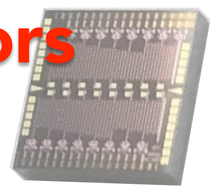
Development of Microwave Multiplexer Readout System Based on SQUIDs Directly Coupled to Resonators for TES X-ray Microcalorimeter

PB-11



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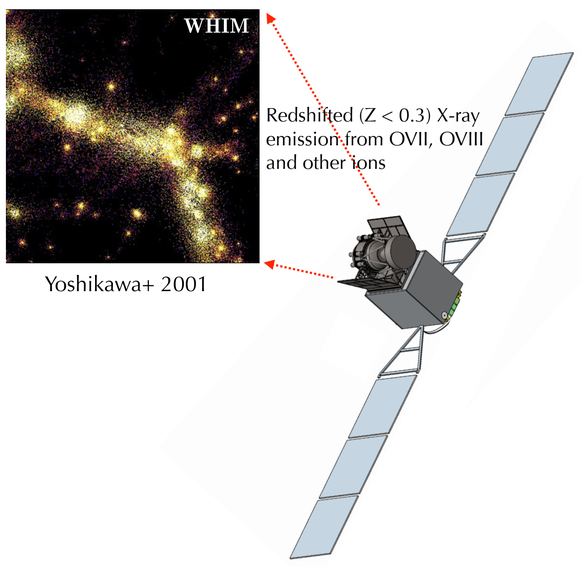
FUTURE X-RAY SATELLITE MISSION



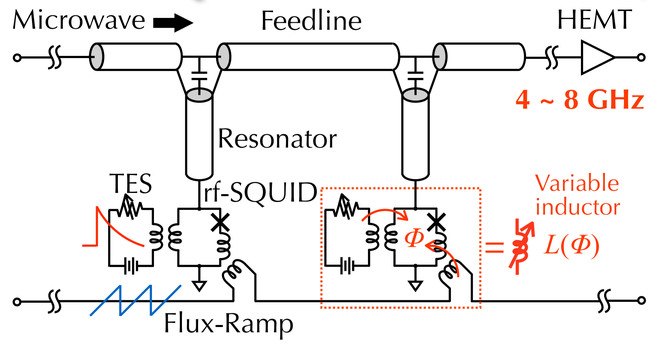
Yoshikawa+ 2001

s-DIOS
(super Diffuse Intergalactic Oxygen Surveyor)

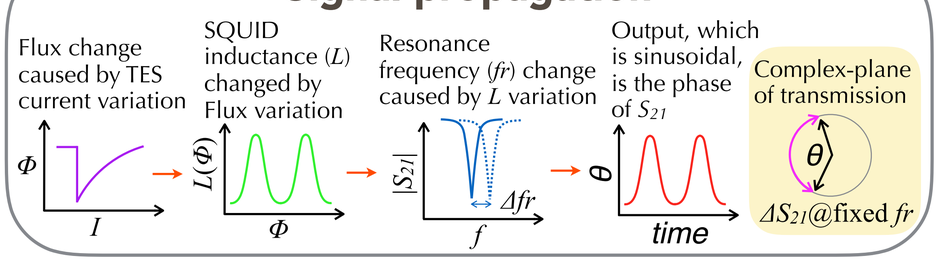
- Missing baryon surveyor
- Warm-Hot Intergalactic Medium (WHIM) is the best candidate of missing baryon
- 3D mapping of WHIM
- Large-FOV and High-resolution X-ray spectroscopy with more than 10^5 pixel TES array

More information, S. Yamada+ in this workshop (PE-58)

MICROWAVE SQUID MULTIPLEXER (MW-Mux)



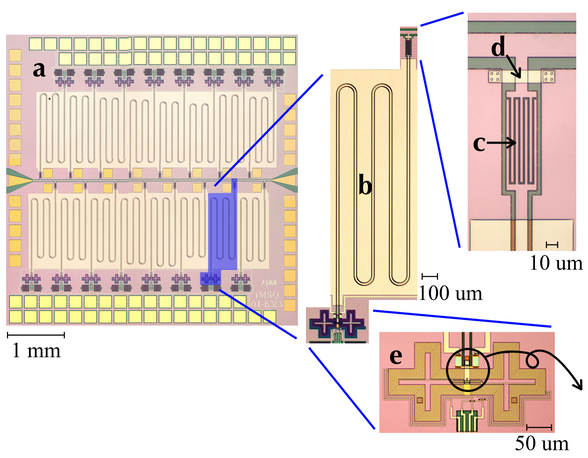
Signal propagation



DESIGN and FABRICATION of MW-Mux

- Designed MW-Mux for TES X-ray signals with a rise time of 5-20 μs
- To avoid suppressing energy resolution due to sampling rate, Sampling more than 480 kS/s is required.
- Bandwidth (BW) > 3MHz needs 480 kS/s sampling under condition of Flux-Ramp Modulation (FRM) with $3\Phi_0$ sawtooth amplitude.
- MW-Mux with 3, 6 MHz BW are designed and fabricated.
- Hysteresis parameter λ ~ 0.2
- Micro-strip SQUID directly coupled to Resonator

Photograph of fabricated MW-Mux by CRAVITY



Resonance frequency
- BW = 3 MHz : 4.93 to 5.53 GHz with 40 MHz spacing
- BW = 6 MHz : 4.69 to 5.89 GHz with 80 MHz spacing

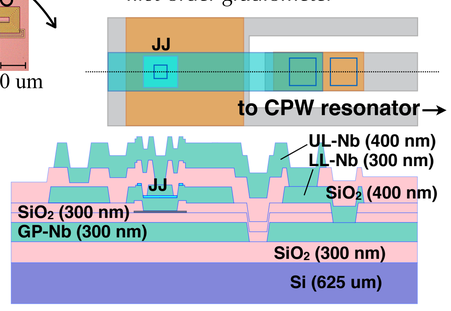
a : Substrate
- 625 μm thick Si with300 nm thermal oxide

b : λ/4 CPW resonators
- 300 nm thick Nb removed SiO_2 on that

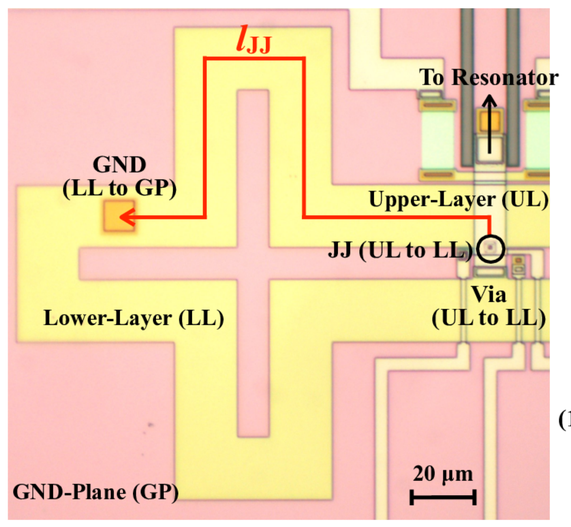
c : Coupling capacitor
- 300 nm thick Nb
- changed finger length for each resonator to make *BW* constant all the channels

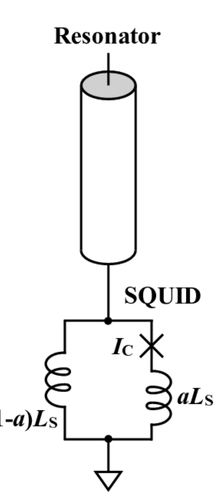
d : Ground bridge
- 400 nm thick Nb

e : rf-SQUID
- 300 nm thick, 20 μm wide Nb stripline
- I_C=10 uA (250 A/cm², 2.0×2.0 um²)
- Input-coil turned 7 times above that
- first-order gradiometer



- Introduced fractional parameter "*a*", which divide SQUID loop inductance, to optimize simply and accurately the SQUID-Resonator coupling



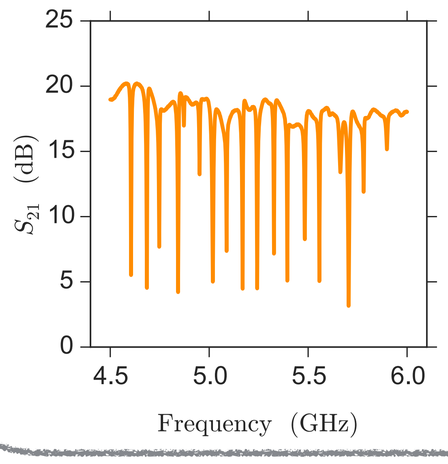


Photograph and equivalent circuit of micro-strip SQUID directly coupled to resonator (Nakashima+ 2017)

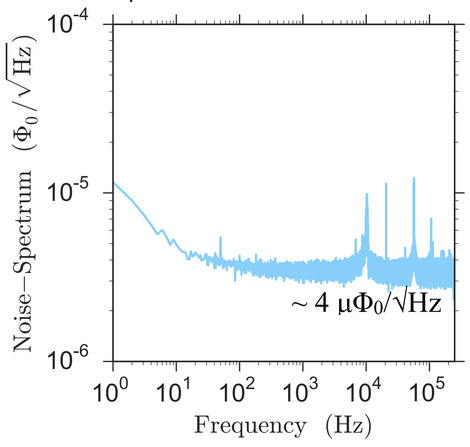
MW-Mux CHARACTERISTICS

- 4 times higher noise floor than that of TES (~ 1 $\mu\Phi_0/\sqrt{\text{Hz}}$)

Resonance of MW-Mux with 6 MHz BW

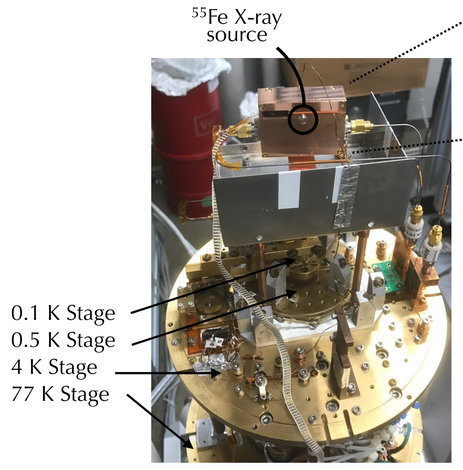


Noise spectrum of MW-Mux with 6 MHz BW



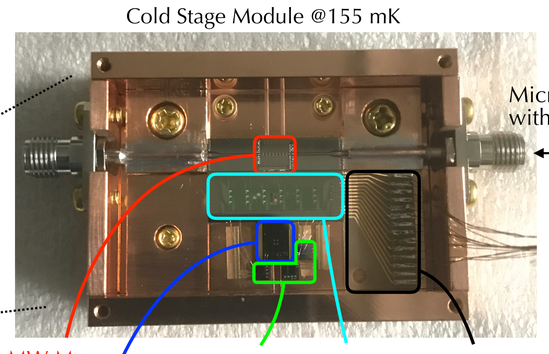
EXPERIMENTAL SET-UP of 2-ch MULTIPLEXING READOUT

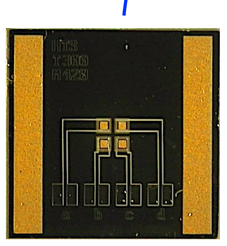
- X-ray irradiation test of 2 TES channel simultaneously
- 480 kHz Flux-Ramp Modulation
- 250 nH inductor is expected to damp TES pulse rise time from 1 μs to about 10 μs.



ADR-Refrige

Cold Stage Module @155 mK

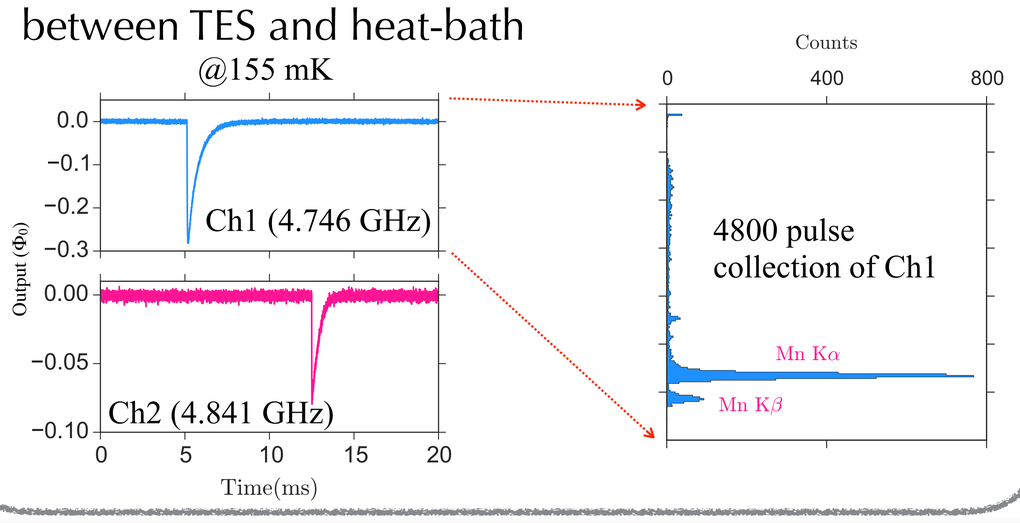




4-pixel TES
- Ti/Au bilayer
- Au absorber
- Non-dampen Rise/Fall time constant ~ 1/80 us respectively
- Noise ~ 30 A/√Hz@10 kHz
- Expected energy resolution ~ 5 eV
- See H. Muramatsu in this workshop on Tuesday (O-25)

PRELIMINARY RESULT of 2-Ch MULTIPLEXING

- Successful pulse detection from 2-ch simultaneously
- Rather degraded Energy resolution because of readout noise, baseline fraction and weak thermal contact between TES and heat-bath



SUMMARY and FUTURE WORKS

- Designed MW-Mux with 3, 6 MHz BW for TES X-ray pulse with 5-20 μs rise time const
- Succeeded in 2-ch simultaneous pulse detection
- Data analysis is underway, but the dominant noise source is caused by SQUID and readout circuit noises
- A new MW-Mux design with an input mutual inductance of 120 pH will suppress SQUID noise to a comparable level with that of TES