A transfer standard for the low power / few photon regime – the trap detector plus switched integrator amplifier

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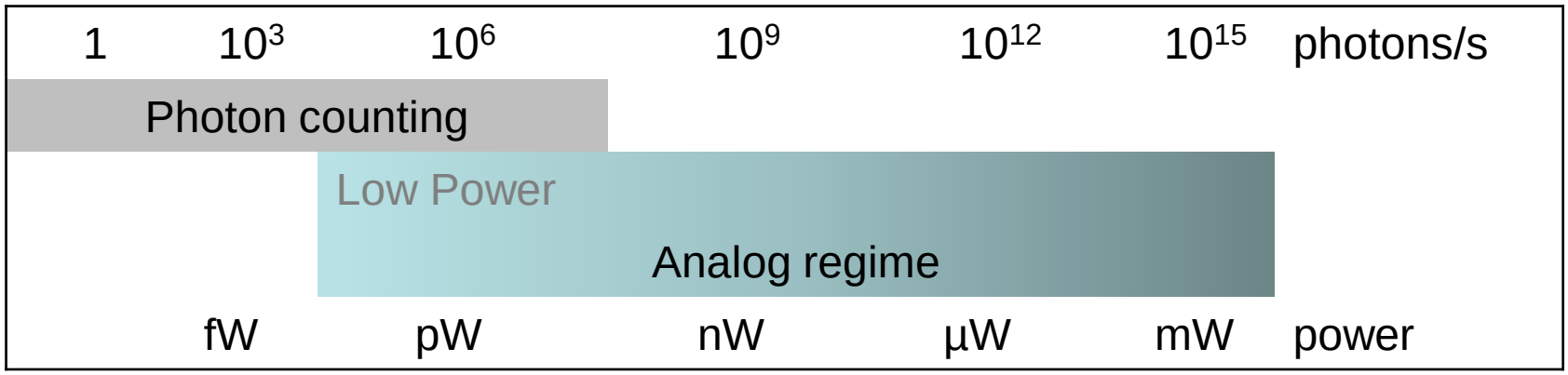
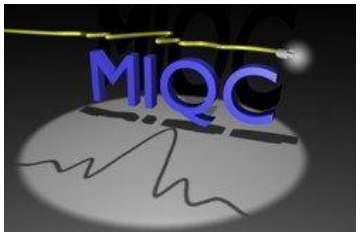
Maui, Hawaii

Overview

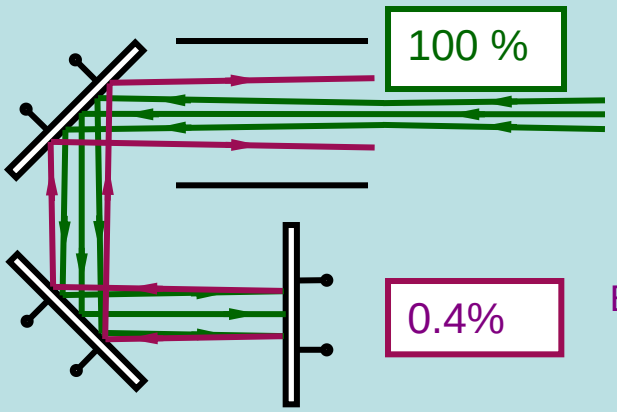


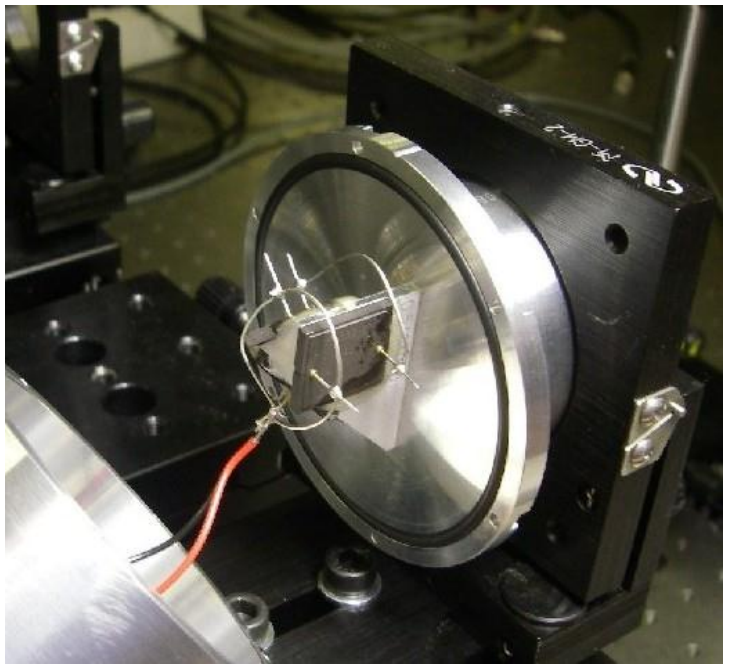
- Si Trap detector detection limit
- Switched integrator amplifier (SIA)
- Trap – SIA as new standard at low power
- Performances
- Measurements
- Conclusions



Primary transfer standard : trap detector

- Reference trap detector[1] provides link to the primary standard, the cryogenic radiometer



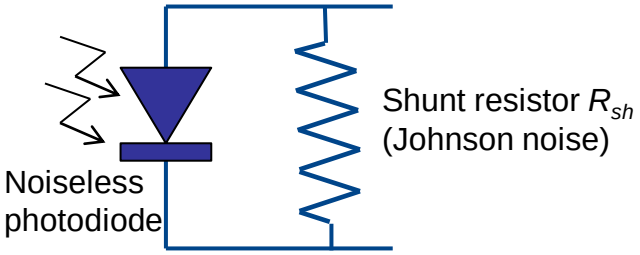


- 3 Hamamatsu S1337 photodiodes connected in parallel (currents sum)
- Low spatial response non-uniformity (~ 0.03% for 0.5 mm spot)
- Responsivity measureable with 0.02% uncertainty (k=2)
- Measured linearity better than 10^{-4} from 10^{-11} to 10^{-3} [2]

[1] Fox, N.P., Metrologia, **28**, 197-202, (1991)
[2] K. Nield et al "Evaluation of the linearity performance of silicon trap detectors with switch integrator amplifiers at low optical fluxes" CIE 2010

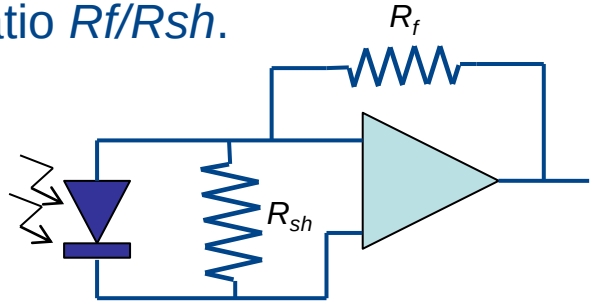
Low power measurement with photodiodes

- Noise at low power is dominated by the (Johnson noise) generated by the shunt resistor $N_j = \sqrt{\frac{4kTB}{R_{sh}(T)}}$
- The shunt resistor decrease with temperature (typically 15%/C)



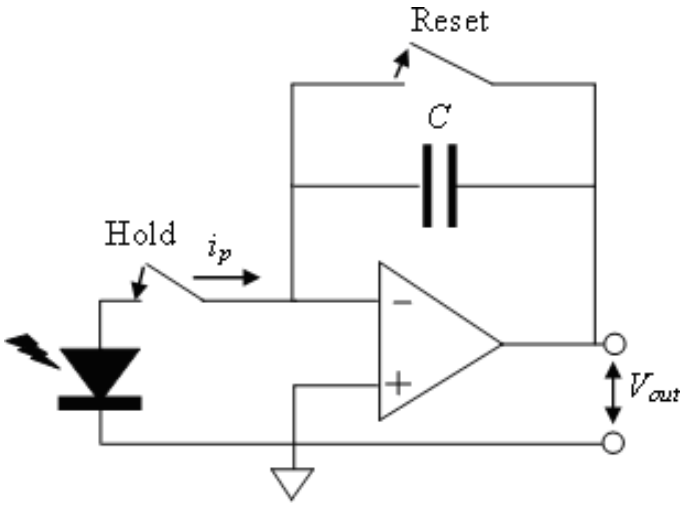
Trap detectors

- shunt resistor of 3 elements trap detector is ~1/3 of the single element
- dark current can be as high as few pA at room temperature. Measuring low photocurrent levels requires sequence of dark and light measurements.
- The output voltage noise N_o of a transimpedance amplifier is proportional to the ratio *Rf/Rsh*.



$$N_o \propto \frac{R_f}{R_{sh}}$$

Switched integrator amplifier (SIA)[3]



Capacitor stores the charge created in the photodetector

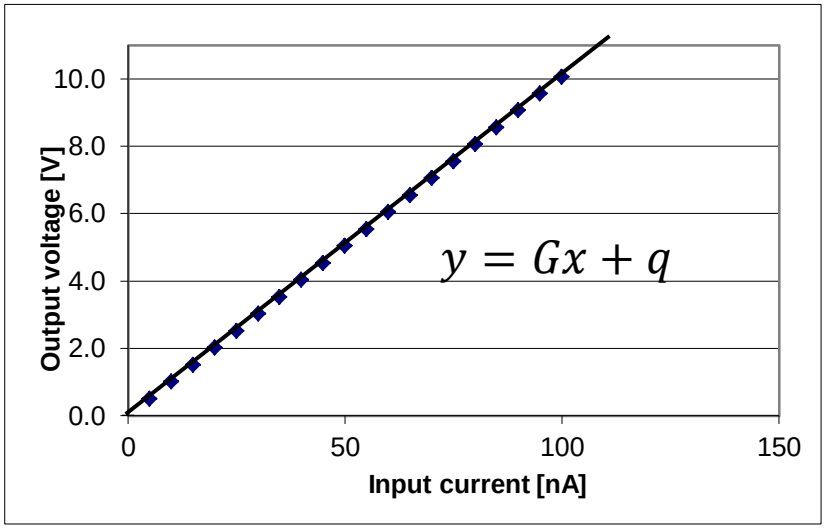
$$V_{out}(t) = -\frac{i_p \cdot t}{C}$$

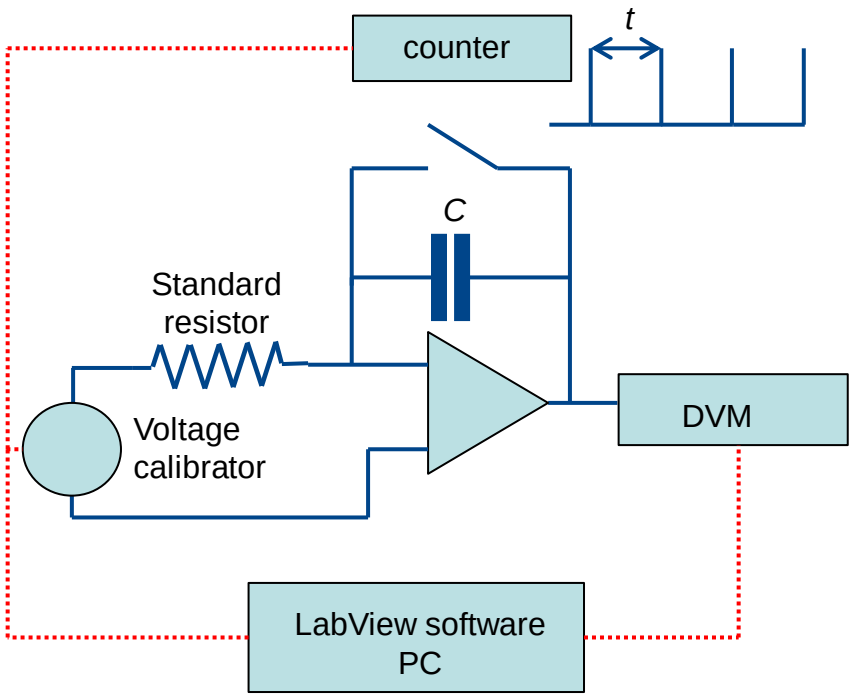
- Increase gain by increasing integration time
- with 1 pF capacitor, I/V Gain 10^{11} with integration time of 0.1 s
- Better NEP when coupled with trap detectors compared to transimpedance amplifier (NEP 25 fW/Hz^0.5 at room temperature with trap detector for a gain 10^{11})

[3] Mountford et al, Applied Optics 47, 5621-28 (2008)

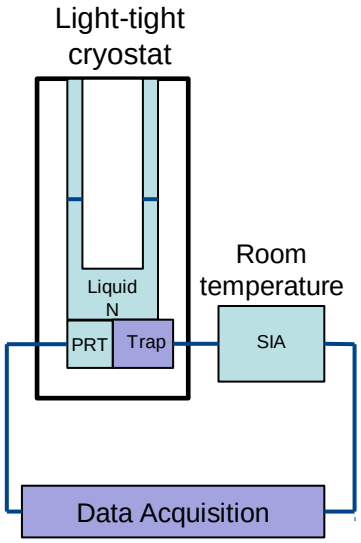
SIA calibration

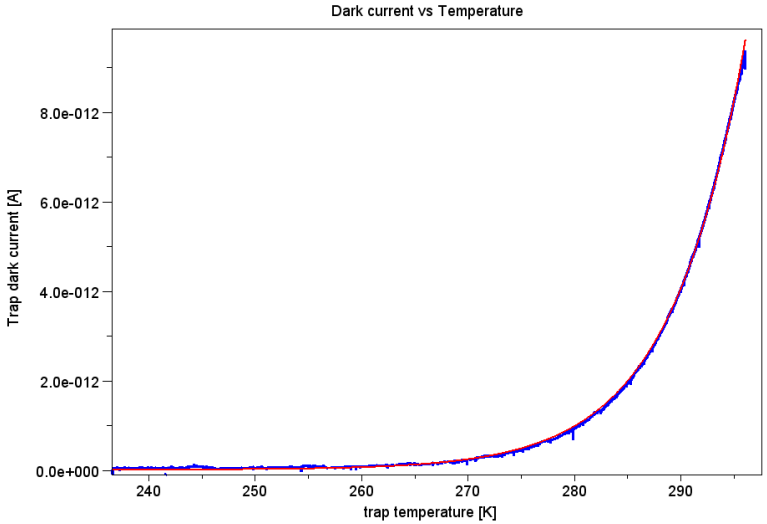
- With a voltage calibrator and a standard resistor we generate 20 values of input current from 1nA to 10nA (good SNR ratio)
- A DVM reads the voltage output values
- We calculate the slope of the curve G
- A counter measures the integration time t
- We derive the capacitor value like C = $\frac{G}{t}$
- Gain values from 10^6 to 10^{11} with uncertainty 0.01%

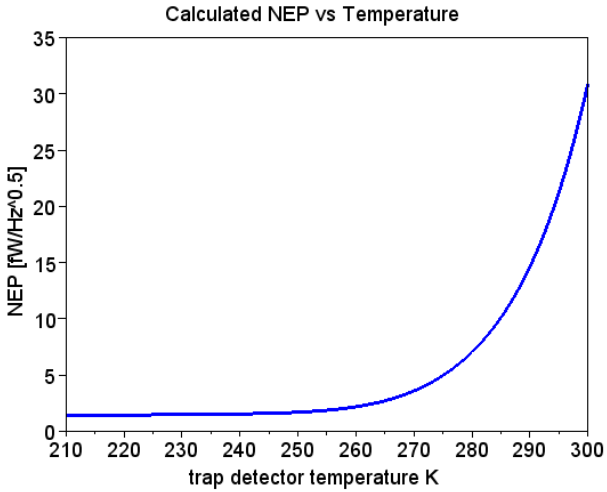


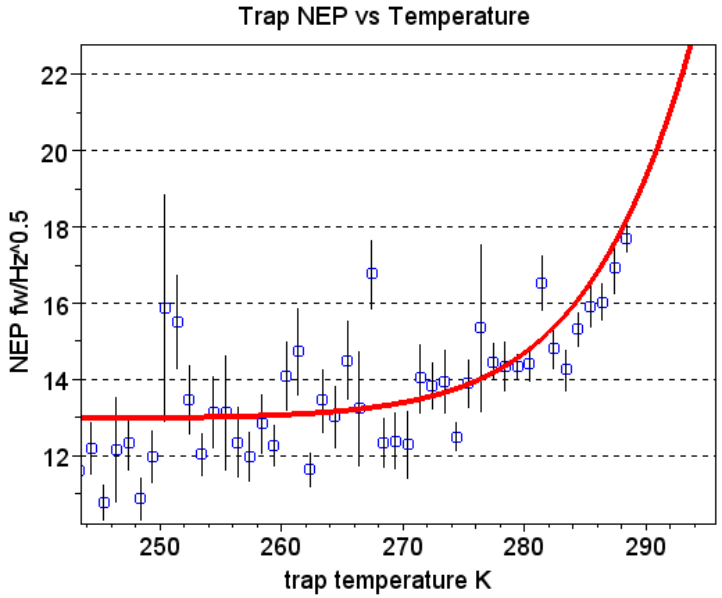


Trap + SIA : noise vs temperature







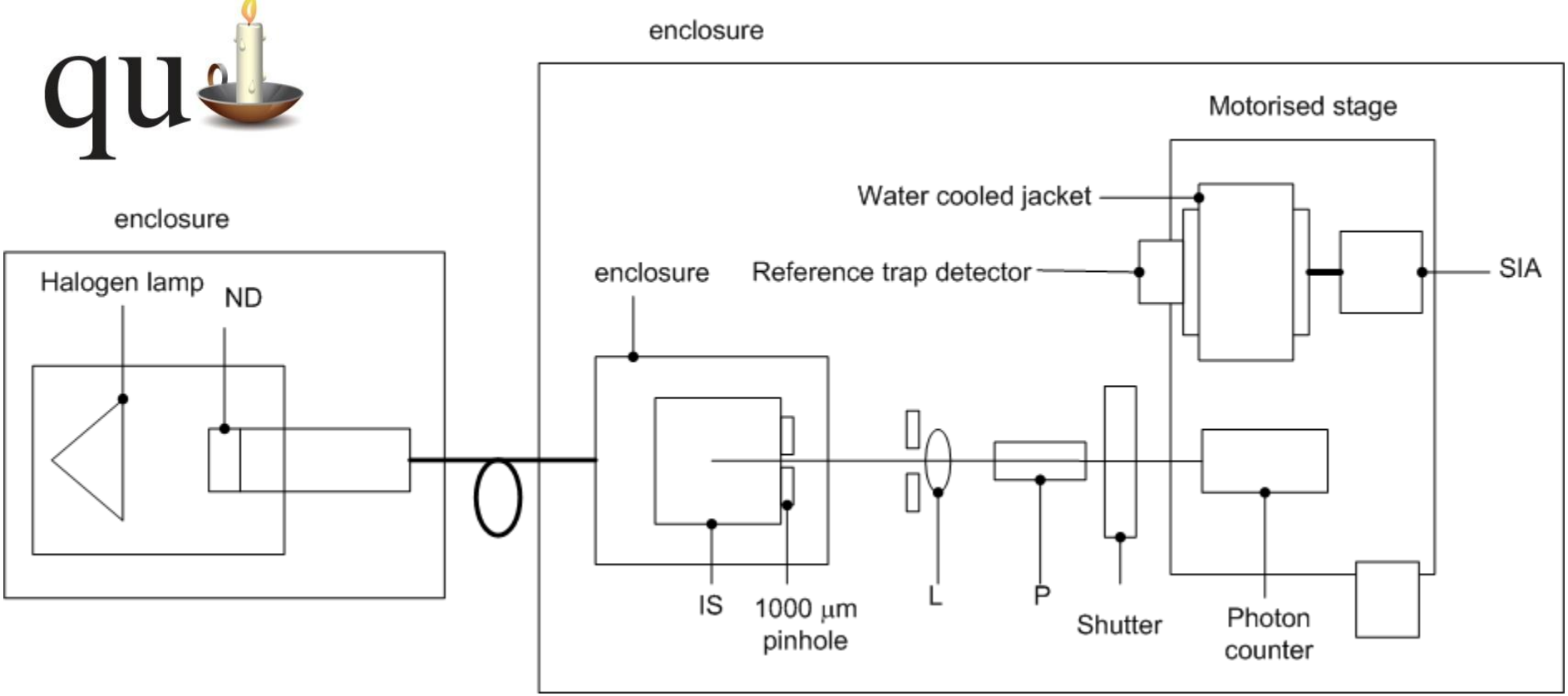


SIA NEP 13fW/Hz$^{1/2}$

Trap NEP 295k ~22 fW/Hz$^{1/2}$

At room temperatures dominant noise is from trap detector

Measurement of photoncounter detection efficiency

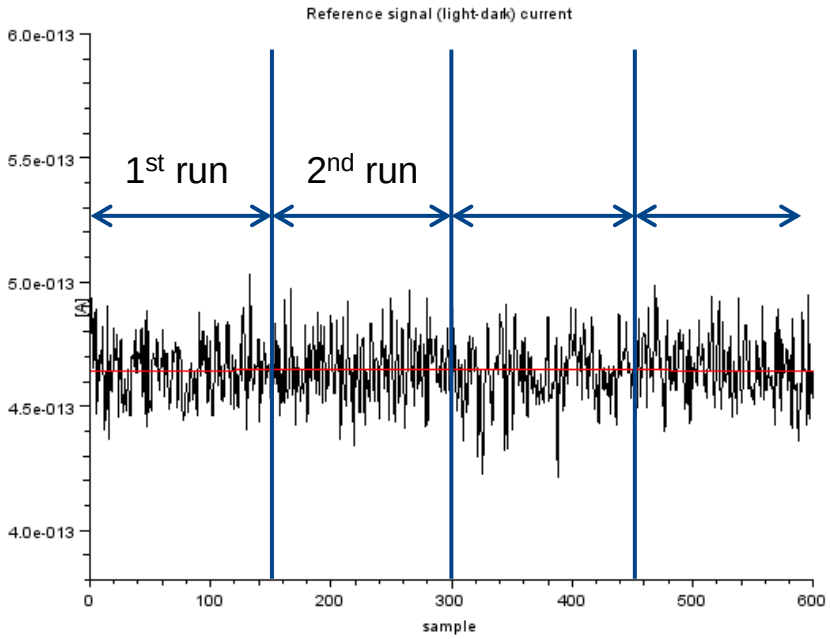


- Temperature stabilised (16 ºC): just above dew point.
- SIA gain 10^{11} - reference trap
- Power level of the stabilised lamp (~200 000 cps, ~ pW).

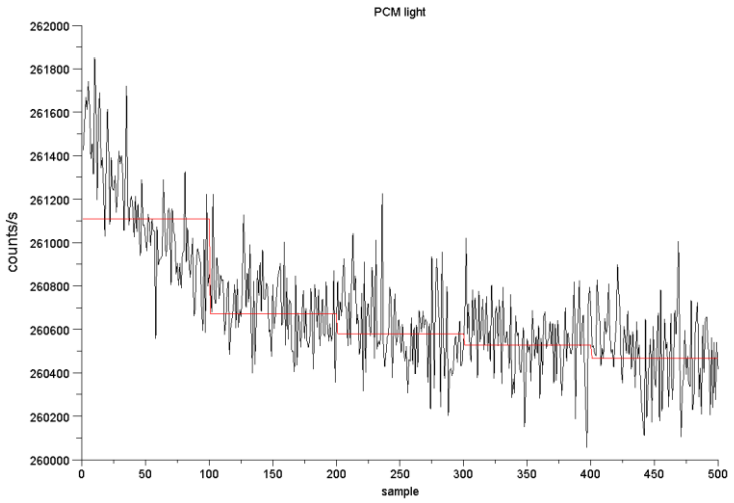
NPL campaign 2008-2009

0.14% agreement with parametric photon down conversion [4]

Dominant uncertainty contribution photoncounter noise



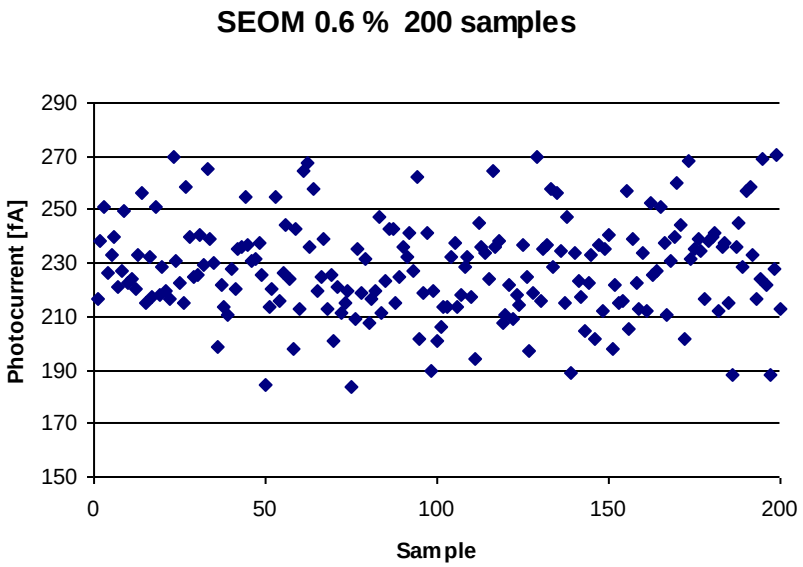
Reference trap signal 0.1% ~1pW

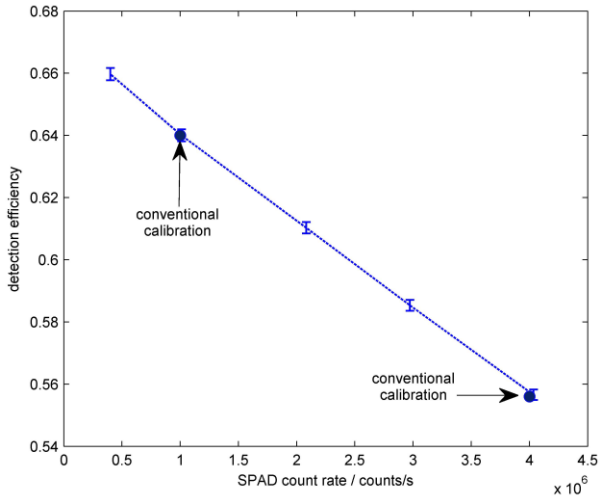


Long settling time photo counter

[4] J. Cheung et al “Low optical power reference detector implemented in the validation of two independent techniques for calibrating photon-counting detectors” Optical Express 2011

PTB campaign Berlin 2010 [4]





Absolute Measurements of irradiant flux 600 fW

[4] G. Brida et al “Toward Traceable Few Photon Radiometry”, submitted to Optics Express, (2011)

Conclusions

- Trap detector and SIA – new low power transfer standard
- High accuracy conventional based techniques for measurement of detection efficiency now achievable with SIA, 0.2%
- Cross validation carried out with two entirely independent techniques and campaigns with agreement ~ 0.1%

Acknowledgements

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To find out more:

www.quantumcandela.org

www.photoncount.org

Coming soon:

www.miqc.org

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