Properties of the SQUID readout chain under development for the ATHENA X-IFU instrument

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abstract

Superconducting Quantum Interference Devices (SQUIDs) are used as the standard first-stage amplifier for the readout of cryogenic TES-based detector arrays, and multiplexing techniques are used to minimise the heat loads and complexity of TES readout systems.

Frequency domain multiplexing is the baseline for the readout of an imaging array of TES-based microcalorimeters the X-IFU instrument on the future ESA Athena X-ray telescope. SQUID properties such as flux noise and bandwidth are crucial for the performance of the readout system for the X-IFU.

In this paper we present the measured properties of the two-stage SQUID system which has been developed for the readout of the X-IFU detector array. One of the crucial results is the observation of a flux noise level of 0.2 $\mu\Phi_0/\sqrt{Hz}$ over a flux range of approximately 0.3 Φ_0. Besides that, properties such as the dynamic resistance, and power dissipation will be discussed, as well as the direction for further optimisation.

Baseline design requirements

- Minimized power dissipation (<1.3nW/channel@base temperature)
- Maximized dynamic range density (>1e6$\sqrt{Hz}$)
- Sufficient bandwidth for FDM (> 5MHz)
- Sufficient power gain to exceed LNA noise power (T_N ~ 75K)

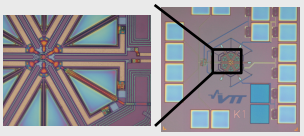
Resulting design

- 2 SQUID stages
- Gradiometric to minimize sensitivity to magnetic environment
- 1st stage at base temperature, 2nd stage at 2K
- Critical current density driven by bandwidth (>500A/cm^2, set by backaction noise corner).
- Power dissipation 1st stage driven by interstage cable length (~15cm).
- 2nd stage dimensioned to drive the cable and LNA

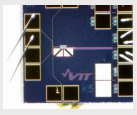
1st stage SQUID designs

2 design approaches:

- single multi-loop SQUID (K1)
  Defluxing not needed
  Junction diameter: 1.8um

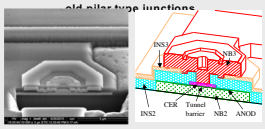


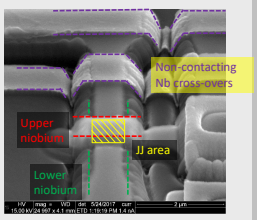
- 2-array SQUID (K5)
  Classical design based on heritage
  Junction dia-
  meter: 2.0um



Future steps

- Increase J_c to 1.5kA/cm^2 -> dynamic range margin
- Shrink junction size to 0.6X0.6um^2 -> size control
- Add extra damping structures to damp out-of-band resonances

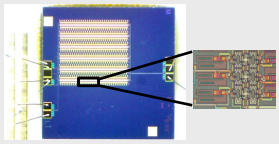


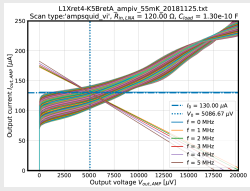


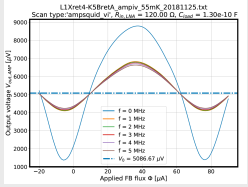
New crossed line junctions -> improved size control

L1X 2nd stage

- (128 cells in series) x (3 in parallel)
- Junction diameter: 2.5um
- Differential output
- L_{in}=70nH
- P=750nW

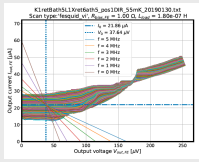


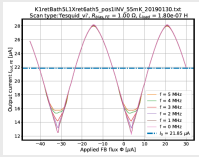


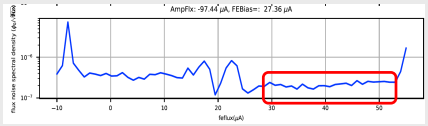


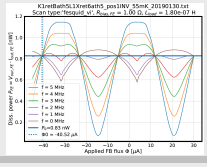
K1retJ-multiloop flux noise vs flux bias point

- 7 resonators @ input
- Flux noise @ 1MHz: 0.2 – 0.3 uPhi0/rtHz
- Bias power: 0.8 nW
- Underdamped resonances observed



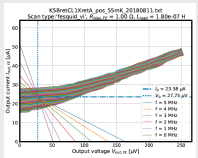


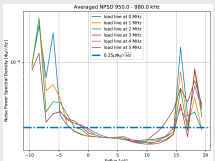


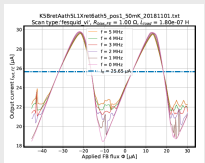


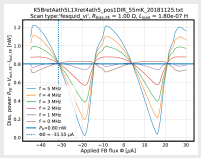
K5BretA – 2-array flux noise vs flux bias point

Flux noise @ 0.95 MHz < 0.25uPhi0/rtHz over 0.4 Phi0
Bias power: ~0.8 nW
LC resonators as input load









Conclusions

- Dynamic range, operating power, and flux noise within the X-IFU requirements
- Observed flux noise 0.2 – 0.3uPhi0/rtHz @ 0.8nW
- Resonances observed outside operating region
- Improved control on junction size desirable to improve yield, therefore crossed line junctions under development as next step.
- Extra damping structures will be added to further damp the spurious resonances.