Module Assembly and Testing (MAT) [WBS1.05] Status

Bradford Benson (he/him)

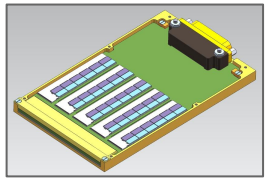
CMB-S4 Collaboration Meeting
May 9-13, 2022

Outline

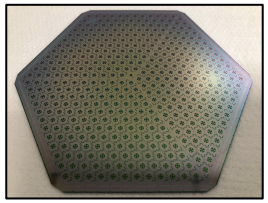
- Overview of MAT Scope
- Technical Highlights and progress made in the last year
- Plans through mid-FY23

MAT WBS Workflow And Scope

1.04.03
Cryo 100mK
Electronics
1.04.03.01 thru 05



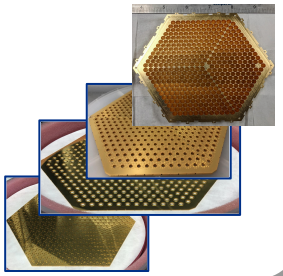
1.03
Detectors
(Detector Wafer)
1.03.02 thru 07



1.05.02
Module Mech.
Structure

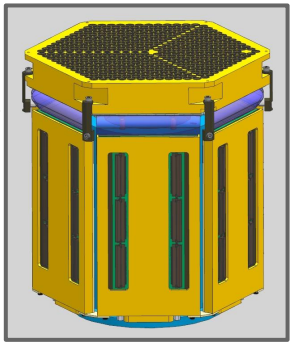
1.05.03.01
Horn Arrays

1.05.03.02
Coupling Wafers

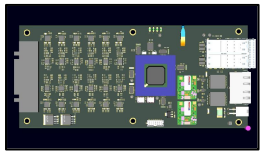


Readout
Detector
Modules

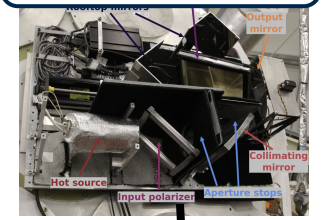
1.05.04
Module Assembly



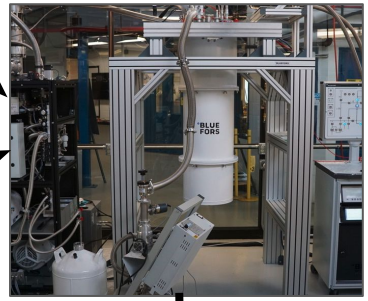
1.04.04 & 05
Cold 4K Electronics
Warm Electronics



1.05.06
Test Equipment



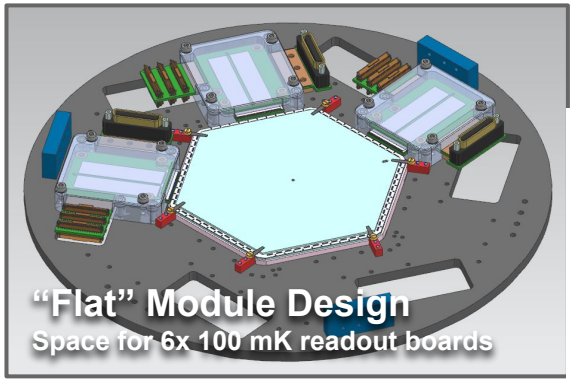
1.05.07
Module Testing

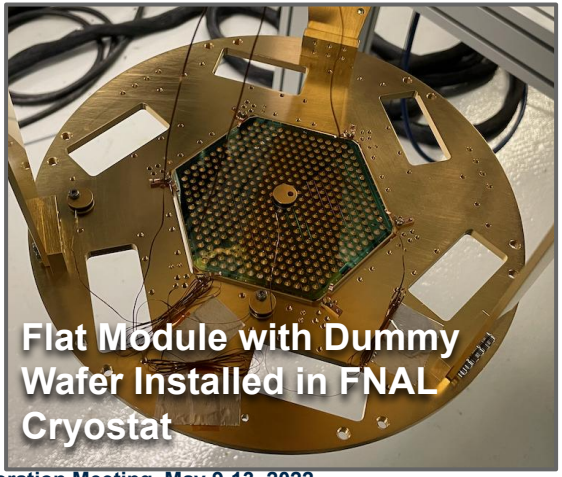


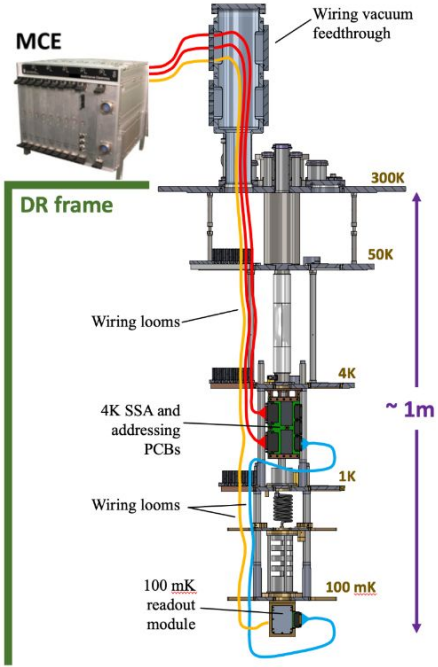
1.06 LAT and 1.07 SAT
Integration and Test in US

Overview of Prototype Development: “Flat” Module Concept

- **Module prototype:**
  - Initial development is focused on the design of a “flat” module to facilitate first “string tests” of prototype detectors and readout.
- **Detector Types/Flavors:**
  - Initial focus on developing LAT MF, SAT MF2, LAT LF types, coordinating with Detectors WBS.
- **Approximate Schedule:**
  - **Summer:** Ramp-up three Module testbeds, focusing on dark module tests.
  - **Fall:** Begin optical tests on LAT MF detector type. Transition from dark to optical tests for SAT MF2 during first half of FY23.







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,
  - Bond-pad layout and sizing; wiring routing
  - Detector-coupling wafer 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

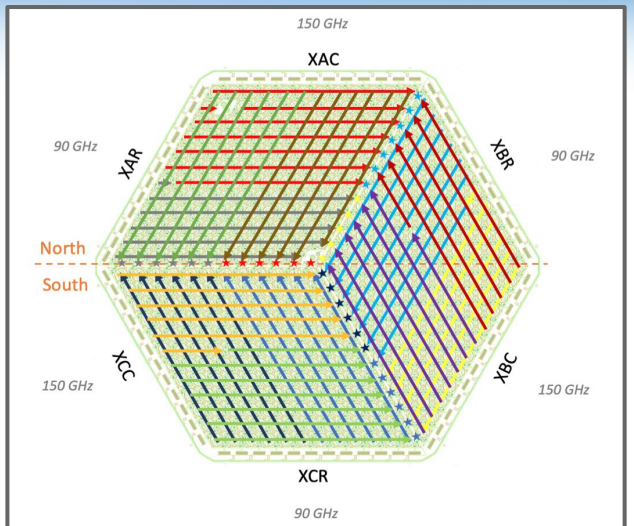


Figure: Detector wafer schematic showing labeling of wafer sides distribution of 90 GHz and 150 GHz bolometer bondpads.

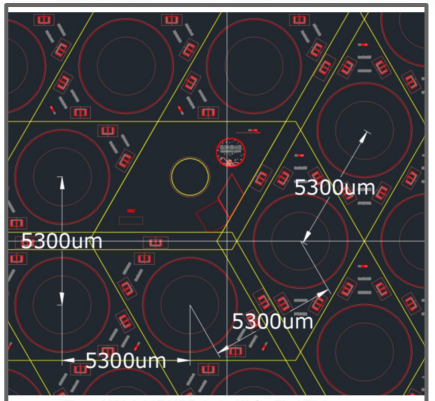


Figure 0030.1: LAT MF Detector Wafer, Pixel Pitch

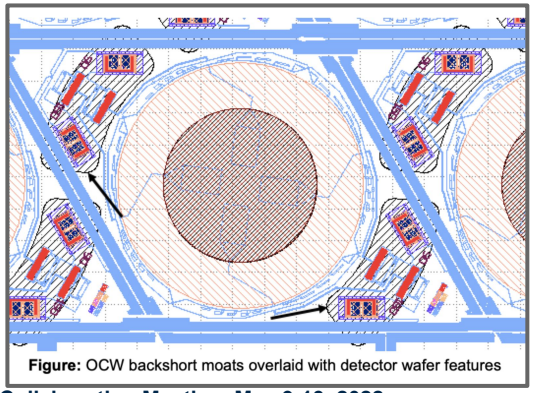


Figure: OCW backshort moats overlaid with detector wafer features

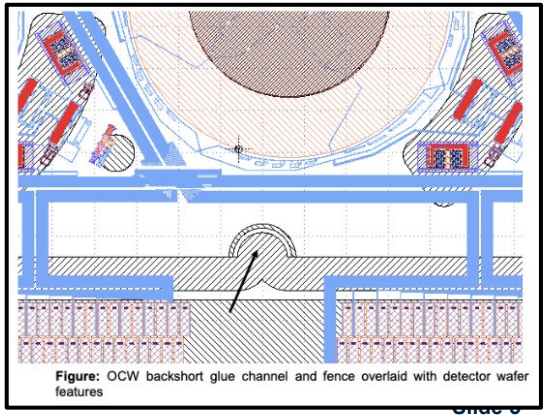
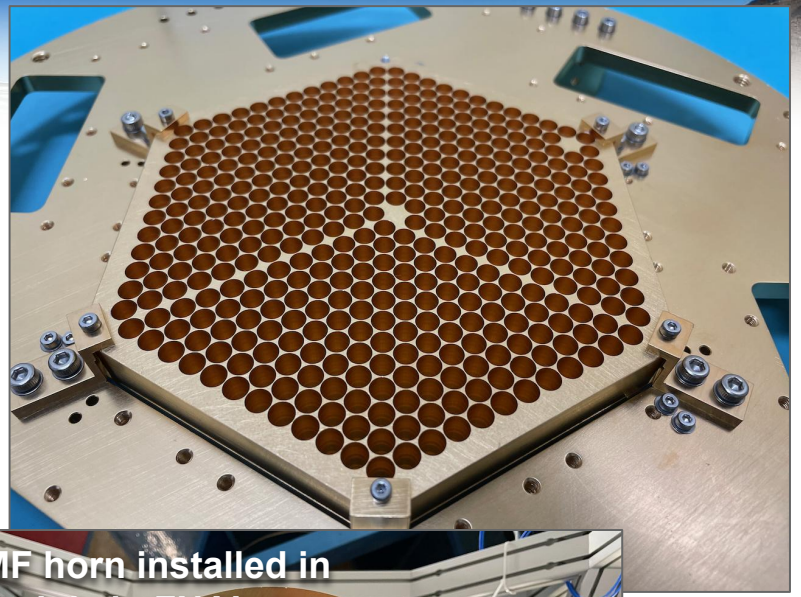
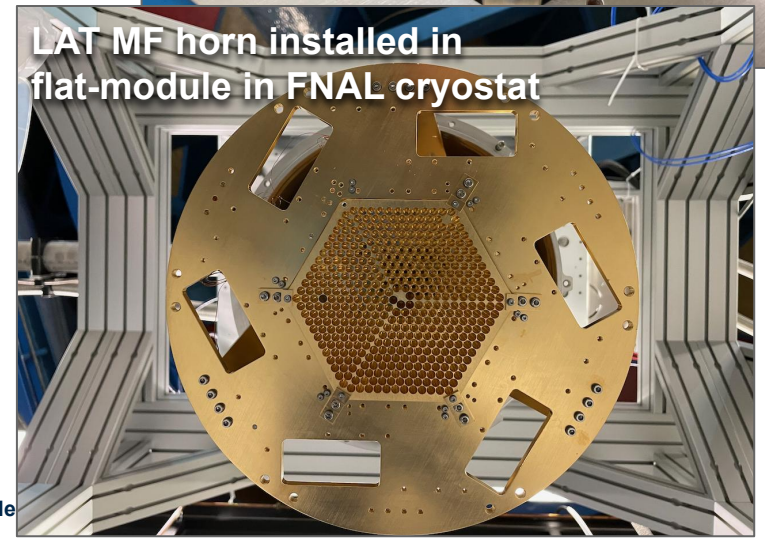


Figure: OCW backshort glue channel and fence overlaid with detector wafer features

Prototype Horn Arrays

- Currently doing a cryogenic and fit test of the module assembly with a pre-prototype LAT MF horn array with a dummy wafer at FNAL.
- In addition, fabrication has begun on a new vendor on a set of 5x LAT MF prototype horn arrays.
  - This aims to verify overall prototype design, and that vendor can meet horn specifications.
  - If successful, next plan to fab a set of 5x SAT-MF2 horn arrays, aiming to begin in Summer 2022.





Prototype Coupling Wafers

- "Coupling wafers" historically have been fabricated by NIST
  - e.g., for SPTpol, ACTpol, SO
  - Typically consists of 3x wafers: Choke, WIP, Backshort
- Working with NIST to develop design, and demo a couple commercial vendors that can scale-up for CMB-S4 needs.
  - Layout complete for LAT MF coupling wafer set (see Figure)
- Ordered a set of 5x LAT MF coupling wafers from new vendor (SeeQC), which should be ready for Module assembly by August.
  - If vendor meets QA specifications, plan to order a set of 5x SAT-MF2 wafers in late Summer 2022

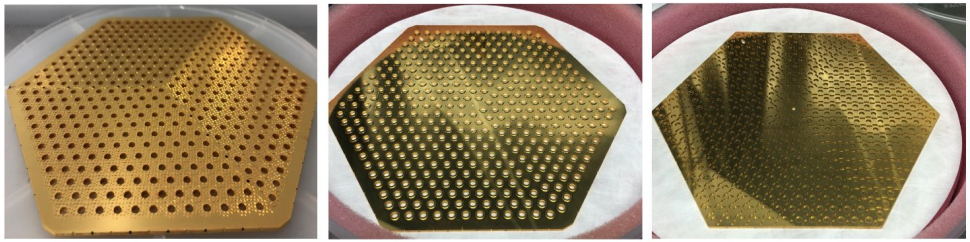
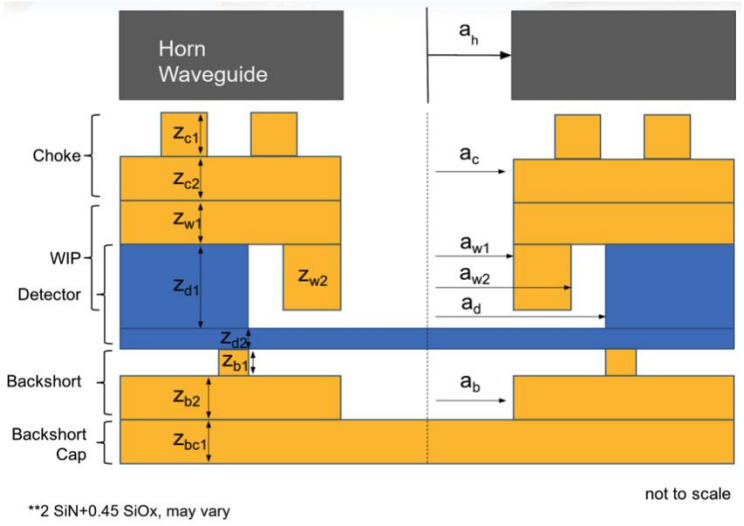


Figure 43: **Left:** A photonic choke wafer. **Center:** A waveguide interface plate. **Right:** A backshort array.

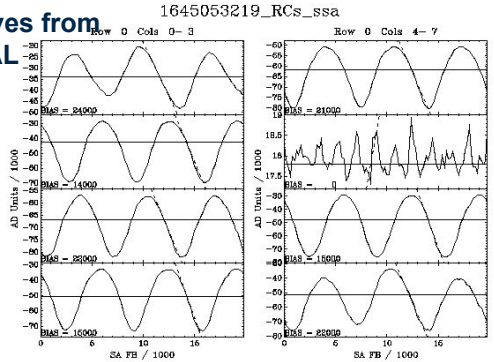


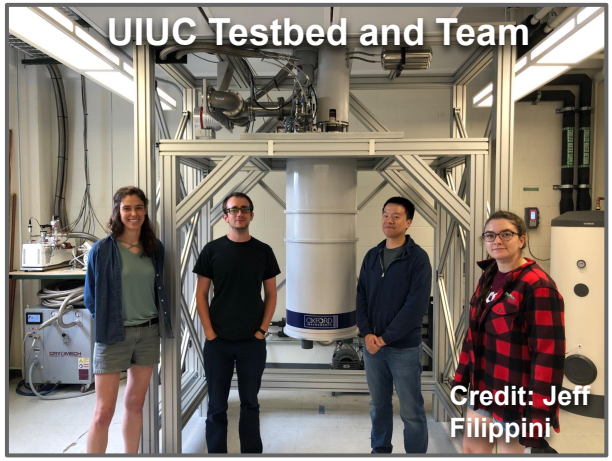
Example of required coupling wafer dimensions needed per horn / OMT (taken from Det-Module ICD)

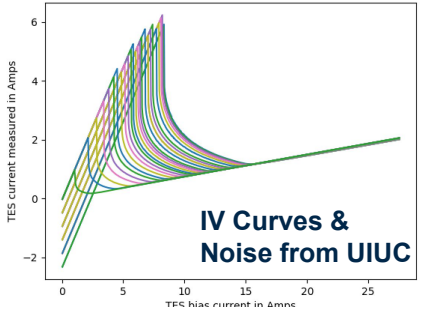
Module Testbeds

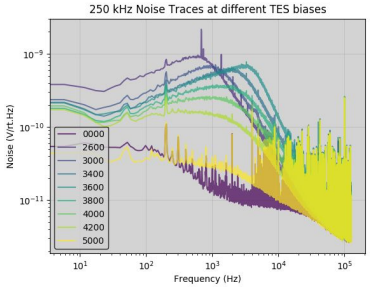
- Fermilab cryostat
  - Successful operation of MCE crate with 4K SQUID arrays, with SQUID performance matching SLAC.
  - Initial cryogenic cooldowns of flat-module with “dummy” detector wafer.
- UIUC cryostat
  - Successfully demonstrated load curves with 4K SQUID arrays, 100mK readout, test TESs using MCE crate
- SLAC cryostat
  - Successful operation of MCE crate with 4K SQUID arrays.

SQUID V-Phi curves from FNAL



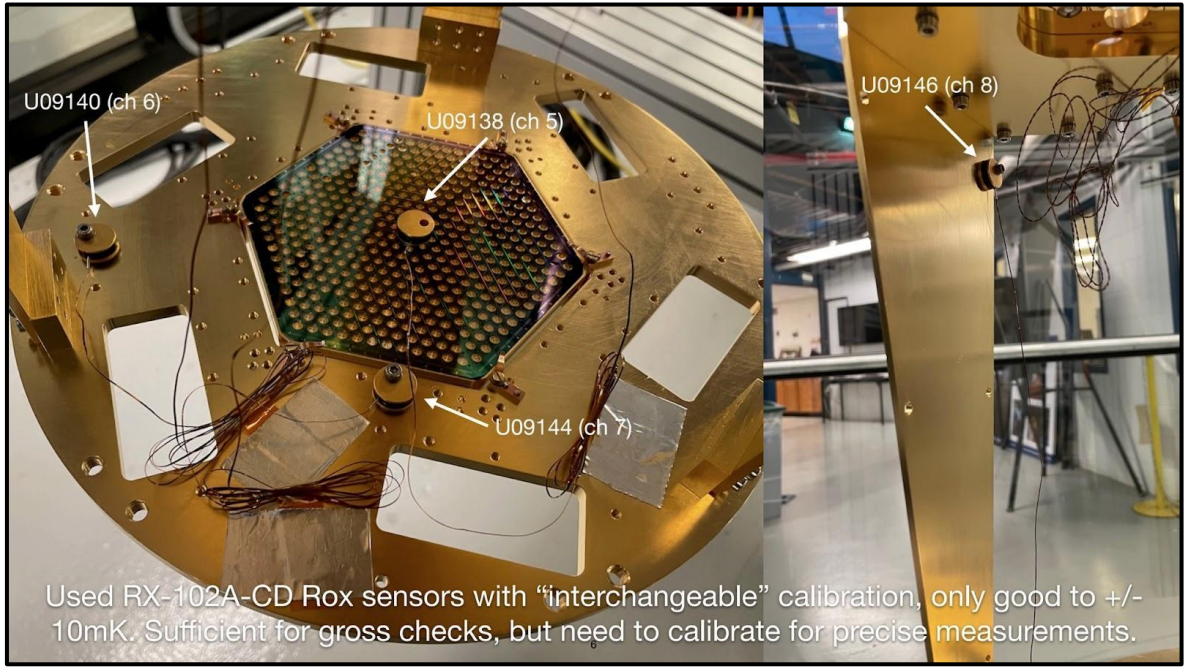






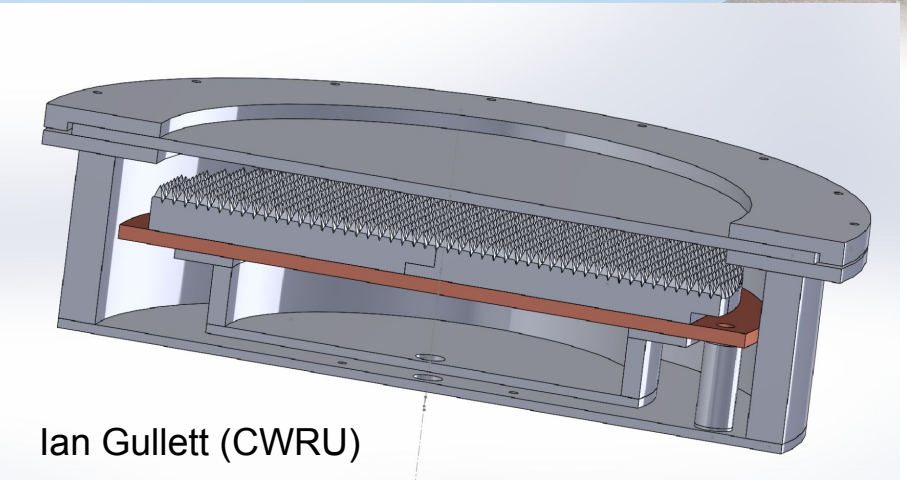
Cryogenic Demonstration of “Flat” Module

- 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.

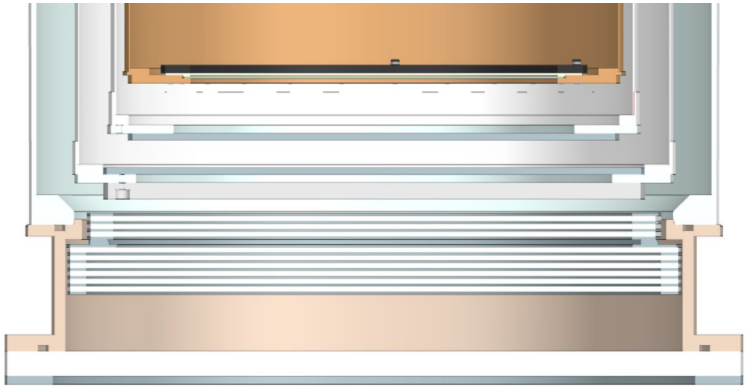


Module Test Equipment

- **Beam-mapper:** Building a warm beam-mapper at FNAL to characterize horn arrays.
  - Status: Assembly at FNAL underway, aim to be online later this summer.
- **Cold-load:** Designing a prototype cold-load for characterizing optical efficiency.
  - Status: Prototype assembly at Case currently underway, with cryogenic-tests at WashU later this summer.
- **Window/IR Filter Stack:** Designing a vacuum window and filter-stack for testbeds.
  - Status: Configuration near-final, aiming for prototype by end of Summer 2022.



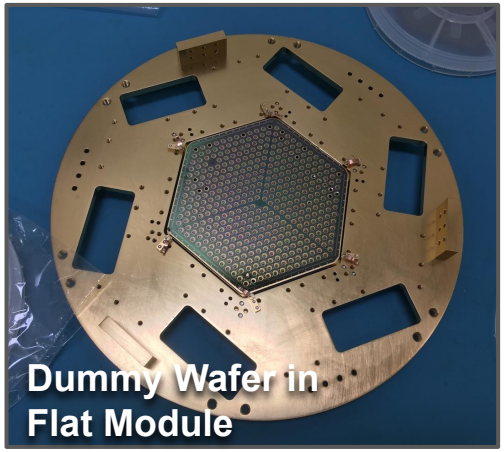
Ian Gullett (CWRU)

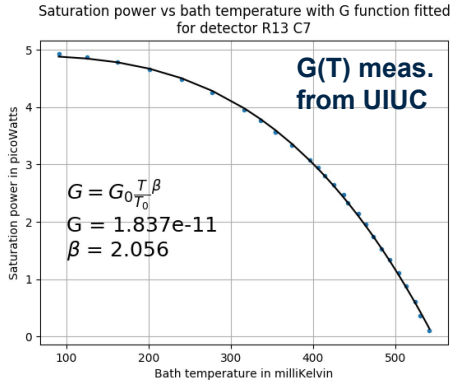


Hemanth Gutti (FNAL)

Notional MAT Dev. & Testing Schedule: Next 6-12 months

- ***Today to end of FY22:***
  - Demonstrate “flat-module” concept, and perform initial DRM string test.
  - Install flat-modules at FNAL, UIUC, SLAC, aiming for testing throughput of at least 1x wafer per 2-months per site
  - Demonstrate vendors for horn array and coupling wafer fab for LAT MF.
  - Focus on LAT MF, SAT MF2 dark testing, with sufficient throughput to test ~6x wafers in FY22.
  - Complete prototype SAT MF2 and LAT LF layout.
- ***First-half of FY23:***
  - FNAL testbed transitions to optical operation; first adding a cold load, then a window/IR filter stack.
  - Measure optical performance of LAT MF module.
  - Begin, then complete, fabrication of horn array and coupling wafers for SAT MF2.
  - Measure optical performance of SAT MF2 modules.

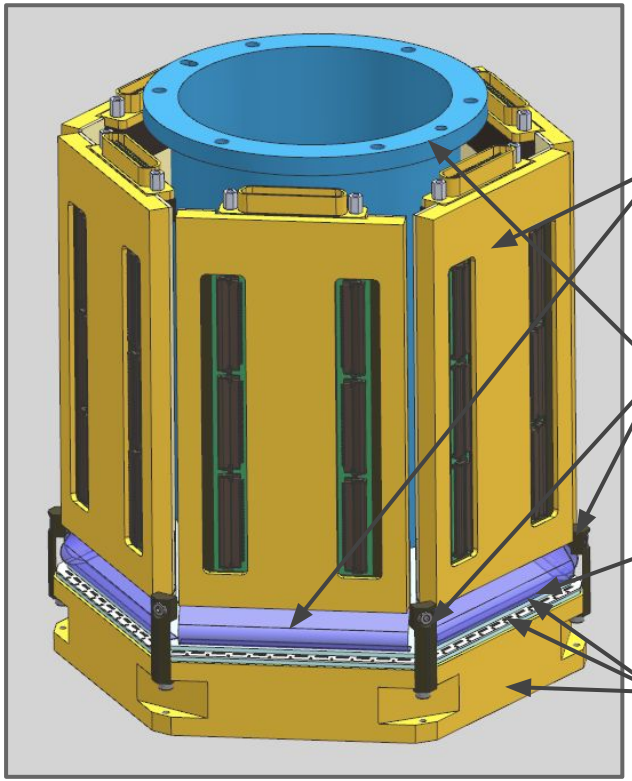




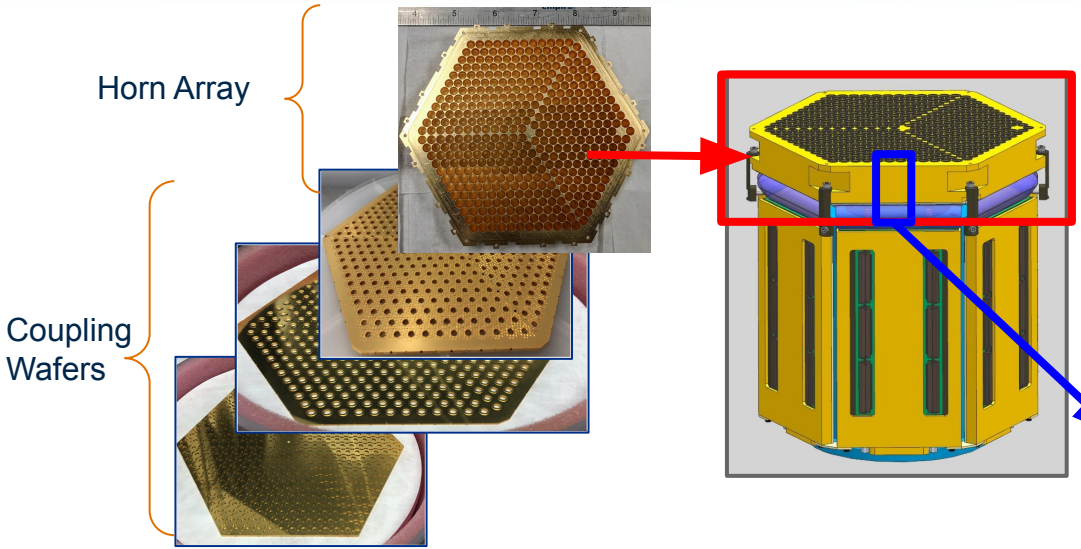
Extras

Module Assembly and Testing (MAT) Scope

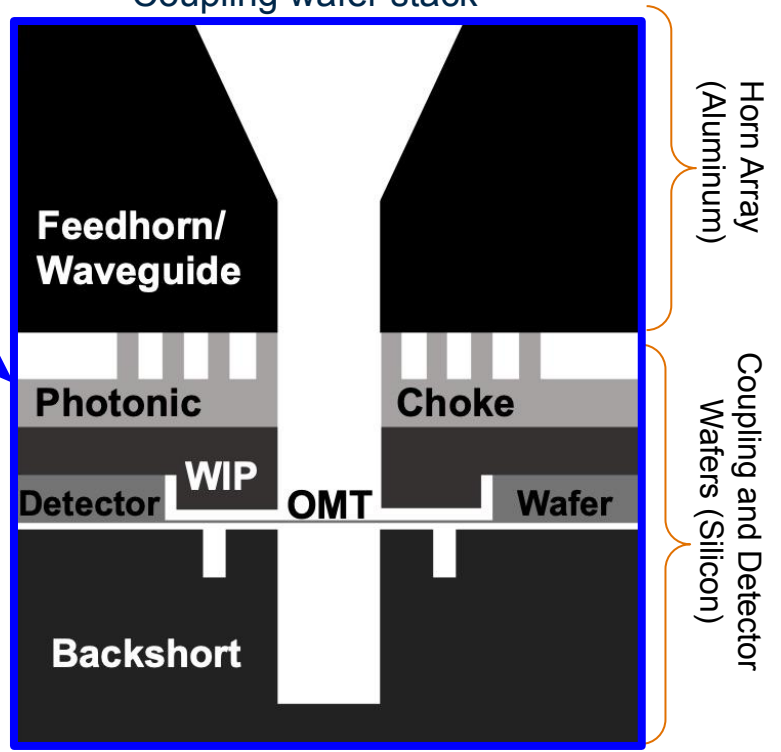
1. **Module structure and assembly**
   - Design “module” that connects Detector, Readout, and Module (DRM) components into one integrated 100mK assembly.
   - Assemble and wire bond components into “testable” detector module.
2. **Optical coupling**
   - Design mm-wave coupling to detector wafer, and build mm-wave coupling components (the feedhorns and coupling wafers)
3. **Module testing**
   - Perform optical and dark tests of integrated module to validate performance of detector module.
   - ***Deliver 471 science-grade detector modules to LAT and SAT groups***



MAT Design: RF Coupling To Detector Wafer



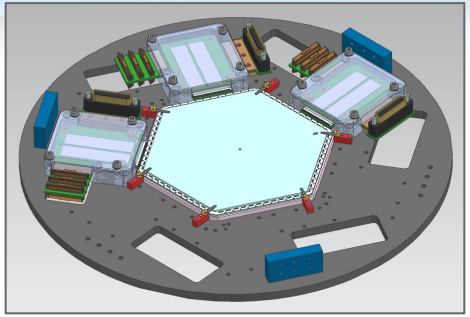
Cross-section of Feedhorn and Coupling wafer stack

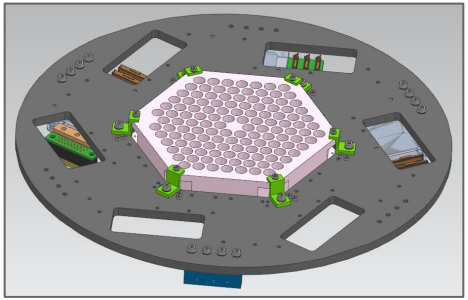


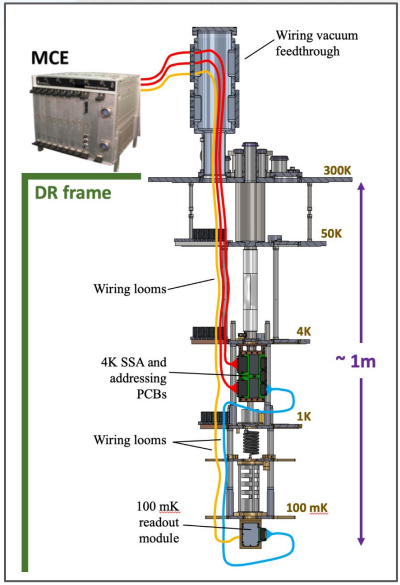
- Mm-wave power coupled to Detector Wafer through an ortho-mode transducer (OMT), effectively an antenna that feeds power to a transition edge sensor (TES) on the detector wafer.
- Power from the sky is coupled to the OMT via an integrated cavity formed by a Horn Array and Interface Wafers.
- Based on heritage design from several previous experiments (e.g., SPTpol, ACTpol, AdvACT, CLASS, SO)

Next Steps Towards CD-1

- **Module prototype:** Design a “flat” module to facilitate first “string tests” of prototype detectors and readout.
- **Interface wafer prototypes:** RFQ to two potential interface vendors to prototype LAT MF and SAT MF2 design.
- **Develop module test sites:** Outfit 4x testbeds with readout and test equipment to characterize and develop integrated detector modules.







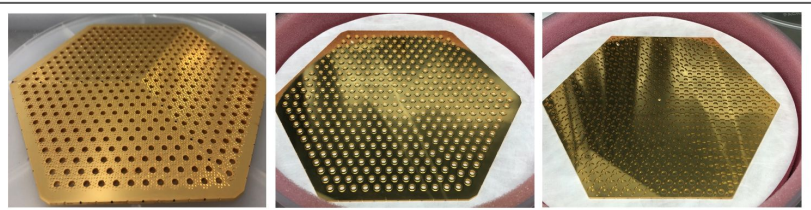
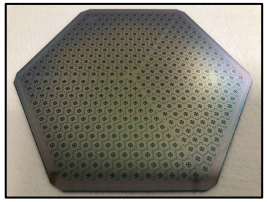


Figure 43: **Left:** A photonic choke wafer. **Center:** A waveguide interface plate. **Right:** A backshort array.

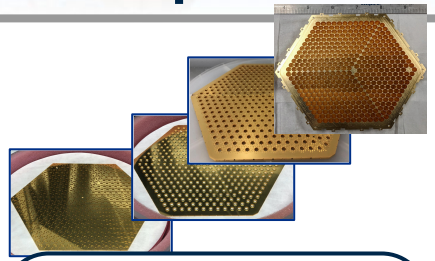
Component and QA Steps Before Handoff to MAT being developed



1.03
Detectors (Detector Wafer)
1.03.02 thru 07

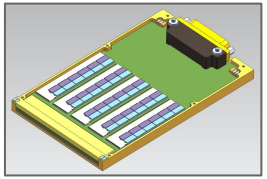
QA Steps:
- In-process tests of Tc, profilometry.
- Test Structures, single pixel array and tests
- Wafer visual inspection
- Warm probe of each TES, measuring resistance, and nearest-neighbor shorts

(08/2020 Review Recommendation)



1.05.03.01
Horn Arrays
QA Steps:
- Visual inspection
- Beam maps of subset of pixels and frequencies
- Profile metrology

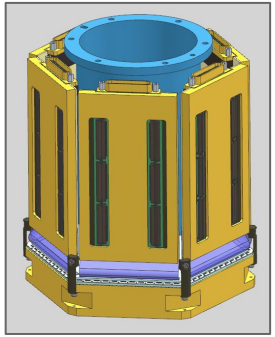
1.05.03.02
Coupling Wafers
1.05.02
Module Mech. Structure
QA Steps:
- Visual inspection
- Micrometer spot check



1.04.03
Cryo 100mK Electronics
1.04.03.01 thru 05

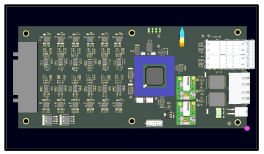
QA Steps:
- Visual inspection of individual components
- Warm continuity measurements
- Cryogenic testing of integrated unit, continuity of ea. channel

1.05.04
Module Assembly



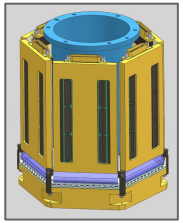
Science Grade Modules handed off to SATs and LATs after testing

MAT Component and QA Steps Before Handoff



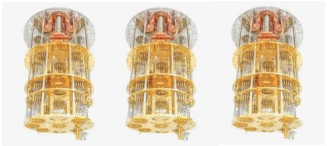
1.04.04 & 05
Cold 4K Electronics
Warm Electronics

QA Steps:
- Visual inspection of individual components
- Cryogenic testing of integrated unit, continuity of ea. channel
- Electrical, network, QA tests of fully populated warm boards



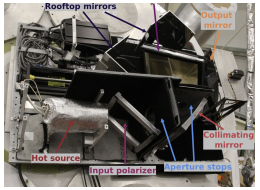
1.05.04
Module Assembly

QA Steps:
- Visual inspection
- Warm probe of full assembly, check resistance and shorts to ground.



1.05.05
High-throughput test cryostats

QA Steps:
- Cryogenic testing (cooldown time, base temp, etc.)
- Tests of wiring
- Test of computer control

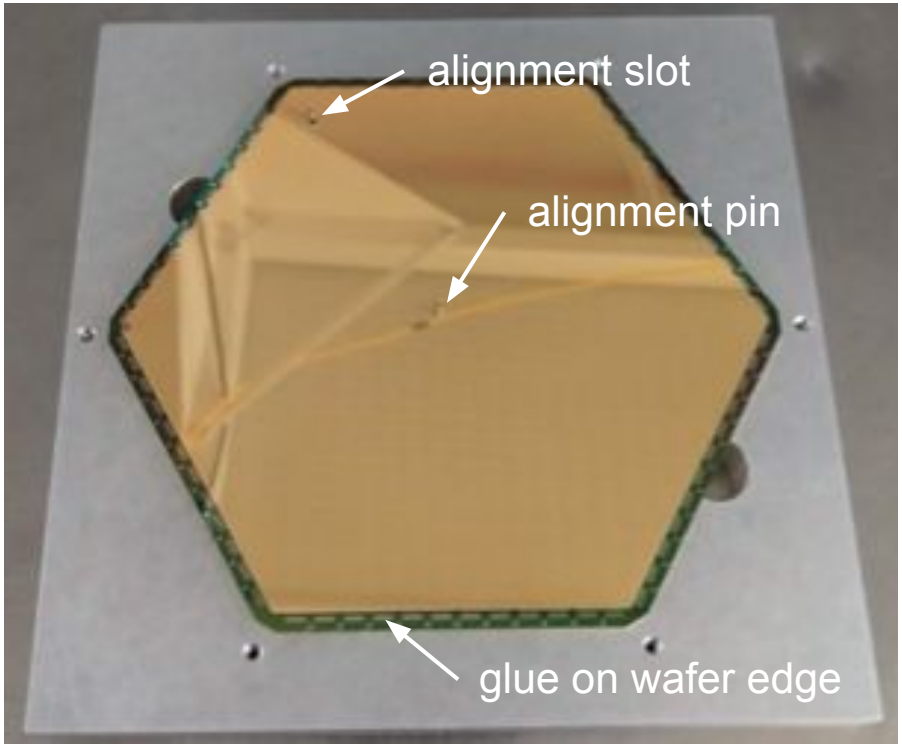


1.05.06
Test Equipment

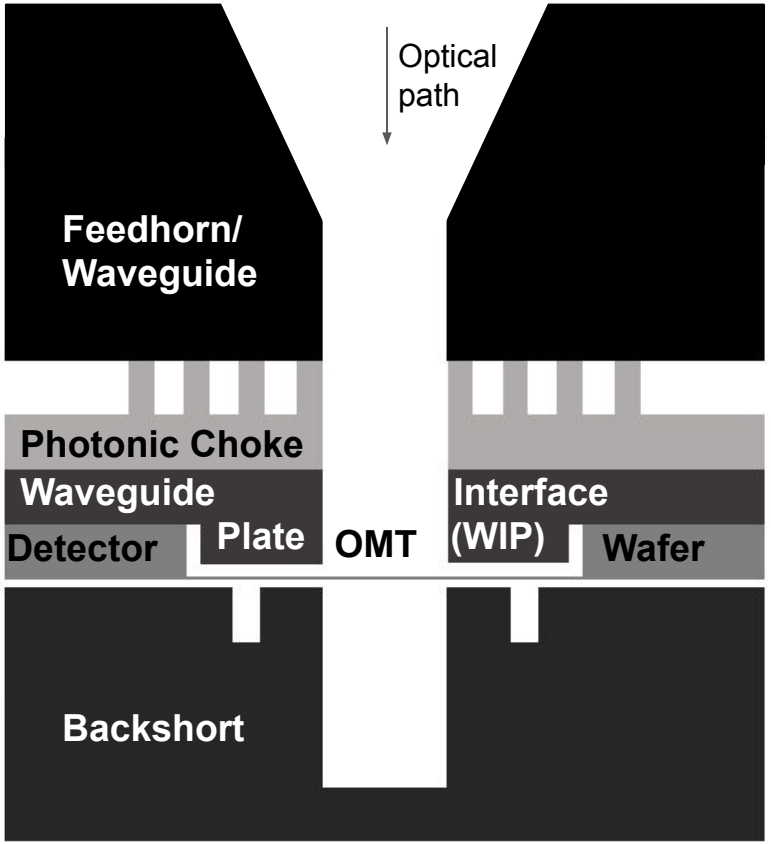
QA Steps:
- Visual inspection
- Test of computer controls, IO, ADC
- Electrical tests

1.05.07
Module Testing

Assembly #1: Feedhorn And Interface Wafers



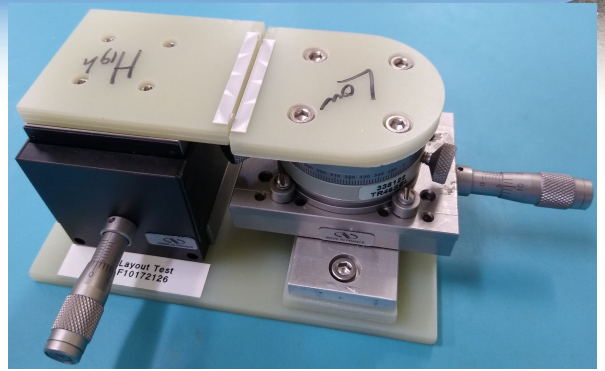
Align wafers with pin and slot in jig, then glue around perimeter



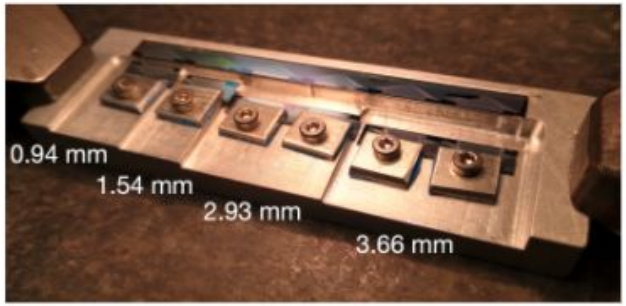
see Optical Coupling talk (S. Simon)

Assembly #2: Wirebonding Flex (MF/HF)

- SAT MF density requires bonding inwards, up on top of backshort
- Wirebond aspect ratios are tight for low frequencies, requiring intermediate step
- Area of ongoing R&D, but early tests (right) for all frequencies are promising



	20 GHz	30/40 GHz	90/150 GHz	220/270 GHz
Bond height [um]	3393	2609	1175	760



All step heights successfully bonded with minimum length/height ratios between 0.65 and 0.82