AC/DC characterization of a Ti/Au TES with Au/Bi absorber for X-ray detection

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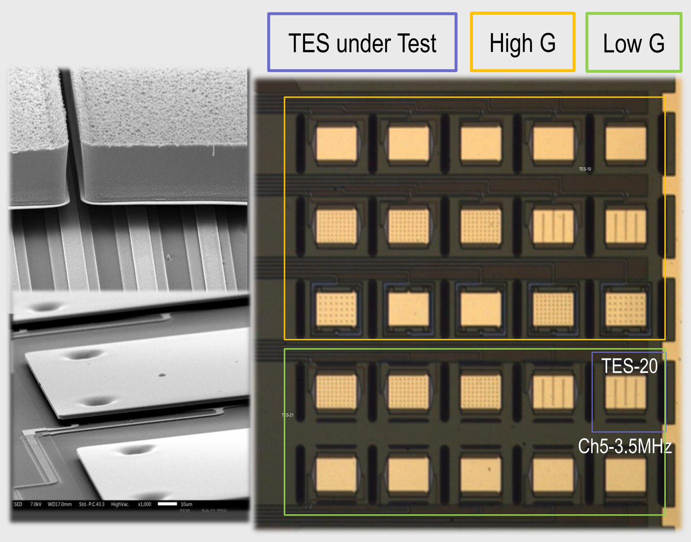
Introduction

Transition-edge sensors (TESs) are used as very sensitive thermometers in microcalorimeters aimed at different wavelengths detection. In particular, for soft X-ray astrophysics, science goals require very high resolution microcalorimeters with a high number of pixels which need to be multiplexed in the readout stage. Frequency Domain Multiplexing (FDM) is a common scheme and is the baseline proposed for the ATHENA mission. Recently there has been reported degradation in performances under AC with respect to DC bias. In order to assess the performances of TESs to be used with FDM, it is thus of great interest to compare the performances of the same device both under AC and DC bias. We report in this work the preliminary results of a single pixel characterization performed on a TiAu TES under AC and under DC bias in different facilities.

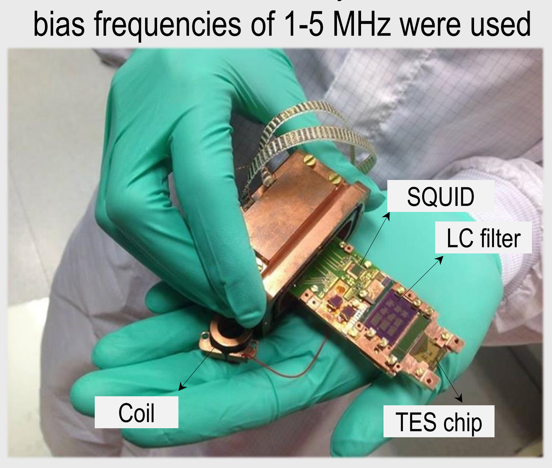
SRON Array and TES under Test

- Ti/Au TES bilayer, T_c around 100 mK
- Normal state resistance around 250 mΩ
- 240x240 μm² full size absorber of Bi (3.5μm) & Au (3 μm)
- Same size TES (100x140 μm²)
- Different G, absorber coupling and alpha tuning structures
- Fabricated by DRIE but only horizontal Si support structure
- Devices are separated by SiN slots

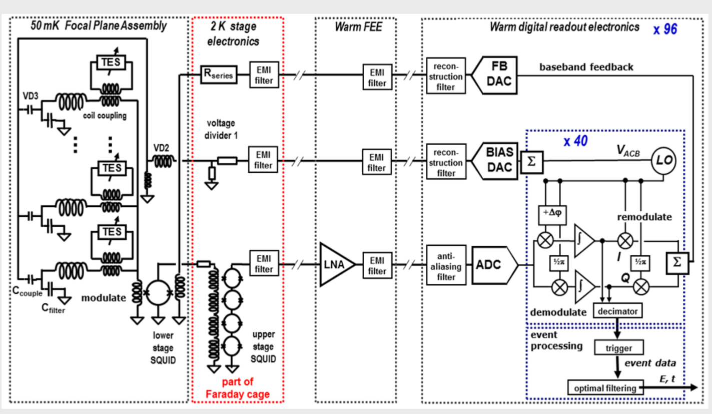


FDM readout system

18 channels FDM system and bias frequencies of 1-5 MHz were used



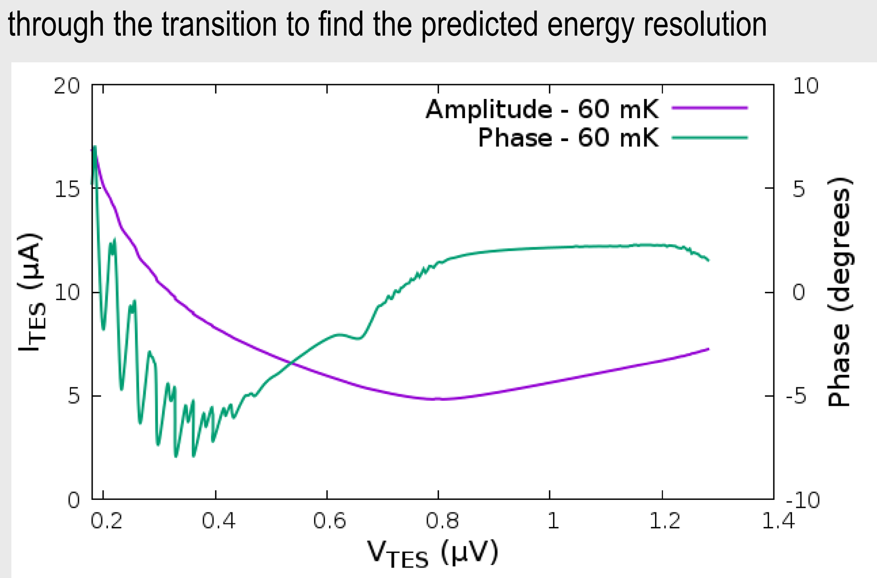
Simplified schematic of a single readout channel in the present baseline for FDM read-out system

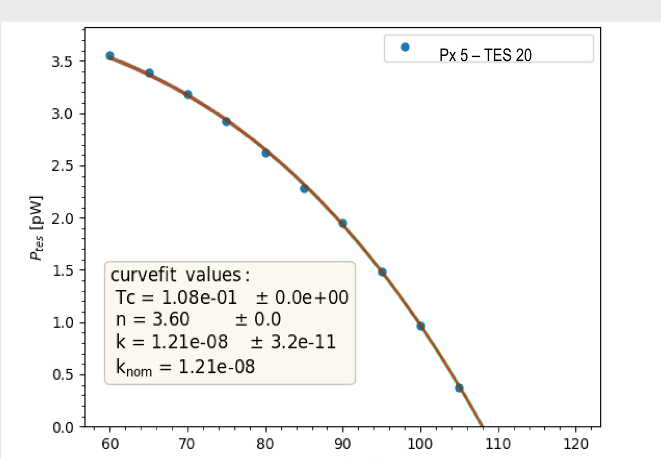


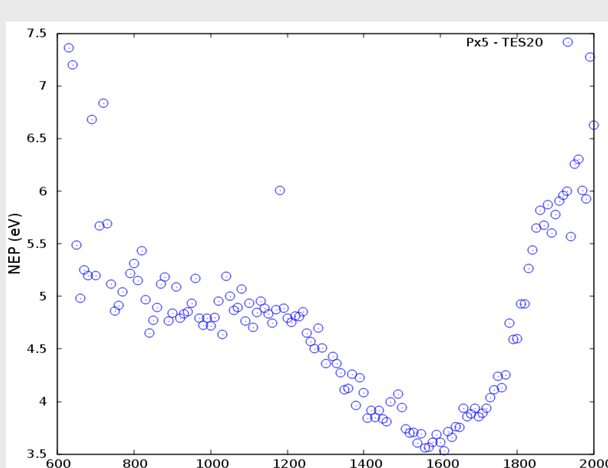
- TES is biased by a carrier signal $B_c \cos \omega_c t$ with $\omega_c = 2\pi f_c$ and f_c between 1-5 MHz.
- TES current is picked up by the SQUID, then amplified and digitized. It can be written as: $A_c \cos(\omega_c t + \theta)$.
- It is demodulated using the original carrier, resulting in I and Q proportional to $\cos\theta$ and $\sin\theta$, respectively.
- The carrier can be phase shifted (carrier rotation) before it is used for demodulation to change θ. Typical we set $\theta = 0$ when TES is in normal state and purely resistive to have the entire demodulated signal in I while Q is almost zero. When TES is in the transition, θ varies as a function of the bias point, which shows is a signature of the weak-link phenomena.
- FDM readout is in a closed-loop and a Base-Band Feed-Back (BBFB) scheme, where the I and Q signals are re-modulated and combined to provide a feed-back to the SQUID to enhance the dynamic range and the linearity.

AC measurements description

- IVs were measured at different bath temperature
- Power levels are taken at minimum of the IV curves
- $Z(\boldsymbol{\omega})$ from 5 Hz up to 10 kHz
- NEP scan through the transition to find the predicted energy resolution

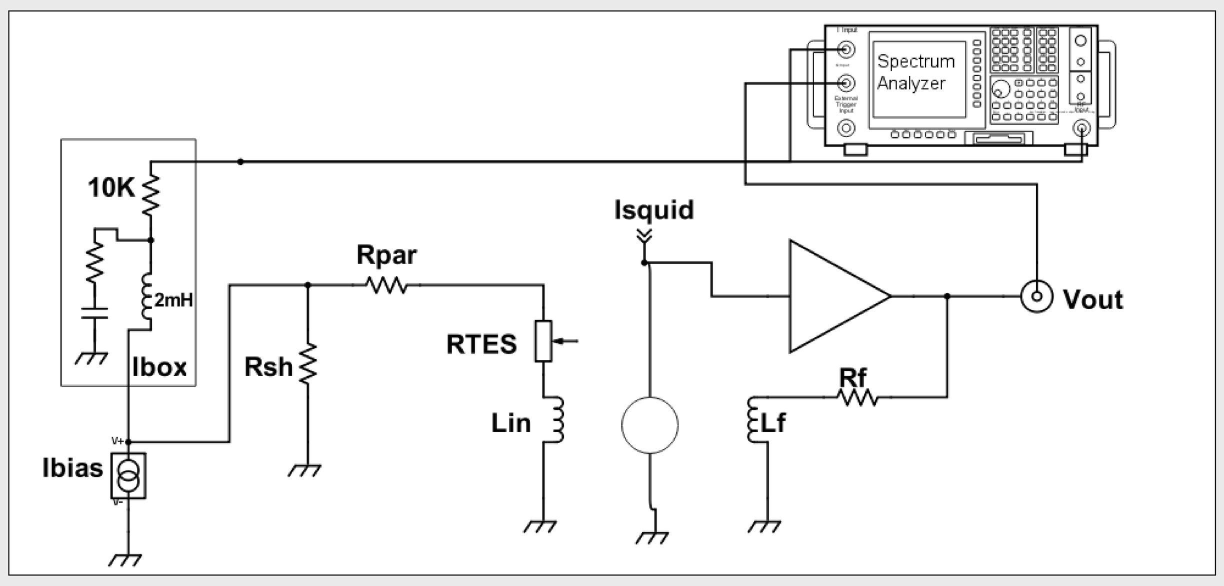






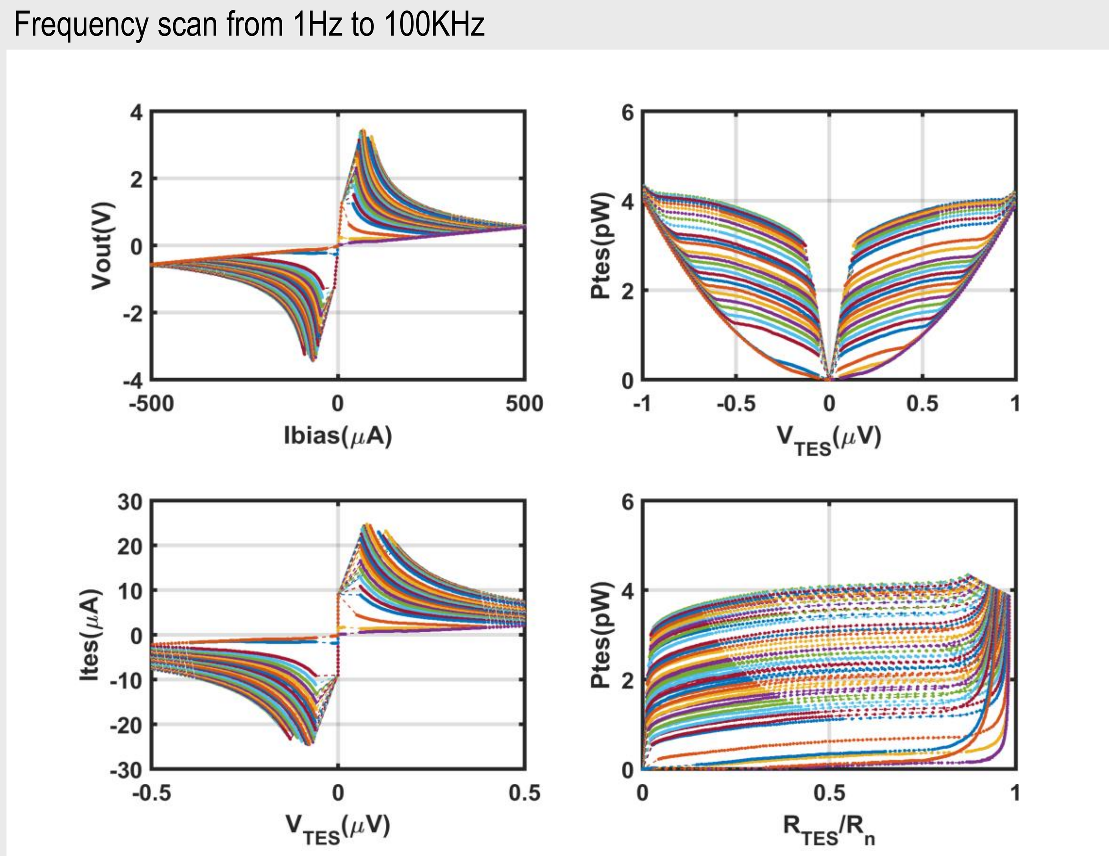
DC characterization set-up at ICMA

- Oxford Kelvinox dilution refrigerator, 30 mK base Temperature
- μ-metal shield
- Field compensating coil
- 2-stage PTB SQUID read-out
- 2mΩ R_{shunt}



DC measurements description

- I-V scans with magnicon DC current source
- $Z(\boldsymbol{\omega})$ and noise measured with HP3562A spectrum analyzer
- Frequency scan from 1Hz to 100KHz



Monte Carlo Markov Chain (MCMC)

Calibration formula to get real TES impedance

$$Z_{TES} = R_N \frac{Z_m - Z_m^{SC}}{Z_m^N - Z_m^{SC}}$$

For MCMC we define:

1. Likehood function: One-body model

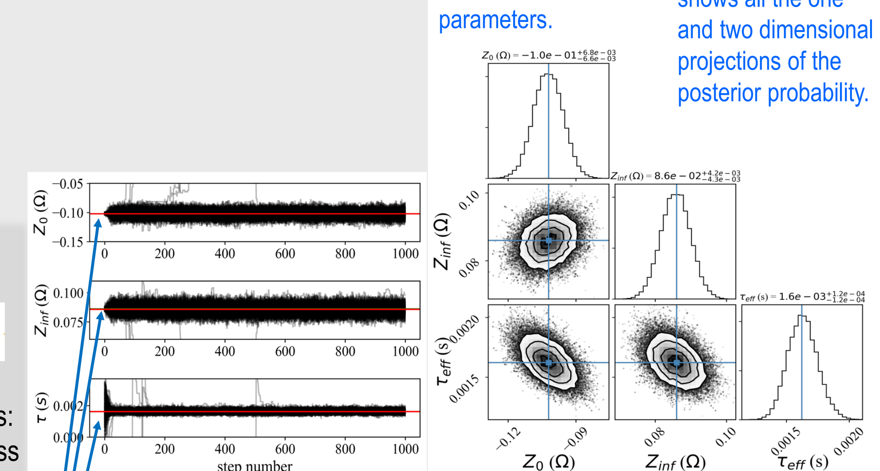
$$Z_{\mathrm{TES}} = Z_\infty + (Z_\infty - Z_0)\frac{1}{-1 + i\omega\tau_{\mathrm{eff}}}$$

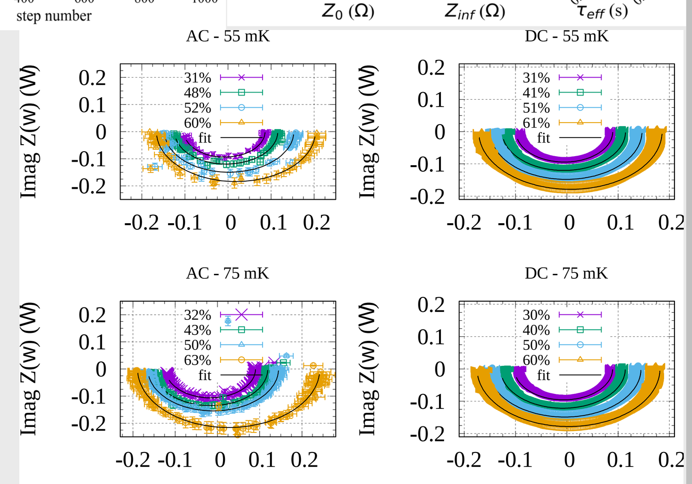
2. Prior probability for the fit parameters: Normal distribution is the educated guess
3. Posterior probability: Conjunction of the previous ones

We initialize the walkers (more than twice of the dimension of the parameters space) in a tiny Gaussian ball around the maximum likelihood result (got starting first with the usual least-squared fit).
Then run the MCMC for 2000 steps starting from the tiny ball defined above.

This can quickly demonstrate all of the covariances between parameters.

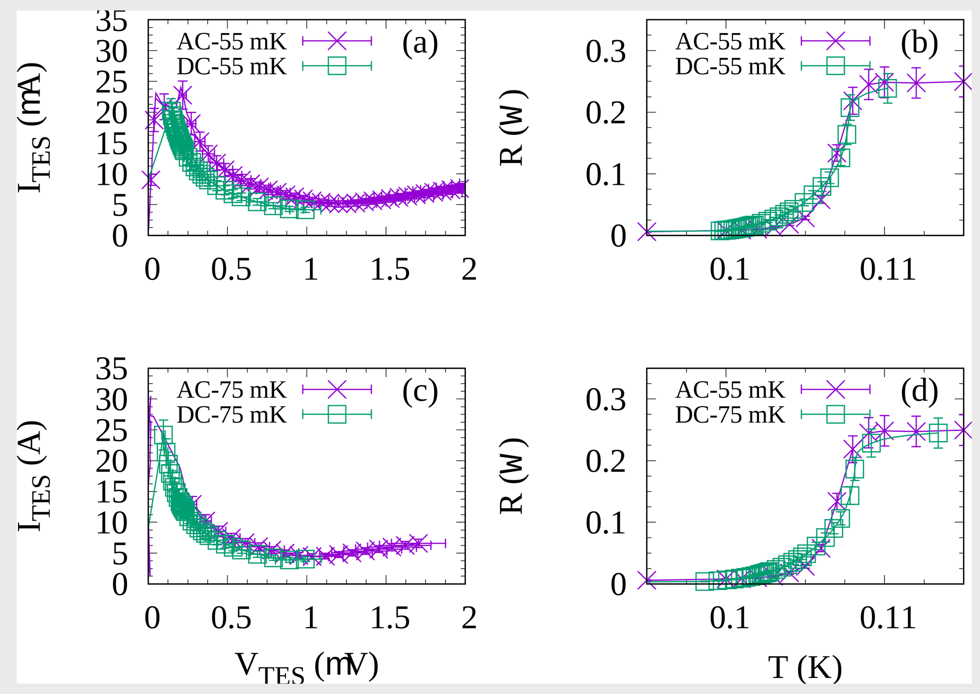
The corner plot shows all the one and two dimensional projections of the posterior probability.





Comparison of Measurements

- Comparison of IV measurements under AC and DC show good agreement
- Slight offset maybe due to non optimal field cancellation in DC

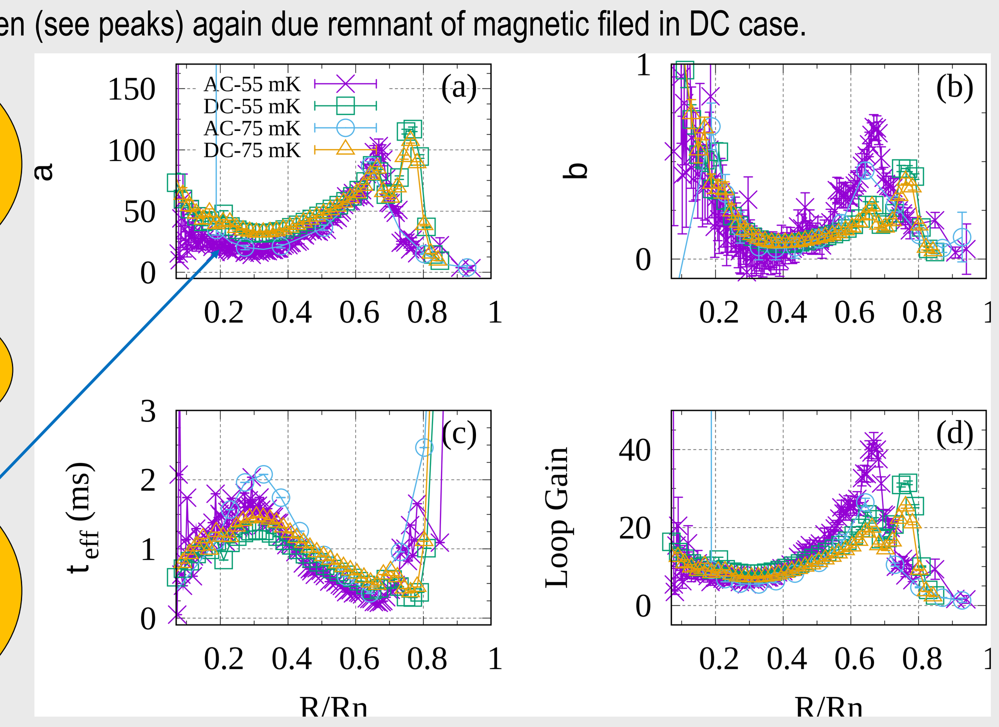


- Dynamical parameters show same qualitative behavior.
- Difference are more visible lower in transition.
- Lower values and smother curve in AC case
- Slight offset between (see peaks) again due remnant of magnetic filed in DC case.

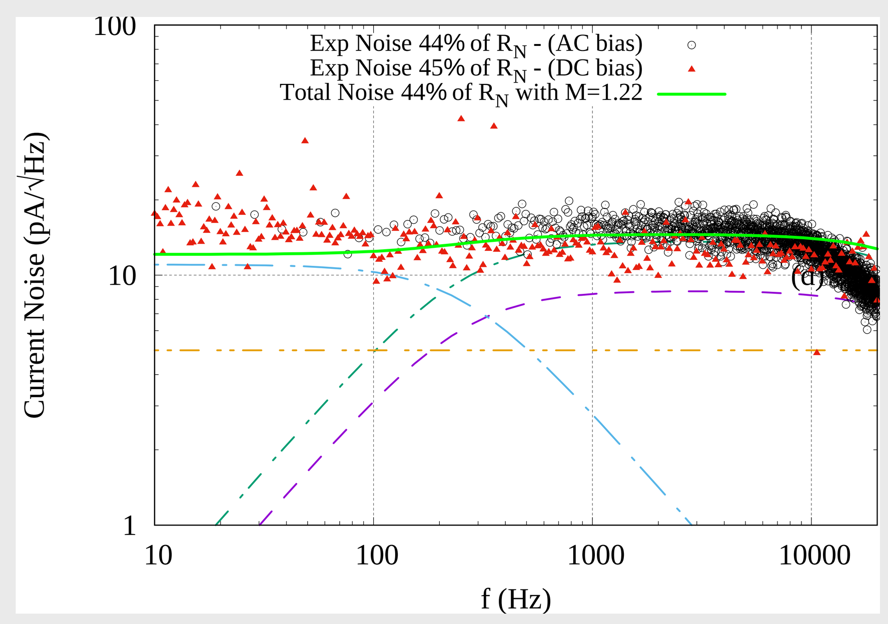
in AC case α and β are lower and appear smoothed out, especially in presence of peaks

Differences begin at working point lower in the transition

Difference on predicted X-ray ΔE between AC and DC goes from 10% down to 44% where the diverging begins



- Noise spectra show also similar values.
- Slight indication of higher Johnson excess in AC to be investigated.



CONCLUSIONS

- Preliminary results on Ti/Au TES characterization under AC and DC by using two different set-ups show coherent results.
- IV curves and dynamical parameters from $Z(\boldsymbol{\omega})$ fits show similar values with smoother behavior and lower value of α and β in AC. This lead to higher predicted X-ray resolution specially at low %Rn.
- Noise levels look similar , but slight indication of higher Johnson excess under AC to be investigated.

What is next?

- More refined measurements needed with proper field cancellation.
- Future comparison on the new SRON 5x5 mixed TES array with different high-aspect ratios to investigate the effect of AC losses and interaction with the voltage bias.
- Including of X-ray spectra in future comparisons thanks to new Fe55 source in the DC set-up.

Acknowledgement

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