Detectors Plenary presentation slide from Brenna Flaugher [link]

Detector Parallel

Darks Lorenzo's [slides]

- dark SQUIDs to monitor drifts in readout (mostly for magnetic pickup and occasionally crosstalk)
- dark TESs (abbrev DT throughout presentation), 3 types, details like number, location and bias matter
  - taped horn, or no horn (dark spot on wafer)
  - cut feedline
  - no resistor (darkest of darks)

From Chat: Hannes/Adrian: Dark Resistor is one more flavor: readout channel coupled to a resistor of resistance equal to the operating resistance of the TES. This would most mimic the electrical pickup in the TES to SQUID wiring.

General agreement to have them but need to decide on:

Number per wafer

Location

Biasing

Dark SQUID soft recommendation: 1 per mux column

  - implementation could be "shorted" as in BICEP3, "open" as in BICEP2, or resistive (as mentioned in chat seen above)
  - dark SQUIDs can inform how much of ground-subtracted component is due to mag pickup (maps shown)

Dark TES in BICEP/Keck, cut feedline type

- important for optical/thermal/electrical diagnostics but did not use for high-level analysis
- noise analysis shown dark vs light pixel showing good noise stability

Dark TES in Stage 3 LATs (ACT, SPT), cut feedline type

- ACT: used to separate thermal drifts from atmosphere, important to have good spatial coverage, cut feedline type
  - (Sara Simon) AdvACT 27/39 GHz less sensitive to atmosphere, so darks may be more useful for calibrations
- SPT: used for assessing on-island pickup or optical cross-talk and noise issue diagnosis, SPT-SZ used taped horn type, SPTPol used cut feedline, and SPT-3G used both cut feedline and no resistor types
  - (Adam Anderson) some arrays had as many as a few percent of total as darks

Dark TES recommendations:

- number: SATs = a few per wafer, LATs =
- biasing:
  - dark Psat < opt Psat
    - must know dark/light Psat in advance?
  - separate bias lines for darks
    - not easy for readout

        - different shunt resistor darks
            - different gains
        - (Hannes) change Rn of dark TES
- location:
    - on-chip cut feedline: not really dark
    - off to the side or no resistor: less sensitive to pickup and crosstalk (really dark)
    - optically sensitive area taped horn: sensitive to photons bouncing around behind horn array

Consensus that both dark SQUIDs and dark TESs should be included

- Readout: 1 of 11 channels set aside for darks
- Potential plan: 1 DS per mux column (30/1920 channel module), combination of cut feedline with adjusted Psat, no resistor with adjusted Psat, and taped horn during development only

Toki: asks if we need to operate darks simultaneously with optical TESs, proposes same Psat for both. Lorenzo - optimal to operate simultaneously - wish list
Toki would like dark and regular bolometers to be same for simpler detector fab

John Ruhl: surprised to hear from readout that there may be room for many darks, Gunther states that more bondpads and how the routing works determines this as well as max count for optical TESs
Gunther states that 1872 may not be maximum, depending on length available per side for pads

Gunther for lower density wafers - there is more flexibility to have more darks and potentially route all to one side.

Gunther: can you operate with one bias once in a while to use the darks, then go back to normal bias for science data.
Zeesh: sounds like things drift and this might not work.

Lorenzo:It is not clear the darks need to be in transition during science observations, but it would be nice.

Jamie: Why do the darks vs lights need to be biased with different parameters? Lorenzo: optimize for lights and darks not optimally biased. Jamie: is responsivity actually that different, benefit of getting darks interleaved in the data stream. Lorenzo: darks are definitely noisy compared to lights

From Chat: Jeff Filippini:Jamie's point is a good one, about dark TES noise being excellent even when not optimally biased. Should be good as long as the transitions are wide enough to overlap substantially in bias, which depends on e.g. safety factor. Need to work it out.
Hannes:Agree with Jeff. I'd be concerned about the highest bands with high Psat. Can we simultaneously bias a UHF optical and dark in a stable config?

John K.: If darks aren't on transition with standard bias, rather than adjusting R why not adjust G?
Jeff Filippini:
Yes, you could adjust G instead. Depends what parameters we have most control over, and which will make the dark TES data easiest to interpret.

From Chat: Jeff Fillippini The short/open difference in the prior generation of TDM (current-summing) mostly affected crosstalk: the nearest SQ1 was the DS, which crosstalked to the column's common SQ2. I don't think this is as important in the current-generation of TDM (voltage-summing).

Toki from Chat:Adjust G (usually by changing bolometer leg length or Tc) is possible, but one of pick up mechanism is slot used to fabricate bolometer act as slot antenna... ideally we keep same physical geometry. Changing Tc is way more challenging than R

Jamie: vote against taped over horn, nice to have darks in situ

Detector Options John Rhul's slides

- 11 different wafer types as of DSR, 8 different wafer types as of PBD, possibly more with same Psats

Q1: only one type of SAT MF wafer with mixed bands?

- Pros: one type of wafer
    - Toki: relative shifts in bands easier on one wafer compared to absolute between two wafers, John states that bigger problem is not being able to hit absolute band edges
- Cons: keeping data straight is more difficult, potential biasing issue (different P_elec for 85 vs 95 and 145 vs 155)
    - Sara: possibly different interface for horn/OMT
    - John Kovac: AR coatings more difficult, larger range of frequencies to cover
    - Jamie: may be harder for fab to hit band edges

Q2: three high-density wafers (SAT UHF, LAT MF, LAT UHF), should they (can they) be the same?

- Pros: fab overlap, homogenizes readout, same feedhorn design for UHF
    - Sara: yes, same horn array and interface if same layout for UHF, but MF would have to be different. LAT MF is the most mature design, so would actually lose a fully vetted design by changing that.
    - Toki: emphasizes ease of assembly and readout
    - Zeesh: fewer types of assemblies to handle (not doing 1872, dropping to 1728)
    - Adrian: pixels different, readout the same, therefore could choose to not use some number of pixels?
    - Gunther: ideally 5 groups of pads (5 columns) with gaps between
- Cons: rhombus vs hex
    -

Q3: can SATs adopt LAT frequency bands at 30/40 and 220/270?

- SAT: 30/40, 220/270; LAT: 27/30, 225/278
- Pros: fab overlap, makes testing easier to analyze?
- Cons: need to validate SAT foreground subtraction
  - Adrian: was there a science driver for the difference? John Kovac: SAT bands are matched with what we have experience using, so risk exists by changing
  - Ruhl: crossover point has changed, total bandwidth has not changed
  - Jamie: same bands a good thing for foregrounds

Q4: are low density wafers wired out using only one side?

- Pros: easier readout
- Cons: large wafer area on one bias, incompatible with NIST wiring?
- Zeesh to John Ruhl, I understand your point about Psat spread over wafer and possibly needing more than the single bias per frequency. Missed that earlier

Things to keep in mind:

- Detector stability
- Variations in P_elec across wafer, e.g. wiring from center of wafer
- Can we flash detectors to unlatch? Zeesh says it can be designed in. This is something that should be done, would put a requirement on readout (which Zeesh says may be easy)

Slides on layout from Toki Suzuki - [slide]

Brenna states fab benefits to switch some detector layouts to hex

3 types of layouts, experiments and fab sites:

- Hexagon: all sites have stepper compatible with hex-shaped pixel, direct write for wiring layer (single), no crossover, both frequencies mapped to all sides
  From Chat: Dale Hex can be direct-write or contact (or as a complex stepper job).
- Rhombus: all features printed with stepper, 3x masks if no rotating stepper, crossovers, single frequency mapped to same side of wafer
- From Chat: Dale: Rhomb can be direct-write, contact, or stepper
- Square: all sites have compatible stepper for all layers, density is lower

UCB recently produced array with all direct write, 45-50 min per lithography layer per wafer

Pixel pitch for each type of array presented in table (hex layout pitch smaller in all cases, which results in higher pixel count per wafer)

Layout study suggests hex layout works for all cases, but it is unclear if all RF structures will fit

Need to study mapping speed, beam truncation and shape and flow up …

Bandpass filter differences between fab sites described

Wafer size should be fixed - interface with other groups (SAT, modules, e.g.) to finalize

Is 124mm wafer pitch enough?

Ruhl: certain horn diameters and pixel counts are in PBD spreadsheets, changes have implications on designs

John Kovac: some changes may require optimized horn designs and optic designs

Adam: 124mm SAT wafer pitch, nice to iterate on detector wafer size to optimize packing (e.g., CDFG wafer has a lot of unused space at perimeter), even 1-2 mm smaller detector array size
Dale: misunderstanding in difference between rhombus vs hex, original rhombus was meant to be same as hex closepack, with shift added to relax requirement to pack toward center, suggests study similar to Toki's for rhombus layout

Question: have people used direct write and did they work? yes, spt3g and others say yes.

Chat:
Sara Simon We should keep in mind that horn designs take ~1 month to fully optimize. Quick designs can be ~1-2 weeks and should be pretty close for design studies, so I'd suggest that for these tradeoff studies we use those and carefully consider how many of them we require (i.e. can we use scalings). They also require a number of inputs to optimize so we would need those inputs.

Dale: Rhombus and Hex could have the same pitch. In both cases the unit cells need to shrink to make room for wiring. Dale will work on detailed analysis
Shannon - it is really important to do the same analysis for Rhombus as Toki has done.
Cross overs/under - there is no ground plane and this reduces pin-hole shorts.
Toki: it is easy to remove the ground plan under the wires for the Hex layout.

Brad concerned that there is a lot of work in the LAT MF already and would not want to step away from it without thinking hard about it.

Suggested homework:
Dale/Shannon: Rhombus analysis (like Toki's for Hex) (can they do a hex layout with rhombus shaped pixels (can drop center).
Analysis of on chip filtering: does it fit in a hex shaped pixel and what is needed. Lumped element vs Hybrid Tee
Need more detailed analysis of wafer edge length and spacing for pads.- will be discussed in module session.

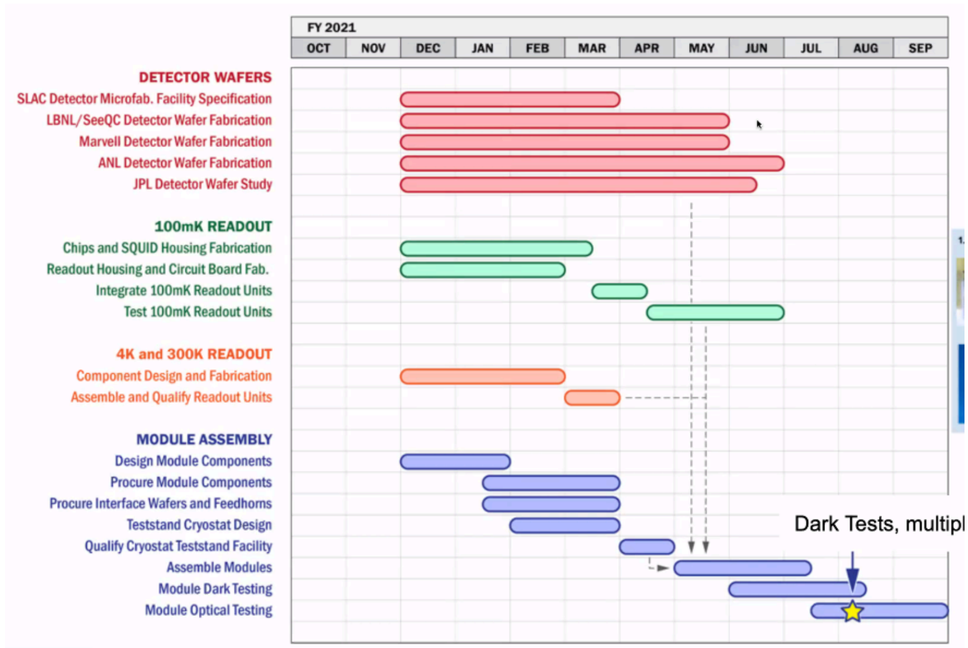
Shannon will focus on LAT MF (get rid of raceways) to make comparison
Then next is SAT MF (Toki and Shannon will exchange info)

Plenary Notes taken by Zhilei Xu

Introduction of Brenna's background
Introduction of detectors

1. 550k detectors on 503 wafers, need to fabricate 800 wafers
2. 8 different wafer types
3. CMB-S4 Detector Fabrication Group (CDFG) established in Jan. 2020

a. Goal 1: Intellectual properties and conflict of interest
b. Goal 2: CDFG prototype detectors
    i. two layouts for LAT MF and SAT-like MF
    ii. FY21 plan: detectors, readout, and modules/testing
    iii. Overall schedule



c. Goal 3: detector fabrication plan
    i. Start with the MF type
    ii. Site selection, each type will be fabricated by at least 2 sites
    iii. Current V5 plan

PRODUCTION		Split years into part A and B for transition to new detector type									
	FY23A	FY23B	FY24A	FY24B	FY25A	FY25B	FY26A	FY26B	FY27A	FY27B	Total
Site 1 = ANL	2	8	8	10	10	10	10	8	10	10	86
Site 2 = JPL	2	8	8	8	14	16	16	16	12	6	106
Site 3 = SEEQC	2	8	10	10	16	16	16	16	4	4	102
Site 4 = NIST	2	8	8	8	10	12	14	16	16	14	108
Site 5 = SLAC					8	12	16	11	11	10	68
Site 6 = Marvell	1	3	4	5	4	4	4	4	4		33
Total Science Grade	**9**	**35**	**38**	**41**	**62**	**70**	**76**	**71**	**57**	**44**	**503**
~ Number of wafer modules to test (inc. 12% overage and 67% yield)	**15**	**59**	**64**	**69**	**104**	**117**	**127**	**119**	**95**	**74**	**841**

4. Recent progress from different sites
5. Recent challenges:
    a. matching wafer layouts to Fab. site expertise
        i. Hex vs Rhombus layout: with different masks and lithography steps
        ii. Wiring crossover/under and mapping freq. to bond pads
        iii. RF structures internal to the pixel differs
    b. Preliminary Baseline Design has all Rhombus (except SAT HF), not well matched to Fab. site expertise
    c. Toki has a presentation (above) to explain the different layouts in more details
6. FY22 R&D and pre-production

    a. Possible deployable wafers with several issues to be resolved,
7. Conclusion
8. Q&A
    a. Q: the order of wafers for SAT and LAT?
    b. A: SAT wants MF first; LAT also wants MF but not very particular

Chats:

Hannes to All:
can imagine one more flavor: readout channel coupled to a resistor of resistance equal to the operating resistance of the TES. This would most mimic the electrical pickup in the TES to SQUID wiring.

Adrian to All:
people have used a “dark resistor” that may be outside your list
Hannes and I have the same comment.

Jeff to All:
The short/open difference in the prior generation of TDM (current-summing) mostly affected crosstalk: the nearest SQ1 was the DS, which crosstalked to the column’s common SQ2. I don’t think this is as important in the current-generation of TDM (voltage-summing).

Parallel Chat:

Jeff Filippini to Everyone (3:16 PM)
John K.: Yes, you could adjust G instead. Depends what parameters we have most control over, and which will make the dark TES data easiest to interpret.
Aritoki Suzuki to Everyone (3:18 PM)
Adjust G (usually by changing bolometer leg length or Tc) is possible, but one of pick up mechanism is slot used to fabricate bolometer act as slot antenna... ideally we keep same physical geometry. Changing Tc is way more challenging than R
Lorenzo Moncelsi to Everyone (3:19 PM)
note taker: please make sure chat gets copied over to the notes, we had to do that yesterday at readout because it was too good to not record
Shannon Duff to Everyone (3:20 PM)
Thanks, we are capturing the chat discussion as well.
Zeeshan Ahmed to Everyone (3:47 PM)
@John Ruhl, I understand your point about Psat spread over wafer and possibly needing more than the single bias per frequency. Missed that earlier
Dale Li to Everyone (3:48 PM)
Hex can be direct-write or contact (or as a complex stepper job).
Rhomb can be direct-write, contact, or stepper
J. Ruhl to Everyone (3:49 PM)
Great, glad we’re on the same page. I think it would be great to hear what fractional variation in Psat across a wafer detector fab folks expect.
Dale Li to Everyone (3:49 PM)
Sounds the same in that case
James J. (Jamie) Bock to Everyone (3:49 PM)
The unwrapping of 4 interleaved bands is another reason to be leary of 4 bands/wafer

J. Ruhl to Everyone (3:49 PM)
Jamie, by “unwrapping”, do you mean getting the right assignments in the hardware map?
James J. (Jamie) Bock to Everyone (3:50 PM)
Getting the same detector bands to the same bias
Dale Li to Everyone (3:50 PM)
Also, rhomb IS a hex pattern, and doesn’t need to have the offset. The hex and rhomb can be made to have the exact same pixel pitch and count.
J. Ruhl to Everyone (3:51 PM)
Dale, that’s true locally, but not if you’re filling a fixed area, right?
(Because of the lattice dislocations)
Or maybe I’m missing your point… can you do the nits-style stepper-wiring-fab in a true fully HCP layout?
Dale Li to Everyone (3:52 PM)
The rhomb currently is three hex with relative shifts. That’s true. But it wasn’t originally. Those shifts were added to ease a requirement. But they don’t need to be there.
J. Ruhl to Everyone (3:53 PM)
Oh wow, that’s interesting! So can you make the 469 layout (maybe missing center pixel) using your stepper-wiring scheme?
Dale Li to Everyone (3:53 PM)
YES, NIST wiring can be done with a full HCP layout
J. Ruhl to Everyone (3:53 PM)
Very cool, I did not know that!
Dale Li to Everyone (3:54 PM)
The 469 pixels still needs to be squeezed into a small unit cell to accommodate the wiring bus (same bus width in both cases).
Dale Li to Everyone (3:54 PM)
This is a question of unit cell: hex or rhomboid. But also leads to the readout wiring differences.
I have to go to a 2:00 meeting, but for what it is worth I agree with Toki's points about what should be frozen and going to hexes
Brad Benson to Everyone (4:03 PM)
Yeah, echo Ruhl's point

This question is off-topic for layout, but: Toki mentioned “leave it to fab sites to achieve …bandpass” and showed different RF filter approaches. How are the requirements for blue leak rejection currently defined?
J. Ruhl to Everyone (4:21 PM)
I don’t think they’ve been written down. I welcome suggestions!
John M Kovac to Everyone (4:22 PM)
zero response to photons above the band :)