Penn Array Receiver Detector Array IPR - July 31, 2006

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Penn
University of Pennsylvania

PAR-GBT Detector Array

Outline

- Detector Array Context
- Desired Performance
- Detector Array Design
- Associated Components
- Fabrication & Verification
- Some Results
- Thoughts on the Future

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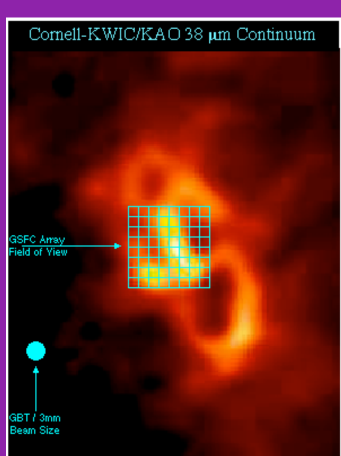
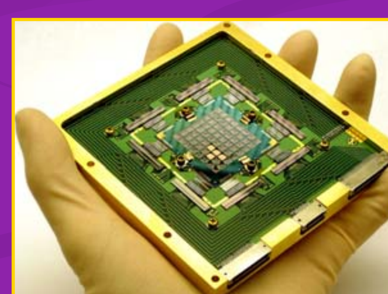
GBT 3mm Camera

U.Pennsylvania, NASA/GSFC, NRAO, U. Wales - Cardiff

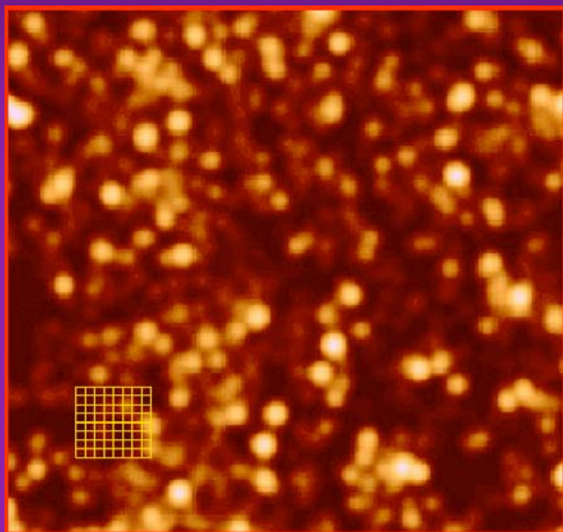
- First NRAO bolometer camera
- Sensitivity ~500μJy in 1 s
- Great for extragalactic surveys
- Can do amazing Galactic science



- 3.3mm wavelength - 8x8 array
- Features 64 pixels = 32''x32'' FOV, with 8" resolution



Detector Overview

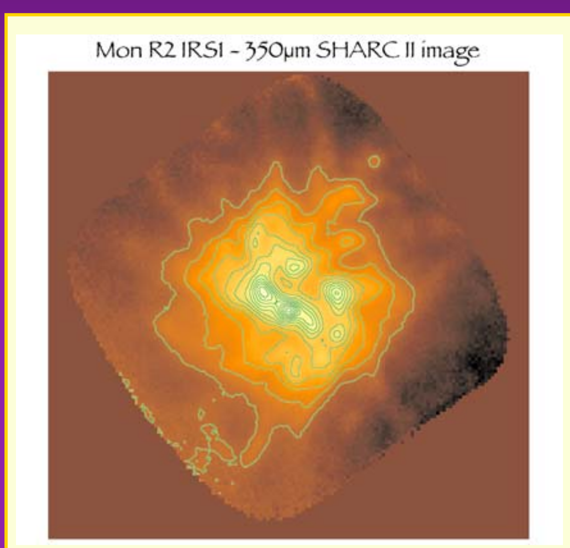


Cartoon simulation of PAR image of distant galaxies in one shift observation.

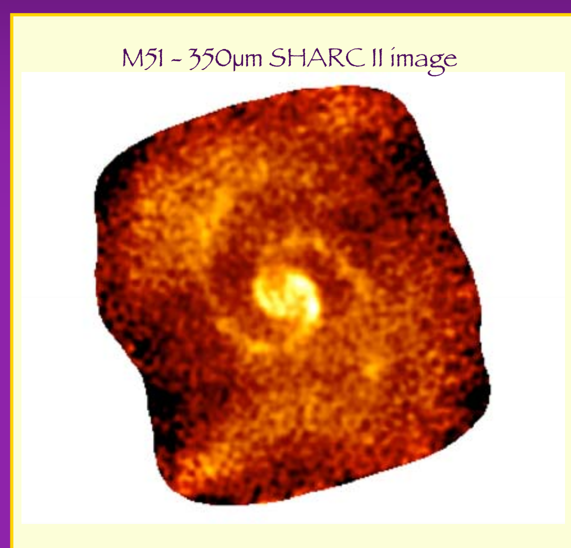
- Detector system for the Penn Array Receiver is a superconducting transition edge sensor (TES) bolometer array and readout electronics
- Made at NASA/GSFC; 64 pixels, close-packed 8x8 for 32''x32'' image
- Operating wavelength of 3.3mm (beam 8'')
- Read out by a super-conducting quantum interference device (SQUID) amplifier, produced at NIST/Boulder

The Power of Large Arrays

Images from SHARC II on CSO



Data taken with $\tau_{350\mu m}$~3



Data taken with $\tau_{350\mu m}$~1

Detector Development Laboratory

Unique devices conceived and developed

- Microshutters (JWST)
- Large-format bolometers (SAFIRE, future)
- Micromachined x-ray calorimeter (Astro-E2)
- Silicon CCD imager (SAGE, GAMS)
- Cross delay line (SOHO)
- Silicon bridge chips (IRAC, HAWC, SHARC)
- Low noise Si JFETs (GP-B)
- Internal reference source(COBE,SIRTF)
- 1K x 1K GaAs QWIP (ESTO NRA)
- High Meg SiCr resistors (HAWC, SHARC)
- Thinned Si JFETs
- Silicon pop-up detector array (SHARC, HAWC)
- HgCdTe PC detector array (CIRS/Cassini)
- TES detector (Con-X, SAFIRE, SPIRE)

Historical Context

- Conceptual Design Review in Nov 2001
  - Focus on TES noise performance; readout electronics development
  - Detector development funded by NASA planar array funds
- PDR? in Dec 2002
  - Still working fundamentals of TES on SiN_X
- Critical Design Review in Oct 2003
  - Mechanical models working; much to be done (thermal/noise performance, electronics, software)
  - Development funded by internal GSFC sources

Context

Personnel

GSFC:

- Troy Ames (IRC software)
- Dominic Benford (design & implementation)
- Ernie Buchanan (cryo-address driver)
- Jay Chervenak (detector fabrication)
- Josh Forgione (warm electronics)
- Steve Maher (IRC software)
- Harvey Moseley (project overview)
- Johannes Staguhn (detector testing)

NIST:

- Kent Irwin (SQUID Mux)
- Carl Reintsema (electronics)

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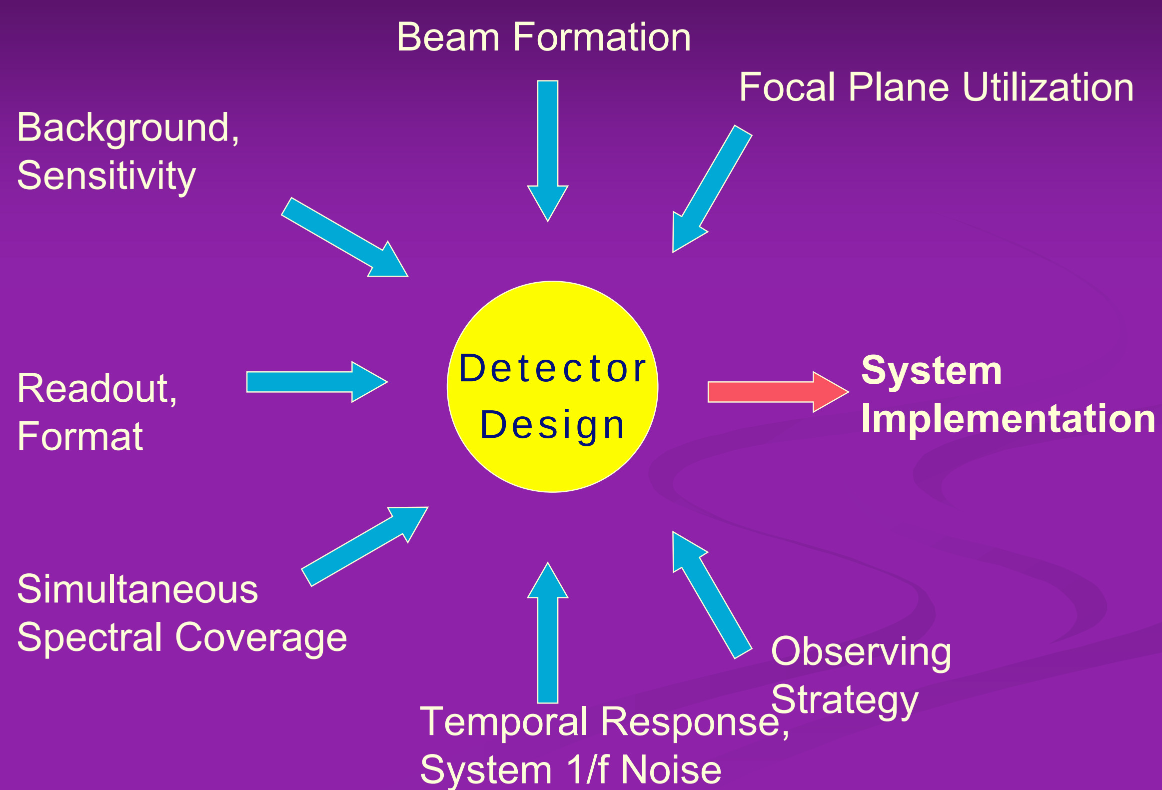
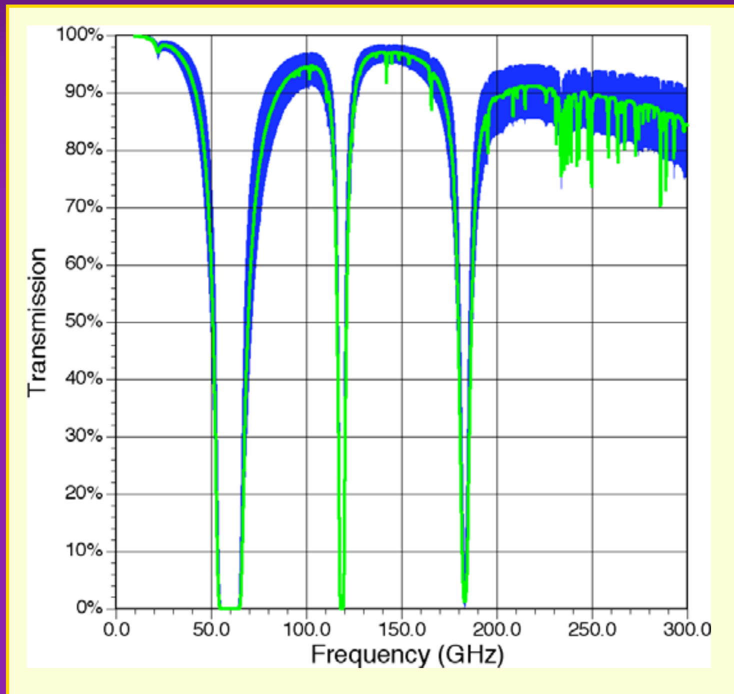


Filled Arrays = Feedhorns

- An ideal imager detects all the photons incident on a focal plane and determines their positions.
- A filled array with $\lambda/2d$ pixel spacing is a good approximation to this ideal.
- For unknown source locations, *a $\lambda/2d$ filled array maps faster than a feedhorn array.*

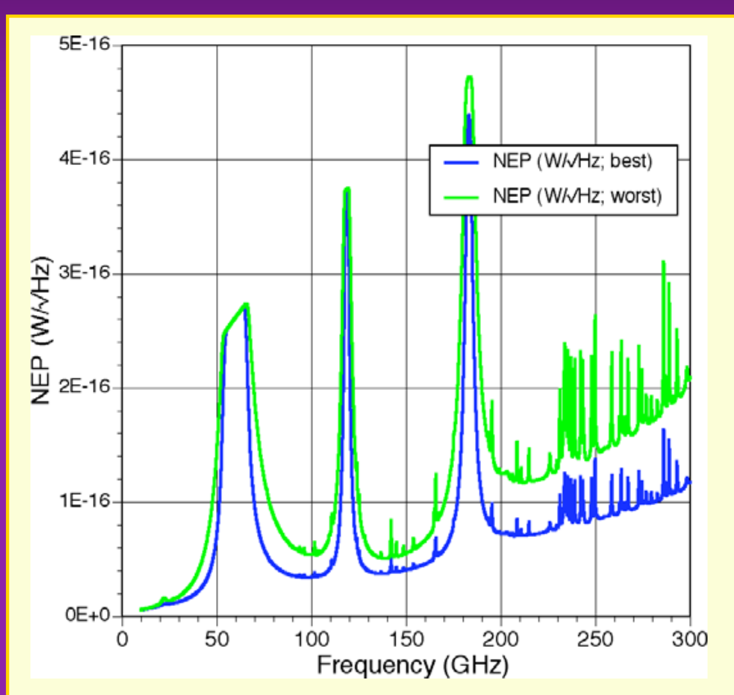
Performance

Atmospheric Transmission @ GBT



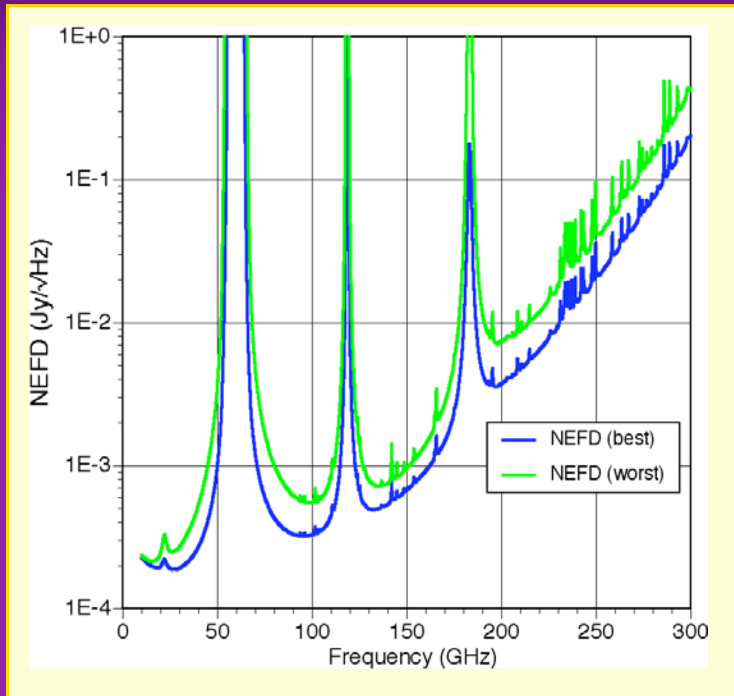
Performance

Atmosphere+Telescope Photon NEP



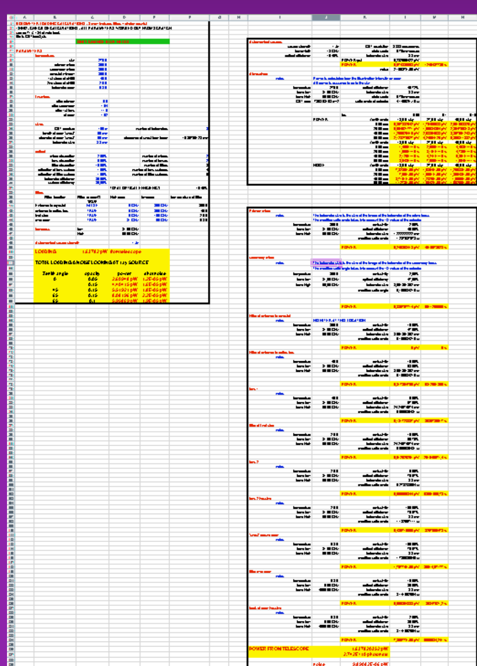
Performance

NEFD of Bolometer on GBT



Performance

Bolometer Loading Calculator



- Complete description of optical system
- Gives power and photon noise
- Includes source flux

tau	0.05	0.1	0.15
Zenith angle	13.5 K sky	27.0 K sky	40.5 K sky
0.00 deg	0.897332942 pW	1.79466588 pW	2.691998825 pW
20.00 deg	0.954921771 pW	1.90984354 pW	2.864765313 pW
45.00 deg	1.269020416 pW	2.53804083 pW	3.807061248 pW
65.00 deg	2.123270627 pW	4.24654125 pW	6.369811882 pW
Zenith angle	13.5 K sky	27.0 K sky	40.5 K sky
0.00 deg	1.499E+10 /s	2.999E+10 /s	4.498E+10 /s
20.00 deg	1.595E+10 /s	3.191E+10 /s	4.786E+10 /s
45.00 deg	2.120E+10 /s	4.241E+10 /s	6.361E+10 /s
65.00 deg	3.548E+10 /s	7.095E+10 /s	1.064E+11 /s
Zenith angle	13.5 K sky	27.0 K sky	40.5 K sky
0.00 deg	1.47E-17 W/√Hz	2.1E-17 W/√Hz	2.54E-17 W/√Hz
20.00 deg	1.51E-17 W/√Hz	2.1E-17 W/√Hz	2.62E-17 W/√Hz
45.00 deg	1.74E-17 W/√Hz	2.5E-17 W/√Hz	3.02E-17 W/√Hz
65.00 deg	2.25E-17 W/√Hz	3.2E-17 W/√Hz	3.91E-17 W/√Hz

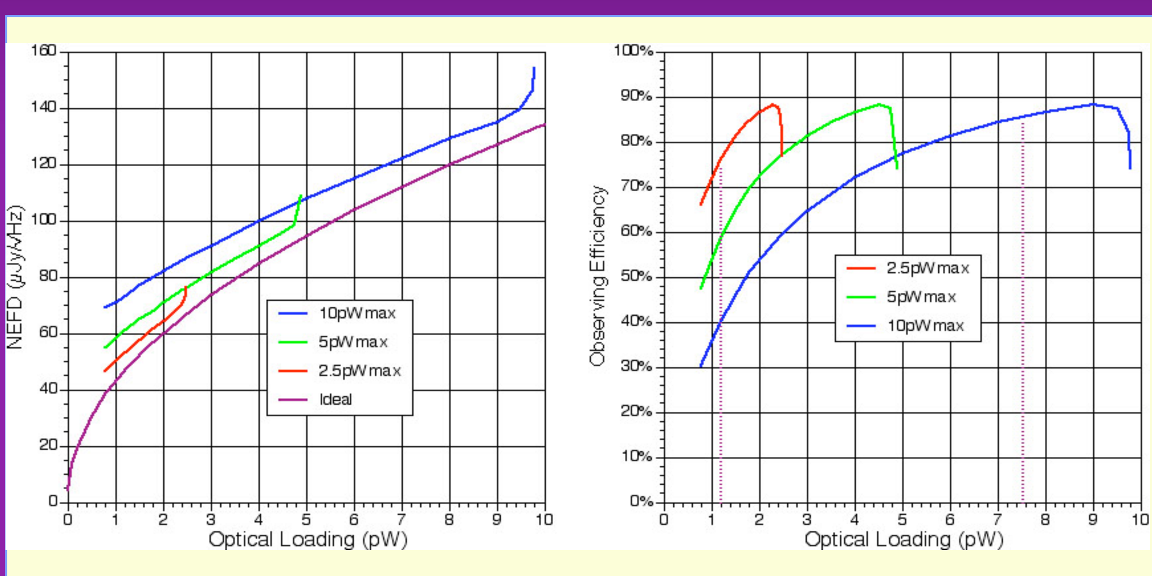
Performance

Detector Calculator

A	B	C	D	E	F	G	H	I	J
Multiplexed Readout Calculator									
DjB 02/06/25; revised 02/07/30 & 02/10/19									
R_N	normal state resistance	100	mΩ			5e-17=sqrt(2Phnu)			
P_max	optical loading (max)	8.1	pW			0.628835899			
λ	Wavelength	3300	μm						
NEP_photon	photon noise	5.02E-17	W/√Hz	9.59201E-17		P_extra	Power factor (sat/max)	1.3	
T_C	Transition temperature	375	mK						
T_bath	Bath temperature	270	mK			B	Bias point	10%	
NEP_phonon	Phonon noise	1.73E-17	W/√Hz			R_bias	Resistance at bias	10	mΩ
NEP_det-etf	ETF Total Noise					P_sat	Saturation power	10.53	pW
						V_bias	detector bias setpoint	0.32449961	μV
V_bias	detector bias voltage	0.0200	V			I_bias	nominal bias current	32.4499615	μA
R_load	load resistance	100	Ω			P_heat	bolometer heater power	0	pW
R_shunt	detector shunt resistance	2	mΩ			P_opt_max	maximum optical power	9.477	pW
V_TES	voltage across TES	0.01	μV			P_opt	optical power	8	pW
P_bias	bias power	8.1	pW	(assuming zero optical input)		R_operating	operating resistance	41.6205534	mΩ
R_bias	resistance at bias point	0.012345679	mΩ						
S	Responsivity	1.00E+08	A/W	(approximation)		S	Responsivity	3.08E+06	A/W
NEP_Johnson	Johnson noise current	1.29E-09	A/√Hz			NEP_Johnson	Johnson noise current	2.23E-11	A/√Hz
	Johnson noise power	1.29487E-17	W/√Hz	(approximation)			Johnson noise power	7.24E-18	W/√Hz
NEP_Detector	Detector noise power	2.16E-17	W/√Hz			NEP_Detector	Detector noise power	1.02E-17	W/√Hz
	Detector noise excess	9%		(over photon only)		NEP_phonon	Phonon noise	1.97E-17	W/√Hz
						NEP_front	Front end noise	5.07E-17	W/√Hz
M_in1^-1	SQUID #1 input inductance	6.5	μA/Φo						
M_fb1^-1	SQUID #1 feedback inductance	76	μA/Φo			M_in1^-1	SQUID #1 input inductance	6.5	μA/Φo
R_fb	Feedback resistor	5.11	kΩ			M_fb1^-1	SQUID #1 feedback inductar	76	μA/Φo
V_out/I_in	transfer resistance	59.75	kΩ			R_fb	Feedback resistor	5.11	kΩ
L_Nyquist	Nyquist inductor	2.5	μH			V_out/I_in	transfer resistance	59.75	kΩ
I_N1 , Detecto	Current noise into stage 1	332.49	μΦo/√Hz			L_Nyquist	Nyquist inductor	1	μH
I_N1 , SQUID	Current noise from SQUID 1	20.00	pA/√Hz	3.07692E-06		I_N1 , Detector	Current noise into stage 1	24.04	μΦo/√Hz
I_N1 , SQUID	Current noise from SQUID 1	1	μΦo/√Hz			I_N1 , SQUID	Current noise from SQUID 1	20.00	pA/√Hz
N	Number of muxed inputs	32				I_N1 , SQUID	Current noise from SQUID 1	1	μΦo/√Hz
I_N1	Total stage 1 noise	332.54	μΦo/√Hz			N	Number of muxed inputs	8	
	SQUID noise excess	0%		(over Detector only)		I_N1	Total stage 1 noise	24.39	μΦo/√Hz
τ_electrical	L/R time constant	2.0E-01	s				SQUID noise excess	1%	
τ_thermal	Min. thermal time constant	1.2E+00	s			τ_electrical	L/R time constant	2.4E-05	s
f_switch	Mux switch rate	0.2	kHz	6328.125	μs	τ_thermal	Min. thermal time constant	1.4E-04	s
f_frame	Mux frame rate	0	kHz			f_switch	Mux switch rate	333.0	kHz
τ_address	Max. address risetime	632813	ns			f_frame	Mux frame rate	42	kHz
						τ_address	Max. address risetime	300	ns
I_N1 (A)	Total current noise	2161.52	pA/√Hz	(referred to input)					
V_N1	Total voltage noise	129.15	μV/√Hz			f_t	time reduction factor	0.48057549	
Signal Conversion		5.98	V/pW	(approximate)		N_excess	All noise / Photon Noise	1.036	
Dynamic Range		20822	per frame						
Bits		17							

Performance

Sample Calculator Output



Desired Specifications (I)

Required Parameter	Specification: Goal Minimum	Derivation
Array format	8x8 8x8	Field of view desired; convenience of multiplexer format
Pixel size	~3.3mm ~1.7mm	Coupling size scale of ~λ
Filling factor	95% 80%	Focal plane utilization
Optical Efficiency	80% 40%	Point source sensitivity
Wavelength of response	3.3mm	Bandpass from 3.0-3.7mm
Response time	20ms 5ms	Telescope slew speed modulating signal flux.

Desired Specifications (II)

Required Parameter	Specification: Goal Minimum	Derivation
Saturation Power	12pW 8pW	Optical loading prediction of ~8pW max.
Noise Equivalent Power	$1 \cdot 10^{-17}$ W/√Hz $3 \cdot 10^{-17}$ W/√Hz	Photon noise predicted to be ~$3 \cdot 10^{-17}$ W/√Hz at P_{sat}
Stability of base temperature	64nK/√Hz 191nK/√Hz	Equivalent sky flux noise
Adjacent pixel crosstalk	10%	Optical correlation
Power dynamic range	15 7.5	Min/Max optical loading
S/N dynamic range	$6 \cdot 10^{5}$ $2 \cdot 10^{5}$	Ratio of photon power to photon noise
Operating temperature	450mK 300mK	Capability of ^{3}He fridge

PAR-GBT Detector Array

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Elements of Detector Array Subsystem

1. Good superconducting transition edge sensors
2. A good mechanical implementation for bolometer
3. A good amplifier with multiplexing
4. A way to integrate the detectors and the amplifiers compactly
5. Capable readout electronics
6. A good system design

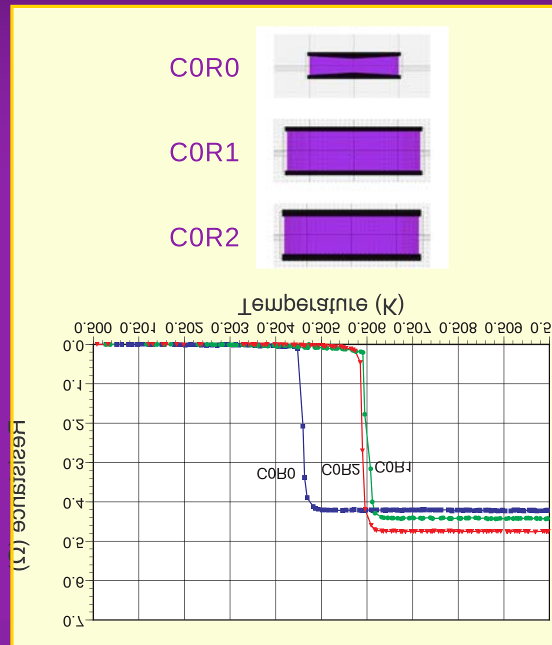
Design

First: the TES

- Need to have a sharp transition between states
- Need low stray series resistance
- Need repeatability

$$R(T) \sim \frac{R_N}{2}\left[\tanh\left(\pi\alpha\left(T - T_C\right)\right) + 1\right]$$

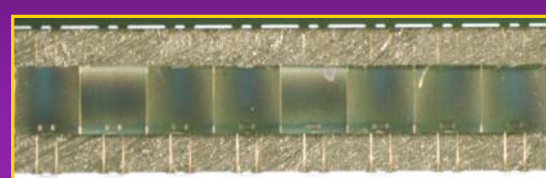
$$\therefore\ \alpha \approx \frac{T_C}{R_N}\left(\frac{0.8\,R_N}{T_{90\%} - T_{10\%}}\right)$$



Design

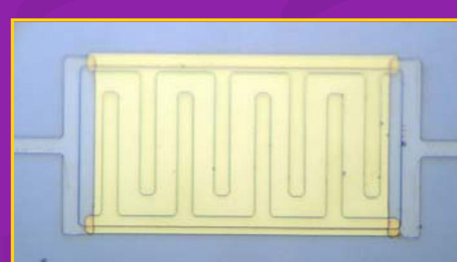
TES Bolometers

- Thermally isolated structure with absorber to yield proper phonon noise & saturation power



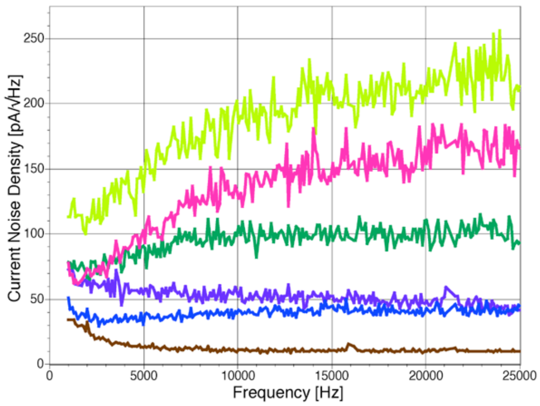
Above: 1x8 array of TES bolometers

Below: Enlargement of GBT TES

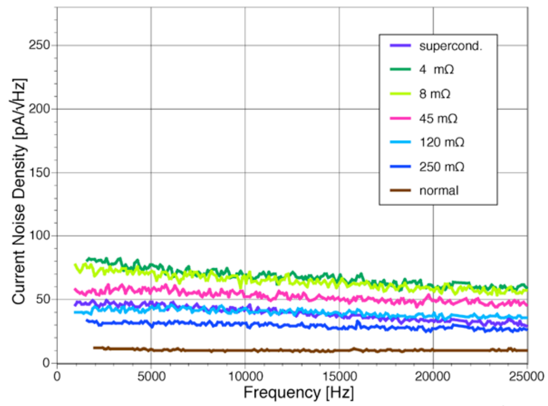


Design

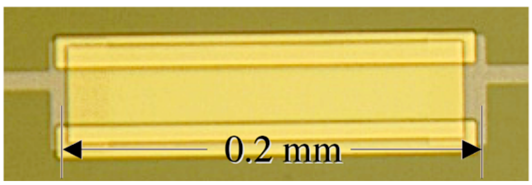
TES Noise

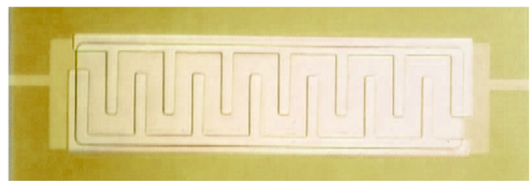


Bars parallel to current path



Bars transverse to current path





Noise better with right geometry

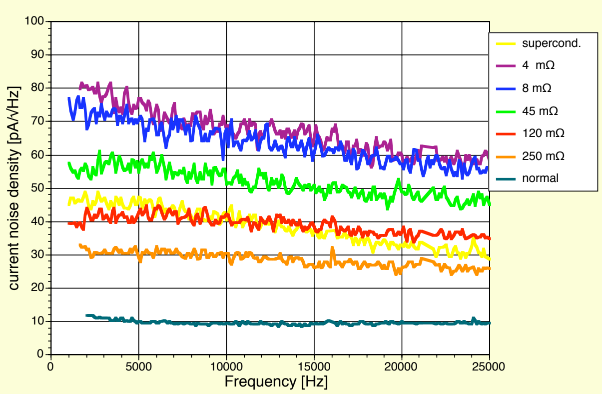
See, e.g., Staguhn et al., NIMPRA, 2003

Design

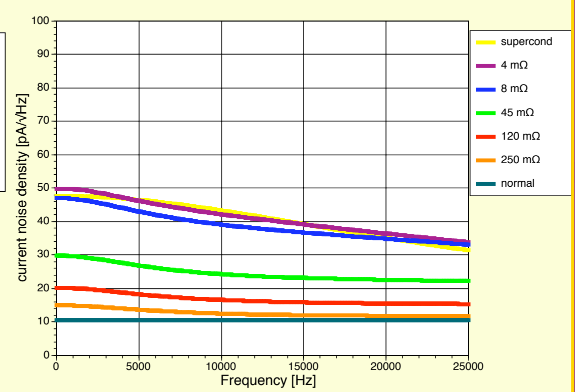
Phonon-Limited Performance

Mo/Au TES noise data compared with modeled noise
(including phonon, Johnson, SQUID, aliasing)

Measurement



Theory

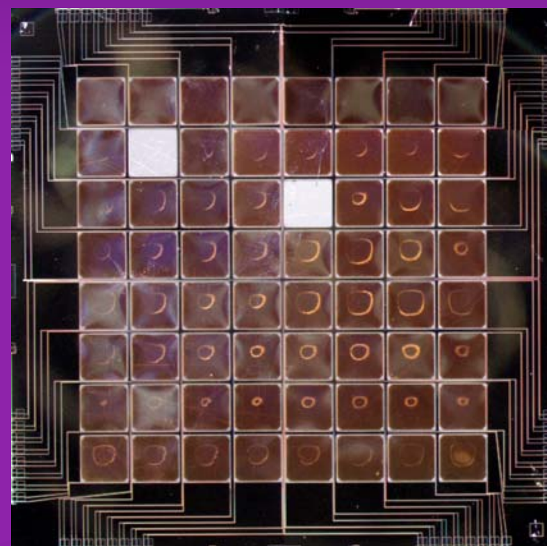


TES Detectors can be made with close to ideal performance

See, e.g., papers by Staguhn et al. 2003 and Benford et al. 2003 in *NIMPR-A*.

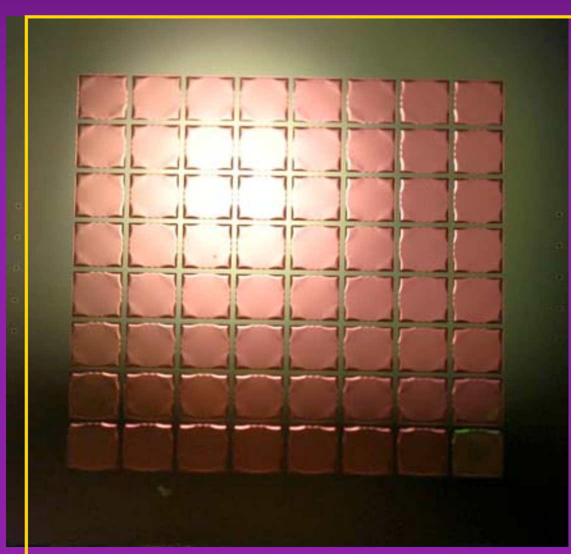
2. Planar Array Mechanical Design

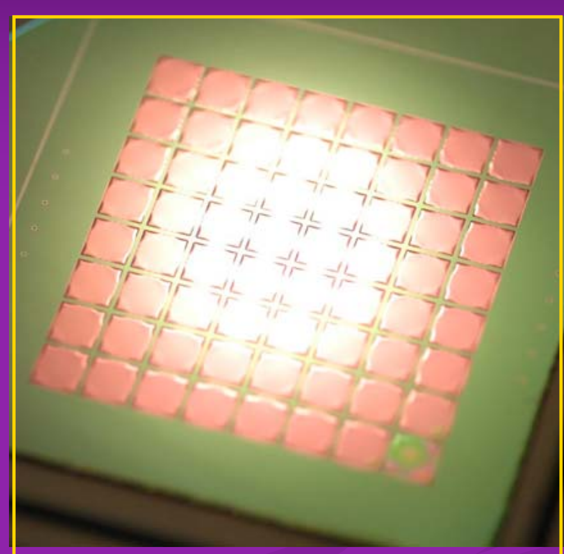
- Close-packed geometry in a planar format
- 80% optical filling factor
- Mechanically tricky to get close packing + thermal isolation
- Wiring tricky too



First mechanical prototype in Si

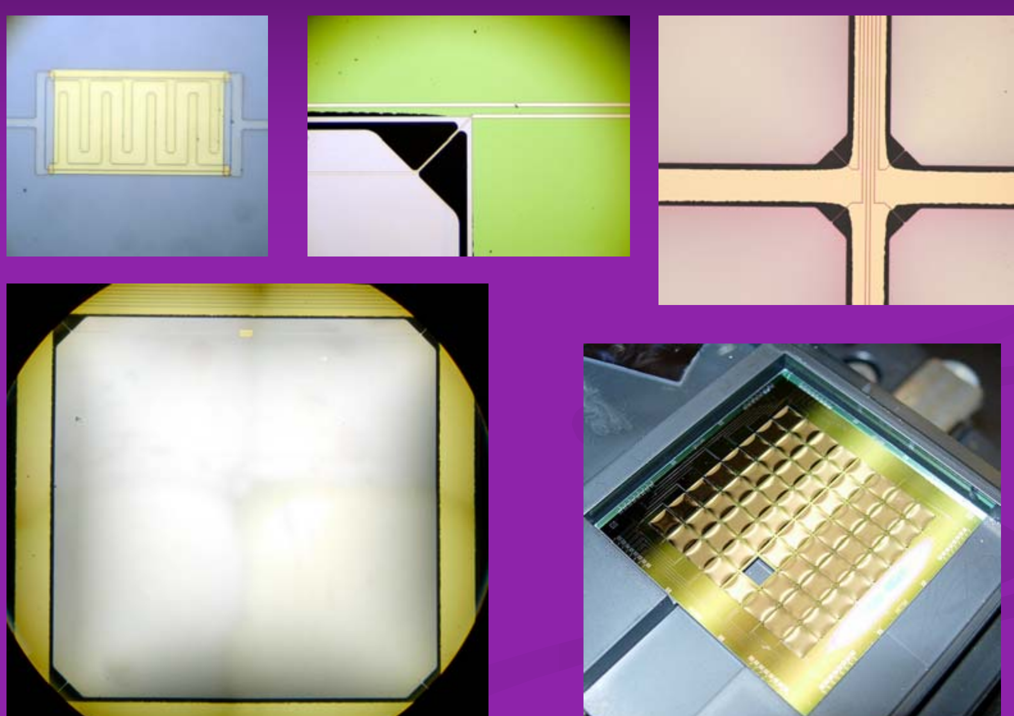
Mechanical Model 8x8 Array





Early 8x8 Array Design

Detector Pixel Design



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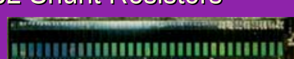
Cryogenic Detector Components

All detector components have been produced:

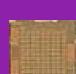
- 8x8 TES Bolometer Array
- 1x32 Nyquist Inductors

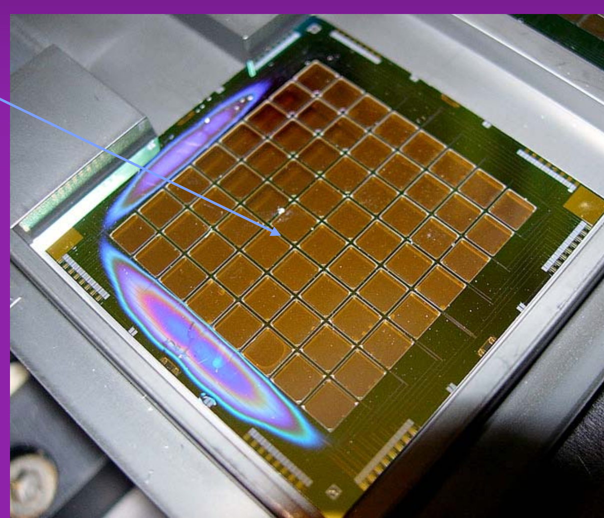
- 1x32 Shunt Resistors



- 1x32 SQUID Multiplexers

- SQUID Series Array Amplifiers





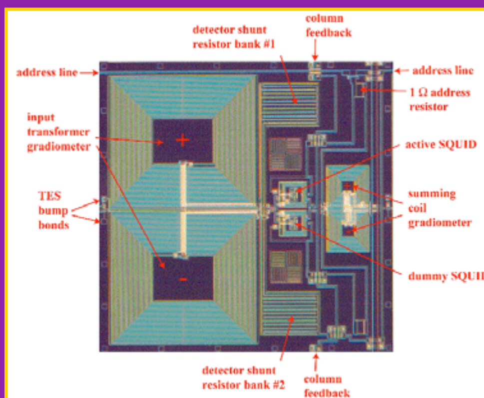
All parts to scale

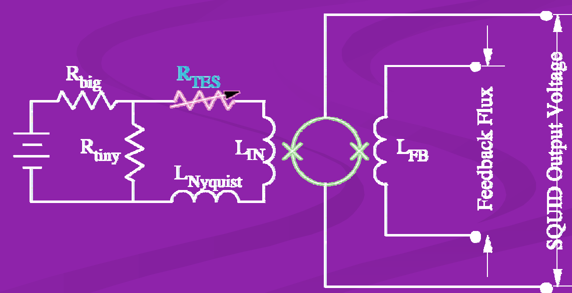
1cm

Components

3. SQUID Amplifiers

- SQUID amplifiers are well-matched to TES detectors
- Operate at detector temperature
- Low noise makes multiplexing feasible

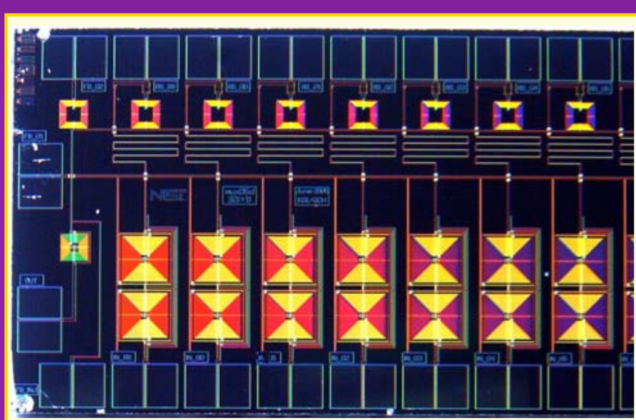


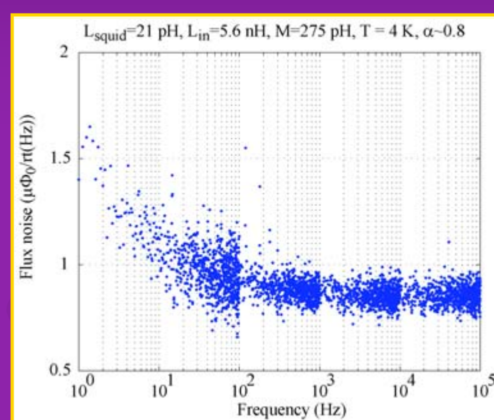


Components

First Stage SQUID Multiplexer

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

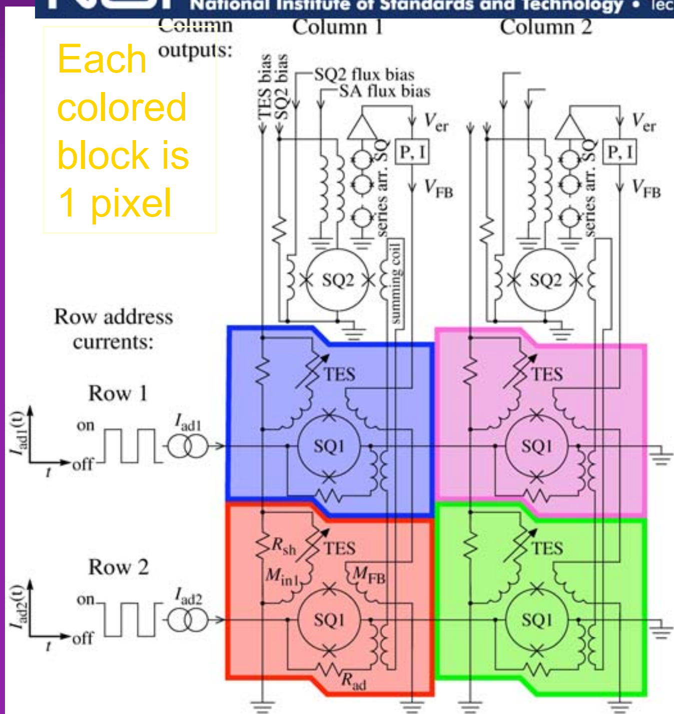




Components

The NIST TDM architecture

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce



- 2 x 2 array is shown as example
- of *N*-row by *M*-column array

- TDM operation:
  - each TES coupled to its own SQ1
  - TESs stay on all the time
  - rows of SQ1s turned on and off sequentially
  - wait for transients to settle, sample I_{TES}, move on
  - SQUIDs are nonlinear amplifiers, so use digital FB
  - V_{er} sampled, V_{FB} stored for next visit to pixel
  - each column: interleaved data stream of pixels

Components

SQUID critical currents

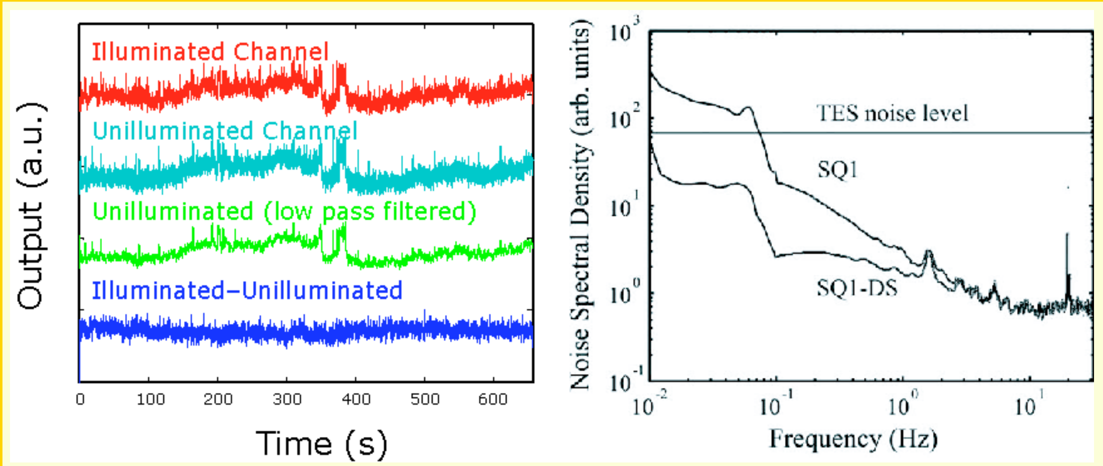
NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

- Much of NIST's recent development has been to achieve more uniform SQUID I_cs in production volume (enables biasability across array).

- Have used split-mask design to eliminate stepper-lens defects on the chip size scale (MUX05d mask set).
- Have developed two trilayer (Nb-Al(AlO_x)-Nb) recipes:
  1. Highly-uniform Ic over wafer (5-10% band) with high defect count (10% of SQUIDs bad).
  2. Gradient of Ic (50-60% across wafer) with low defect count (1% of SQUIDs bad). Useful for SCUBA-2, not for ACT & GBT-PAR.
- Recipes differ in how long Al is cooled before O exposure. New chuck ordered, hope new process will combine best features of each recipe (high uniformity, low defect count).

Components

1/f and SQUID Multiplexing



- (Right) Noise of amplifier much lower than detector, so plenty of headroom for multiplexing
- 1/f noise removed by correlating unilluminated SQUID - removes noise/drifts from all later stages

Components

Shunts & Nyquists

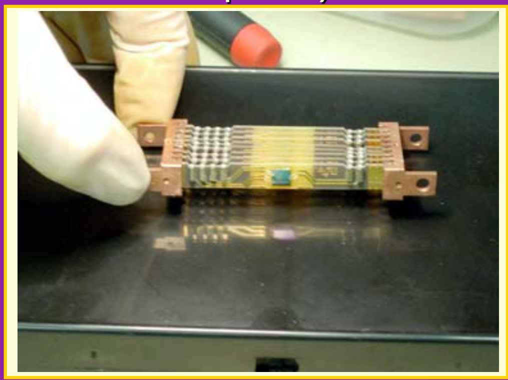
- Shunt resistors at ~1 mOhm produce voltage bias

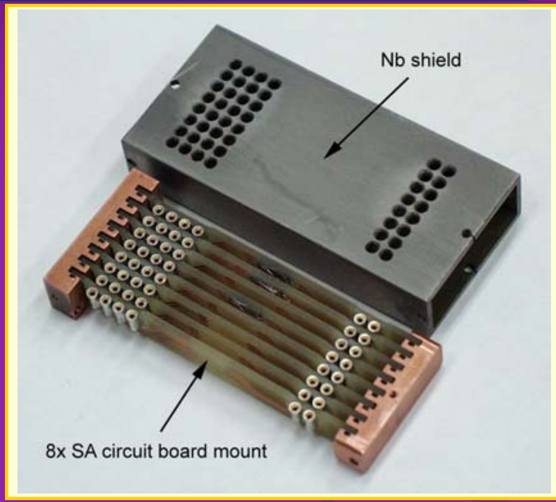
- Nyquist inductors at ~1µH produce bandwidth limitation (and hence signal integration)

Series-array SQUIDs

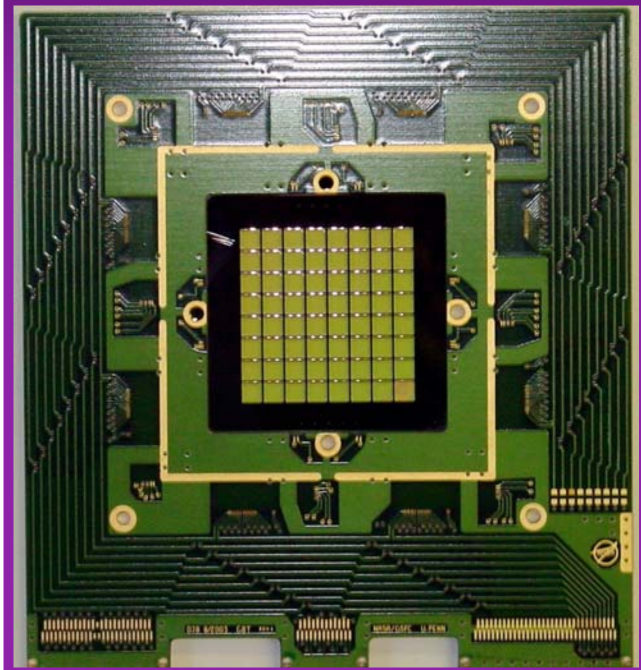
NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

- GSFC provides 8-SQUID-array modules
- (8 Series Array SQUIDs per module, + spares)



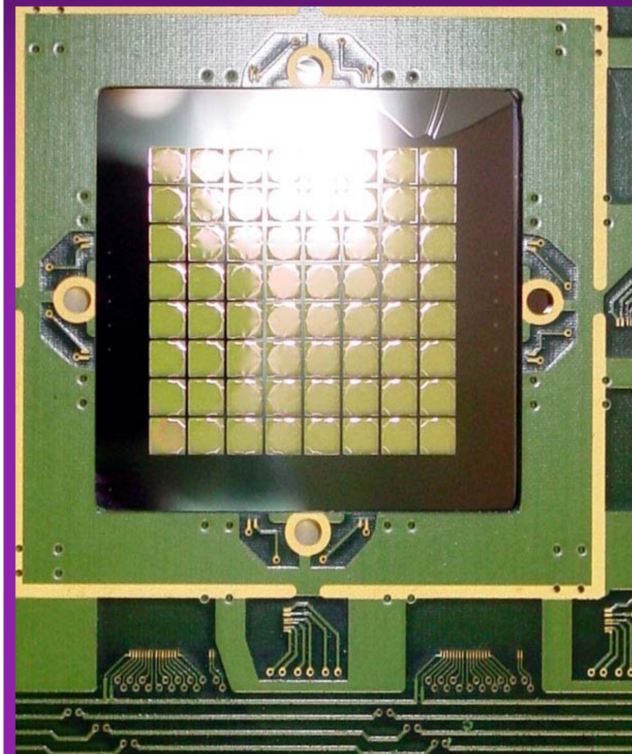


4. Readout Circuit Implementation



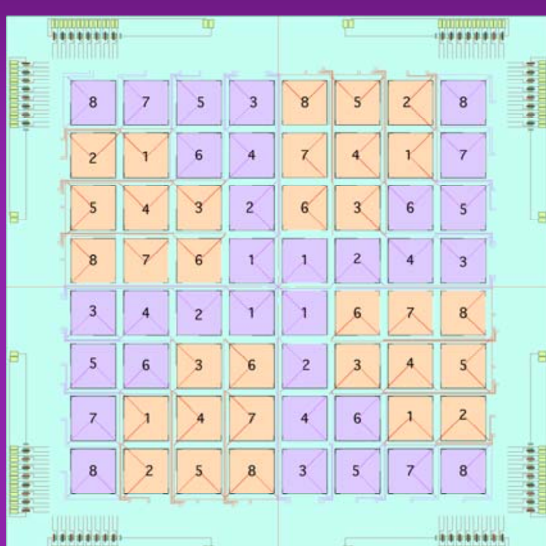
- Wiring is complex:
  - 8 layer circuit board
  - 576 wirebonds
- Outside area is impedance-controlled “bus” architecture.
- All connections brought out at Nanonics connectors.

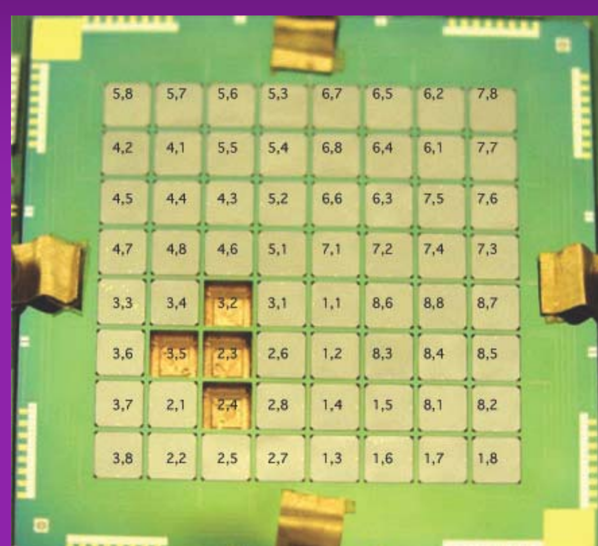
4. Readout Circuit Implementation



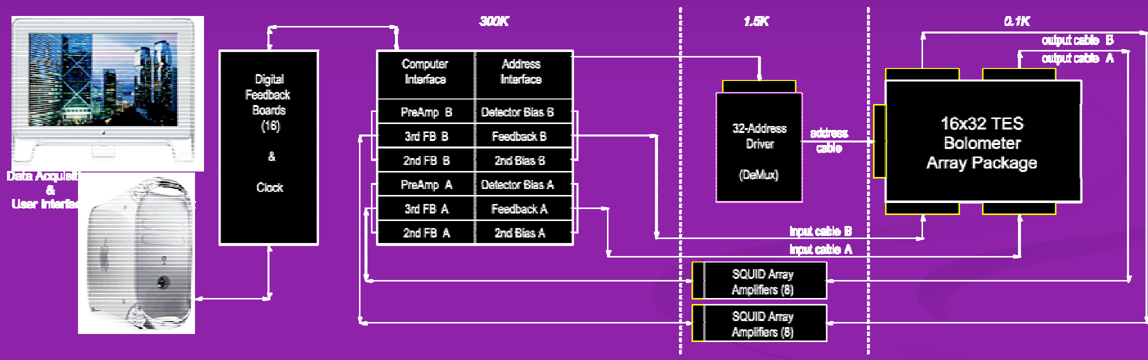
- Wiring is complex:
  - 8 layer circuit board 576 wirebonds
- Outside area is impedance-controlled "bus" architecture.
- All connections brought out at Nanonics connectors.

Logical Layout



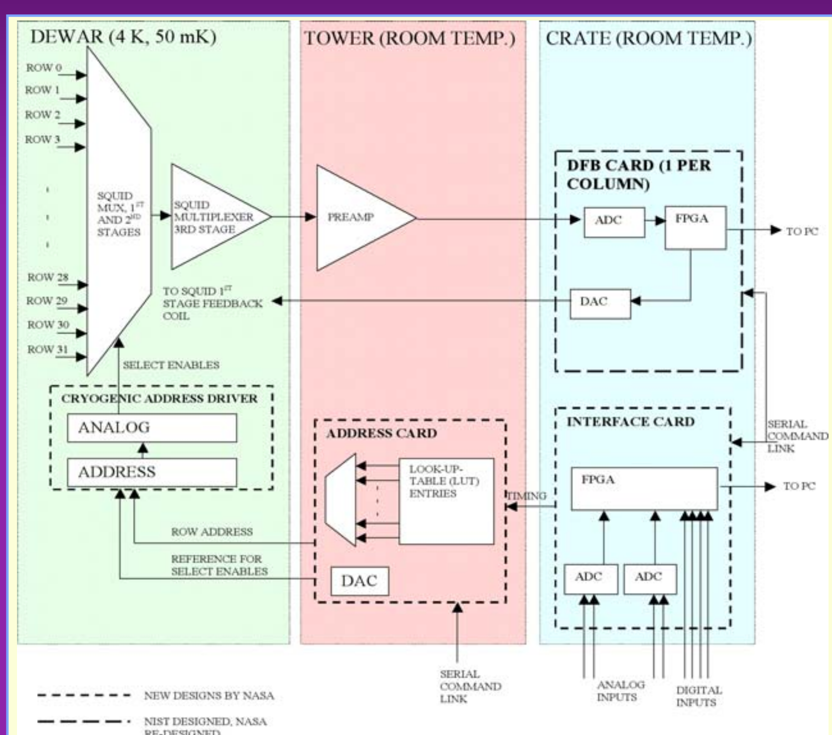


5. Readout Electronics



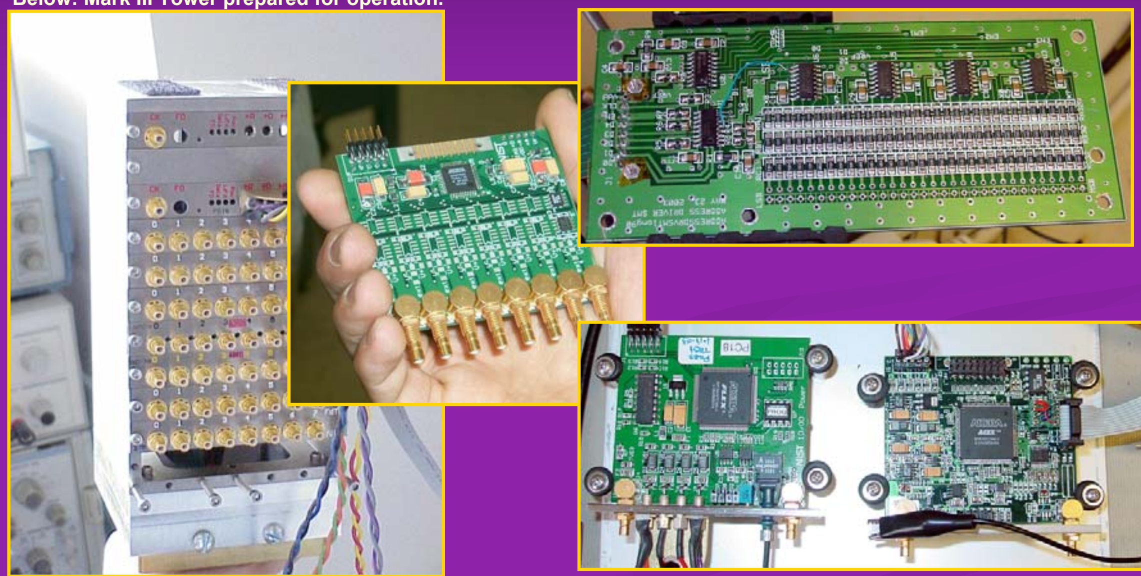
Layout of 512-element (16x32) bolometer array system

Electronics Block Diagram



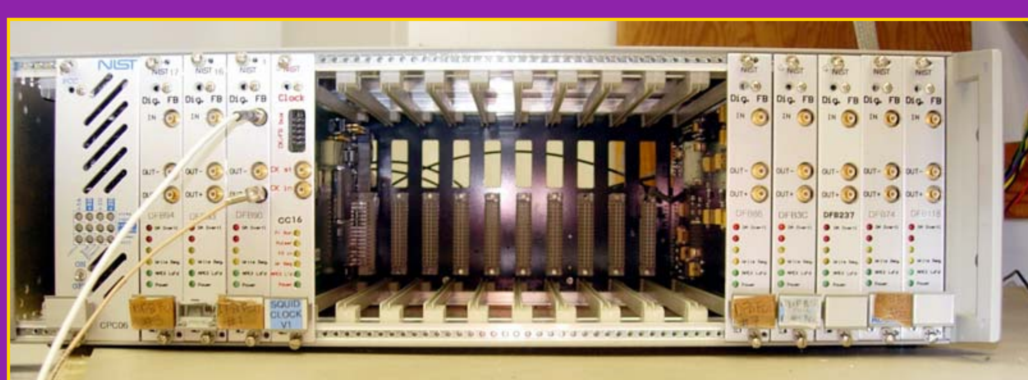
Electronics Photos

Below: Mark III Tower prepared for operation.



Electronics Status

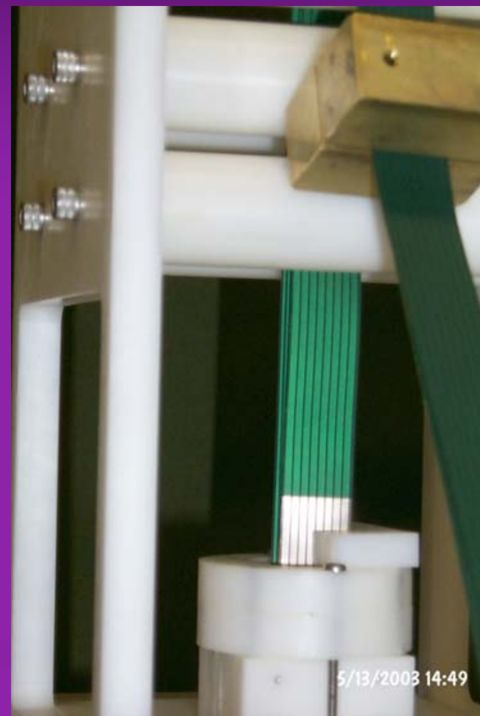
- Mark III electronics essentially complete; multiple installations
- Synchronization hardware/software (timing & interfacing) exists
- Individual 16x32 array control fits in a modest size



Components

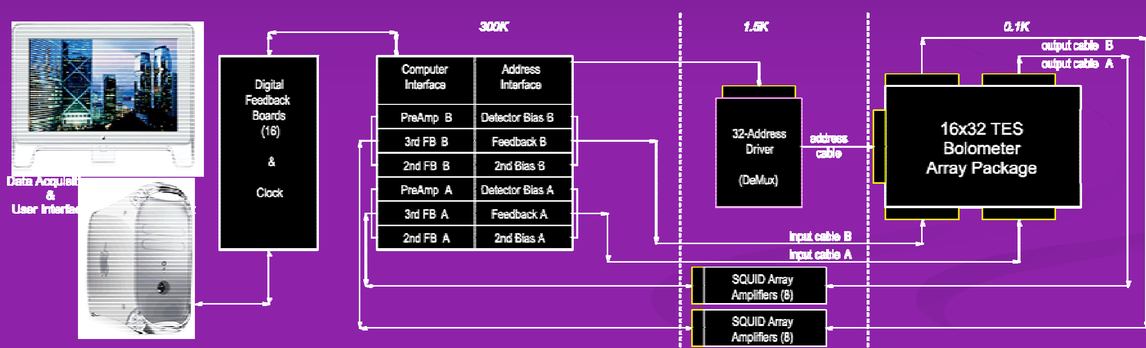
Harness for 300K-4K

- Flexline cables used for all signal lines going into dewar
- Assembly fixture permits cable with 64 signals to be passed into cryostat
- Vacuum tight feedthrough developed & successfully tested



Components

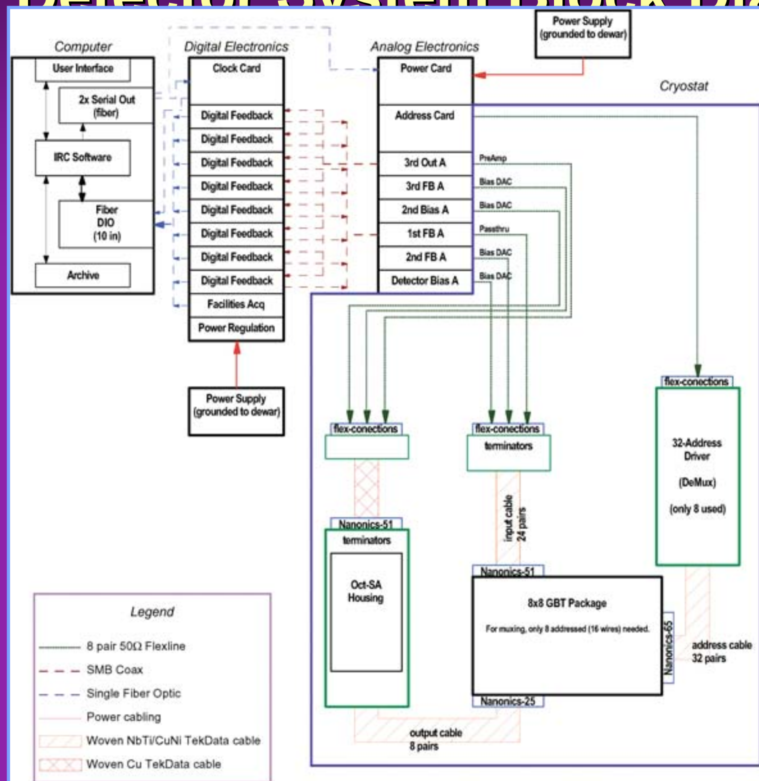
6. Systems Engineering



Layout of 512-element (16x32) bolometer array system

Components

GBT Detector System Block Diagram



PAR-GBT Detector Array

Outline

- Detector Array Context
- Desired Performance
- Detector Array Design
- Associated Components
- Fabrication & Verification
- Some Results
- Thoughts on the Future

Key Process Attributes

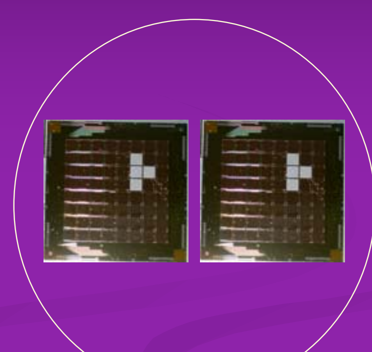
- Bilayer deposition early in process
- Minimization of secondary metallizations
  - Avoid difficult cleaning steps
- All metallization occurs on solid membrane/wafer
- Membrane release occurs on solid wafer
- High mechanical and electrical yield

Summary of current design (1/4)

SOI wafer 1.4 micron device layer

SOITEC product - high uniformity, zero defect rate

2 arrays per wafer (plus diagnostics)



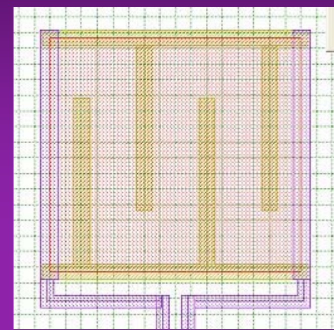
Wafer Layout

Summary of current design (2/4)

Mo/Au TES
80x75 μm^2

Characterize Tc, R on witness wafers deposited for each product wafer

Patterned with ion mill down to Mo layer

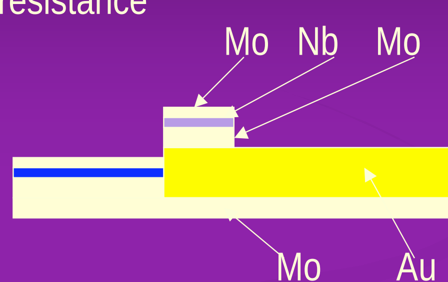


Cad w/ 5 μm Grid

Normal metal bars
And leads shown
(4 micron widths)

Summary of current design (3/4)

Deposit Mo/Nb/Mo for High Ic, corrosion resistance



Pattern and dry etch.

Normal Au bars, Al pads

Patterned by liftoff resist

E-beam deposited

High reproducibility, good yield

Au contributes to device R: ~40% reduction in R_N with bars added

Summary of current design (4/4)

Front etch pattern: photoresist applied; 5 micron leg

Mounted in wax - degassing is critical to mechanical yield; high reproducibility wafer press now in use

To be “punched through” with dry etch after silicon micromachining

Backetch design:

Deepetch – high-rate etch only

Liftoff in TCE as chips with membranes

Fabrication flow + in-line metrology

Wafer clean
Alignment marks - frontside
Regrow thin oxide
TES deposition
Deliver dummy wafers to Tc evaluation
Au ion mill to Mo
Metrology on etch depth
Mo/Nb/Mo deposition
Metrology on dummy wafers
Leads Pattern (Dry etch/protecting absorber area)
Metrology on overetch
Absorber clear of leads metal (dry/wet)
Au liftoff (n.m. dev. feat)
Metrology Au film thickness
Al liftoff - contact pad
Metrology Al film thickness

Back etch alignment marks
Metrology Si etch depth
Front etch streets
Front etch punchthrough pattern
Wax mount
Inspect for wax bubbles
Deep etch
Liftoff to chips
Punchthrough membranes
O2 clean and inspect
Deliver to mechanical and test

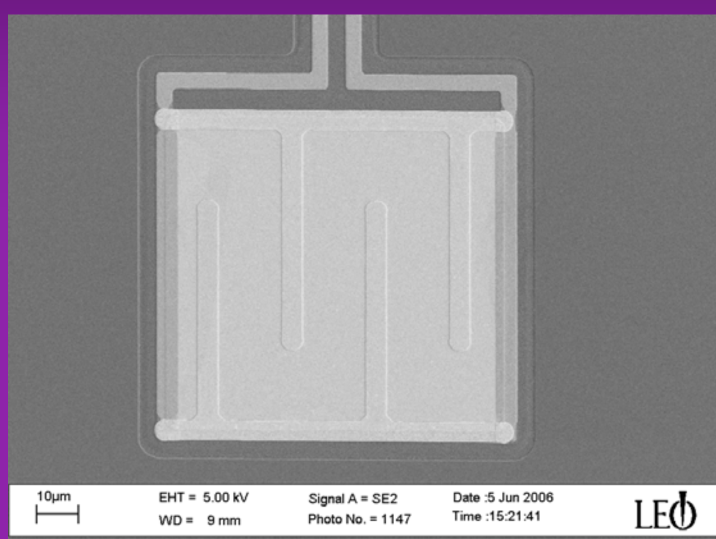
Fabrication

Estimated Schedule

TES dep/test	7 days
Metallizations	8 days
Micromachining	8 days
Chip Inspection	3 days
Totals	5 week minimum 8 weeks with contingency

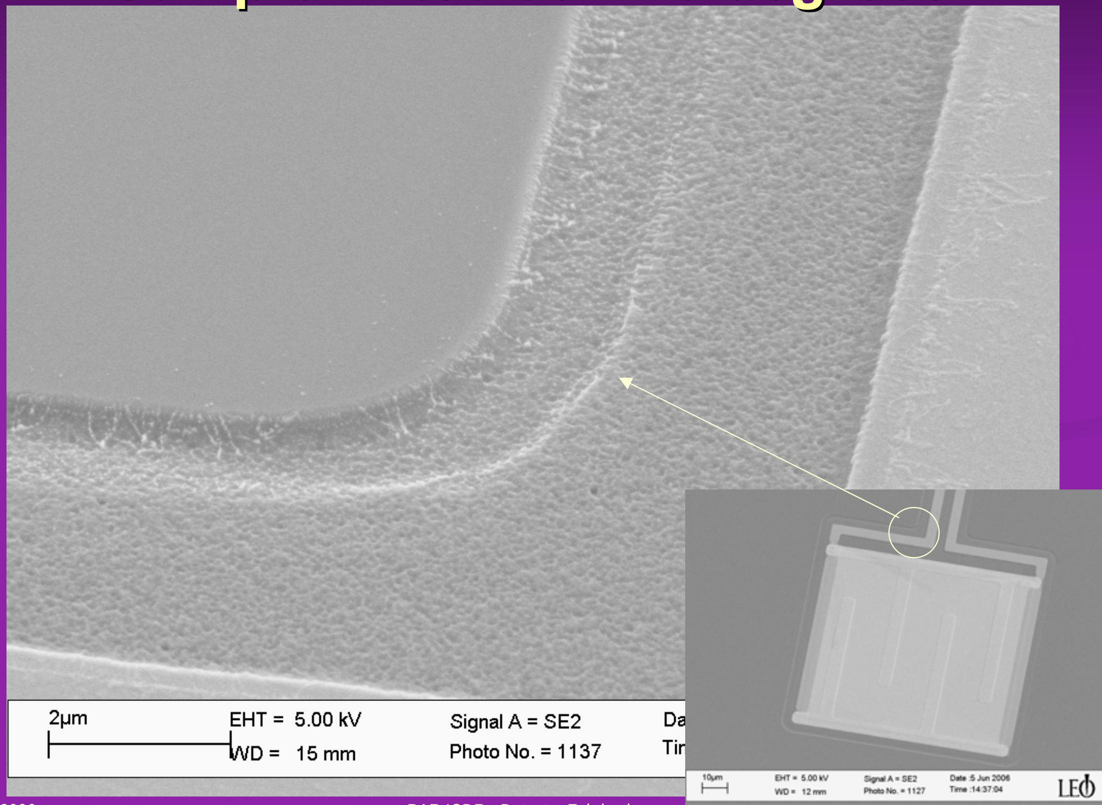
Fabrication

SEM of ACT TES



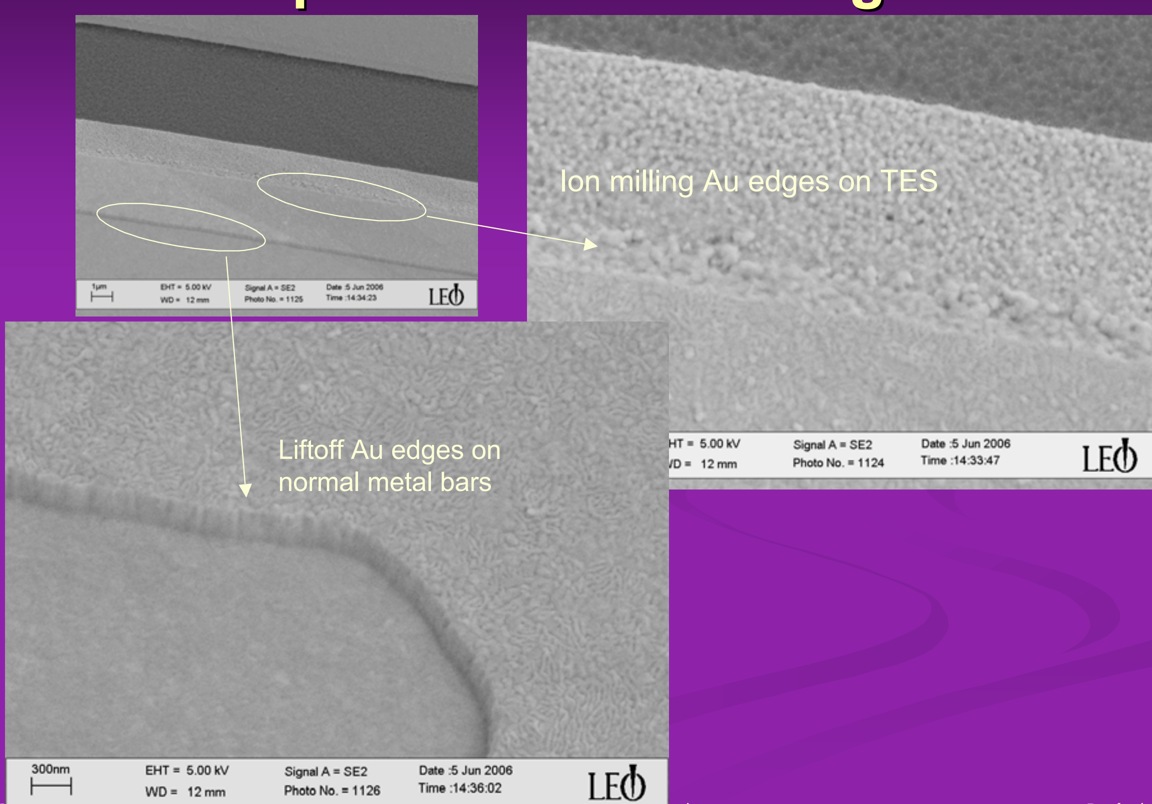
Fabrication

Sample Tilted at ~ 45 degrees



Fabrication

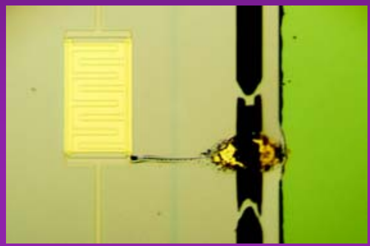
Sample Tilted at ~ 24 degrees

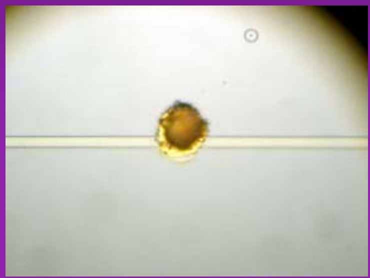


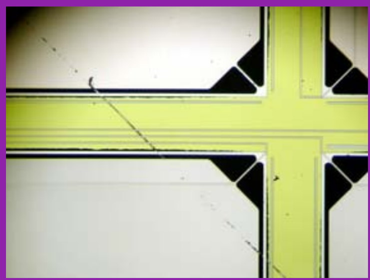
Types of defects

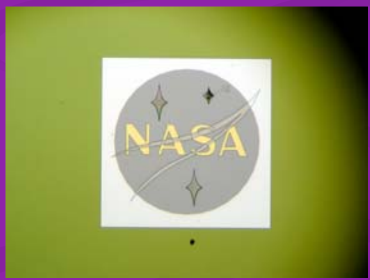
- Cosmetic - causes no electrical or mechanical failure. Will not necessarily be noted on the inspection report. Note: All other types of defects will be noted and in most cases, photographed.
- Electrical - Could cause an electrical open or short in at least 1 pixel. The pixels affected will be noted.
- Mechanical - Likely to cause pixel failure.
- Thermal - May cause a thermal short between pixel and frame.
- Optical - Small (<10% coverage) metallic defect on the pixel body. Will cause a reflective area.

Representative Defects









Detector Array Inventory

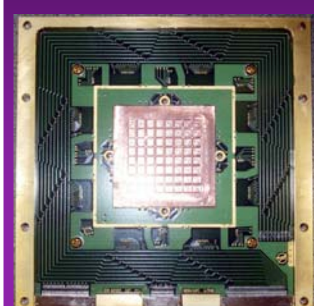
Array 1

Array 2

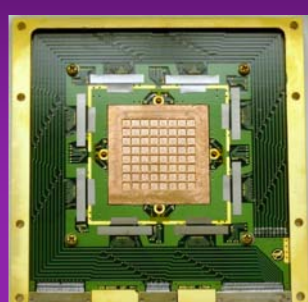
Array 3

- Array 1: 10µm legs; 4 missing pixels; some pixel distortion: suitable for testing
- Array 2: 10µm legs; 100% yield: suitable for observing run
- Array 3: 5µm legs; 1 missing pixel; fragile: might be suitable for observing run

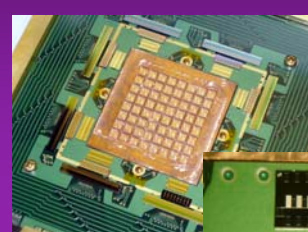
Package Assembly



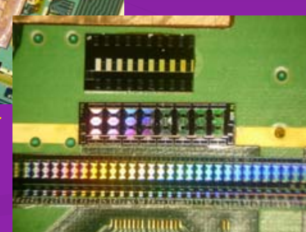
Assemble board & backshort into box

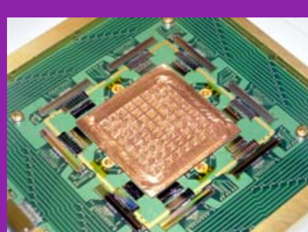


Attach Nb foil

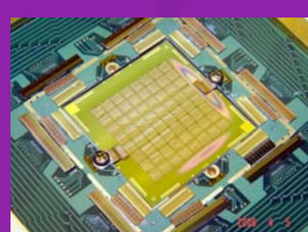


Attach readout chips

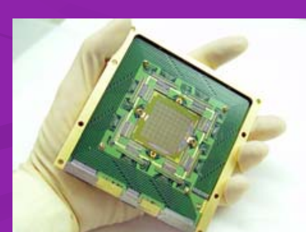




Wirebond chips



Attach detector array

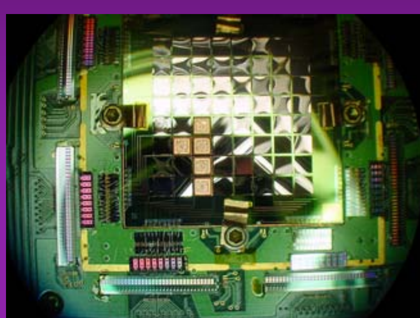


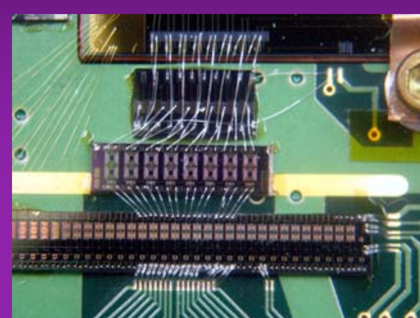
Wirebond & test

Timeline of Array Deliveries

- Nov 2005 Delivery of Array 1 package
  - Metal backshort; slow breakage of 50% of pixels
- Dec 2005 Rework on Array 1 package
  - Broken bond wires & chips repaired
- Apr 2006 Delivery of Array 2 package
  - Ceramic backshort - array survives cooling
  - Unscreened SQUID muxes = dead columns

Some Problems





- (Left) First package had breakage problems on thermal cycling; ceramic backshort seems to have fixed.
- (Right) Wirebonds and chip detachment are a problem; may have been fixed by better shunt design, better chip gluing procedure, and can be further aided by improved circuit board manufacture.

GBT-PAR Array Design Parameters

SOI wafer with 1.4 micron device layer
450 micron overall thickness
2.95 mm sq pixels on 3.30 micron pitch
5 µm and 10µm Si legs
Legs connected to wide beams 300 µm wide
TES 800/1400 Å Mo/Au recipe (~20 Ohm/sq recipe) 75 micron sq
Wiring: Mo with Nb cap, 5 microns wide
Au liftoff feature: 5 micron wide/ spanning 75 % of device width
Al Pad: 4000 Å thick
Backetch feature: 8x8 grid

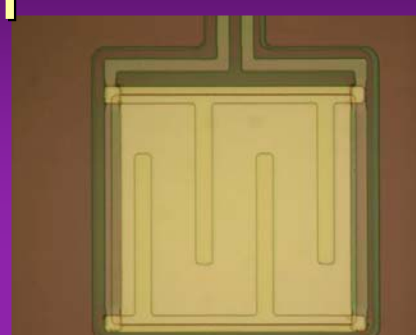
Shunt resistor: Recipes 0.5 - 1.0 mOhm developed
Optical components: Bismuth recipes developed

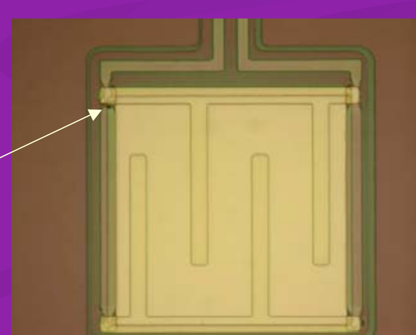
ACT – Process robustness & wiring design

Au bar overlapping lead is a design flaw

Chemistry of PR remover and water corrodes Mo at Au interface

Procedure to suitably dilute PR remover requires longer soaks in intermediate solvents





Possible lost pixel or Parasitic resistance

Fabrication

Normal metal features - liftoff

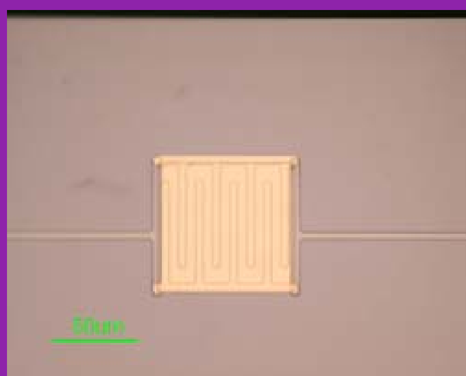
Noise mitigation, time constant tuning

0, 4, and 8 bar recipes under test

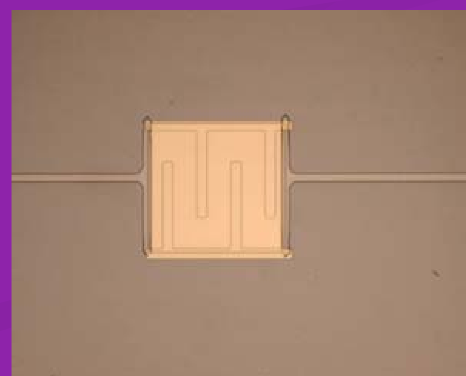
Rsq drops: 30 to 20 mΩ in 1400 Å Au
20 to <10 mΩ in 2000 Å Au

Tc, Ic dependence on feature density in small devices

8 bar design



4 bar design



Fabrication

GSFC Process Control Responsibilities for ACT Deliverables

Maintain process for Mo/Au Tc and transition sharpness

Measure Tc w/bars on wafer diagnostic of delivered chips

Measure shunt material properties

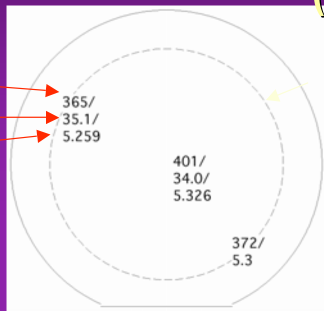
Measure impedance of implanted layers on witness samples

Fabrication

Tc Uniformity on 4 inch wafer

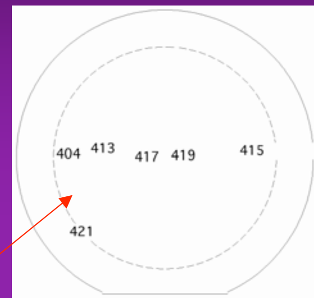
(Au=1400 A)

Tc
mW/sq
RRR



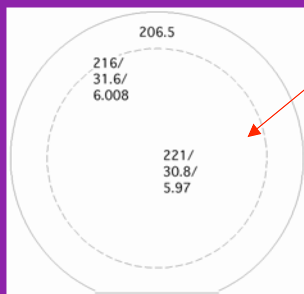
3" diam on
4" disk

Mo/Au on a-Si

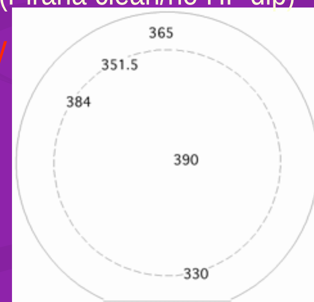


Mo/Au on thin oxide
(Pirana clean/no HF dip)

Verifying
good uniformity



Thin Mo/Au on thin oxide



Mo/Au on bare Si
(Pirana clean plus HF dip)

Fabrication

Shunt Resistor Fabrication

Leads (Nb/Mo or MoN)

Pattern leads (RIE)

Deposit and liftoff Ti + Au/Pd

Deposit and liftoff Al

Dice to chips

Clean up for test/delivery

Contact pads

Heatsinking

Shunt Resistor Delivery

Non-uniformity arose in first fab flow design - identified at Aug 2005 ACT PDR

Rework to identify better leads to alloy interface

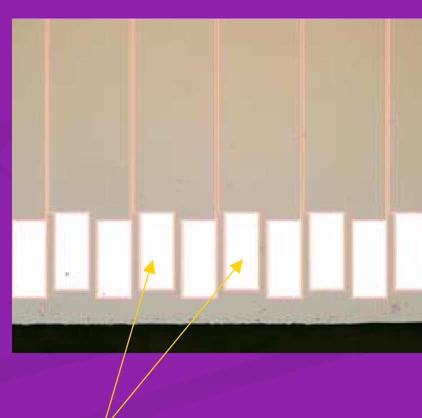
Uniformity achieved; shunt resistance dropped

Assessment of chip-to-chip uniformity plans to restart in summer 2006

Shunt Chip Pictures

1.7 mm x .3 mm on .55 mm pitch

10 micron leads for higher Ic



Aluminum Pads 550 micron pitch

PAR-GBT Detector Array

Outline

- Detector Array Context
- Desired Performance
- Detector Array Design
- Associated Components
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- Some Results
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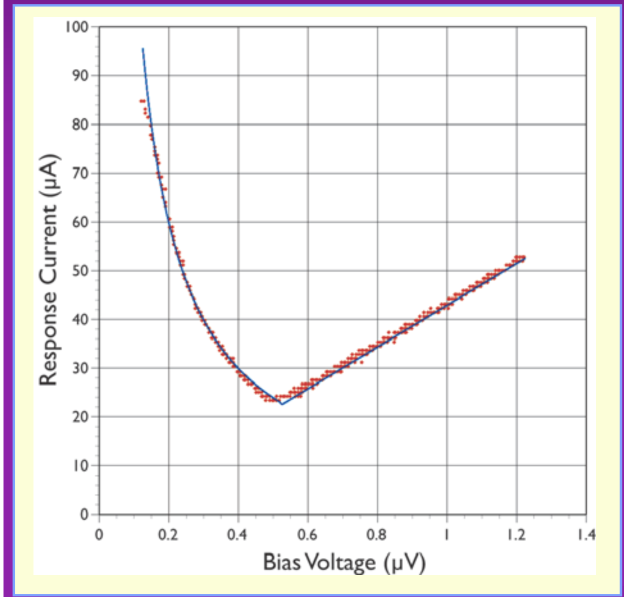
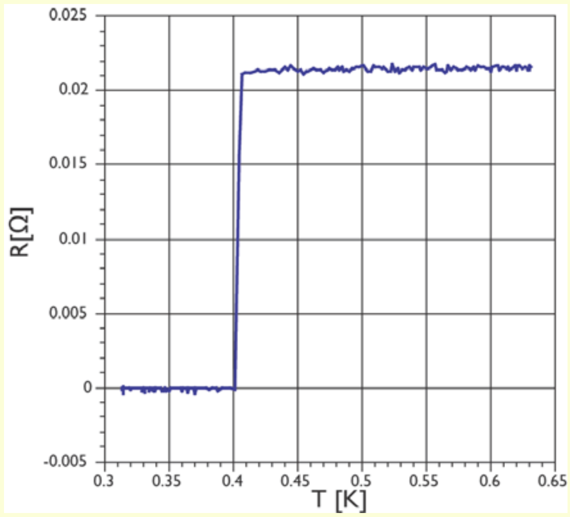
Detector I-V Curves



- Normal region at high voltage provides ohmic definition of zero point
- S/C region is hyperbolic

Results

Detector R(T) Curves

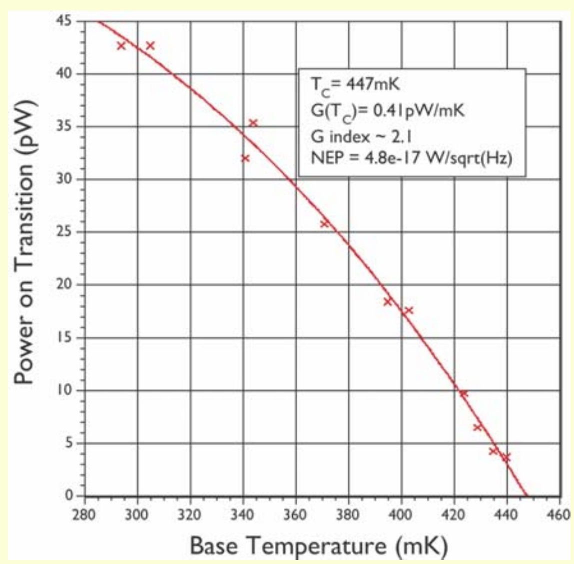


- Transition temperature close to what was desired (may not be so for final product)
- R_N as expected

Results

Thermal Conductance

- Defines saturation power *(with T_C, T_{base})*
- Defines phonon noise
- Similar devices are well-measured
- Best guess: P_{sat}~10pW @ T_{base}=270mK, T_C=370mK



Results

Actual Specifications (I)

Required Parameter	Specification: Goal / Minimum	Actual
Array format	8x8 8x8	8x8 ✔
Pixel size	~3.3mm ~1.7mm	2.95mm ✔
Filling factor	95% 80%	80% ✔
Optical Efficiency	80% 40%	TBD
Wavelength of response	3.3mm	TBD
Response time	20ms 5ms	~7ms ✔

Results

Actual Specifications (II)

Required Parameter	Specification: Goal / Minimum	Actual
Saturation Power	12pW 8pW	~20pW (but 10pW array exists) ✔?
Noise Equivalent Power	$1 \cdot 10^{-17}$ W/√Hz $3 \cdot 10^{-17}$ W/√Hz	TBD, but must be higher
Stability of base temperature	64nK/√Hz 191nK/√Hz	TBD
Adjacent pixel crosstalk	10%	TBD
Power dynamic range	15 7.5	TBD
S/N dynamic range	$6 \cdot 10^{5}$ $2 \cdot 10^{5}$	TBD
Operating temperature	450mK 300mK	>450mK

PAR-GBT Detector Array

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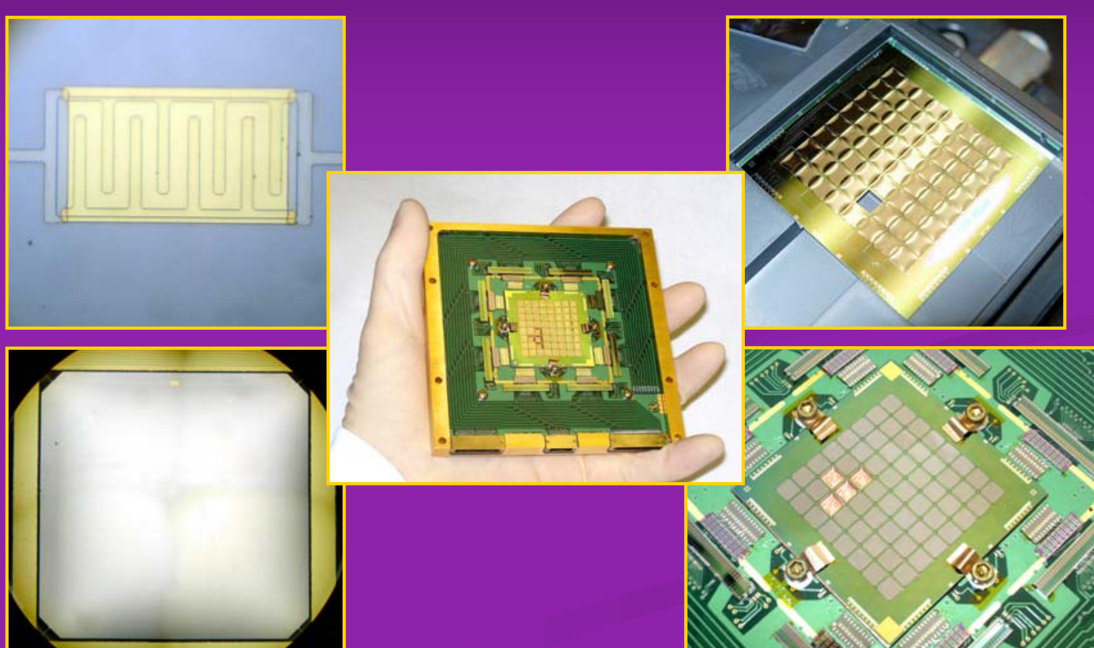
Future

A Sample Detector Assembly

8x8 array for GBT-PAR; λ=3.3mm (90GHz)



TES Detector Array Key Thoughts

Progress:

- TES bolometers work
- SQUID multiplexers work
- System appears to work
- Much learned…

Challenges:

- Proper thermal conductance & speed simultaneously
- Better uniformity (✔?)
- Optical efficiency?
- Noise in various frequencies?

Final Summary

- All the pieces of the TES multiplexed array have been demonstrated to work together – in the lab.
- Actual array working near to spec in most areas.
- Need to determine what else has to be known before next arrays made (actual sky load, actual timescales; 1/*f* and optical efficiency).
- Goddard (both ObsCosmo and DetectorDevelopment) engaged in future collaboration.