Chapter 1

Measurements

On the developed chip multiple measurements have been performed to determine the noise charateristics of the chip under different readout powers and different temperatures. The different temperatures can be seen as a proxy for various loading conditions because interested in the ratio of the various noise contributions on diffent operating points. The results of these experiment will give a good indiction if the noise propeties of the detectors are good enought to be a viable option for further developent.

1.1 Cryostat

The chip has been mounted in the cryostat called the ADR because of it's cooling mechanism. Adiabatic Demagnetization refriguratior.It is shown in Fig. Insert image

Figure 1.1: Describe image cryostat.

This cryostat uses a Matroska doll design in which there is a large cylindrical vessel that forms the first cooling stage that cools to 50K. In this cylindrical vessel, a second heatshield in which a second Pulse tube stage cools to 3K. Inside the 3K stage, are two plates with two Adiabatic Demagnetization salt tubes that cool to 800mK, and the final plate cools to 120mK temperature.

A scematic representation of the parts of the cryostat are given in Fig. ref figure

For all these experiments, the chip is mounted in a so-called Box-in-box configuration, as shown in the dissertation of [?]. Care is taken to avoid any Light of frequencies higher than the gap freq of aluminum entering the chip holder.

The temperature of 120mK has been chosen because the hold time for the system is longer(1.5 day) when the temperature is higher[?]. This is a comprimize between GR-noise contribution and hold-time.

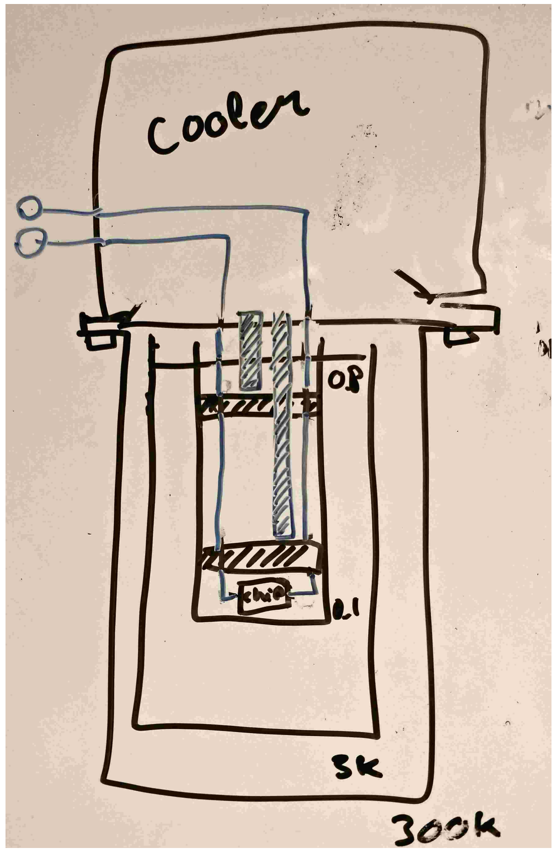


Figure 1.2: Describe image cryostat.

1.2 Method: Exp.1 - VNA

Reference Source: [?] A vector network analyzer (VNA) is a measurement device that generates a sweeping tone(GHz) between two frequencies for characterizing the device under test(DUT) to determine the transmission properties of the DUT. After the sweep we can see a trace of $|S_{21}|$ and $arg(S_{21})$

In our case, we want to use the VNA to determine the resonance frequency, optimal readout frequency, and Quality factors of the CKIDs on the chip. With the VNA we will first do a sweep of the approximate frequency range in which we expect the F_0 of the set of CKIDs to be. This is the range of 5.5 to 6.5 GHz.

When we found the approximate location of the resonance frequencies we want to reduce the sweep range to see one CKID dip in detail. Then after determining the $|S_{21}|$ a Lorentzian can be fitted to this curve to obtain Q_c and Q_i.

The step of determining the Quality factors is repeated for all readout powers from -120dBm upward in steps of 4dBm until we see that the Lorentzian dip gets skewed as can be seen in [?]

TODO: make scematic image about whole setup! Reference Source:

1.3 Results: Exp.1 - VNAsweep

TODO:

1. Table of resulting F0,Qi,Qc @120mK
2. Graphs of P_{opt}

Data ID	CKID	$F_0[GHz]$	Q_c	Q_i	Q_{tot}	$f_{-3db,ring}$
1	C7G3	4.9084	19845	1.0648e+05	16728	1.5e+05
2	C9G3	5.0762	21537	86065	17226	1.47e+05
3	C8G3	5.5424	27833	2.2685e+05	24791	1.12e+05
4	C10G4	5.8222	24451	4.1079e+05	23078	1.26e+05
5	C11G5	5.9134	48491	5.5221e+05	44576	6.63e+04
6	C12G6	6.0052	34370	3.9022e+05	31588	9.50e+04

Table 1.1: Data from running the Power script. The kid with Data ID 3 stands out as not having the approximate 0.1 GHz spacing as is more or less the case with the other CKID. While looking at the chip under the Optical microscope it can be seen that there is a particle present on the C8G3 CKID. This could short out a part of the hybrid line giving this CKID a higher resonace frequency than designed. Overall we can see that the Groups are not exactly on the place that was designed which could be due to slight changes compared to designed values. Why the spacing between the two groups is not the designed 0.2 GHz is unknown. In the last column the resulting ring time can be found which rules out that we are seeing the ringtime of the resonator. As temperature is increased the internal quality factor of the resonator decreases and thus the 3db freqency for the ring time roll off increases.

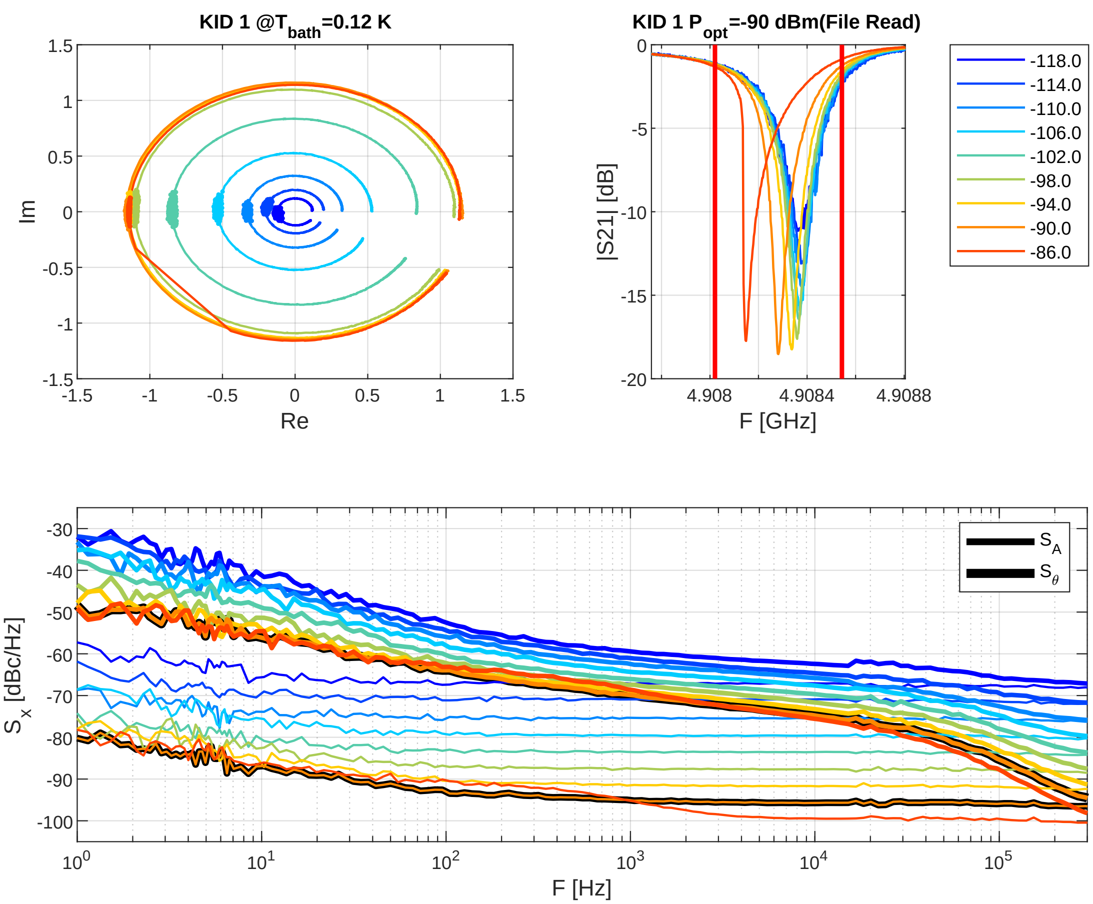


Figure 1.3: Here you can see how a change of the readout power influences the linearity of the MKID. We can see that if the readout power is increased too far we obtain a step in the resonace circle shown in the top left plot. If a MKID is driven too hard you can see a dip in the resonance circle which indicates that the MKID is overdriven. This can also be seen in the trace of S_{21} parameter over frequency on the top right. If a resonace curve gets skewed this is an indication that the MKID is overdriven as shown in [**?**]

1.4 Discussion on Exp.1 - VNA: F0, Qc, Qi

1.5 Method: Exp.2 - PSD

The dataset used to do the PSD analysis is

Reference Source:

In the previous experiment in section 1.2 the resonance frequencies for the optimal readout power have been detemined.

In this experiment we will use the found resonace frequencies to set up a single tone readout at the frequency F_0 of one of the CKIDs shunted resonace frequency. That CKID is then the current KID under test.

The generated signal is split into two parts. One part is fed into the cryostat and is then attenuated by the various passifisation stages that prevent 'hot' electrons from heating up the final stage of the cryostat which than does not reach the target temperature.

When the signal passes through the chip the KID under test will modulate the amplitude and phase of the signal. The important takeaway here is that The GR-noise and TLS noise processes of the KID will change the resonace frequency of the KID under test. Thus these noise processes modulate the signal and after the signal has passed the KID under test both noise sources have been encoded into the signal in the form of the aplitude and phase modulation of the signal.

The first step after the signal leaves the chip is that a HEMT amplifier(T_{noise} $3 - 4K$[**?**, p.83]) at the 3K stage is used to amplify the signal by $\sim$ 35dB[**?**, p.83]. Because the gain of this first stage is high the HEMT amplifier determines almost exclusivly the noise propeties of the total system.[**?**, Eq 8.37]

When the signal leaves the cryostat it is mixed using an IQ-mixer with an attenuated version of the signal from the signal generator which is illustrated in Fig. **??** The resulting baseband signal is digitized using an ADC so that the timestream of the Aplitude and phase can be determined. The welch method is employed to obtain a direct PSD of this signal.

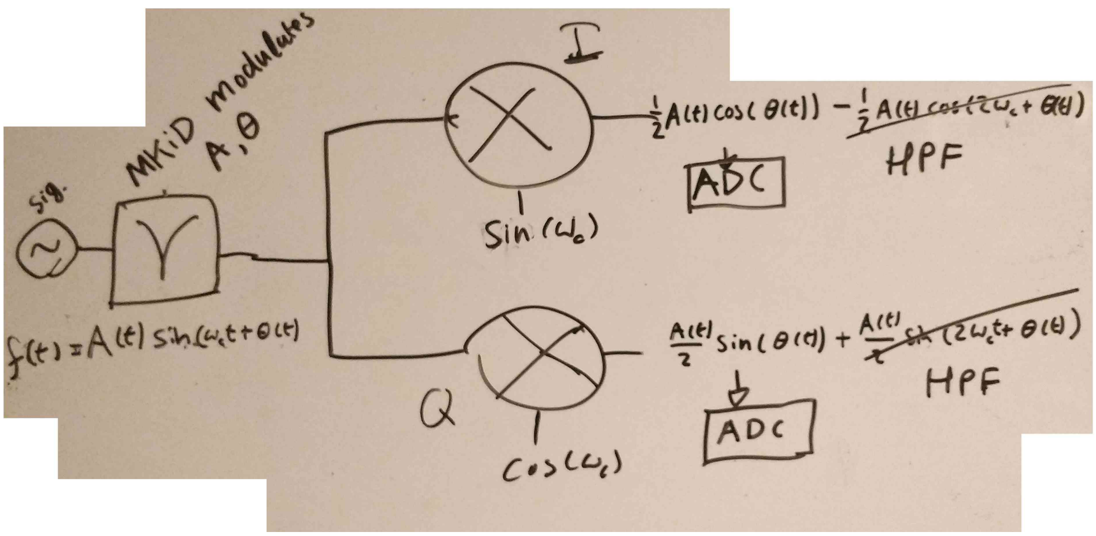


Figure 1.4: An overview is shown of the simplified signal chain. A readout tone is generated on the left. Then the signal is fed into the cryostat into the chip. The noise in the MKID modulates the amplitude and the phase of the readout tone as a function of time. This modulates the readout tone on the readout frequency. an IQ mixer is used to retrieve the In-phase and Quadrature(90 deg out of phase) components in the signal. This signal is then fed into a High-Pass filter that removes all the high frequency components and is subsequently fed into a Analog-to-digital converter. In the data processign software a PSD is calculated.

1.6 Results: Exp.2 - PSD

preliminary analysis

preliminary results!!! while i am at it i might better write it down.

Slope TLS noise: TLS noise is given in general by

$$S_{\theta,TLS}(f) = C(P_{read})\frac{1}{\sqrt{f}} \tag{1.1}$$

So we want to know what the slope is of this in log-log plot. so first we want to make the function not a variable of f but of $f = 10^x$ So we obtain

$$S_{\theta,TLS,log}(x) = C(P_{read})\frac{1}{\sqrt{10^x}} \tag{1.2}$$

And then take the $10log_{10}(...)$ of the whole function:

$$S_{\theta,TLS,log-log}(f) = 10log(C(P_{read})\frac{1}{\sqrt{10^x}}) \tag{1.3}$$

split..

$$S_{\theta,TLS,log-log}(f) = 10log(C(P_{read})) + 10log(10^{-0.5x}) \tag{1.4}$$

Which then simplifies to

$$S_{\theta,TLS,log-log}(f) = C_1 - 5x \tag{1.5}$$

Which means that TLS noise has a slope in log-log plot of 5dB per decade!

Readout noise: From Eq. **??** we can obtain the noise line that the readout circuit gives. from [**?**] we know that the $T_{noise} \sim 7K$

$$S_\theta = \frac{4 * 1.38E - 23 * 7}{10^{-3-\frac{86}{10}}} = 1.53 \cdot 10^{-10} \tag{1.6}$$

In dB by doing $10 * log_{10}(1.53E - 10)$

$$10 * log_{10}(1.53E - 10) = -98dBc/Hz$$

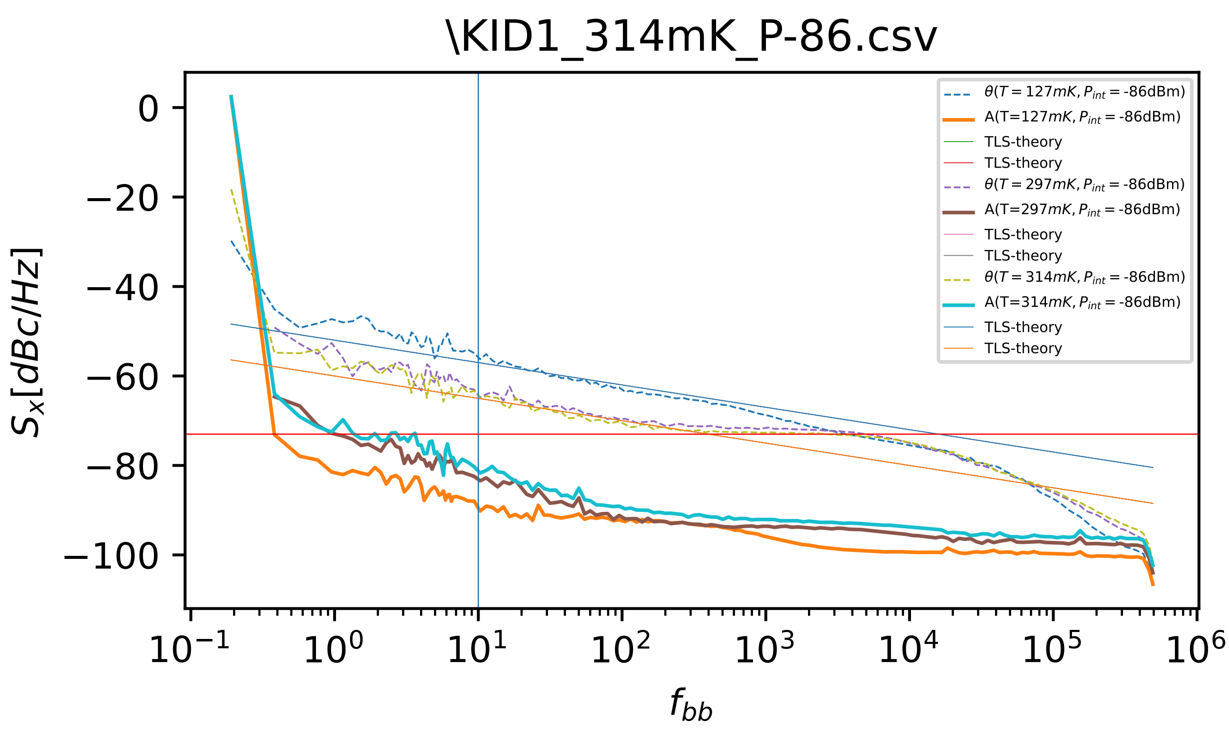


Figure 1.5: KID1:

My Jochem stitch code seems to explain the GR noise level! Look into if it is ok!

1.7 Discussion on Exp.2 - PSD

1.8 Method: Exp.3 - Dark NEP

TODO: temperature variation. TODO: write about DC measurement

1.9 Results: Exp.3 - dark NEP

$$NEP_{elec}(f) = \frac{\sqrt{S_x(f)}}{\frac{\eta_{qp}\tau_{qp}}{\Delta}\frac{dX}{dN_{qp}}}\sqrt{(1+(2\pi f\tau_{qp})^2)(1+(2\pi f\tau_{ring})^2)} \tag{1.7}$$

$$\frac{dx}{dP_{dark}} = \frac{\eta_{pb}\tau_{qp}(T)}{\Delta(0)}\frac{dx}{dN_{qp}(T)} \tag{1.8}$$

The overall dependency flowchart is given in Fig. **??**

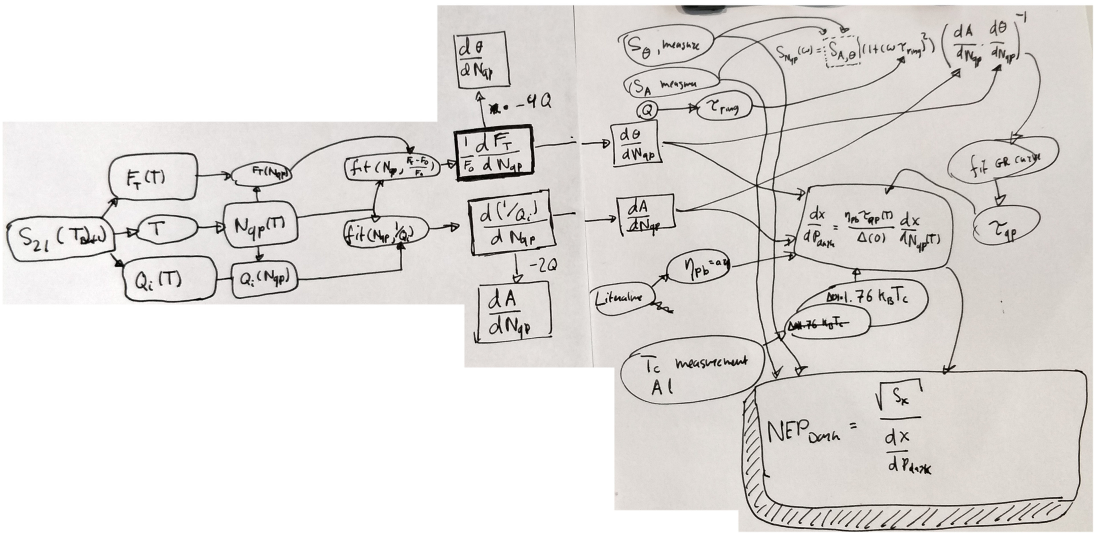


Figure 1.6: An overview is shown of the of how all parameters depend on eachother and how they should be obtained.

Checking Popt.

First we want to check if Popt is ok! Because if it is not then we are in trouble because the relation between the phase and the incident radiation becomes nonlinear. This is shown in the following Fig. 1.71.81.9

KID#	$P_{opt}(dBm)$	$\sim F_0$ (Graph)	Supected KID
1	-94	4.9083	C7G3
2	-90	5.0762	C9G3
3	-94	5.5424	C8G3
4	-87	5.8222	C10G4
5	-92	5.9134	C11G4
6	-87	6.0052	C12G4

Table 1.2: Table with optimal readout powers. You can judge from the skewness of the S_{21} dip and the Lowpass charateristic that you have overdriven the MKID into non-linear regime. The second is the suspected MKID number based on only the C9G3 MKID had a piece on Hybrid CPW which explains the higher readout freq.

asdfaf

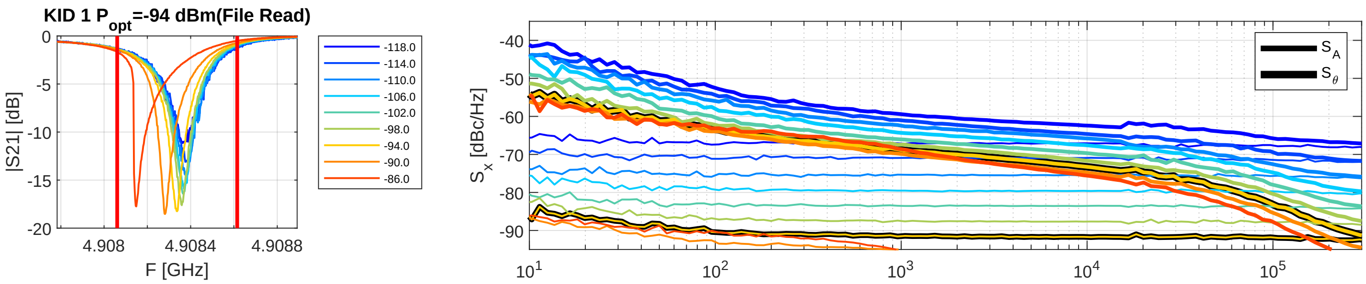


Figure 1.7: asdfffffffdsa

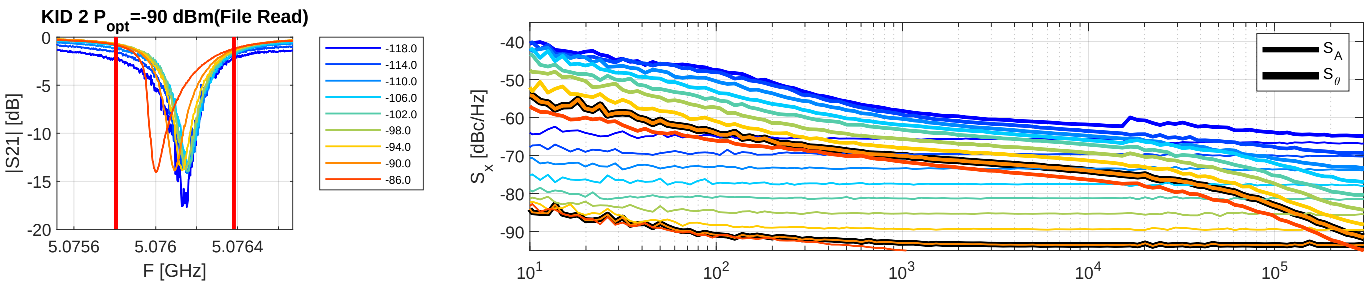


Figure 1.8: asdffdsa

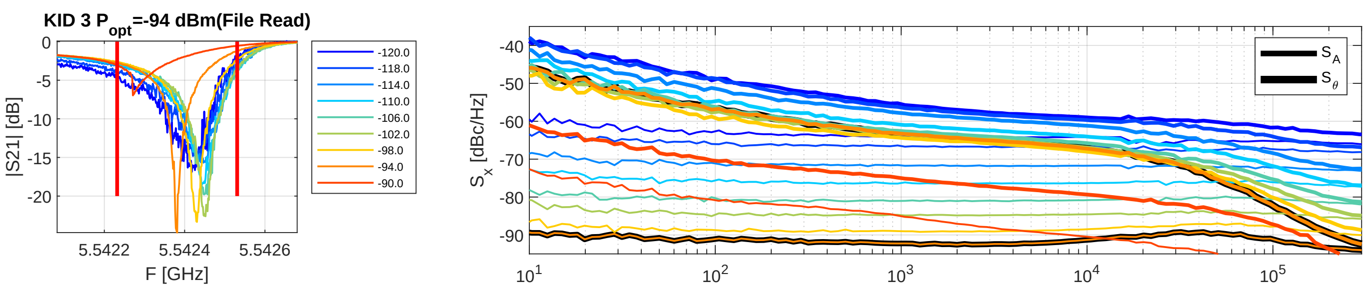


Figure 1.9: asdffdsa

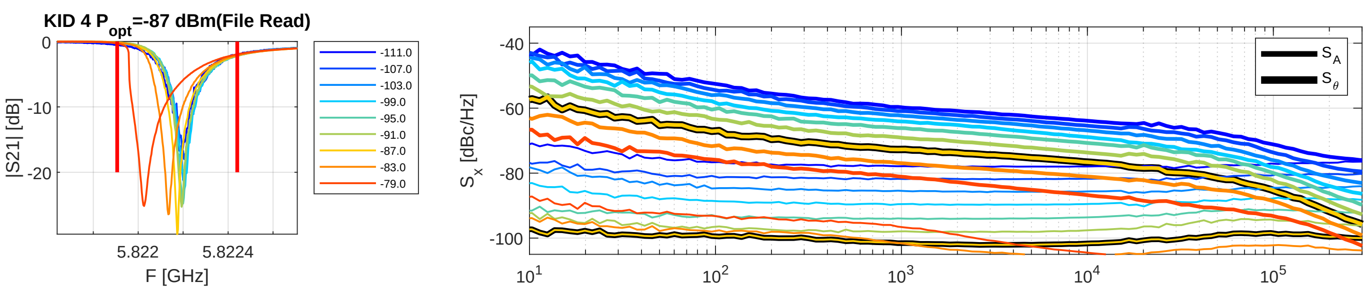


Figure 1.10: asdffdsa

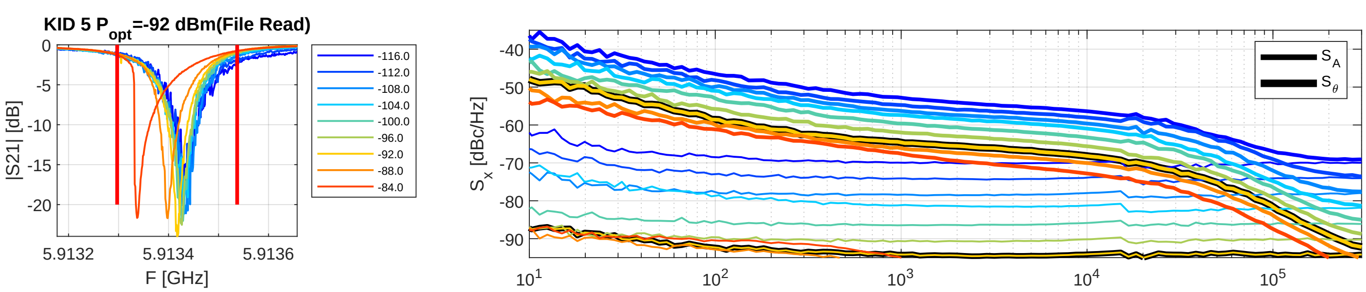


Figure 1.11: asdffdsa

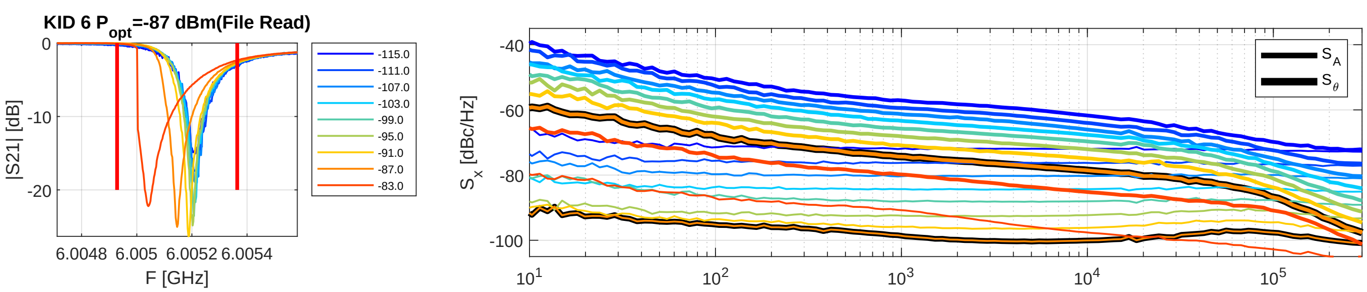


Figure 1.12: asdffdsa

Find S21 dips for all temperatures and Powers.

Find the following expressions (In code): [?]

$$\frac{F_T(T) - F_0}{F_0} \text{ Vs. } T \tag{1.9}$$

$$\frac{1}{Q_i(T))} \text{ Vs. } T \tag{1.10}$$

1. Find all dips in S21 data for all temperatures and T

Convert T to N_{qp}

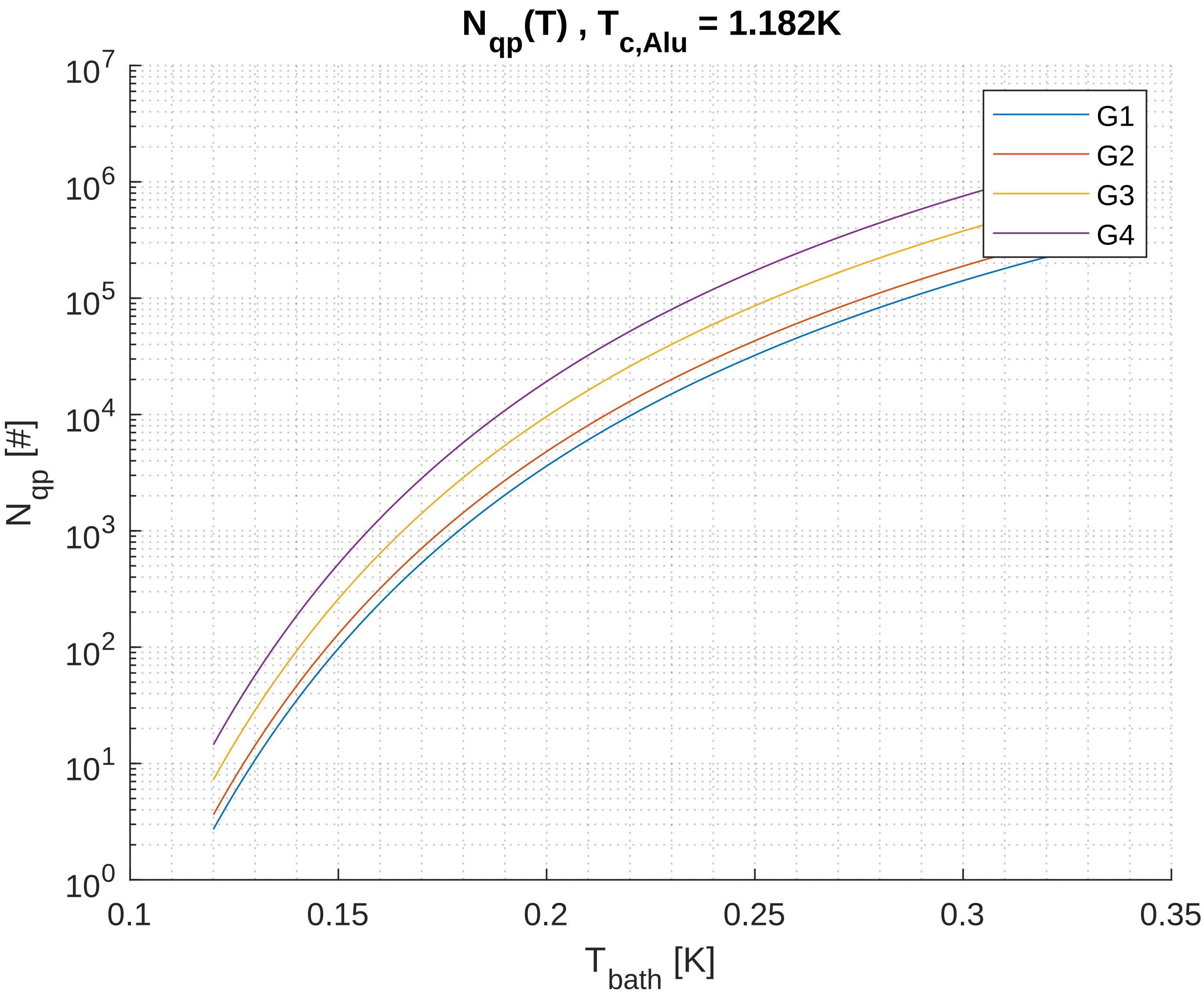


Figure 1.13: Relation between the bath temperature and N_{qp}. Code based on getNqp_Tbath.m function. Author: J.Baselmans

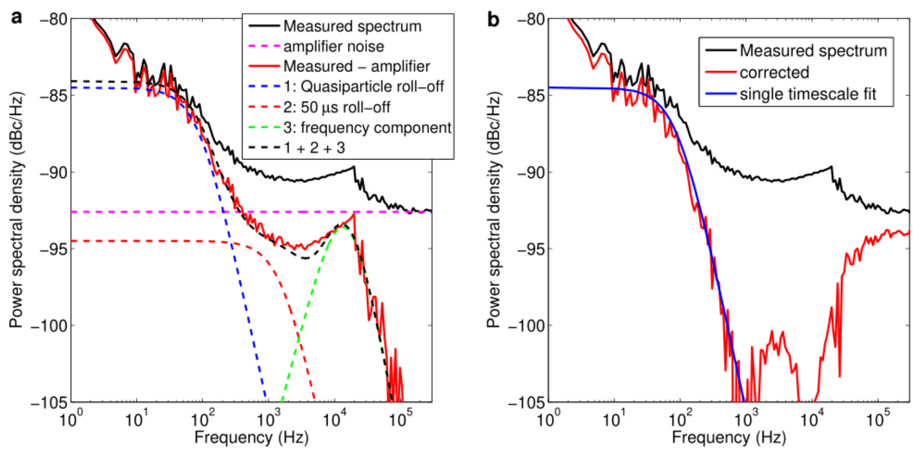
Determine $\tau_{qp}$with cross power spectral density - fitting

Workflow is as follows:

1. (Done)Find P_{opt} with Noiseanalysis_PdepV7.m
2. (Done)Find all PSD curves with Noiseanalysis_2DV1.m

3. (Done)Use TDanalysisV2.m to find CrossPSD
4. (Done)Find offset of TLS-noise spectrum.
5. (Done)Remove TLS noise spectrum by subtracting in normal domain
6. (Done)Use CrossPSDJBV2.m to fit τ_{qp}. But works poorly!!

How to remove offset First we want to know the offset from lets say 1Hz That is then the value for $C_{TLS,Cross-PSD,dB}$. I don't know yet if this will be the same as C_{TLS}. I don't think so.



Supplementary Figure S2. **Corrections to the noise spectrum to extract the quasiparticle recombination time.** **a**, Different contributions to the noise spectra. The measured amplitude power spectra density at a temperature 120 mK and a microwave readout power of -92 dBm is shown as a solid black line. The amplifier noise is a white noise contribution and is determined at frequencies above 300 kHz. The measured spectrum with the amplifier noise subtracted is shown as the red line. The other dashed lines show the other contributions: the roll-off due to quasiparticle fluctuations, a second roll-off with a timescale of 50 μs and a 10 dB lower noise level, and a symmetric bump around the resonator response frequency due to mixing of frequency noise in the amplitude direction. **b**, The same measured spectrum as in **a**, together with a spectrum that is corrected by subtracting the level at 3 kHz. The correction is done to be able to only fit the quasiparticle roll-off, the result of which is shown as well.

Figure 1.14: Source: Pieter Nature communications 2014 for our case $f_{ring} = \frac{F_0}{\pi Q} \sim 0.1MHz$

Once $C_{TLS,Cross-PSD}$ is found we can put it in the formula:

$$S_{TLS} = 10^{C_{TLS,Cross-PSD,dB}/10} f^{-0.5}$$

Then we obtain the following in the limit that Readout noise is **Low!**

$$S_{GR,lin} = 10^{\frac{S_{CrossPSD}}{10}} - 10^{C_{TLS,Cross-PSD,dB}/10} f^{-0.5ChipInfo_path}$$

The offset was obtained by doing some dirty fitting on the TLS part of the spectrum Then this is transferred to linear scale and it is subtracted In this process it was nessesary to take the absolute value because otherwise you have trouble displaying it on log-log scale.

The resulting fits are the following: I don't think this is really ok. I guess an optical led pulse would have been better but this is for now.

LOG: 30-07: Because of subtracting the resonator ring mixing noise and Putting this into the the fitting function of Jochem and also moving the minimum detectable frequency seems to at least partially solve the problems with the fitting. Also made a bunch of usefull graphs in which you can distigish all the parts of the cross-power spectal density.

other parameters and fill in to obtain dark responsivity

Obtain PSD.

The 2D PSD files are contained In `X:▸DIR▸SUBDIR`

dark NEP plots

1.10 Discussion on Exp.3 - dark NEP