SQUID Multiplexer Update

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TES III
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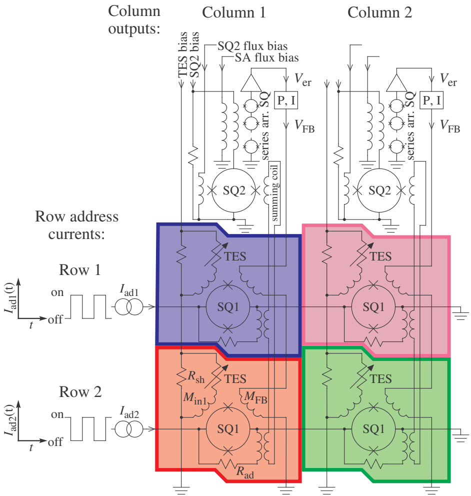
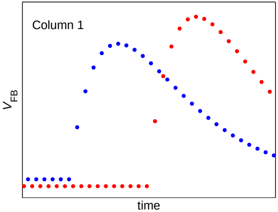
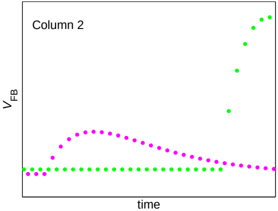
Outline

- Time Domain Multiplexers
    - TDM overview and scaling
    - 4 × 32 test setup - 256 pixels arrays
    - SCUBA wafermux (40 × 32) results
    - Next-generation TDM
- Microwave Reflectometry for Multiplexing
    - Overview
    - High-Q resonators
- Conclusions

SQUID Time Domain MUX Overview







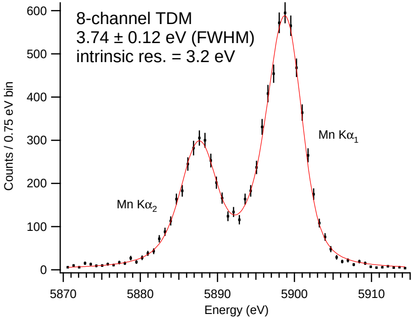
MUX performance constraints

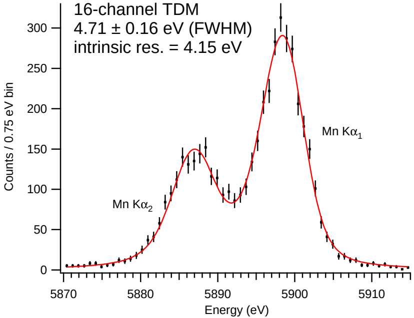
Some constraints from the TES, the SQUIDS, and the system

- System timing: $t_{\text{frame}} = N_{\text{mux}}(t_{\text{settling}} + t_{\text{readout}})$
- Closed loop bandwidth: $f_{\text{closed loop}} = \dfrac{1}{2t_{\text{frame}}}$
- Switching transients : $t_{\text{settling}} \geq \dfrac{1}{f_{\text{open loop BW}}} \quad \Longrightarrow \quad f_{\text{closed loop BW}} = \dfrac{f_{\text{open loop BW}}}{N_{\text{mux}}}$
- Aliasing of Amplifier Noise : $I_{\text{N(tes)}} = \dfrac{\Phi_{\text{N}}\sqrt{\pi N_{\text{mux}}}}{M_{\text{in}}}$
- SQUID Nonlinearity: $\Delta\Phi_{\text{max}} = \dfrac{I_0 N_{\text{mux}} M_{\text{in}}}{\tau_{\pm} \;\; f_{\text{open loop BW}}}$

Apply these constraints to engineer multiplexing solution for desired N_{mux} with allowable degradation

Some muxing results (LTD-11)





Some practical(?) examples

Detector type	τ_+ τ_-	Detector resolution	MUX'ed resolution	Open-loop bandwidth	N_{mux} per column
8-channel	$46 \pm 114\iota\ \mu$s	3.20 eV	3.74± 0.12 eV	1.5 MHz	8
16-channel	$62 \pm 114\iota\ \mu$s	4.15 eV	4.74± 0.16 eV	1.5 MHz	16

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[1] See Joel Ullom's upcoming talk - resolution is quoted as E/δE

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γ-ray[1]	0.60 / 1.9 ms	4125	4125	2.0 MHz	8
γ-ray	1.2 / 1.9 ms	4125	3700	2.0 MHz	32
32-channel	0.42 / 1.7 ms	2.45 eV	2.57 eV	2.0 MHz	32

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"Next"[2]	1 ms	3.6 eV	4.0 eV	3.5 MHz	196
"Con-X"[2]	300 μs	1.8 eV	2.0 eV	12 MHz	95
"Xeus"[2]	50 μs	4.5 eV	5.0 eV	12 MHz	32

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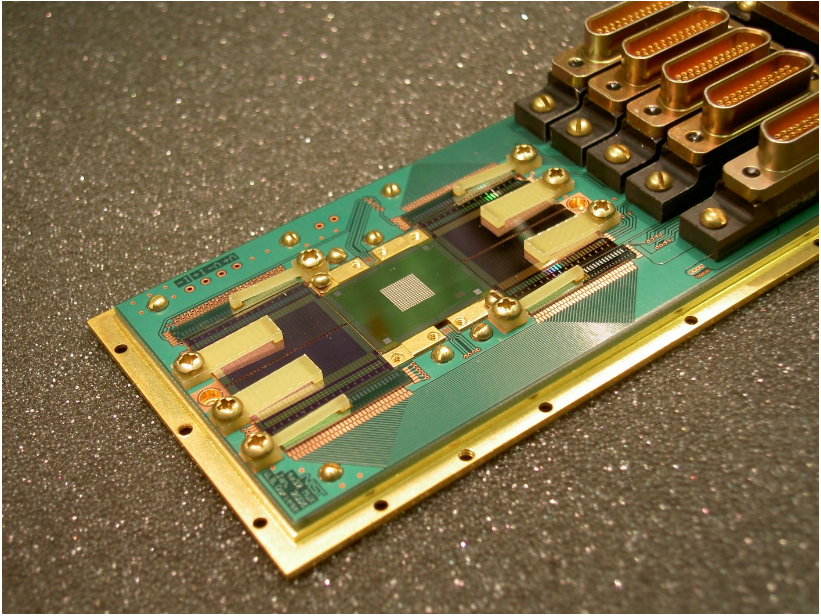
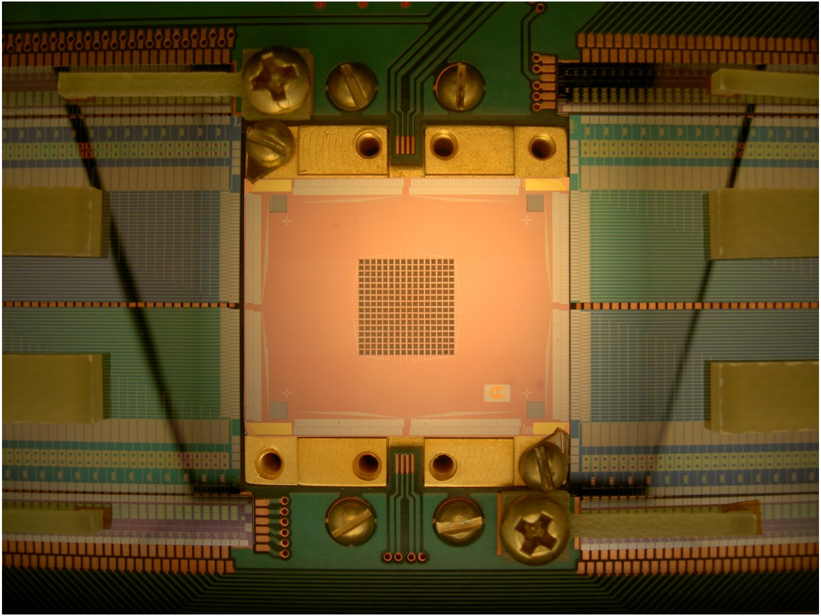
[2] Assumes critical damping

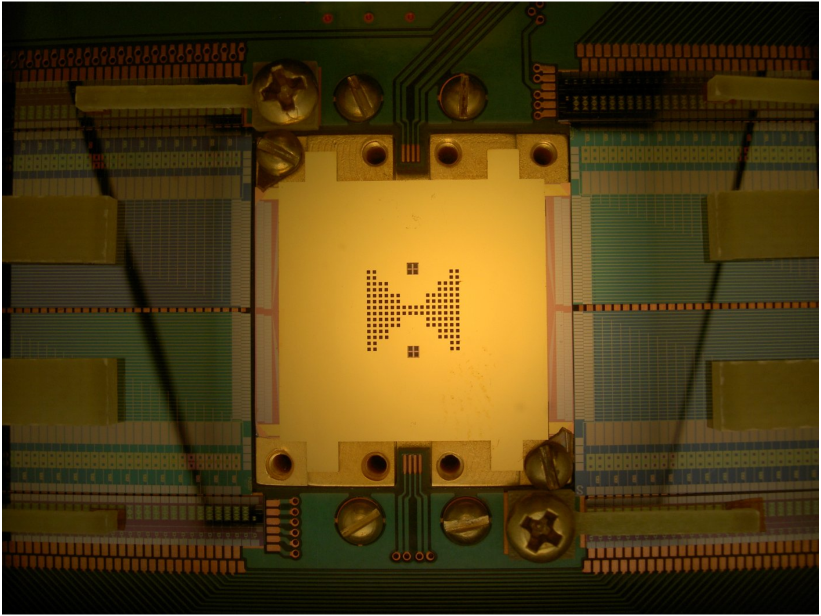
4 × 32 Infrastructure



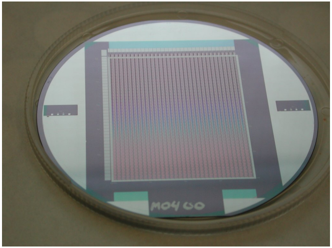
4 × 32 Infrastructure - 256 pixel detector

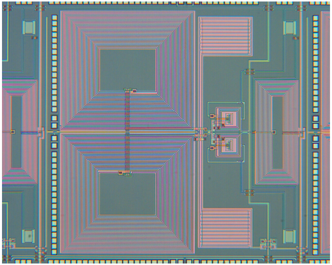


4 × 32 Infrastructure - collimated detector



SCUBA-2 Multiplexers

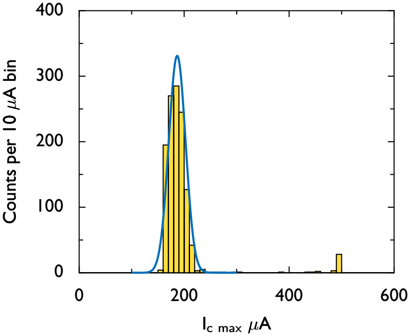




SCUBA-2

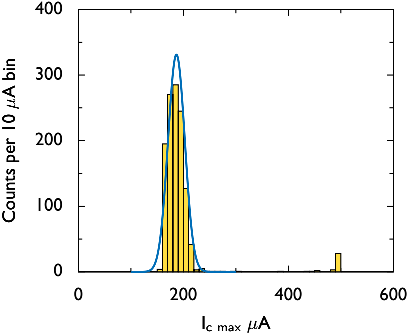
- Wafer-scale processing
- Separate Mux and TES wafers
- Imager assembled with indium bump-bonding
- 40 × 32 pixel sub-mm imager
- Camera consists of 8 imagers (4 at 450 μm 4 at 850 μm)

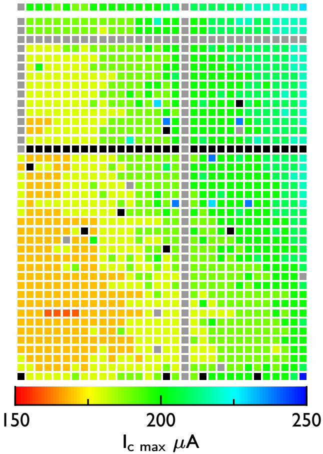
Multiplexer uniformity - wafer “A”



- Strong central peak with outliers
- Mean = 190 μA
- σ = 15.5μA

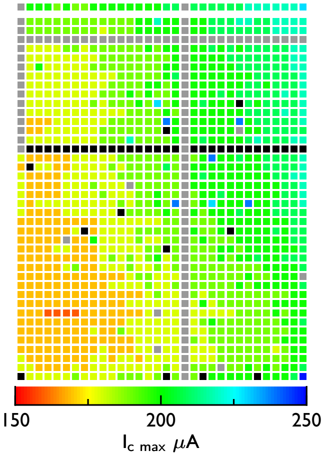
Multiplexer uniformity - wafer "A"



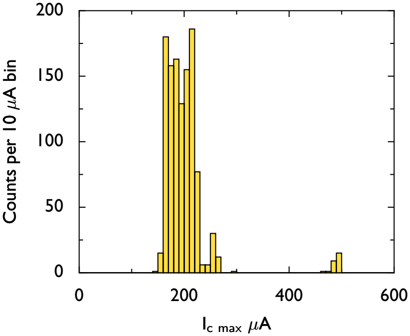


Multiplexer uniformity - wafer “A”

- 1 high I_c row - parasitic short
- 2.5 bad lines
- $\sim$20 bad pixels

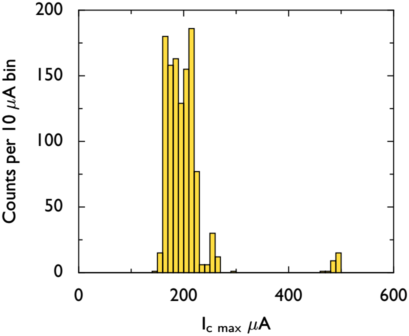


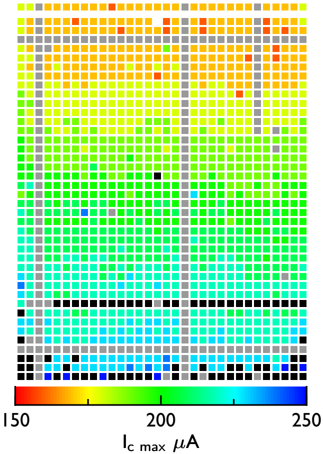
Multiplexer uniformity - wafer “B”



- Much broader - not well distributed
- Can we use this?

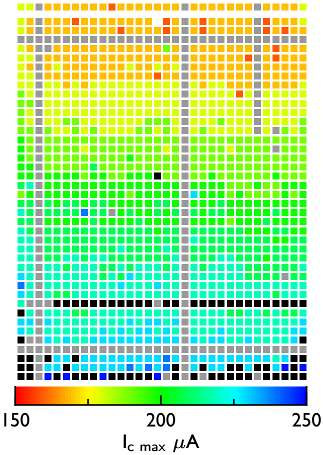
Multiplexer uniformity - wafer “B”





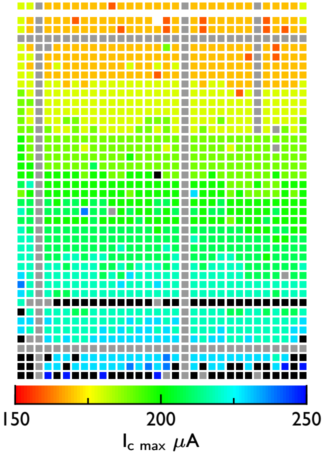
Multiplexer uniformity - wafer “B”

- 1 high I_c row - parasitic short
- 3.5 bad lines
- ∼20 bad pixels



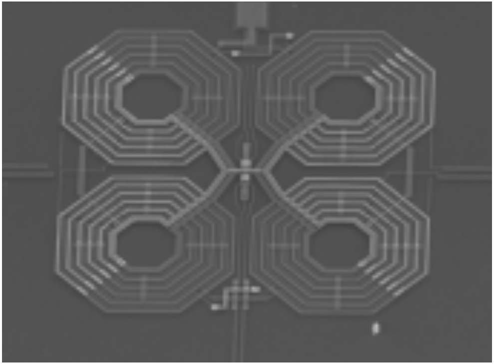
Multiplexer uniformity - wafer "B"

- 1 high I_c row - parasitic short
- 3.5 bad lines
- $\sim$20 bad pixels
- **Strong** gradient across the wafer
- Can compensate by adjusting row-select and second-stage fb values. Algorithm works for a wide variety of low spatial frequency surfaces.



Next Generation TDM Mux

- Second-order gradiometric design (less shielding required)
- Improved resistance to flux trapping



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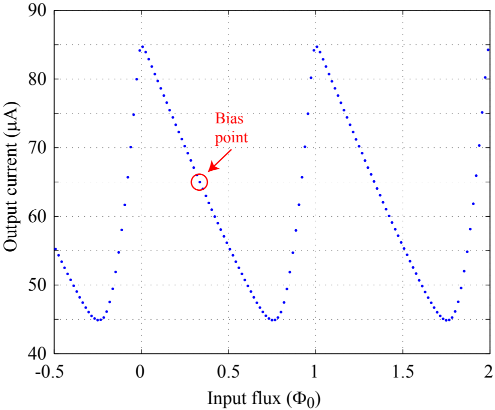
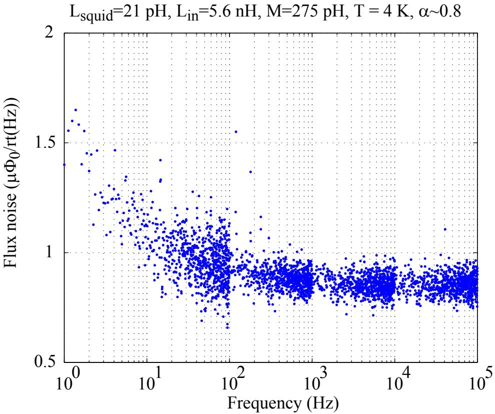
- Improved dynamic range (4× improvement in N_{mux})



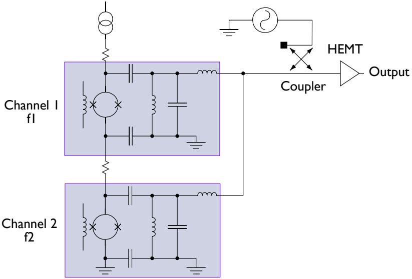
Next Generation TDM Mux

- Second-order gradiometric design (less shielding required)
- Improved resistance to flux trapping
- Improved dynamic range (4× improvement in N_{mux})
- Low noise (∼ 2× improvement at 4K)

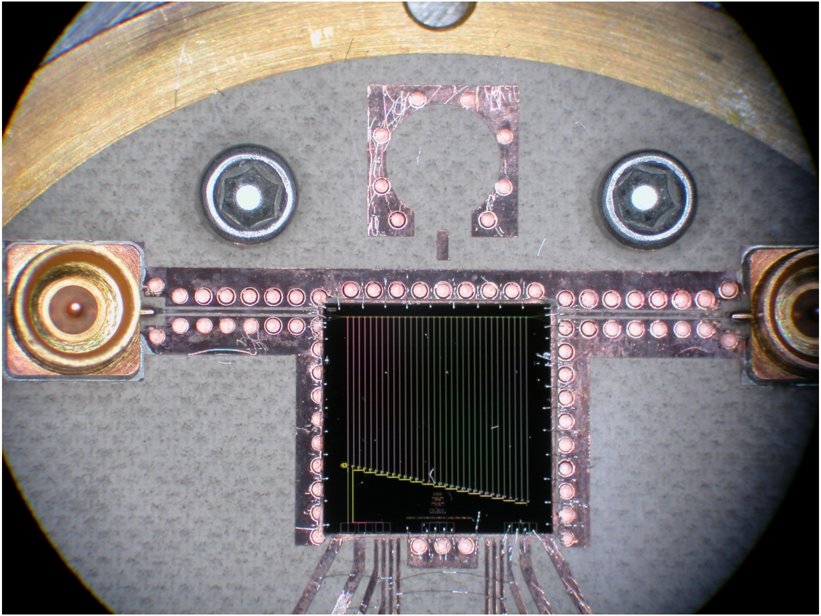


Microwave Multiplexer

- Use microwave reflectometry to implement FDM multiplexer
- Large channel counts possible
- Proof of principle demonstrated using DC SQUIDS (Irwin APL 2004)
- Demonstration experiment for high-*Q* thin film resonators

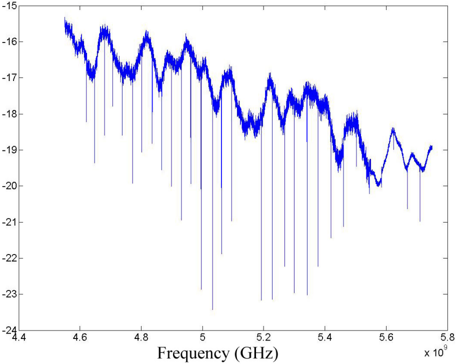


Microwave test resonators



Microwave measurements

- Resonators perform with predicted center frequencies
- Obtain *Q* $\sim$ 100,000
- *Q* limited by loss tangent in ECR SiO_2
- Substrate is UHP (> 17 KΩ-cm undoped) Si



Conclusions

- Time domain multiplexers have been demonstrated to work as predicted with a variety of x-ray and γ-ray detectors
- Soon demonstrate 128 pixels on a 256 pixel detector
- Wafer-scale SCUBA-2 multiplexers show good parameter uniformity
- Next generation multiplexers will improve performance and improve operational simplicity
- Resonant test structures for microwave multiplexers have been demonstrated with $Q \sim 100{,}000$

Outline

1. Outline

2. TDM
   - Mux constraints
   - LTD-11 results
   - Examples
   - 4 x 32 infrastructure
   - SCUBA-2
   - Next generation TDM

3. Microwave mux
   - Resonator chip
   - Resonator results