Performance measurement of a commerical PbSe photoconductor

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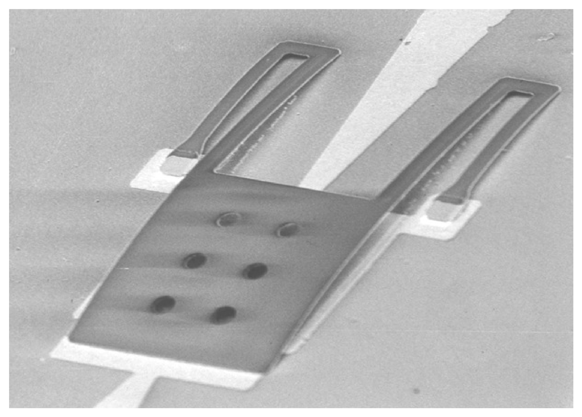
Motivation

We are in development of a radiant energy imager using MEMS cantilevers in a null-position clocking design. Work is based on US Patent No 7977635 (2011) by Oliver Edwards.



Current calculated performance measures are:

- 3.6 mK NETD with F/1 optics and a 30 Hz bandwidth
- *Time* responsivity of 80 nsec per 1˚C or 21 nsec per nWatt incident energy, requiring greater than 12.5 GHz clock pulse for 1mK LSB.
- 1 KHz frame rate

These performance measures need experimental evidence. Demonstration of performance measurements of commercial detectors will validate the experimental technique of measuring the above theoretical claims.

Radiance

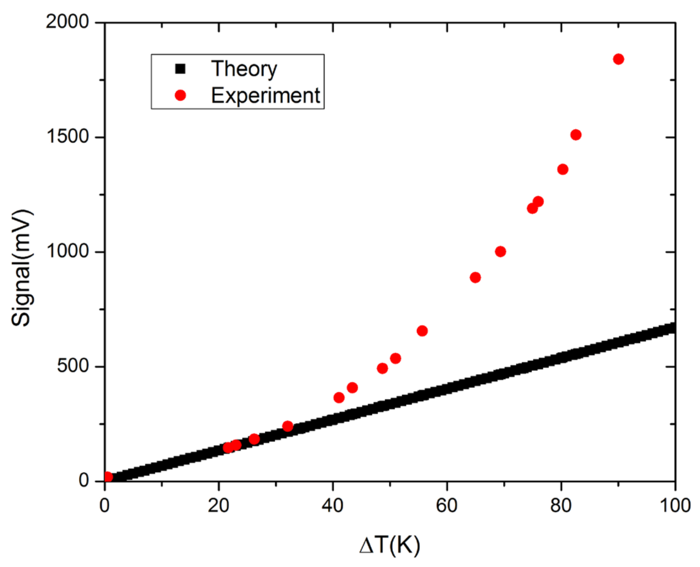
Radiance is the power emitted by a blackbody per unit area per unit solid angle and is described by Planck's Law as

$$L = +\frac{2k^4T^4}{h^3c^2}\int_{x2}^{x1}\frac{x^3}{e^x-1}dx \approx \frac{\partial L}{\partial T}\Delta T$$

The approximation shown above, also used in the NETD derivation, is valid for small ΔT. This can be verified by calculating the signal based upon the detector responsivity, and comparing to experimental data

Calculated Signal:

$$S = R \times \frac{\partial L}{\partial T}\Delta T \times \left[\frac{A_{BB}A_{mirror}\,\tau}{o^2}\right]$$



For ΔT < 40˚C, the approximation yields a difference of under 50%

NEP and NETD

- Noise Equivalent Power (NEP) - The amount of radiant power incident that results in a signal to noise ratio (SNR) of 1.
- $NEP = \frac{Incident\ Power}{SNR}$
- Used to characterize a single detector
- Noise Equivalent Temperature Difference (NETD) The difference between target temperature and background that yeilds SNR=1.
- Used to characterize an array of detectors or an entire IR system
- $NETD = \frac{\Delta T}{SNR}$
- Smaller NEP and NETD mean better resolution
- Both depend upon the electronic bandwidth Δf. Noise power increases proportional to Δf, noise voltage is proportional to √Δf. Therefore is is useful to define NEP as power per root bandwidth (W/√Hz)

Calculation of NETD

Detector Manual specifies NEP= 1.5 x 10^{-10} W/√Hz

$$NEP = \frac{Power}{SNR\sqrt{\Delta f}}$$

$$Power = \frac{\frac{\partial L}{\partial T}\Delta T A_{BB}A_{mirror}\tau}{o^2}$$

$$NEP = \frac{\Delta T}{SNR}\frac{\frac{\partial L}{\partial T}A_{BB}A_{mirror}\tau}{\sqrt{\Delta f}\,o^2}$$

$$NEP = (NETD)\times\frac{\frac{\partial L}{\partial T}A_{BB}A_{mirror}\tau}{\sqrt{\Delta f}\,o^2}$$

$$\left.\frac{\partial L}{\partial T}\right|_T^{\lambda_1-\lambda_2} = \frac{2k^4T^3}{h^3c^2}\int_{x_2}^{x_1}\frac{x^4e^x}{(e^x-1)^2}dx\,, x = hc/\lambda kT$$

$$\left.\frac{\partial L}{\partial T}\right|_{286K}^{1.5-4.9\mu m} = 3.95625\times10^{-6}\frac{W}{cm^2srK}$$

$$NETD = \frac{NEP\sqrt{\Delta f}\,o^2}{\frac{\partial L}{\partial T}A_{BB}A_{mirror}\tau}$$

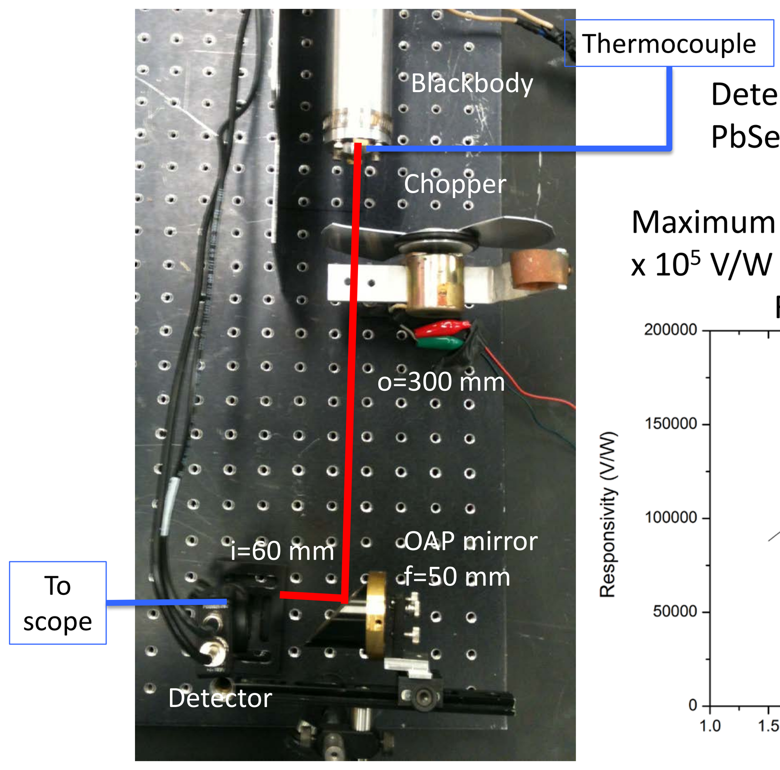
- Δf=1.25 kHz (½ the sampling frequency of the trace on the oscilloscope
- τ = 90% (transmission of the atmosphere)

$$NETD = \frac{1.5\times10^{-10}\times\sqrt{1250}\times30^2}{3.96\times10^{-6}\times0.78\times17.3\times0.9} = 99\ mK$$

Experiment Design and Results

The experiment design is based on ASTM E1543 for measuring NETD. A 1 cm diameter aperture blackbody with 20˚C<ΔT<150˚C is modulated by a chopper at 20 Hz. An OAP mirror focuses radiation onto the PbSe detector active area (2x2 mm)

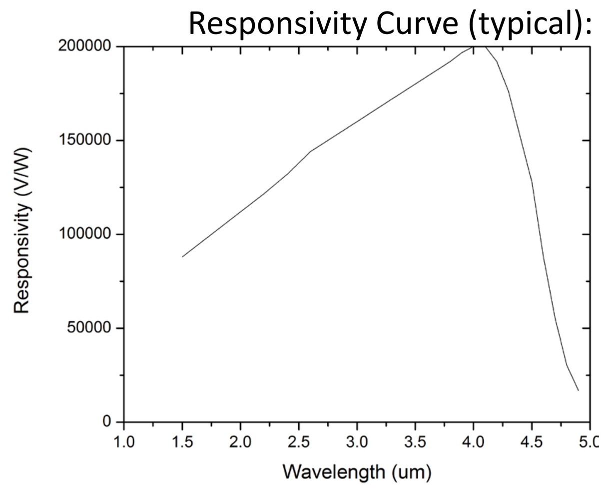
ΔT (˚C)	Signal (mV)	Noise (mV)	SNR	NETD (mK)
41.1	364	1.87	195	210
55.7	656	1.83	358	155

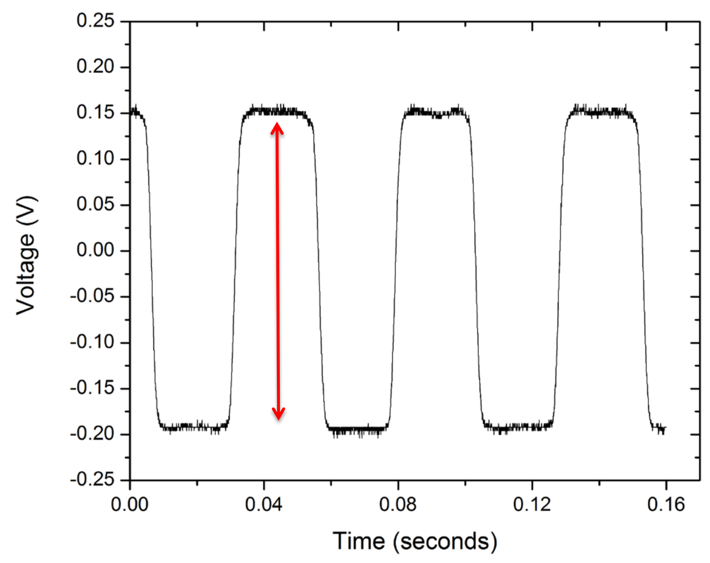


Detector is ThorLabs Inc. PDA20H PbSe preamplified detector

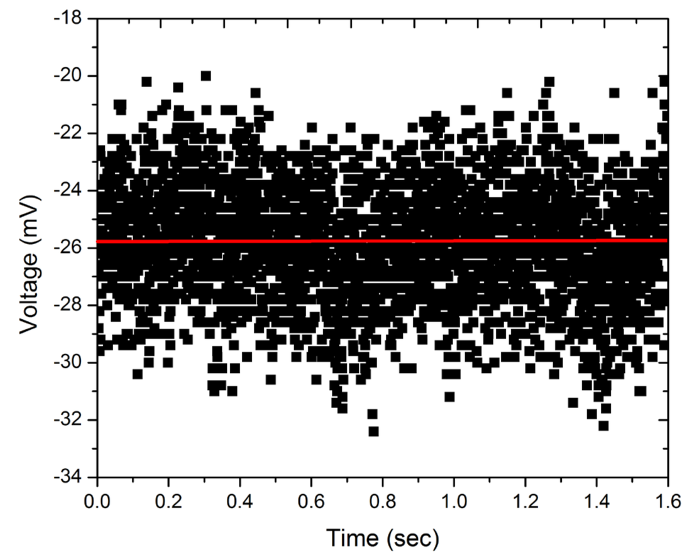
Maximum responsivity at 4 µm with 1-2 x 10^5 V/W

Responsivity Curve (typical):





Signal is the peak to peak voltage 364 mV shown here



Noise is found by blocking the blackbody and measuring the background
Noise voltage is the RMS variance:

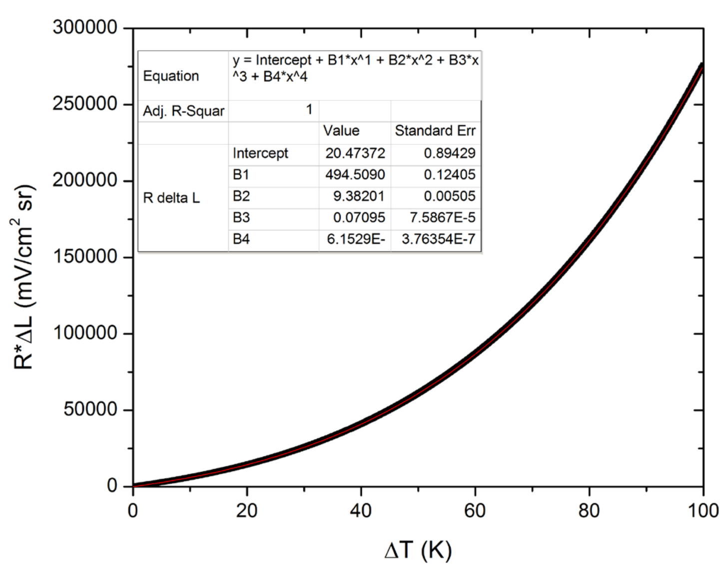
$$V_{RMS} = \sqrt{(V-\bar{V})^2}$$

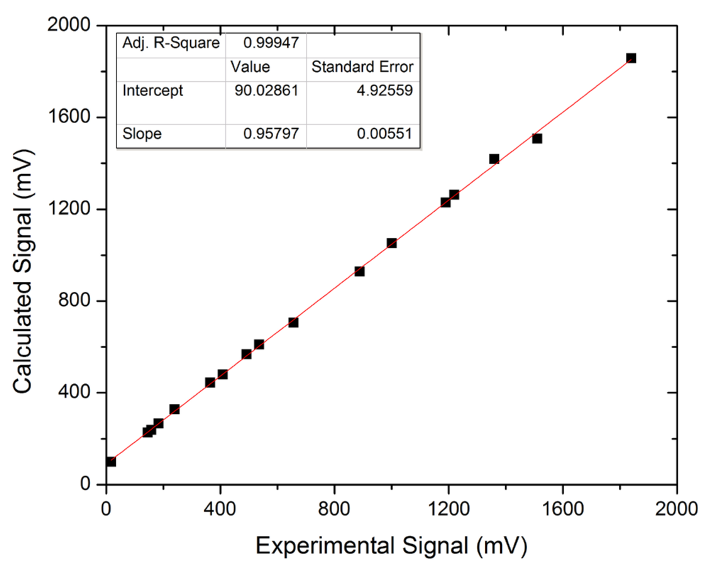
Corrected Radiance

The more accurate way to describe the signal mathematically is to integrate the product of the responsivity curve by the radiance curve over the wavelength interval of the detector:

$$\int_{\lambda_1}^{\lambda_2}\left(R_\lambda L_\lambda(T_{BB}) - R_\lambda L_\lambda(T_{ref})\right)d\lambda$$

The calculated signal can be approximated as a 4^{th} order polynomial and matches with experimental data:





Future Work

- Integrate a faster chopper (f > 600 Hz) and a lock-in amplifier to reduce the noise level and the bandwidth to measure smaller NETD
- Repeat experiment with IR camera systems
- Adapt the experiment to measure clocking duty cycles rather than analog voltage outputs

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