

#### L2 Modules, Assembly, and Testing [WBS1.05] Status

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CMB-S4 Collaboration Meeting April 3-6, 2023





- Subsystem Team
- Scope
- Technical overview/progress/status

- Near-term plans
- Summary





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# AoA Changes

- No technical / design changes in MAT
  - Except of course the overall changes in the detector module counts consistent with the new number of SATs, and some small changes in band definitions (see J. Ruhl's talk).



#### **Module-Detector Interfaces**

- For initial development on each wafer type, significant DRM work has to be done to define interfaces via Interface Control Documents (ICDs), which define (e.g.);
  - Pixel layout and spacing, 0
  - Bond-pad layout and sizing; 0 wiring routing
  - Detector-coupling wafer Ο interfaces (e.g., posts, glue channels).
- Advanced ICDs exist for LAT MF. SAT MF2 wafer types, e.g., see progress at:
  - LAT MF: Detector-Module ICD (23 pages!)
  - L2 Interface Documents Folder 0





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# **Coupling Wafers**

- First CMB-S4 Prototype coupling wafers fabricated and <u>delivered by</u> <u>SeeQC</u> in Feb 2023
  - 2x WIP and 1x Choke wafer for LAT MF design
  - Inspection revealed some lessons learned, but wafers are sufficient for immediate fit & bonding testing for module assembly

#### • Next steps:

- A full set of 4x LAT MF coupling wafers from SeeQC, expected to be complete in the next ~month
- Test assembly of full wafer stack
- Au-plate existing coupling wafers
- Set of coupling wafers should be available for det. module assembly in ~2-3 months
- After QA of LAT MF batch, we will order a set of SAT MF2 coupling wafers
- In parallel, talking with a few other potential vendors, aiming to establish a second long-term vendor





# Horn Arrays

- First set of 5x LAT MF horn arrays delivered to FNAL
  - Uses prototype LAT MF horn and "tower" module mount design
  - Horns meet spec for testing, but <u>warm</u> <u>inspection</u> & QA also found some lessons learned for the fab of future horn arrays.
  - Worked with SAT team to design a prototype <u>MF2 horn array design</u> with angled front and tweaked mount to allow closer packing in SAT

#### • Next steps:

- Warm measurements of proto LAT MF horn beam properties
- Use new horn arrays to practice wire-bonding and detector module assembly for "flat module"
- Start work with vendor to make set of SAT MF2 horn arrays (<u>design</u>), including <u>lessons learned from LAT fab</u>
- Design prototype <u>LAT LF horn array.</u>









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### **Detector Module Assembly**

- "Flat" module update
  - Initial development focused on the design of a "flat" module to facilitate first "string tests" of prototype detectors and readout.
  - Initial tests have been performed that have tested or demonstrated:
    - Fit and assembly
    - Cryogenic gradients
    - Wire-bonding, electrical and gold bonds to detector wafer
  - Some challenges developing wire bonding, e.g., see updates <u>here</u>, <u>here</u>, and <u>here</u>
- Next steps:
  - Try test wire bonds with new horn array, and wafer clamping fixture.
  - Based on test feedback, finalize design for clamps, and bonding parts.
  - Cool down with bonded CDFG detector wafer in next several weeks.



Wire-bonding tests of Flat Module





## Develop QA Processes

- Receiving prototype components also help us to develop QA processes for different components and activities. Some examples thus far:
  - Horn arrays
    - Metrology on first and last horns for each array
    - Predict beam pattern from measured profile, and compare to design
    - Measure beam-maps of machined horn arrays
  - Coupling wafers
    - Visual inspection with microscope
    - Profile measurements of heights of wafer features
  - Module assembly
    - Wirebond pull testing
    - Warm resistance and pinout







### **Detector Module Testing**

- Three detector module test-stands being qualified for detector module tests at FNAL, UIUC, SLAC
- Each test-stand has a set of MCE electronics and demonstrated the successful readout of a prototype 4K SSA SQUIDs, 100mK MUX with TES test-devices
- Next steps:
  - Test beds are effectively ready to go once we've demonstrated the flat-modules



100 mK Readout in FNAL cryostat

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100 mK Readout in UIUC cryostat





CMB-S4 teststand (SLAC pictured)



## **Detector Module Testing**

- Assembly and testing of prototype <u>blackbody cold load</u>, used for bolo total efficiency measurements
  - Characterized cold-load coupling using benchtop tests
  - Measured thermal gradients and time constant at 1K base temp
- Cryogenically tested a prototype UHMW window and IR filtering configuration for "in-room" lab testing
  - <u>Verified filter temperatures</u> met required performance
- Next steps:
  - Test prototype cold load and IR-filtering with a detector module
  - Build copies of the cold load, IR-filtering setup for each of the three detector module testbeds.



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## High-Throughput Cryostats (HTCs)

- Planning to use HTC cryostat during pre-production and prototype testing of detector modules, so we can test up to 7x modules at a time
  - HTC production were on critical path for module testing during pre-production testing
- Updated JAMA requirements
- Developing <u>HTC thermal model</u>
- Next steps:
  - Finalize HTC requirements after larger discussion with modules group
  - Technical study comparing DR vendors / models, appropriate for the HTC
  - Develop "cartoon" concept design, with new FNAL engineer identified and support to begin work in FY23



B. Besuner (CMB-S4 Windchill)



# Next Steps (FY23)

#### • FY23 Focus on LAT MF and SAT MF2 Prototype arrays, LAT LF R&D

- Module components:
  - Horn arrays and coupling wafers:
    - Assemble and demonstrate gold-plated coupling wafer stack
    - QA and test components for LAT MF, then begin SAT MF2 (then LAT LF)
  - Demonstrate flat detector module assembly with new prototype LAT MF module components
- Module testing:
  - Demonstrate each stage of module testing at FNAL, then ramp up SLAC, UIUC sites
  - From L2 Detectors Talk: Spring 2023 first Dark Tests in Flat modules; up to ~ 80 TES/module
    - Demonstrate and characterize end-to-end TES readout with prototype S4 components
    - Characterize dark properties of TES'es, expect to test detector wafers from at least 2 sites in FY23
  - From L2 Detectors Talk: Summer 2023 first Optical tests in Flat Modules; up to ~ 80 TES/module
    - Demonstrate assembly of flat-module with full set of optical module components
    - Demonstrate and characterize optical test setup (window, IR filters) with module
    - Characterize optical response of detector arrays, both total optical efficiency, time constants, and band-passes
  - HTC cryostat: Finalize requirements, compare DR options, start developing "cartoon" closer to concept design



# Summary

- Prototype CMB-S4 module parts are arriving!
  - Detailed ICDs have been developed to meet DRM+SAT/LAT interfaces
  - Prototype module parts are now being delivered, QA'ed and tested, which look promising
  - Flat-module assembly is current bottleneck, but have iterated on bonding and assembly issues, which should be simplified with prototype horn array and coupling wafers now in hand
- Prototype end-to-end detector module testing will begin in FY23
  - Module test-beds are functional and ready for detector module testing, having readout 4K SSAs and 100 mK TES test chips
  - Prototype test equipment (cold load, IR-filtering) seem sufficient for initial module tests
  - Expect first dark module tests in Spring 2023, and first optical detector module tests in Summer 2024





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### 1.05 Module & Testing Update

Module Testing (Anderson):

- Resolved wire bonding issues with the 100 mK prototype RO from SLAC. IV curves from test SO TES devices have been taken.
- Met with SLAC and groups from APC, CEA-Saclay, LPSC-Grenoble to discuss areas of possible collaboration. Main topic of MAT-readout coordination was superconducting flex cables:
  - 5 prototype cables recently delivered by HighTec are in-hand at Fermilab for bonding tests (see right).
  - Following bonding, cables will be distributed to cryostats at SLAC and Fermilab for 4-wire impedance measurements at 100mK. SLAC will perform bending tests.
  - *Key characteristics of interest:* residual resistance at 100mK, wirebond-ability, performance after bend cycles.

UIUC Module testing site (Fillipini):

- DR is commissioned and some automation bugs worked out.
- They have been running the system with old SPIDER hardware to debug issues and train personnel. All systems working, still wrestling with intermittent noise issues.
- Carina (grad student) is now replacing the SPIDER system with S4 parts as they become available. Expect to cool down with SSA hardware this month (SPIDER legacy SSAs + new boards / cables), lower-temperature parts as they arrive.





### **Cryogenic Demonstration of "Flat" Module**

- Currently engaging in a series of cryogenic tests to test the flat-module concept with a dummy wafer to measure performance, e.g.,
  - Overall fit and assembly,
  - Survivability of module components on cooldown (e.g., detector wafer cracks, wire-bond breakage)
  - Thermal gradients across module and wafer with different clamping configurations.





## Adapter Chip Geometry



- What is the thickness of the stiffener to avoid colliding with detector bondpads? 1mm probably safe, but let's measure it.
- Want to specify SiC for stiffener. Use Si chip as backup.



#### **Module Testing Workflow and QA Steps**



QA Steps:

- Suite of production dark and optical tests of modules (next slides)
- Visual inspection of modules post-testing
- Spot-checks of data against reference distributions during testing to check for anomalies, repeat tests if needed





#### **Component and QA Steps Before Handoff to MAT being developed**



#### **MAT Component and QA Steps Before Handoff**



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