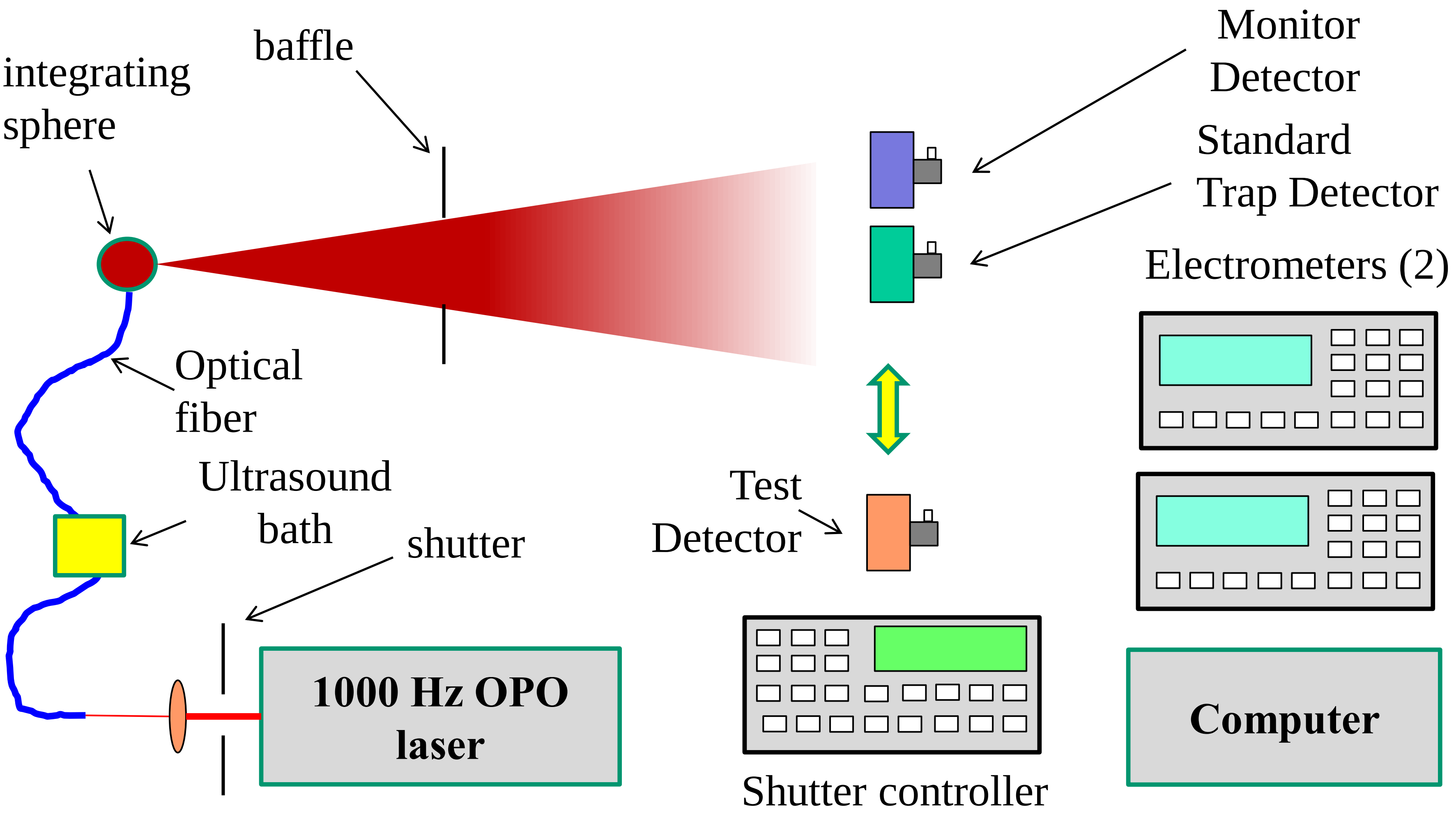
- Narrow pulse width, extremely low duty cycle (eg, 10^{-6})
- Pulse to pulse variation, and hard to be stabilized.
- Transimpedence amplifiers don’t work well.

Have not been used as calibration source yet!

Key questions to be answered

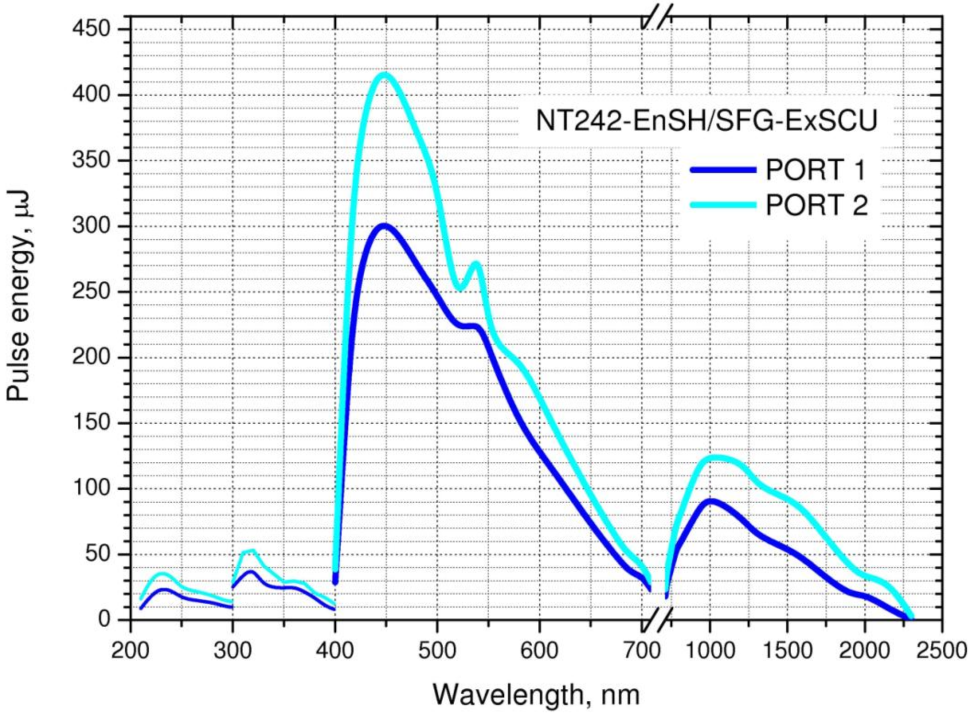
- Can pulse lasers be used for calibration of detectors with small uncertainties?
- How to overcome fluctuation of a pulsed laser and get repeatable results?
- Will detectors be saturated?
- Is a pulse laser equivalent a CW laser for detector calibrations?

Schematic of the new measurement method



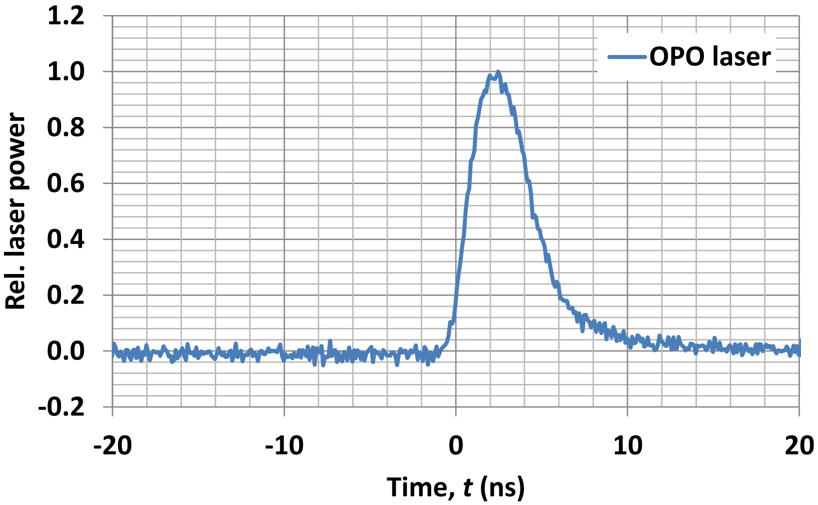
$$R_{test}(\lambda) = R_{\mathrm{standard}}(\lambda) \times Q^{\mathrm{M}}_{\mathrm{test}} / Q^{\mathrm{M}}_{\mathrm{standard}}$$

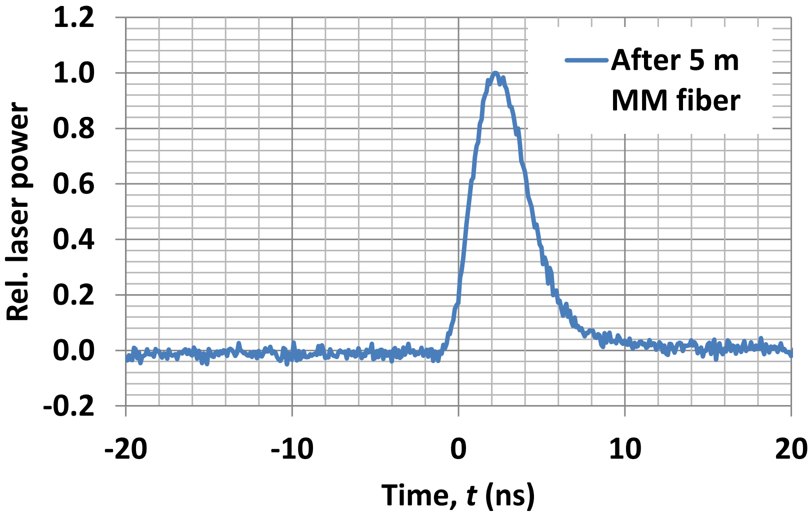
The OPO laser

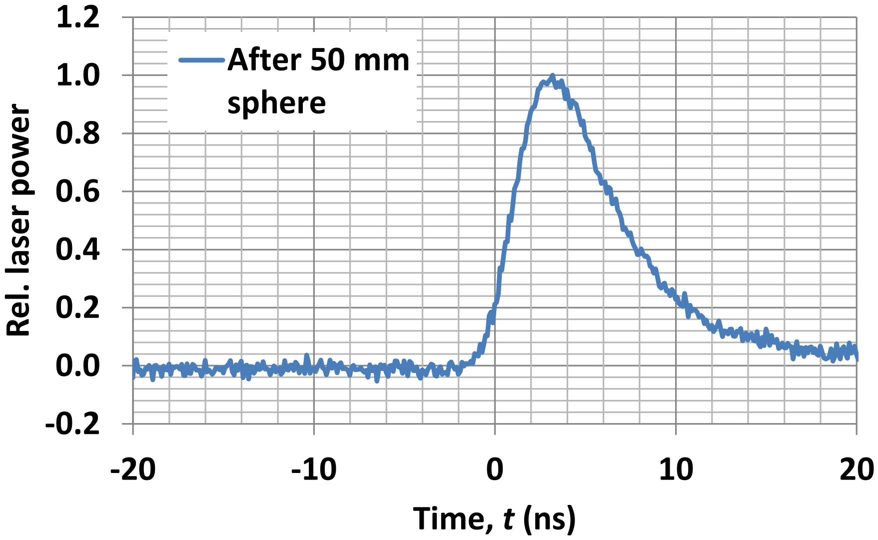


- 210 nm to 2400 nm tunable range,
- 1000 Hz repetitive rate
- 5 ns pulse width
- 5 – 8 cm^{-1} bandwidth

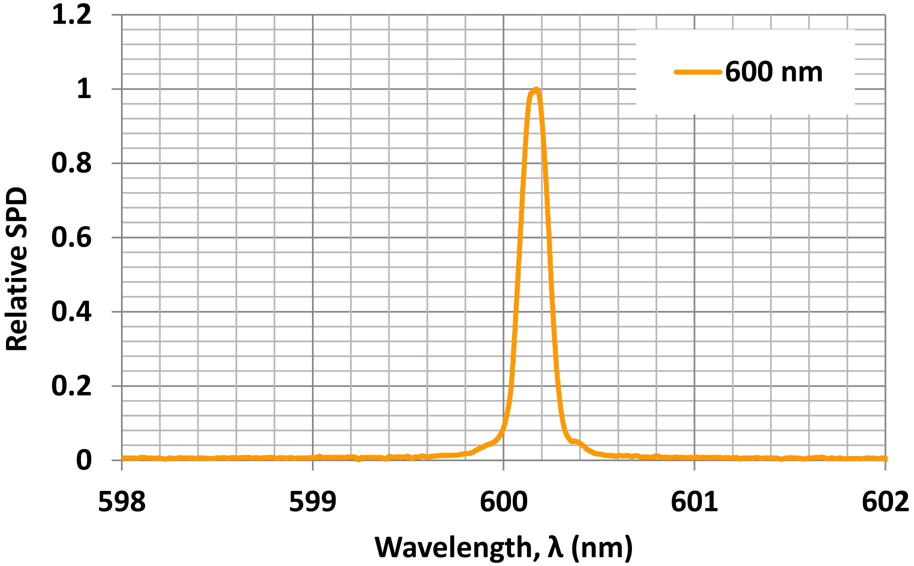
Pulse waveform

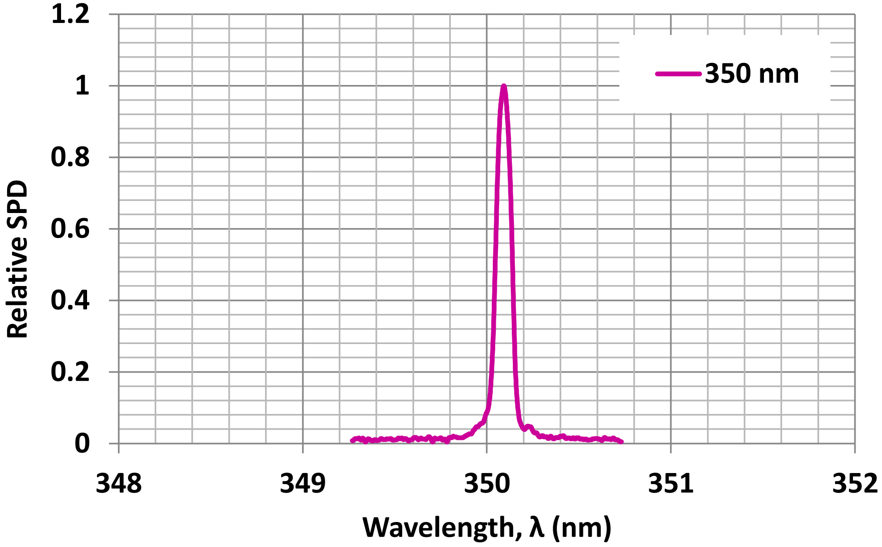


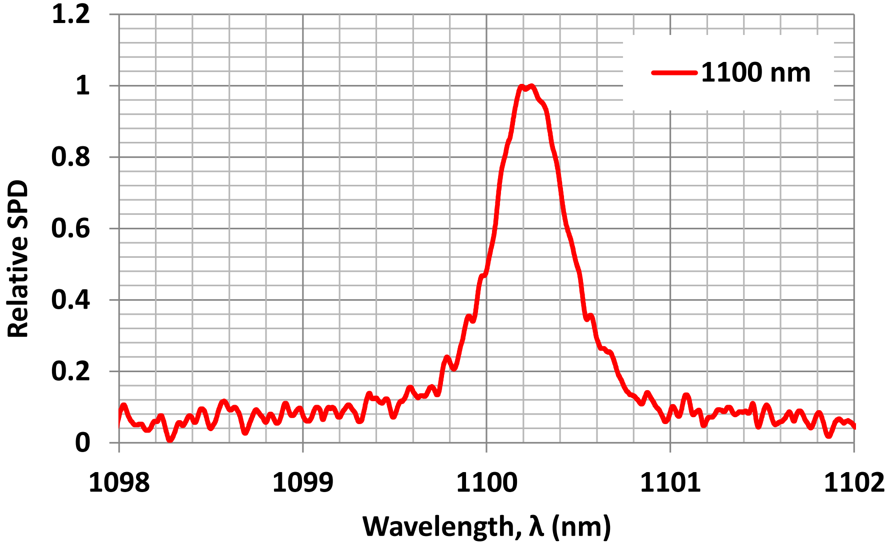




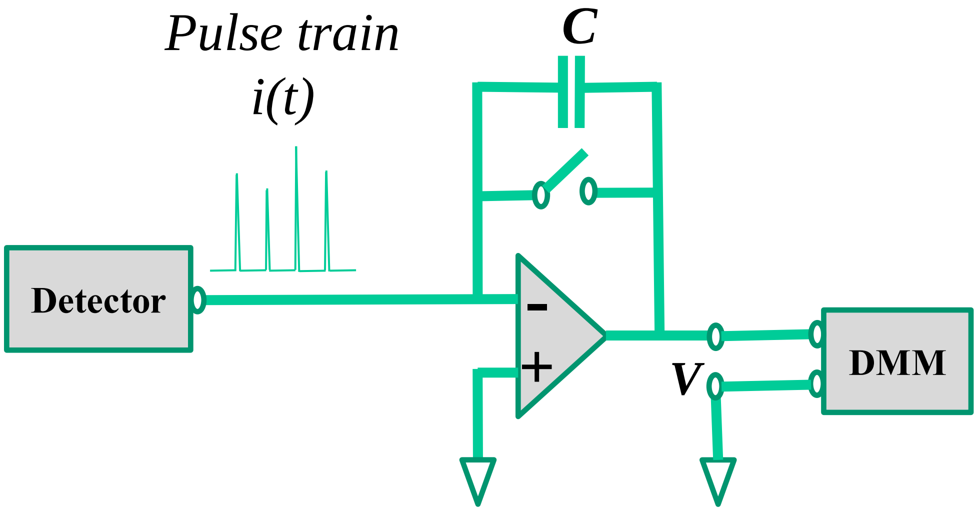
Laser spectrum







The electrometer

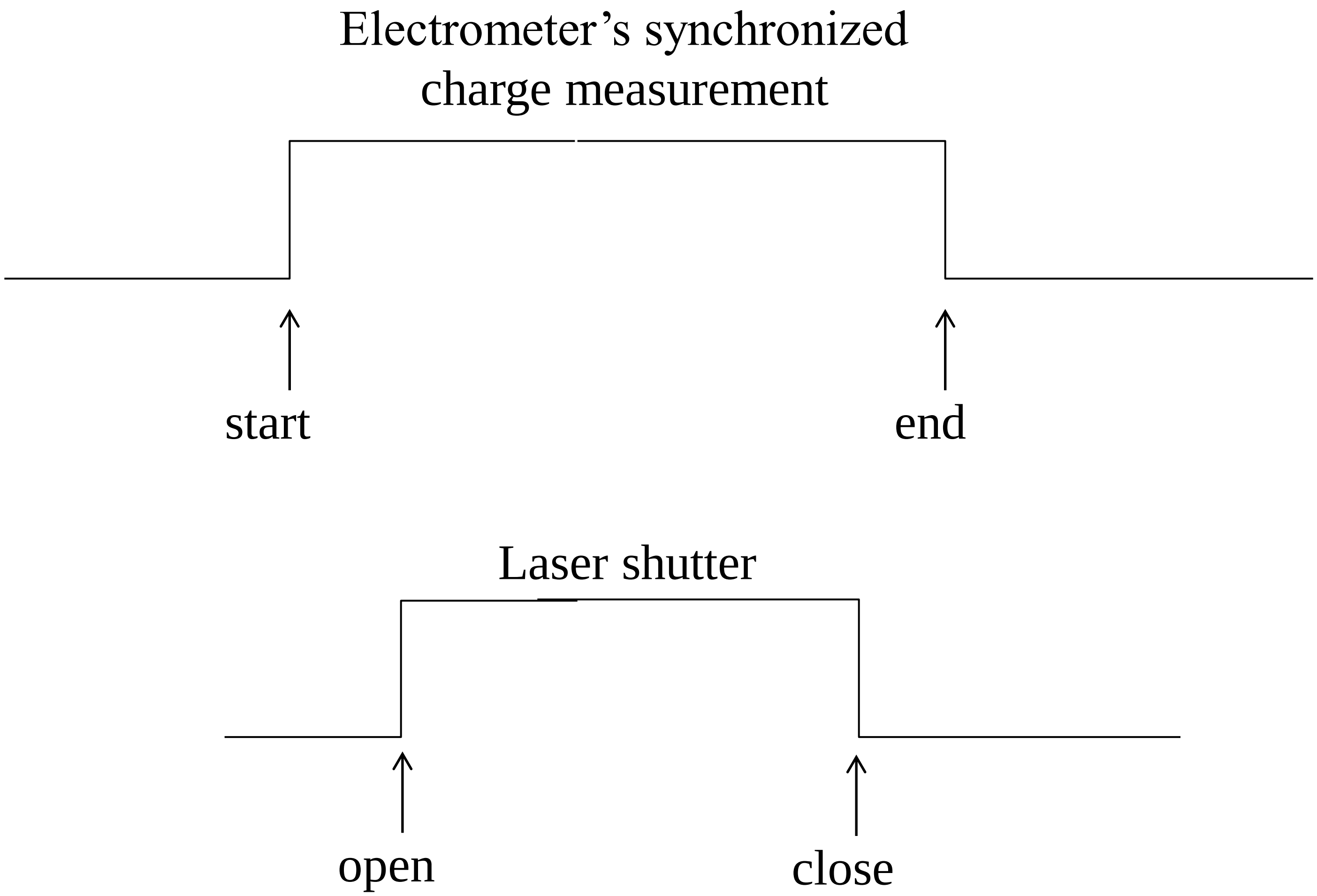


- Charge measurement function from 2 nC to 2 μC
- High performance multichannel switching card
- < 3 fA bias current
- < 20 μV burden voltage
- No accurate timing and switching

With a switched integrator transimpedance amplifier

$$Q = \int_0^T i(t)dt = C \times V$$

Measurement timing



Electrometer's synchronized charge measurement

start

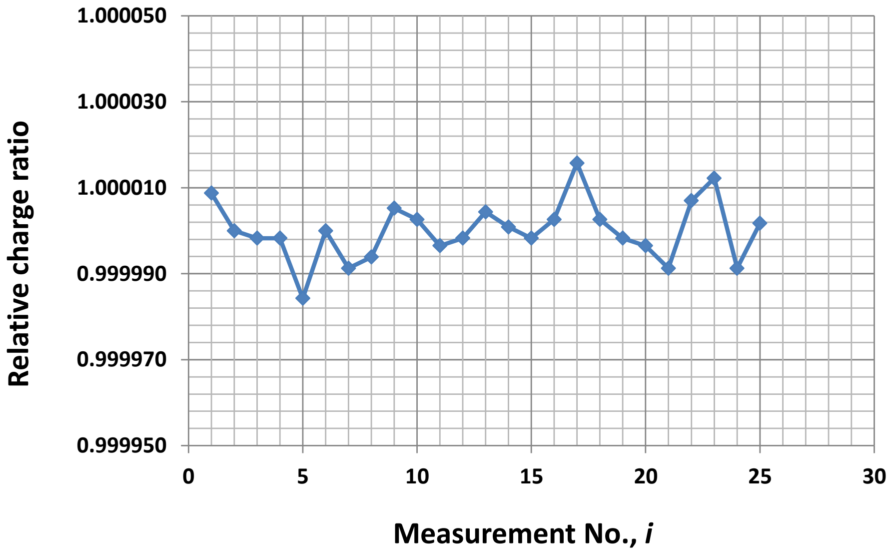
end

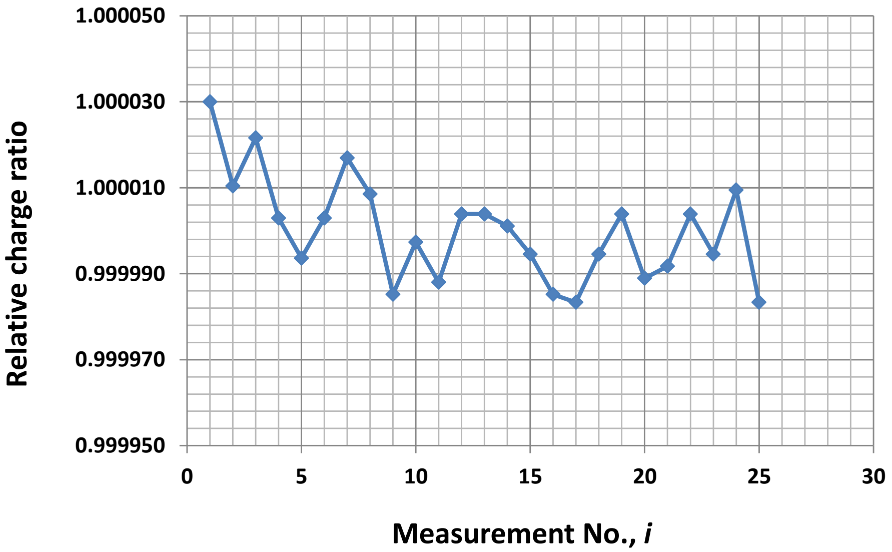
Laser shutter

open

close

Measurement repeatability

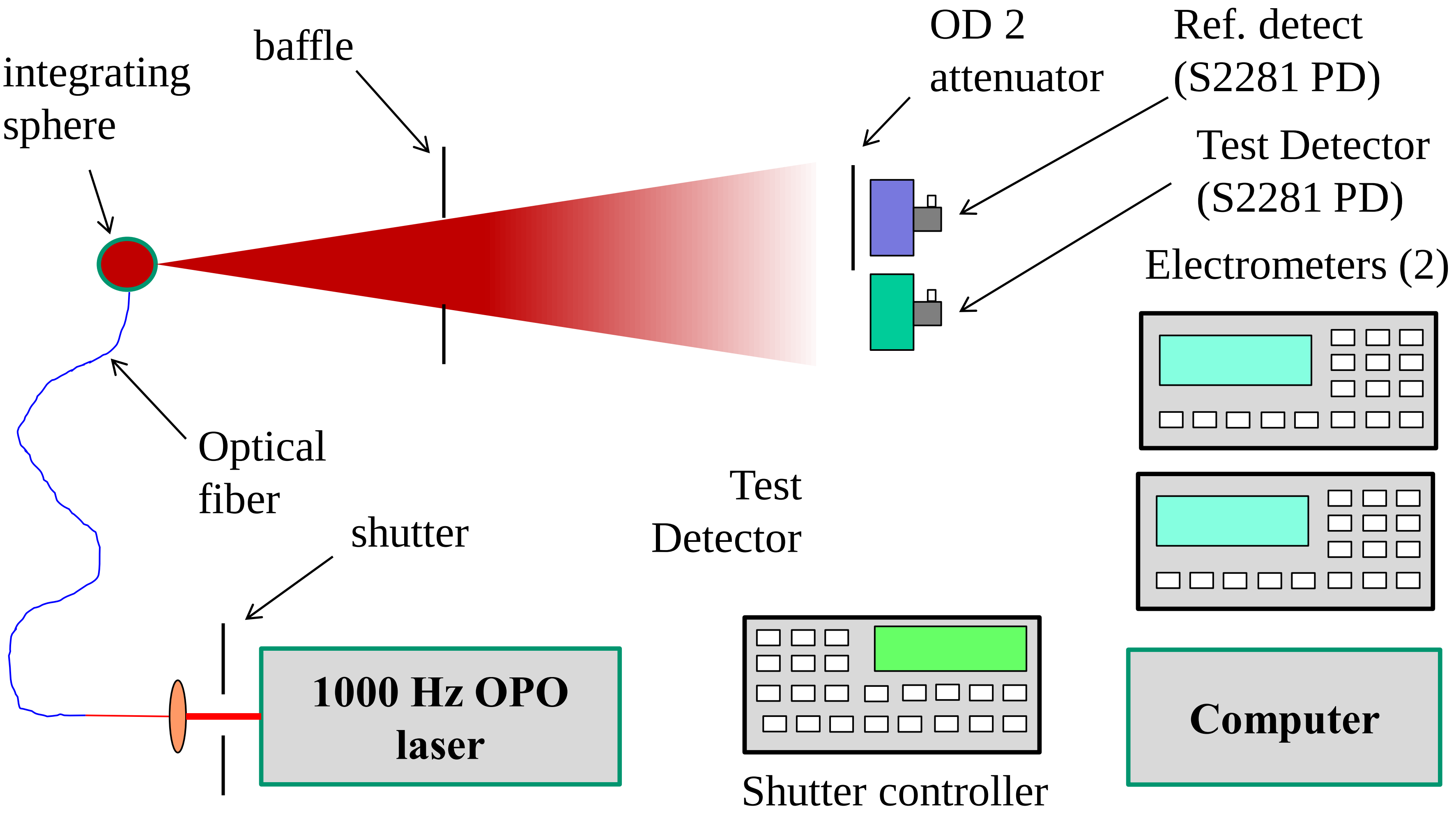




- Two S2281 Si photodiodes (PD)
- standard deviation = **7** ppm!

- One 3 Si PD trap and one S2281 Si PD
- standard deviation = **12** ppm!

Linearity measurement



integrating sphere

baffle

OD 2 attenuator

Ref. detect (S2281 PD)

Test Detector (S2281 PD)

Electrometers (2)

Optical fiber

shutter

Test Detector

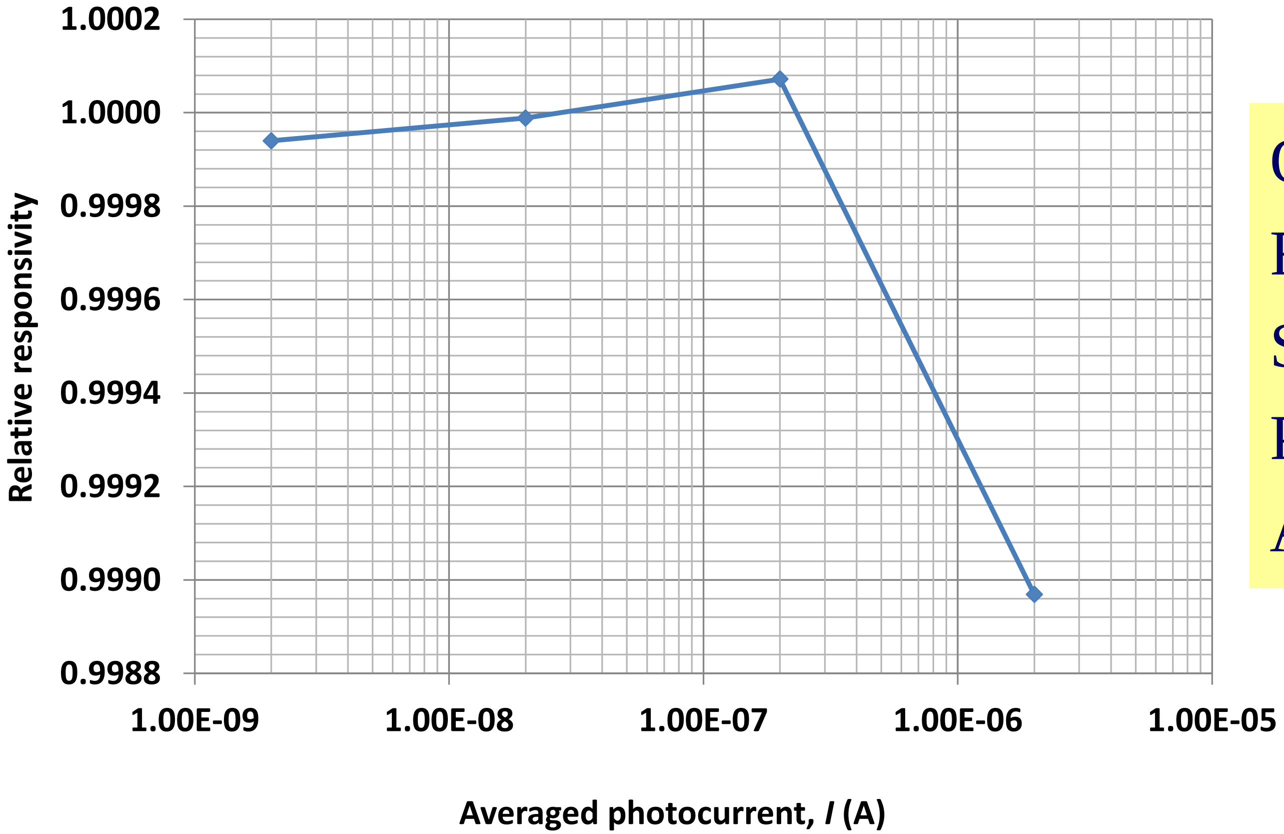
1000 Hz OPO laser

Shutter controller

Computer

$$r(P_i) = Q_{\text{test}} / Q_{\text{Ref.}}$$

Result of detector linearity test



OPO laser at 450 nm.

For a SS2281 PD,

Saturation starts at

Peak=100 mA,

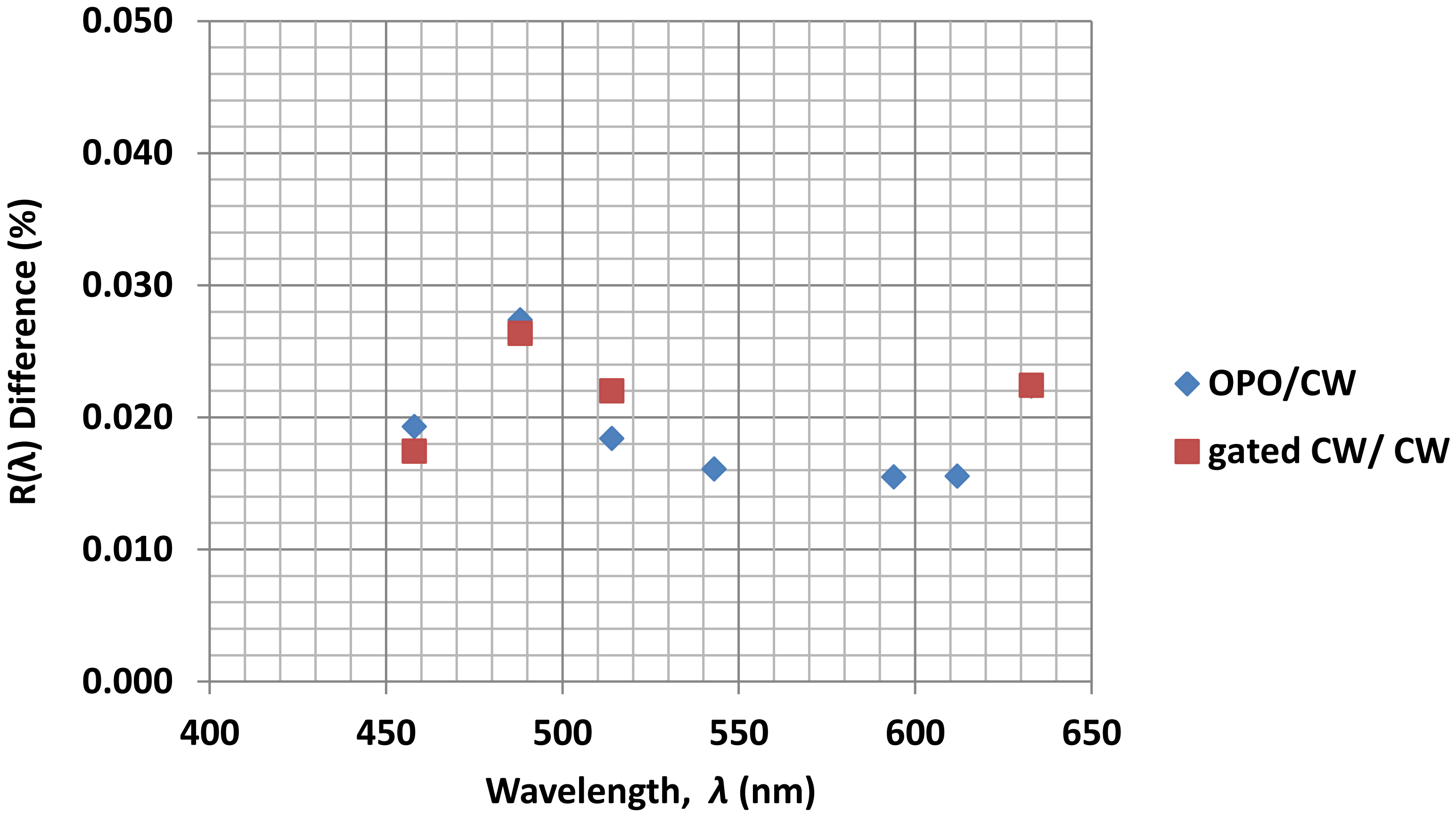
Averaged=10^{-6} µA.

The relative responsivity is obtained by normalizing the charge ratio $r(P_i)$ of the test detector to reference detector .

Points with regard to the linearity

1) Nonlinearity depends on the detector and the laser wavelength.
2) The instantaneous photocurrent without causing nonlinearity is several orders of magnitude higher than the threshold nonlinear DC photocurrent (0.1 – 1 mA typically).
3) The level of allowed averaged photocurrent is several orders of magnitude lower than the threshold nonlinear DC photocurrent.

Validation results using CW lasers



- Difference in measured responsivity is only ≈ 0.02 %, well within the instruments' uncertainty (0.05 %).

Uncertainties

	Relative standard unc. (%)	
Uncertainty component	Type A	Type B
Reference trap detector		0.028
Laser wavelength (0.01 nm)	0.005	
Sphere source irradiance uniformity		0.005
Detector reference plane		0.010
Detector linearity		0.005
Transfer to test detector	0.005	
Electrometer (relative only)		0.01
Combined uncertainty (%)	0.033	
Expanded uncertainty (*k*=2) (%)	**0.066**	

Conclusions

- A new method using pulsed laser sources has been developed for calibration of detectors and instruments.
- The method has been validated and found to be equivalent to CW laser method.
- The averaged photocurrent should be kept several orders of magnitude lower than the threshold nonlinear DC photocurrent to avoid nonlinearity.
- Pulsed laser sources have advantage over CW lasers in reducing interference fringes.

Conclusions

- This method can be used in other applications such as measurement of material property of transmittance and reflectance.
- Compared to a monochromotor-based system, calibration uncertainties are significantly lower (eg, one order of magnitude).

THANK YOU