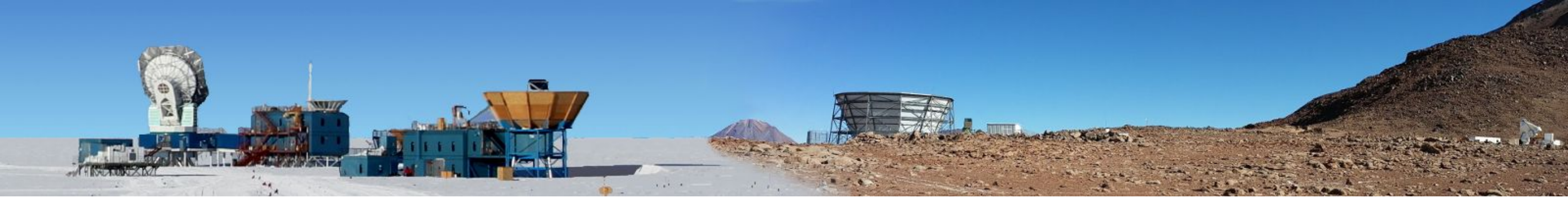

Readout progress & plans

Parallel 2, Tuesday, March 31, 2020

Amy Bender, Zeesh Ahmed

https://lbnl.zoom.us/j/411685173
https://cmb-s4.org/wiki/index.php/LBNL-2020:_Detectors_Readout_Modules

December Readout Assessment Charge summarized

1. Assess state and margins in:
    a. Current & projected performance
    b. Impact on systems engineering and interfaces
    c. Cost, schedule impact, technical maturity
    d. Programmatic benefits
2. Are proposed metrics reasonable and complete?
3. Can performance be reasonably assessed/projected?
4. Will the risk balance change with 3-6 months of R&D?
5. Is the pre-CD1 development plan adequate?

Agenda & presentation materials at: https://indico.fnal.gov/event/22575/ (pw: Readout2019)

Specific Considerations Examined by Presentations

- White noise contribution to NEP
- Low-frequency noise contribution to NEP
- Level and stability of electrical crosstalk
- Post-screening operable channel yield
- Detector interfaces: Loopgain, Stability of V-bias, ETF stability, SQUID/system stability
- Compatibility with Dual-Psat TES
- Compatibility with continuously-rotating HWP
- Readout package modularity
- Cryogenic heat loads within allocation
- Warm electronics power consumption
- 100mK temperature stability
- Requirement on warm electronics temperature stability

- Technical readiness
- Screening Yield/Effort
- Microfab effort
- Cost (& split between prototyping/preproduction, production, M&S, labor etc.)
- Fallback and upscope options
- Programmatic alignment
- Effort, serviceability, lifetime

TDM Dec. Assessment Recap

1. *Current and projected performance*
    a. NEP degradation by readout OK. Tradeoff in MUX factor and readout aliased noise. Crosstalk low (0.2-0.3%) and stable. High operational yield requires stringent screening. Demonstrations include full-scale integrated and fielded instruments.
2. *Systems Engineering/interfaces*
    a. Bias independent of readout. Some constraints linking TES time constants to readout aliased noise. Warm electronics redesign required. Large number of interconnects (wire bonds). Module designs need to be matured to achieve required density.
3. *Cost, schedule, maturity*
    a. Cost and schedule predictable when planned. Component screening substantial, large number of components to be screened.
4. *Programmatics*
    a. NIST single-source vendor of SQUID mux chips is a programmatic risk
5. *Known Challenges from the TDM presentation*
    a. Control of aliased noise and interaction with bolometer bandwidth
    b. Achieving required density in module wiring for some of CMB-S4 bands
    c. Substantial # of components requiring micro-fabrication & cryogenic screening

uMUX Dec. Assessment Recap

1. *Current and projected performance*
   a. NEP degradation by readout projected to be OK (includes significant margin). Crosstalk <0.1%. Crosstalk stability (known modulation) and white noise contributors not fully understood at MUX 1000. Demonstrations primarily in lab at the single module level.
2. *Systems Engineering/interfaces*
   a. Least requirements imposed by readout on detectors (time constants, transition slope etc). Component testing achievable. Module design least mature.
3. *Cost, schedule, maturity*
   a. Significant risks include unforseen system-level integration problems and lack of demo on long-term stability of fab parameters. Therefore, more risk & expense in prototyping & pre-production phases.
4. *Programmatics*
   a. NIST single-source vendor of SQUID/resonator mux chips is a programmatic risk.
5. *Known Challenges from the uMux presentation*
   a. System noise performance depends on high-fidelity microwave packaging
   b. Controlled & repeatable frequency placement of resonators in mux chip
   c. No larger-scale integrated demonstration yet

fMux Dec. Assessment Recap

1. *Current and projected performance*
   a. NEP degradation high when extrapolating from SPT-3G. Proposed modification to SSAs (low input inductance, low output impedance) provides well-defined path to resolution. Crosstalk is known to be at < 0.5% level and stable.
2. *Systems Engineering/interfaces*
   a. Filter bandwidth imposes requirements on minimum time constants for detectors, could have implications for LAT. ETF loopgain lower than in DC bias. LAT wiring length may impose additional constraints on SSA parameters. Calibration TES may have complications with crosstalk. Components have high modularity & low complexity, existing module package has high maturity. Testing requirements modest.
3. *Cost/schedule/maturity*
   a. Requires significant SQUID R&D, therefore more expense & risk in prototyping and pre-production.
4. *Programmatics*
   a. fMux uses higher detector impedance (~1Ω) than TDM/uMux, which limits cross-technology fallback.
5. *Known Challenges*
   a. Demonstration of optimized SSA
   b. Demonstration of system with reduced readout noise
   c. Mitigation of electrical effects due to long LAT wiring

Conclusions from other charge questions

1. *Evaluation and down-selection scheme*
   a. Proposed metrics sufficiently capture the important technical and risk considerations. Management should avoid over-reliance on numerical metrics
2. *Validity of Performance projections*
   a. TDM OK. uMUX has some risk due to limited existing demos, but also has significant margin on noise. Concern that fMux systems will have little margin in noise requirements.
3. *3-6 month R&D that lowers risk or improves ability to build S4*
   a. No fundamental R&D needed for TDM. uMUX can have significant benefits compared to TDM if packaging and MUX1000 scale demos done, but issue of scaling to deployment focal-plane-scale not likely on this timescale.   fMux SQUID development path clear but not likely to retire all risks on this timescale.
4. *Pre-CD1 development plans*
   a. TDM effort OK. uMUX & fMux development plans currently rely heavily on contributions from other projects.

Readout Assessment Committee Conclusion

“The technology presentations represent a well-formed and mostly complete discussion of the issues. TDM has low technical risk compared to the other technologies, and we do not anticipate incoming information in the next 3-6 months that changes this technical risk balance. No opportunities were identified that would be missed by selecting a technology now as compared to 6 months from now. Selecting either of the higher technical risk options (uMux, fMux) would require identifying significant advantages offered by those options.”

Report is in DocDB.
https://cmbs4-docdb.fnal.gov/cgi-bin/private/ShowDocument?docid=150

Incorporation on New Information

Risk/Mitigation	TDM	uMUX	DfMux
Performance	Modernize room temperature electronics	Optimize microwave packaging	Reconcile excess demonstrated noise over theory
		Empirically bound RF non-linearity induced noise floor	Increase margin in series parasitic impedance and bolometer resistance budgets
[illegible]	Optimize component screening for high yield	Frequency placement of GHz resonators	Frequency placement of MHz resonators
Packing density	Two layer cryogenic mux package		
Fabrication	SQUID 6” fab process development		

From October 2019

Some of what we might hear about in the technical updates today.

Questions we are still grappling with

1. What readout parameters become more constrained with the addition of a HWP (interaction with readout non-linearities)?
2. What’s the typical scatter in saturation power of TESs (what’s the target being given to fab for this)?
3. What are the requirements on the absolute level and stability of crosstalk?
4. Are there potential trade-offs with the currently stated 95% yield requirement?

The list grows as we continue….

Current Status and Output

Readout working group meetings include discussions of technical performance & metrics. Minutes at:

- https://docs.google.com/document/d/1KTVO88iM1YgmnpmJ6JmuBJuV8yb3DmXzct9nTBVE0ug/edit?usp=sharing

Summary document with recommendation will be submitted to IPO in April once community discussions conclude.

- Working draft at: https://docs.google.com/document/d/142iWwJRas5cPdXDgPhXqDoL3Slo_bPSPnVjLpmEpx7w/edit?usp=sharing

CMB-S4 Readout Technology Downselect Recommendation Document

April 2020

Rough outline of recommendation document:

- Technology being recommended
- How we came to that decision (process, considerations)
- Known risks for this technology
- Limitations of this recommendation
- Additional recommendation: Keep broader R&D program open (with outside resources) as a fallback

Metric	Description
White noise level	Projected/demonstrated white noise level (based on audio frequency 10-20 Hz) for each of the CMB-S4 observing bands. Targeted maximum level given by TBD/flowdown *(currently 5% increase in total noise budget*).
TDM: Total noise is increased by readout by 2% in primary 90/150 GHz CMB bands with slightly higher contributions at 30/40 GHz. The assumed noise level and resulting projection is based on levels from the fielded BICEP/Keck, AdvACT, and SPIDER experiments. fMux: Current on-sky telescope demonstrations of fMux (SPT-3G, PB2) increase the total CMB-S4 noise by an unacceptably high amount. Two proposed scenarios for CMB-S4 with changes to the SQUID properties, wiring, and bolometer resistance forecast the potential to reduce the readout noise significantly. In the first more conservative projection, the total impact to white noise is	

CMB-S4

Tasks for after down-select

- Support of CDFG detector testing activities
- Prototype design for readout components & module (100 mK)
- Procurement of prototype parts & cryogenic characterization of prototype
  - Independent resources for cryogenic testing (not the same as module testing)
- Development of plan for micro-fabrication (both pre-production & production)
  - Potential conflicts with detector fabrication
  - Has many of the same schedule risks as detector fabrication
- Systems engineering (interfaces with other areas)
- Re-visit risk registry
- Flowdown of requirements to L3 & L4
- Updates to cost & schedule (WBS reorganization, new information)
- Will have to define some ‘roles’ for different institutions
- CD1 level documentation by the end of the year(?) (and for the agency review in August)
  - other pieces of this not listed above?
- ***We will be looking to our working group (you) to support these activities***

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Requirements flowdown template

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Science Requirements for CMB-S4

Doc:
Version:
Date:
Status: Draft
Page 7 of 11

4 Readout Requirements

{insert narrative text describing functionality of this L2 subsystem}.

The requirements for the readout flow from the higher-level system requirements defined in {insert higher level requirements document reference}. Each of the requirements defined in this document have a parent requirement which is referenced as part of the requirement definition.

4.1 {INSERT DESCRIPTIVE NAME OF THIS REQUIREMENT}

{insert any narrative text as you feel is necessary or helpful}

AAA-1.XX-YYYYY-ZZ

This requirement is derived from AAA-1.XX-YYYYY-ZZ {insert requirement title} {add more references if needed}.

4.2 {INSERT DESCRIPTIVE NAME OF THIS REQUIREMENT}

{insert any narrative text as you feel is necessary or helpful}

AAA-1.XX-YYYYY-ZZ

This requirement is derived from AAA-1.XX-YYYYY-ZZ {insert requirement title} {add more references if needed}.

4.3 {INSERT DESCRIPTIVE NAME OF THIS REQUIREMENT}

{insert any narrative text as you feel is necessary or helpful}

AAA-1.XX-YYYYY-ZZ

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Questions, discussion?