Performance of a Low-parasitic Frequency Domain Multiplexing Readout

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Introduction

Frequency-domain multiplexing is a readout technique for transition-edge sensor bolometer arrays used on telescopes including SPT-3G, POLARBEAR-2, and LiteBIRD. Here we present design details and performance measurements for a **low-parasitic frequency-domain multiplexing readout. In this 'modified frequency multiplexing' (mfMux) readout**, low parasitic impedance reduces crosstalk between readout channels, which allows **higher multiplexing factors**, and enables operation of lower-resistance bolometers, which d**ecreases the contribution of readout noise** by decreasing the required voltage bias. Ongoing work seeks to further reduce parasitic impedances, leading to a laboratory demonstration of a readout with low-resistance bolometers.

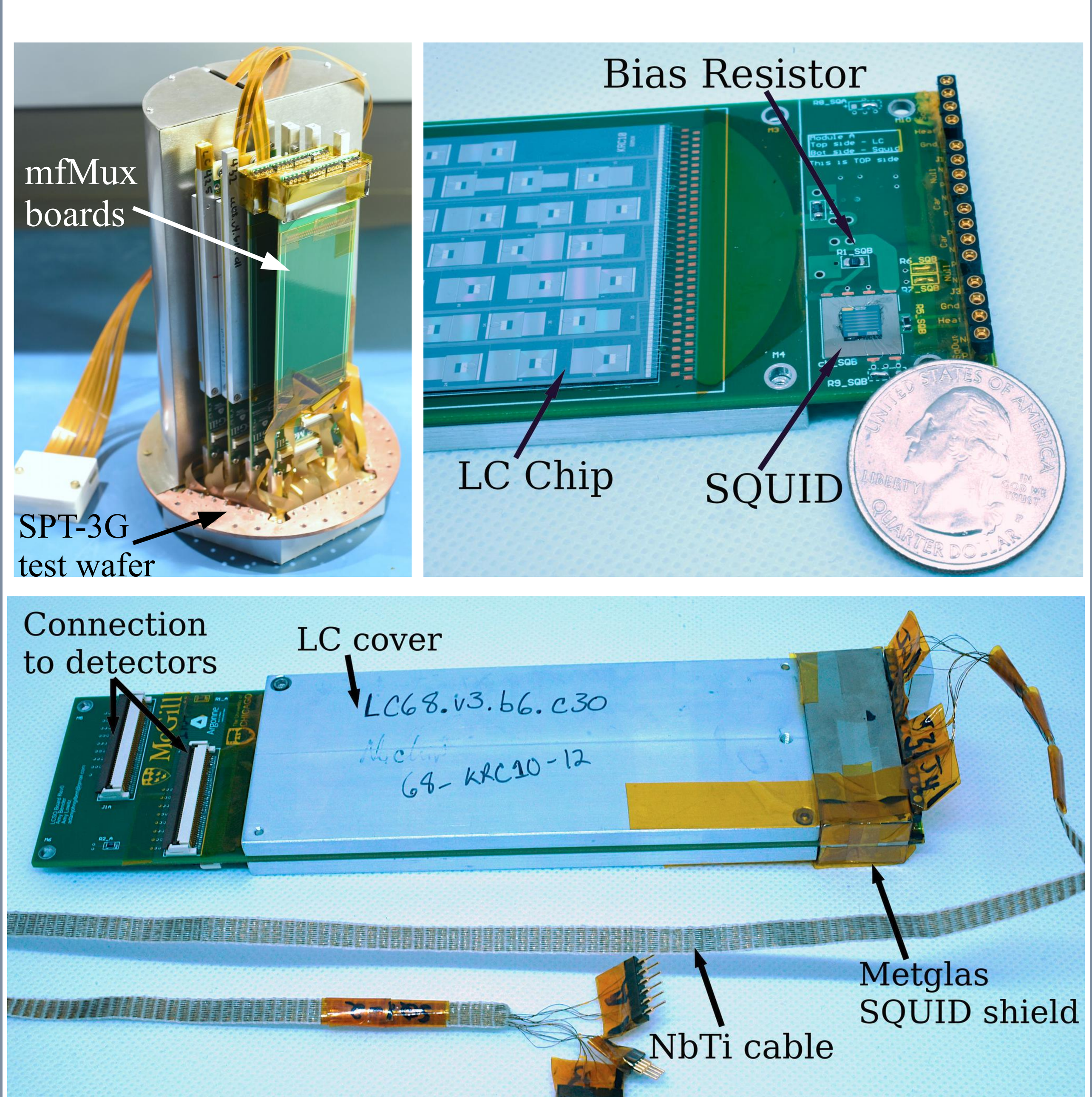
Design and Implementation

- Moving the SQUID from the 4K stage to the 250 mK stage
- This reduces the wiring length between the SQUID and LC chip
  - Reduced parasitic impedance
    - Reduces crosstalk
    - Enables operation of low-resistance bolometers
  - Improves scalability

- Retained as much of the existing dfMux design as possible.
  - This reaps the benefits of **reduced crosstalk, reduced parasitic resistance, and improved scalability, while retaining as much technological maturity as possible.**

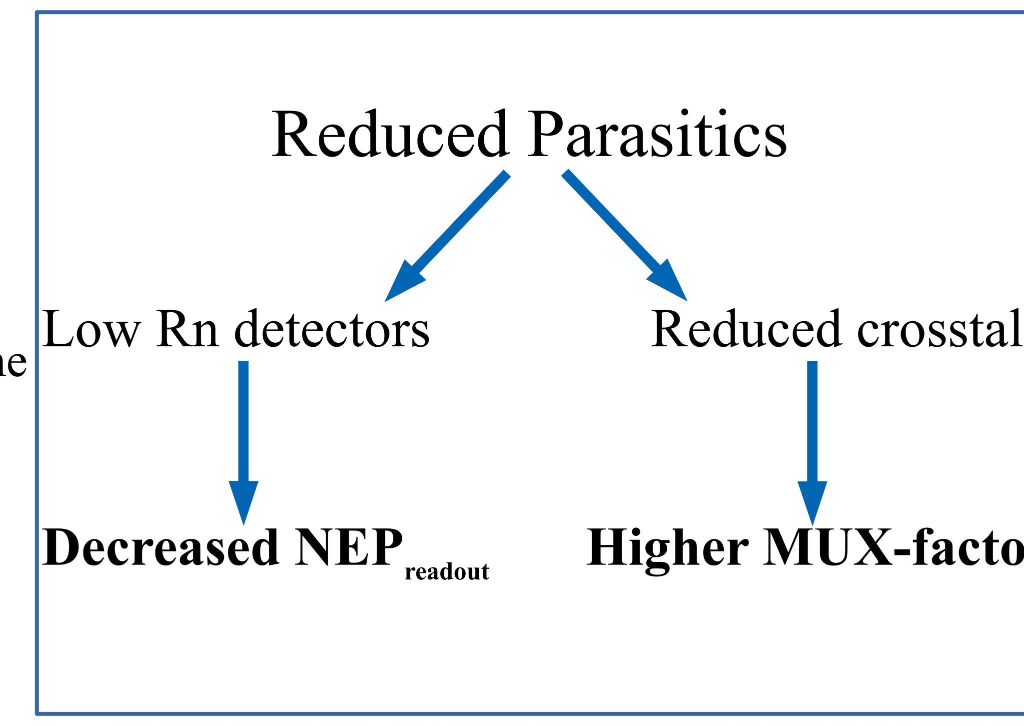
- **Magnetic shielding** for the SQUID is provided by an aluminum shield covered with six layers of Metglas. Additional pinning of any remaining stray magnetic fields is provided by a small Nb foil onto which the SQUID is glued.

- The prototype boards are sized so they can be a **drop-in replacement** for SPT-3G-style LC boards in any of the SPT-3G testbeds or, in principle, the telescope itself.

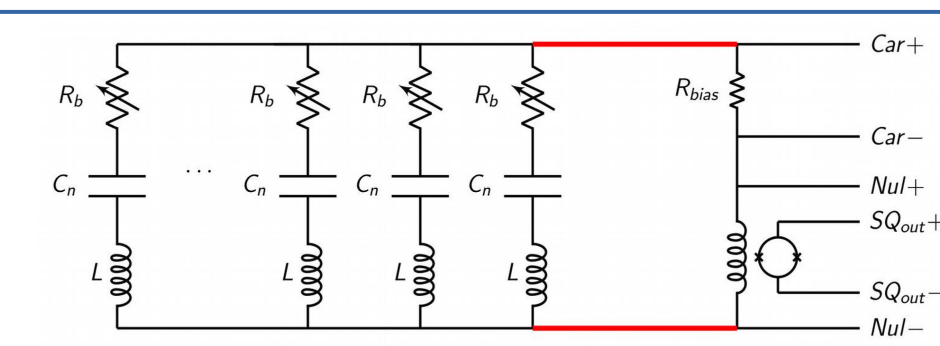


Key benefits

Reducing the stray impedance between the LC chip and the SQUID offers several benefits:



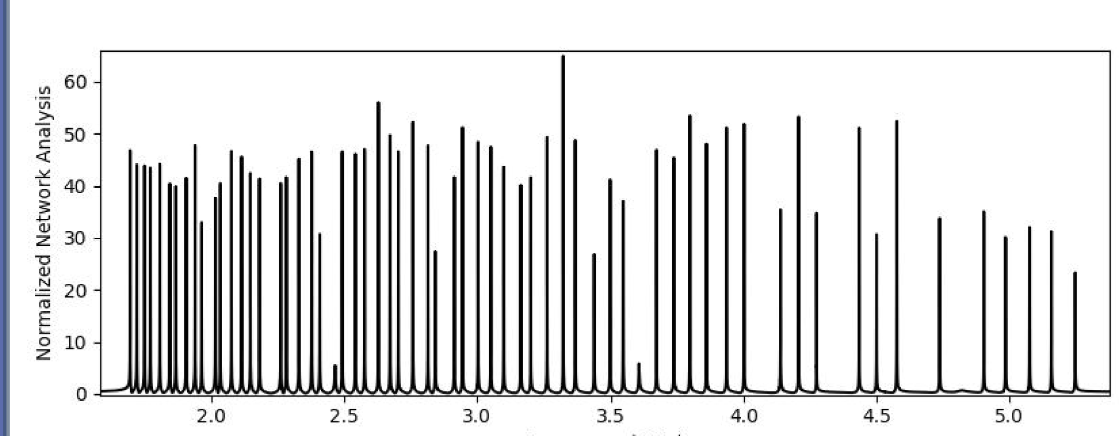
- Decreased stray resistance enables **operation of low-R_{normal} bolometers**.
  - This **reduces $NEP_{readout}$** because the bolometers can be operated with lower V_{bias}.
- Reduced crosstalk enables denser packing of bolometers in frequency space
  - **This allows for higher multiplexing factors and improved scalability.**
- Leverages much of the existing dfMux architecture, which has proven on-sky performance
- Drop-in replacement for 3G-style LC boards

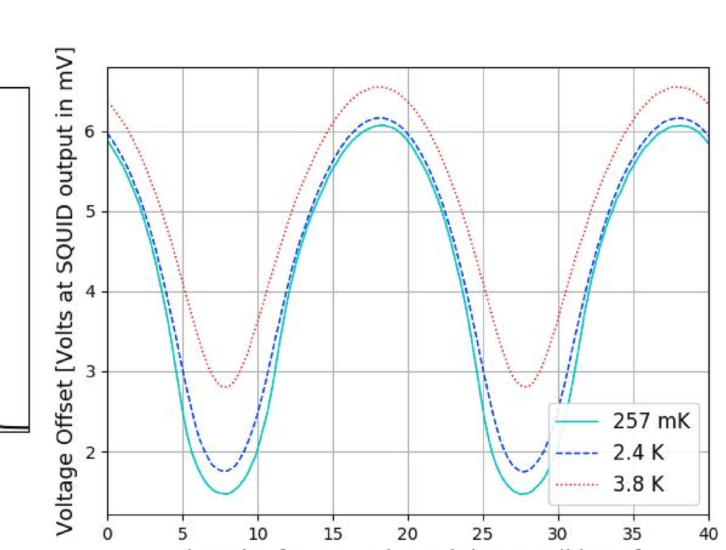


Schematic of the dfMux readout. The wires highlighted in red run between the LC resonators and the SQUID. Stray impedance in these wires create a voltage divider effect which is the dominant source of crosstalk in the existing dfMux system.

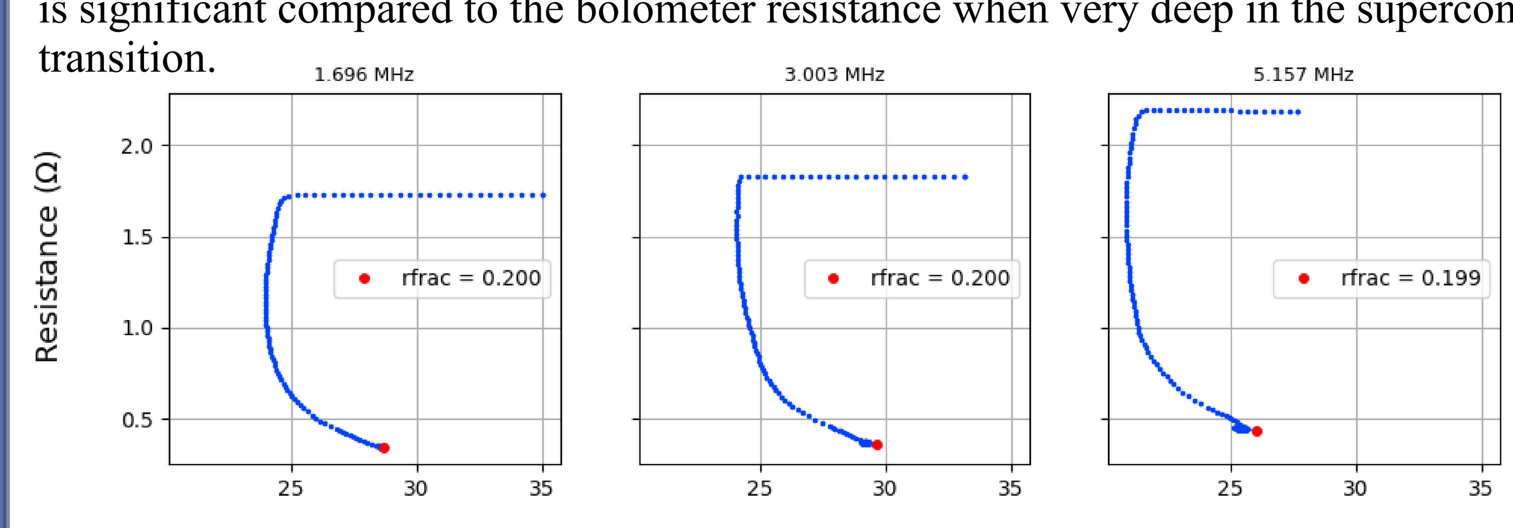
Performance

(Below Left) Shown is a network analysis for one mfMux test comb.
(Below Right) Performance of the NIST SA-13 SQUIDs is similar at 3.8 K, 2.4 K and 257 mK, with small improvements in peak-to-peak voltage and transimpedance at lower temperatures. Shown is a v-phi curve for a representative SQUID at three temperatures.

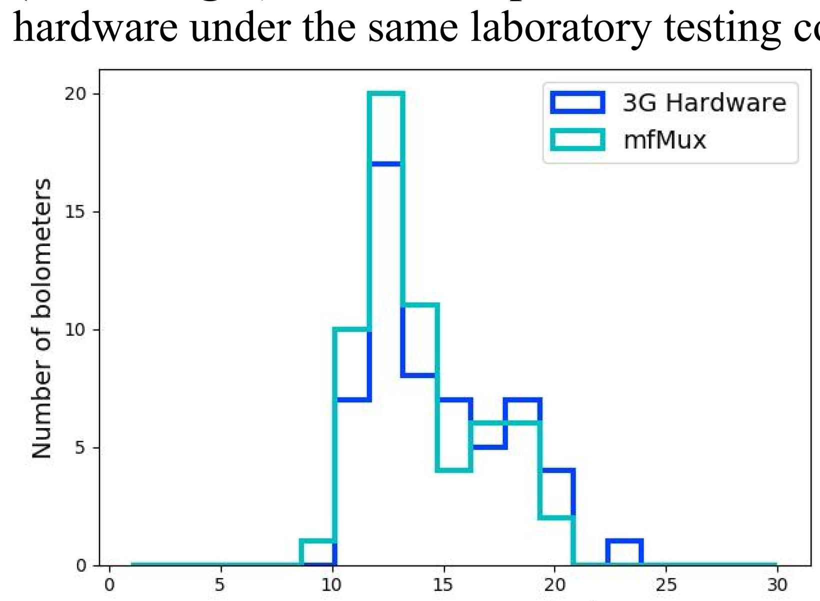


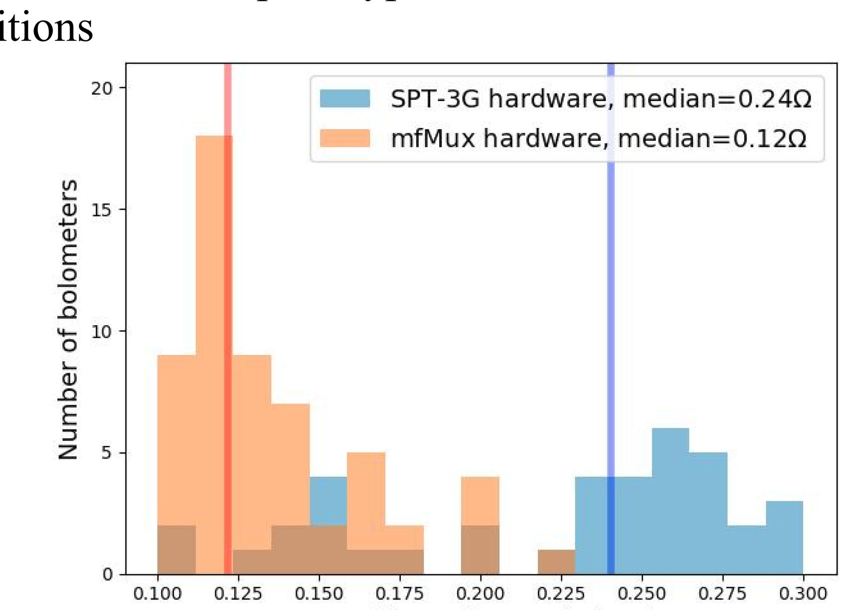


(Below) We have **operated 57 (of a possible 58) bolometers** on a single comb simultaneously in the TES superconducting transition to a fractional resistance of $0.2xR_{normal}$. Shown are RP curves for three representative bolometers. The 'bendback' feature results from the parasitic resistance, which is significant compared to the bolometer resistance when very deep in the superconducting transition.



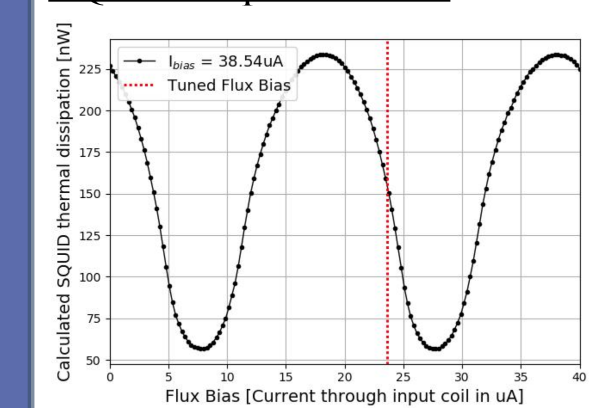
(Below Left) The warm overbiased **noise performance** of the mfMux system is comparable to the performance of the standard SPT-3G dfMux hardware in the same laboratory testbed (shown) and on-sky.
(Below Right) The median **parasitic resistance** of the mfMux prototype is half that of 3G dfMux hardware under the same laboratory testing conditions





Next Steps

SQUID improvements:



NIST SA-13 SQUIDs work well for testing small numbers of prototype mfMux boards, however because of their **thermal dissipation**, putting hundreds of them (as required for ultra-large focal planes) on a cold stage cooled with a typical sorption refrigerator would not work. Either a lower thermal dissipation SQUID or a higher cooling power refrigerator (such as a dilution refrigerator) would be required. We hope to test new, low-thermal-dissipation SQUIDs in the future. **Shown above** is the estimated thermal dissipation from a typical SA-13 SQUID, calculated as the output voltage x the current bias.

Noise and Crosstalk Characterization

While noise and parasitic performance has been promising so far, more detailed study is required to further mature this technology. This will be a key focus of work in the immediate future

Low-resistance bolometer integration

One of the key goals of this technology is to enable operation of **low-resistance bolometers** with a frequency multiplexed readout. We have already shown a significant reduction in parasitic resistance, which is a major step towards that goal. Our next step will be to test the mfMux hardware with a 'detector wafer' where the detectors have been replaced with resistors at a range of resistances. This test wafer has already been fabricated, and will be used for mfMux testing in the immediate future.

Selected References

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