Chapter 4

Measurements under illumination

Up to this point I have discussed only the dark measurements. While most of the procedure remains the same for the corresponding measurements under illumination, particularly the data processing, the experimental setup changes significantly with the addition of an external light source. In this chapter I will explain some of these extra procedural challenges and present the results in comparison with the corresponding dark measurement.

4.1 Optical response measurement

When light is allowed into the cryostat, a change in the power radiated by an optical source leads to changes in x. In this case the response is simply

$$R = \frac{\Delta x}{\Delta P}.$$

The changes ΔP were produced by placing a chopper wheel between a voltage-controlled blackbody and the cryostat window (Fig. 4.1). The chopper wheel was placed behind a sheet of room-temperature absorbing material with a small hole to define the aperture. As the chopper wheel spun, it alternately blocked and passed light from the blackbody behind it, producing an approximately square wave signal of amplitude ΔP. The corresponding frequency changes were recorded as a function of operating temperature and the results are presented in Fig. 4.2.

4.2 Time Constant

While measuring the bolometer time constant is not necessary for computing the NEP, it remains a physically interesting measurement, since it tells us what kinds of time-varying signals we can observe. This measurement is conceptually similar to the response measurement, since in both cases the response of the resonator to a pulse of light is recorded. In this case, we were focusing on the transitions of the resonator to and from its baseline in response to the pulse. A terahertz

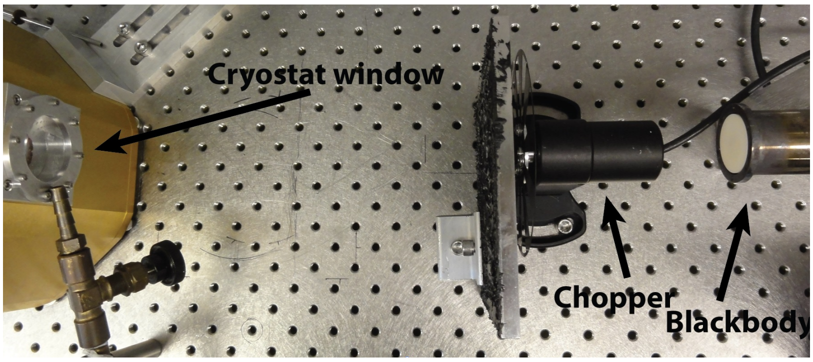


Figure 4.1: Setup for the optical response measurement. Light from a blackbody held at a fixed temperature is modulated by the rotation of the chopper wheel. An aluminum plate covered in an absorbing material placed in front of the chopper with a small hole for the aperture ensures that off-axis radiation entering the cryostat comes from a homogeneous source.

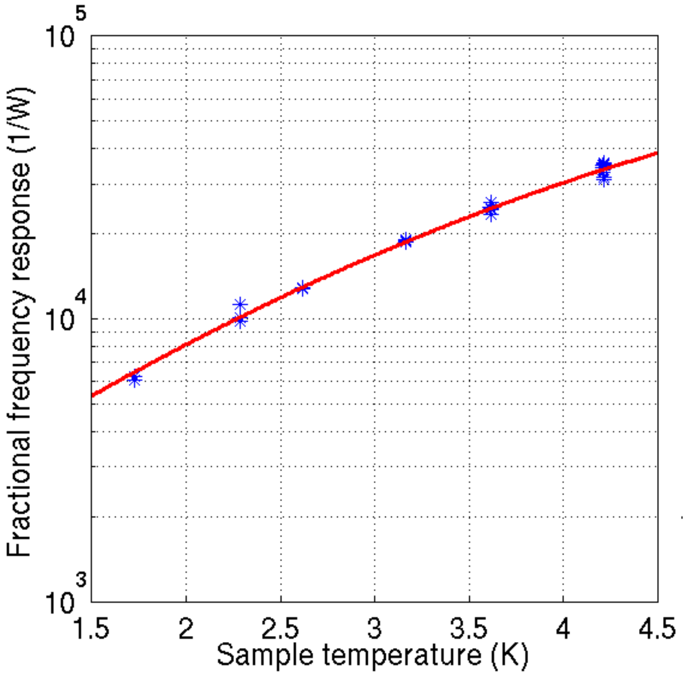


Figure 4.2: Response vs. temperature under optical loading, with a polynomial fit to the data.

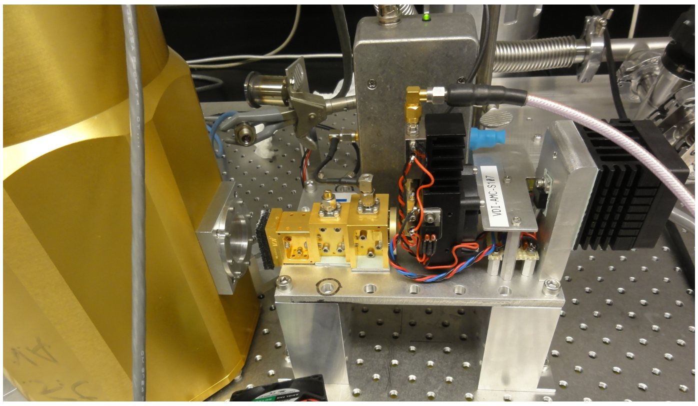
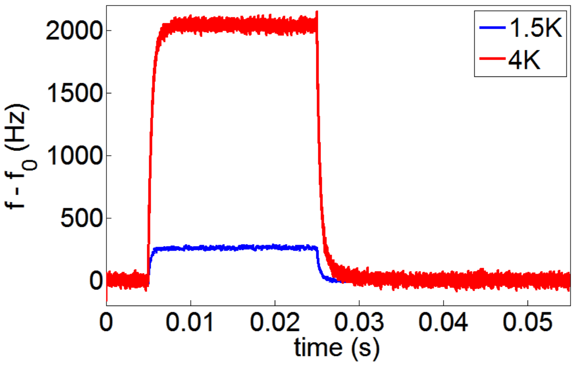
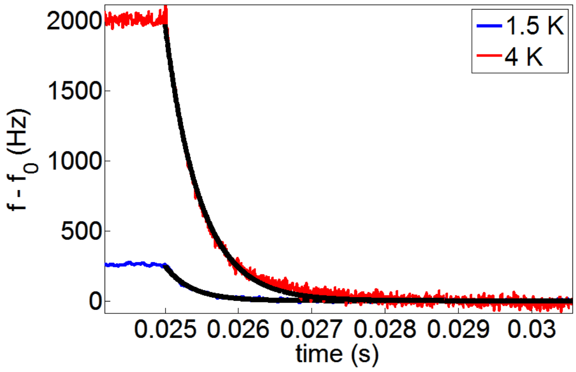


Figure 4.3: Setup for the time constant measurement. A terahertz radiation source was used to ensure that the transitions between low and high intensity were fast compared to the bolometer time constant.



(a) Response to a pulse of THz radiation



(b) Fit to the response decay

Figure 4.4: (a) Responses at low and high operating T to the THz pulse show the substantial difference in the magnitude of the response at these two temperatures. (b) The rise and decay curves may be fit to an exponential (black curves) to estimate the time constant. $\tau_{4\mathrm{K}} = 475\mu\mathrm{s}$ and $\tau_{1.5\mathrm{K}} = 365\mu\mathrm{s}$.

radiation source was used in place of the blackbody and chopper setup to ensure that sharp square pulses were produced when compared to the bolometer time constant (Fig. 4.3).

Sample pulses are shown in Fig. 4.4a. The difference in response between 1.5 K and 4 K is clearly visible. Also evident are the exponential rise and decay of the frequency shift. Fitting the decay curves to an exponential function (Fig. 4.4b) yields $\tau_{4\mathrm{K}} = 475\mu\mathrm{s}$ and $\tau_{1.5\mathrm{K}} = 365\mu\mathrm{s}$; these values agree with the value that may be estimated from the phonon noise roll-off in the noise plots (sections 3.3.2 and 4.3).

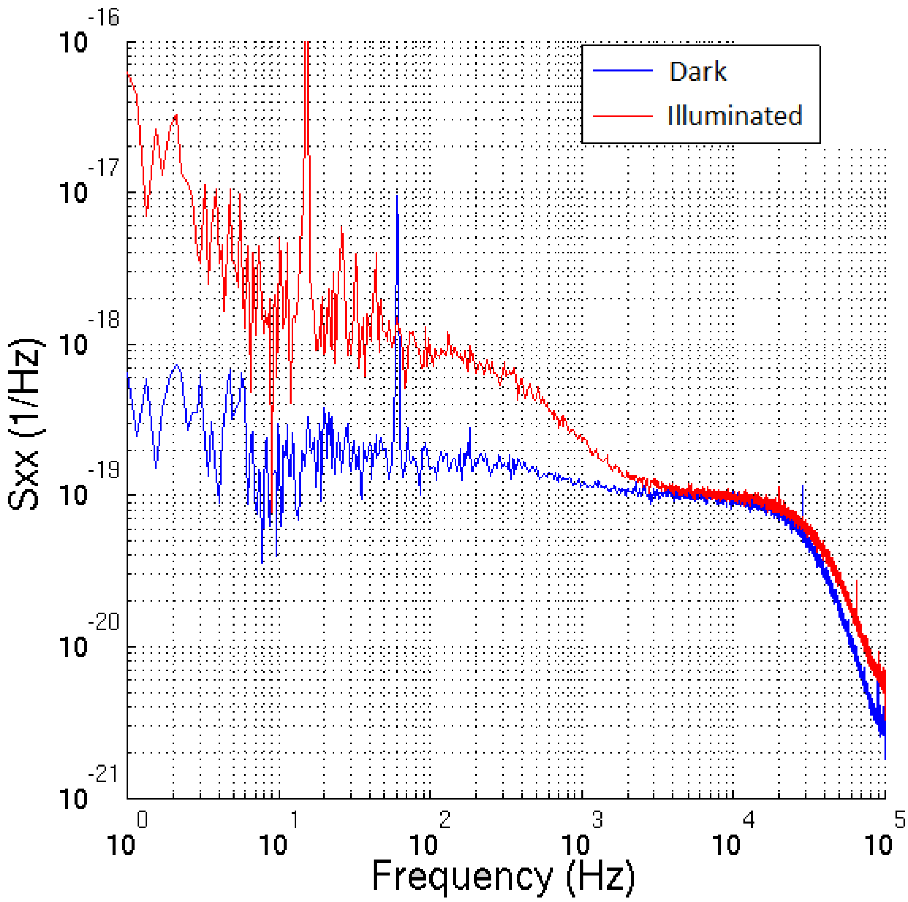


Figure 4.5: Noise plots for a single pixel at a constant temperature ($\sim$ 3 K). While the overall structure is similar, the noise under illumination is higher below the phonon noise roll-off, reflecting the presence of photon noise.

4.3 Noise under illumination

Fig. 4.5 compares two noise plots taken at the same temperature for the same pixel under dark and illuminated conditions. Evidently the structure is the same; both measurements clearly exhibit low frequency thermal instability noise, a phonon noise roll-off between 10^2 and 10^3 Hz, and in this case TLS noise rolled off by the resonator ring-down time (Appendix B) at high frequencies. However, in the illuminated case the noise is higher below the phonon noise roll-off; this reflects the addition of photon noise, which has no intrinsic spectral dependence but which is rolled off by the detector response.

When we again average the noise around 150 Hz over multiple temperatures, we see the added photon noise contribution in the optical data when compared with the dark data (Fig. 4.6). Assuming a constant photon NEP, the photon noise may be calculated:

$$S_{xx}^{\text{photon}} = (\text{NEP}_{\text{photon}} * (\Delta x/\Delta T))^2.$$

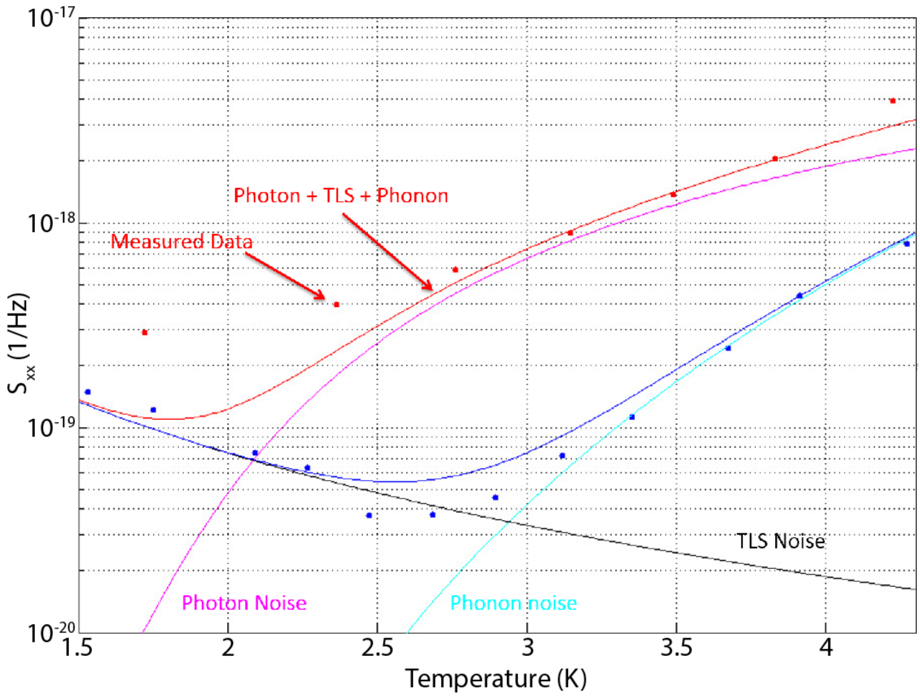


Figure 4.6: Noise vs. temperature at 150 Hz. The red data points are the noise under illumination while the blue data points are under dark conditions. Adding a constant photon NEP modulated by the response of the detector and added to the phonon and TLS noise determined from the dark data produces good agreement with the data for $T > 2.5$K.

$\text{NEP}^{\text{photon}} = 8{*}10^{-15}$ W/Hz$^{1/2}$ produces the best fit to the data. The photon noise is added to the phonon and TLS noise as fit from the dark data.

4.4 Noise equivalent power

The noise equivalent power (NEP) in terms of the fractional frequency noise and response is

$$NEP = \frac{\sqrt{S_{xx}}}{R}.$$

The dark and illuminated NEP are plotted together with the photon NEP in Figure 4.7. A clear minimum is present in the dark NEP around 3 K and to some extent also in the illuminated NEP. The upward trend as temperature decreases reflects the diminishing response, while in the opposite direction phonon and photon noise dominate.

The plot highlights a discrepancy in our data which is currently under investigation. The photon NEP was calculated from a fit to the noise as described in section 4.3. Thus, assuming the response was calculated correctly, the NEP under illumination should equal the sum of the photon and dark NEPs. This is not the case, implying the response calculation is not taking everything into account. The greatest source of uncertainty is our estimated value of ΔP for the response calculation; the

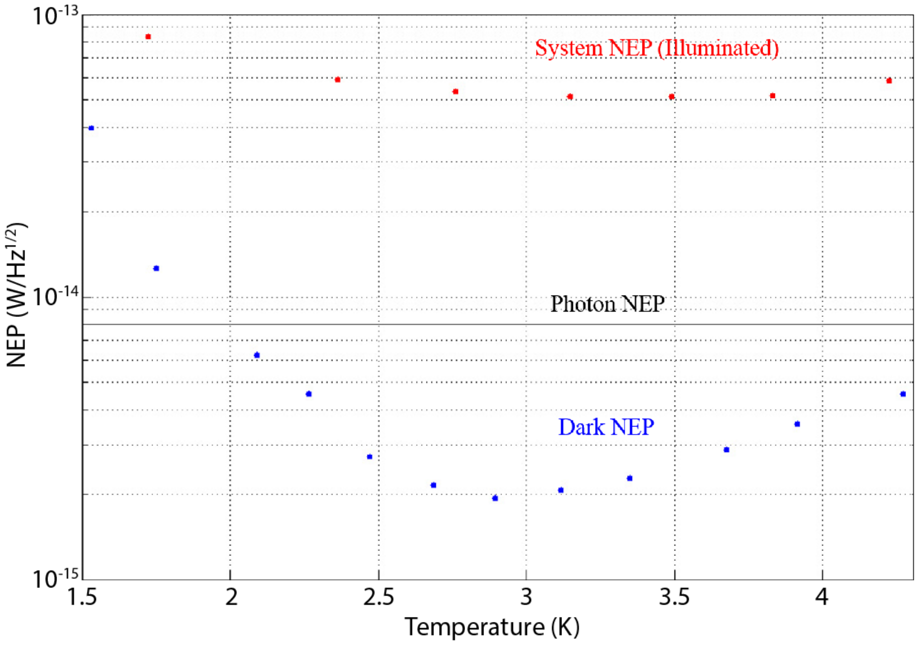


Figure 4.7: Noise equivalent power under dark and illuminated conditions as compared to the calculated photon NEP. A NEP minimum is established around 3 K. The discrepancy between the photon NEP and the measured NEP under illumination is currently being investigated.

discrepancy observed in Fig. 4.7 suggests that light is being absorbed by the detector than originally taken into account. ΔP is the power absorbed by the detector, and as such depends on (1) the optical load entering the cryostat, (2) the characteristics of the filters in the light path, and finally (3) the spectral dependence of the detector absorption. (2) and (3) are currently uncertain and under investigation: (2) because out of band transmission may contribute significantly to the detector loading, and (3) because, as this is a novel prototype device, the resonator bolometer's absorption properties have been neither measured experimentally nor modeled. I am currently working on modeling the device absorption. Appendix C details the analytic solution to the simplest case. Starting with this simplest case, I have been using finite element structure simulator software to approximate the device design.