Cryogenic Readout

Kam Arnold
University of Wisconsin-Madison

B-modes From Space

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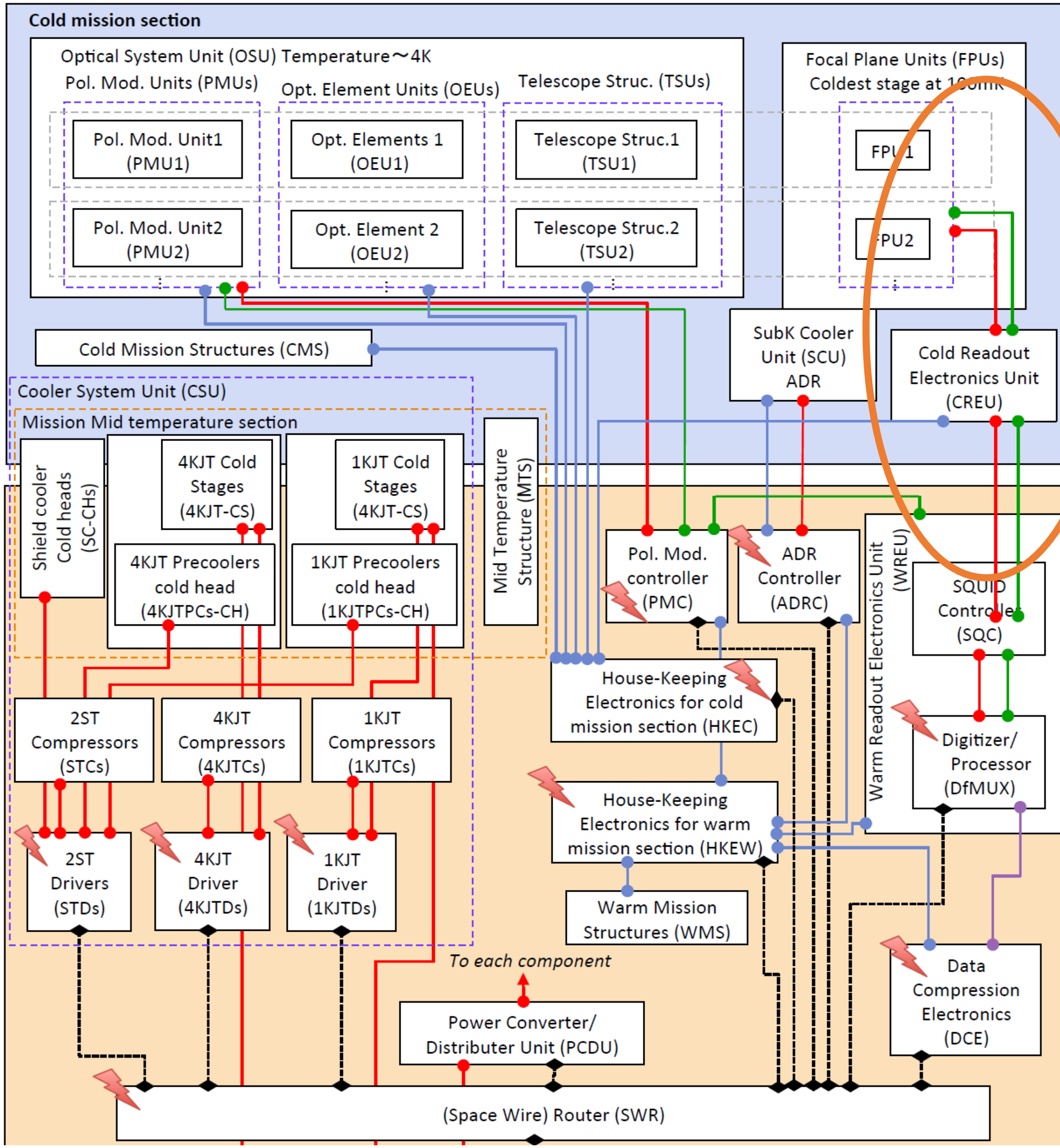
LiteBIRD block diagram ver.3 (in TES option)

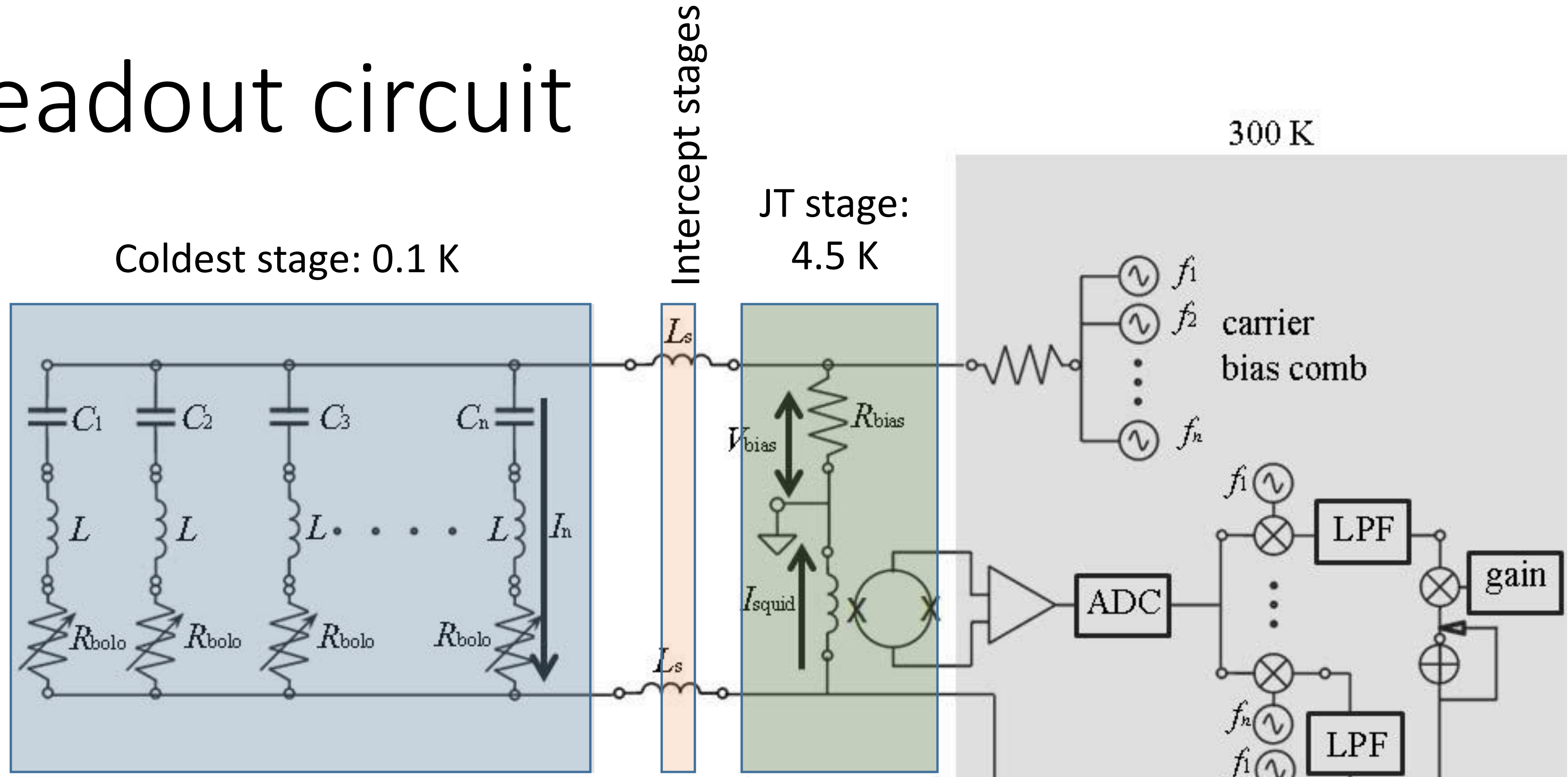
2015-12-1 v1.1e

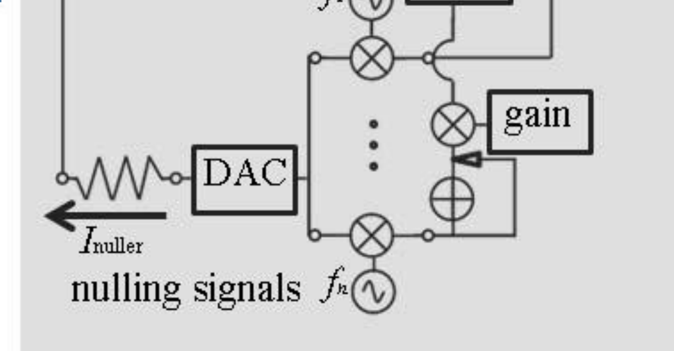


Cryogenic readout: purpose

- Provide low-impedance bolometer bias signals
- Provide first-stage amplification of bolometer signal while introducing negligible noise
- Create negligible thermal load on the sub-Kelvin cryogenic stages

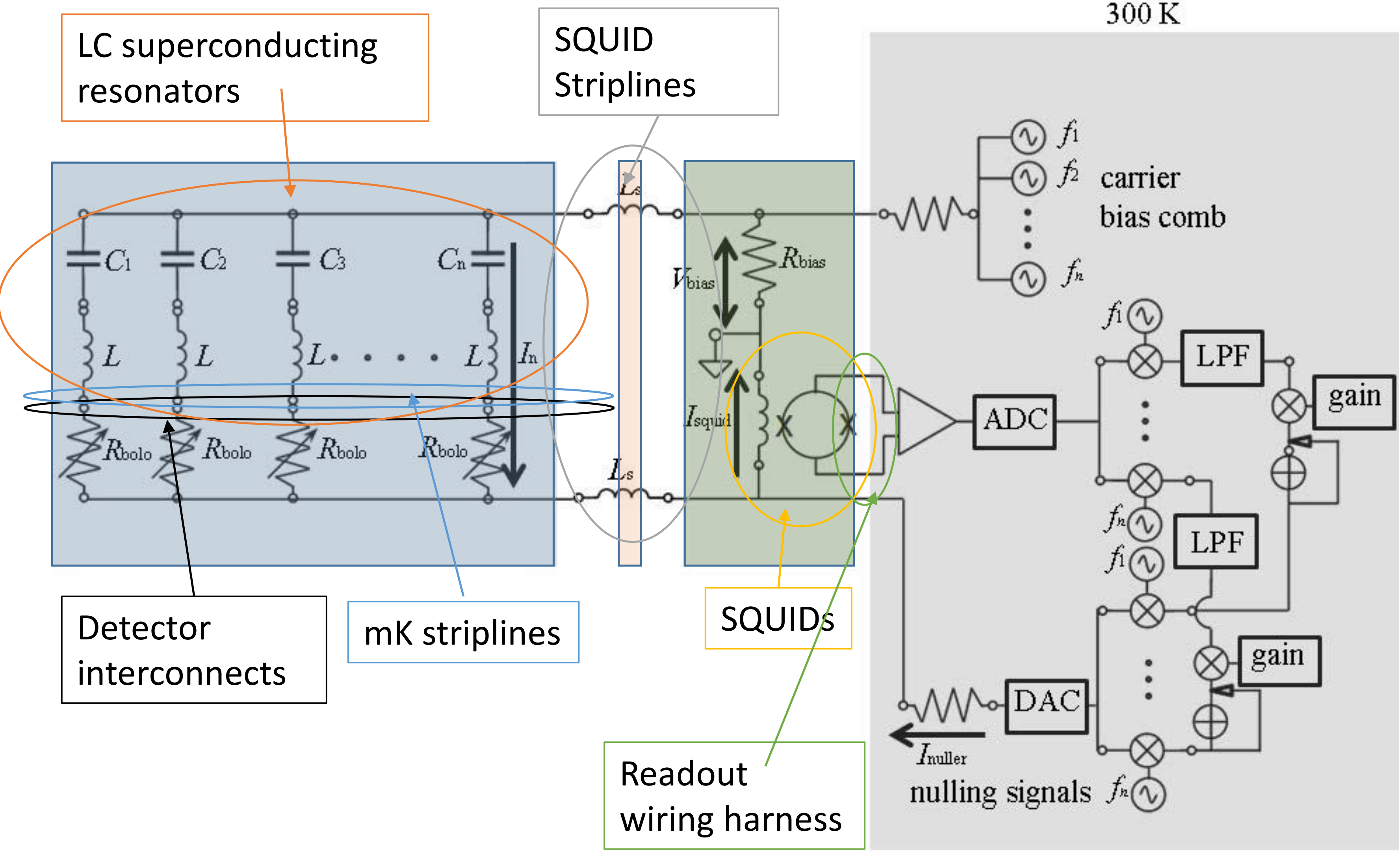
Readout circuit





0.5K/1.2K intercepts		0.3K/1.8K intercepts	
Temperature of stage [K]	Load [uW]	Temperature of stage [K]	Load [uW]
0.1	0.2	0.1	0.05
0.5	1.0	0.3	3.0
1.2	30	1.8	30

Cryogenic Readout Components



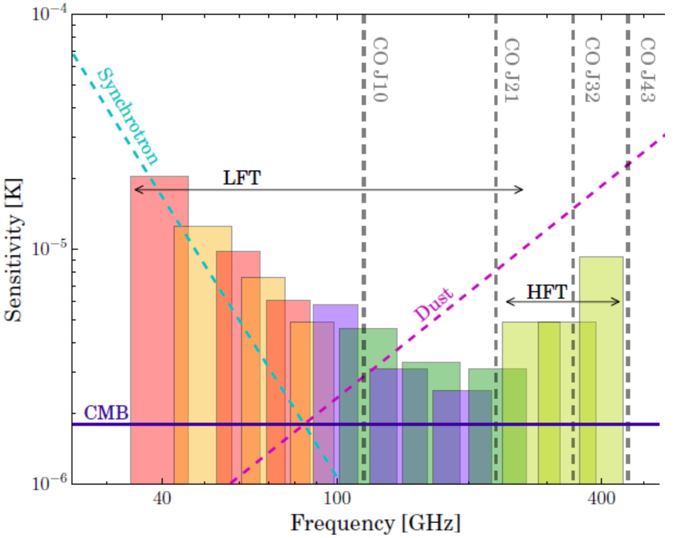
Interfaces

- Detector interconnects: electrical connections to niobium leads on detector wafers: one pair of connections per bolometer
- Readout wiring harness: interface between cryogenic readout and warm readout.
  - 3 pairs of connections per SQUID
  - Mitsuda (yesterday) showed cryogenic specifications based on IXO harness studies
  - Wiring harness specifications being set
- Thermal/mechanical anchor points for electronics at each thermal stage

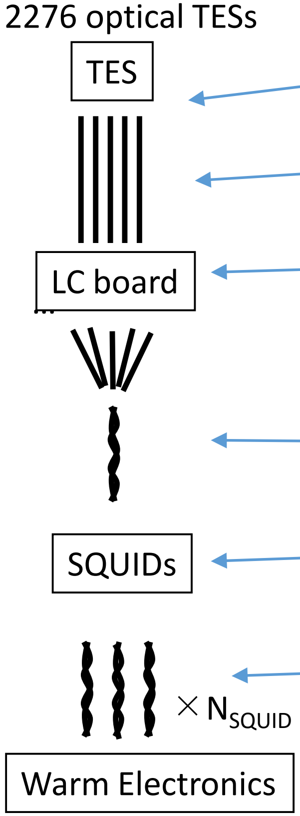
Number of SQUIDs

For modularity and testing simplicity, SQUIDs are not split across two different wafers.

Wafer Type	Number of TESs per wafer type	**Number of SQUIDs per wafer type**	optical multiplexing factor
LF-1	456	**8**	57
LF-2	456	**8**	57
MF-1	666	**12**	56
MF-2	444	**8**	56
HF	254	**4**	64
TOTAL	**2276**	**40**	

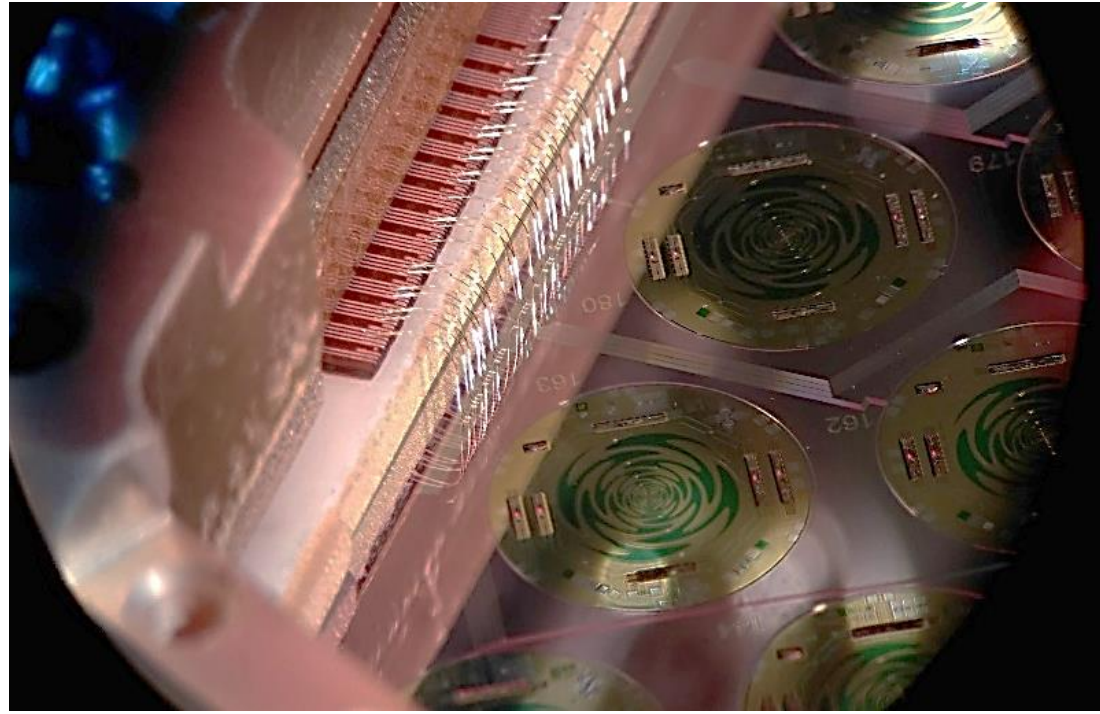


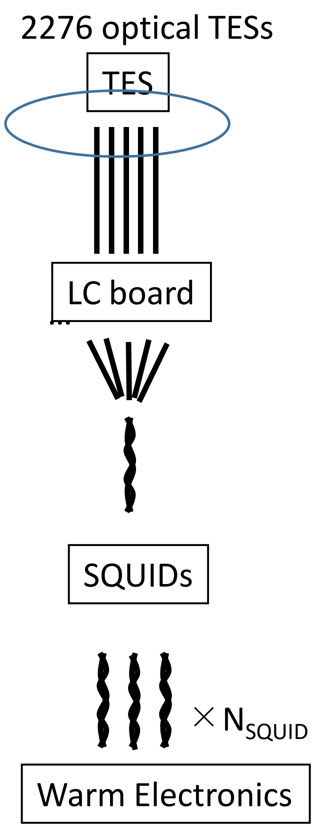
Cryogenic Readout Components



- Detector interconnects
- mK Striplines
- LC superconducting resonators
- SQUID Striplines
- SQUIDs
- Readout wiring harness

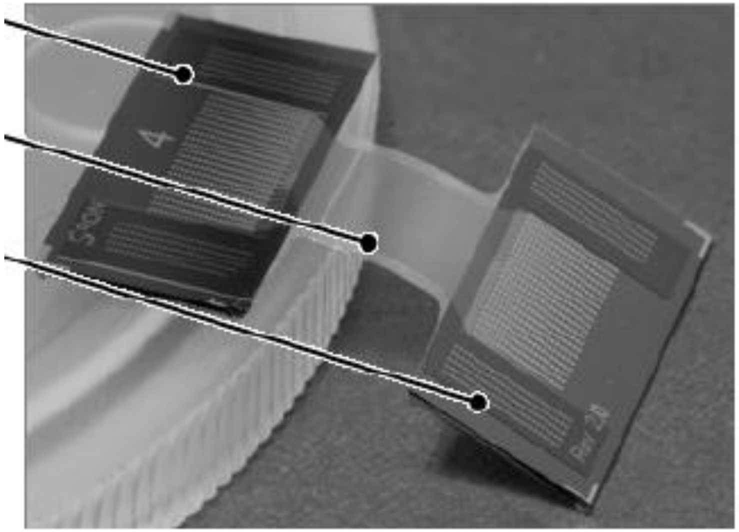
Detector interconnects





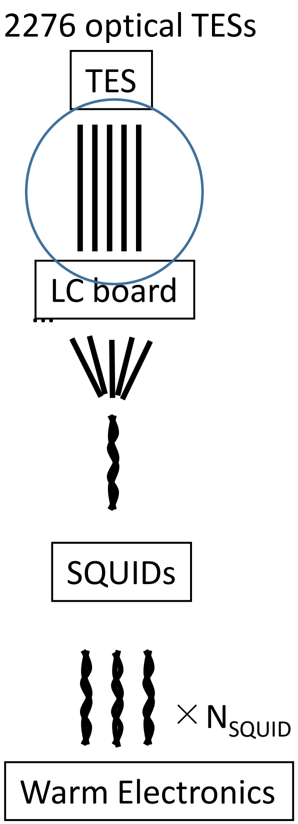
- Polarbear & SPT3G: Robust automatic wirebonding
  - Repeatable pull strength
  - Superconducting connection
  - Repeatable inductance

mK Striplines



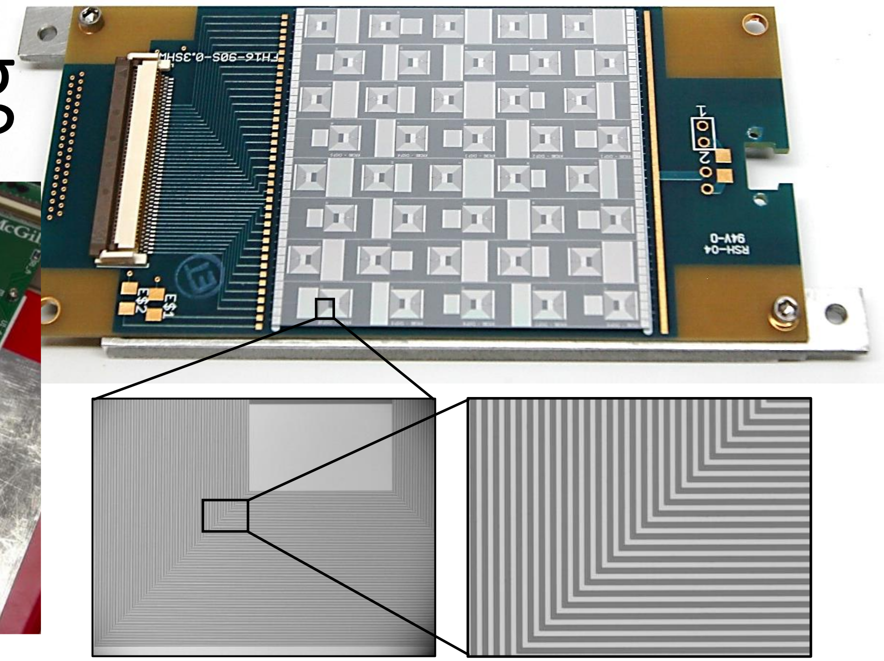
Van Weers et al 2014. Athena/SPICA prototype

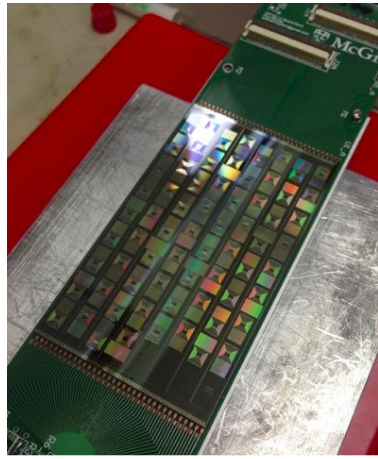
Polarbear & SPT3G: copper on polyimid.

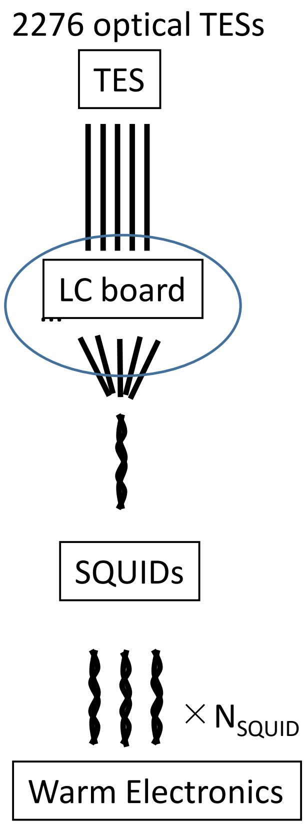


- Lithographed striplines are a natural solution.
- Wirebond interconnects at both ends
- Notes on requirements:
  - L must be consistent to keep resonant frequencies consistent
  - Fully superconducting so R < 0.01 Ohms is no problem.
  - C to ground is controllable to ensure no unexpected resonances in system. Full system simulations have been developed for ground-based systems to ensure important to ensure.
  - Electrical crosstalk on neighboring lines is not critical here.

LC Superconducting Resonators

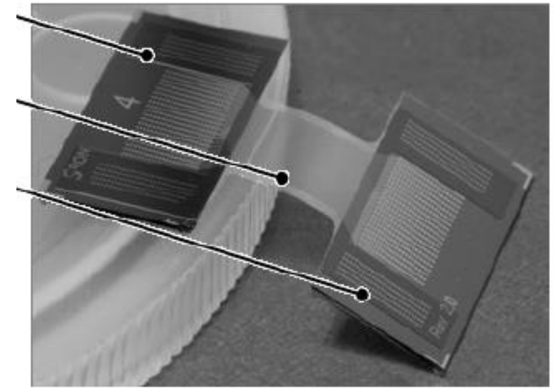






- Polarbear & SPT3G: Aluminum inter-digitated capacitors and planar spiral inductors
- LiteBIRD: commercial Niobium solution
- Mechanical mounting to be designed.
- Notes on requirements:
  - Max crosstalk -> min spacing of resonances -> LC component scatter requirement
  - L set by bandwidth, LiteBIRD with rotating HWP is similar to Polarbear and SPT3G
  - Equivalent series resistance (ESR) from loss in capacitor dielectric increases bias impedance. Necessary ESR achieved.

SQUID Striplines



Van Weers et al 2014.
Athena/SPICA
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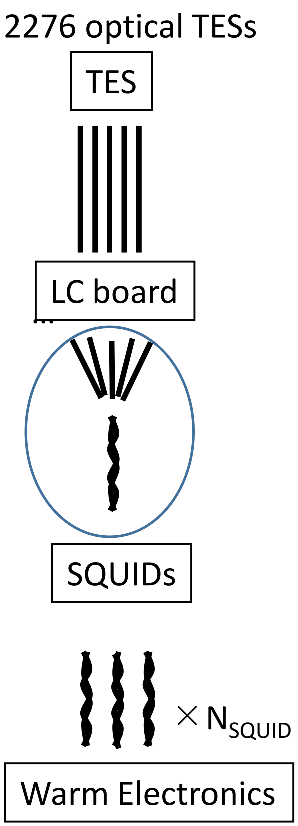
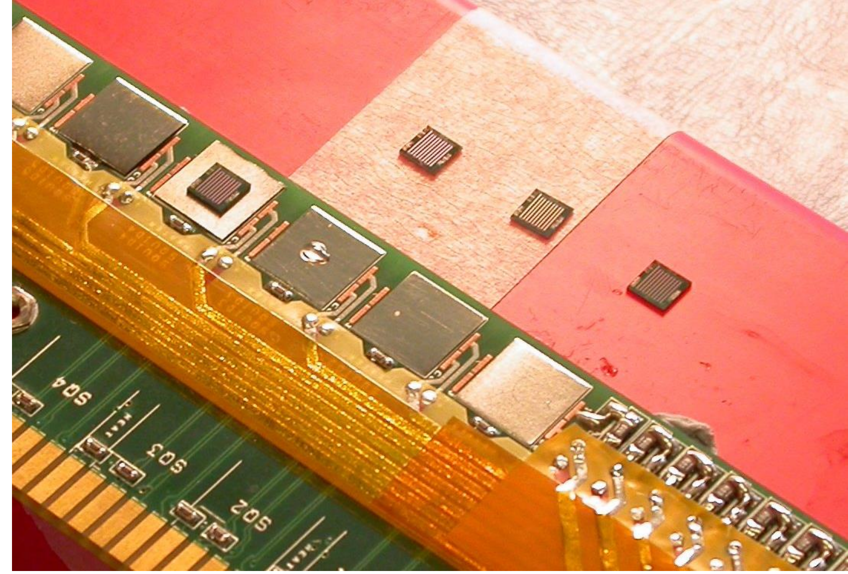
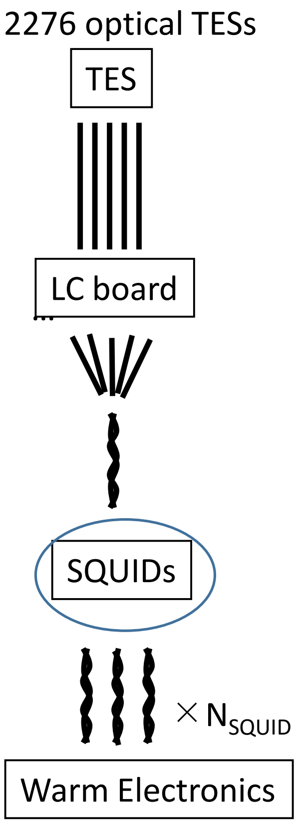


- Polarbear & SPT: NbTi on Kapton – 30 cm sections.
- LiteBIRD: lithographed solution:
  - Achieves the needed thermal resistance in shorter physical distance
  - Allows for modular assembly of mechanically robust stripline modules.
  - Easily interconnect with wirebonds
- Notes on requirements:
  - Inductance must me limited here, as in Polarbear & SPT3G
  - Fully superconducting so achieving R < 0.1 Ohms is easy
  - C to ground is controllable to ensure no unexpected resonances in system. Full system simulations have been developed for ground-based systems to ensure important to ensure.
  - Electrical crosstalk on neighboring lines is not critical here.

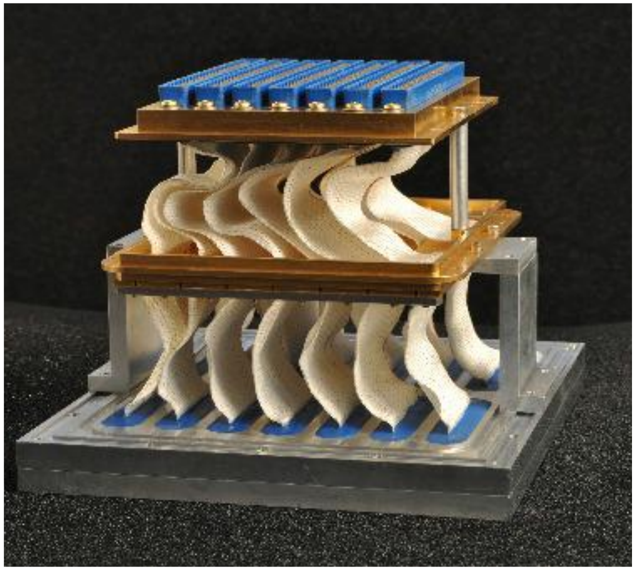
SQUIDs





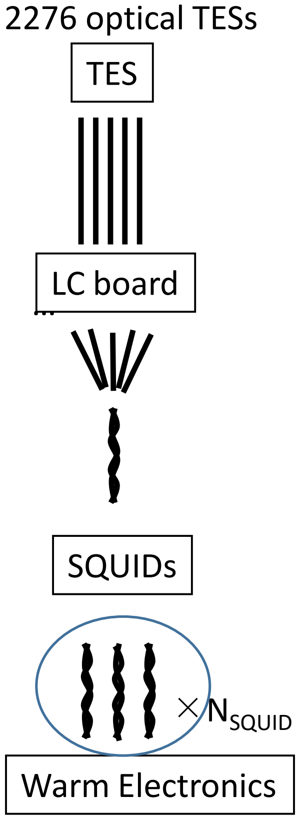
- Polarbear & SPT: Fabricated by NIST. Requirements:
    - Transimpedance > 400 Ohms
    - $25 \pm 2.5\ \mu A/\Phi_0$
    - Noise referred to input: $< 5\ pA/\sqrt{Hz}$
- NIST has produced SQUIDs with a wide range of parameters, will be optimized for LiteBIRD system.
- Mechanical mounting and magnetic shielding requirements to be specified

Readout wiring harness



Three pairs of twisted pair wire per SQUID:

1. Bolometer bias
2. SQUID Bias
3. SQUID Output



- Polarbear & SPT: NbTi twisted pair with copper cladding, fabricated by Cryoconnect.
- LiteBIRD: cryogenic study based on IXO harness study, which has more stringent requirements
- Notes on requirements:
  - Characteristic impedance
  - Maximum resistance
  - Maximum crosstalk
  - Maximum signal loss
  - Cabling electrical shielding and emissivity

Concluding thoughts

- DfMux cryogenic readout systems have deployed on APEX-SZ, SPT, Polarbear-1, SPTpol, & EBEX. They are deploying on Simons Array & SPT-3G.
- Exact impedance requirements for each component still to be established
  - Use the circuit simulation framework for establishing this that has been used for existing systems
- SQUID requirements present the largest number of options and questions still to be answered