Characterization of a prototype SCUBA-2 1280 pixel submillimeter superconducting bolometer array

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Detectors

• Testbed (Cardiff)
  • Peter Ade, Dan Bintley, Julian House, Cindy Hunt, Rashmi Sudiwala, Adam Woodcraft

• Instrument measurements (ATC, Edinburgh)
  • Dan Bintley, Xiaofeng Gao, Maureen Ellis, Wayne Holland, Matt Hollister, Mike MacIntosh, Adam Woodcraft

• Everyone else
  • William Duncan, Gene Hilton, Kent Irwin, Carl Reintsema, Camelia Dunare, William Parkes, Anthony Walton, Jan Kycia, Mandana Amiri, Bryce Burger, Mark Halpern
Detectors - NIST/SMC

• Molybdenum-copper bi-layer superconducting transition edge sensors
• Silicon nitride thermal isolation
• Heater for each pixel to compensate for changes in sky background power

Completed 40 × 32 (1280) pixel prototype SCUBA-2 array (bare pixels)
Detectors - NIST/SMC

- Require 60 mK heat sink
- Over 10,000 pixels in total
  - 2 focal planes; 450 µm and 850 µm
  - Each made up of four side-buttable sub-arrays of 1280 pixels (32 x 40)
Multiplexer - NIST

Uses "in-focal-plane" multiplexer (unlike other TES arrays)
Makes arrays of this size (and larger) practical
Alternative designs would take up too much space and require too many wires between detectors and multiplexer

A full-sized (40 × 32 pixel) multiplexer wafer
Sub-array unit

- Each sub-array housed in a sub-array unit
Focal plane units

• Four sub-arrays fit together in one of two focal plane units

↑ 60 mK
Testbed

- SCUBA-2 requires dedicated facility for testing sub-arrays – located at Cardiff University

- Conventional ("wet") dilution fridge
- Used for characterising prototype and science grade arrays
- Interfaces match instrument; sub-array unit ‘drops-in’
- Can make “fully blanked” measurements, i.e. negligible optical radiation
- Calibrated sub-mm illuminator (SPIRE PCAL) allows optical measurements
  - Modulate at 2 Hz – provides representative load (through filters)
Instrument

- Pulse tube cooled
- “Dry” dilution fridge

• Optical access to external environment controlled by opening and closing cold shutter
Sub-array testing

850 µm prototype

Characterize individually in testbed

Test in instrument

450 µm prototype

Go for science grade construction

Science grade (850)

Characterize individually in testbed

Integrate with instrument

Science grade (450)
Completed

Go for science grade construction
This talk

Go for science grade construction
Readout systems

• NIST hardware
  • Capable of reading quarter of array simultaneously
  • Used for initial characterization measurements
  • Allows a “hands-on” approach to controlling the array

• MCE (Multi-channel electronics)
  • Designed and built at UBC (with NIST & ATC)
  • Prototype used for measurement in Cardiff and Edinburgh
  • Reads out full sub-array (instrument will have 8 sets of MCE)
  • Have achieved considerable automation of measurements using this hardware
Readout systems

• Both readout systems capable of reading out many pixels simultaneously
• However, readout chain (through three series of SQUID) is complex, and requires tuning of several parameters
• Tuning WILL be automatic, but isn’t yet.
• Most measurements therefore on small numbers of pixels

• Settings are stable; if set up one day, settings don’t need to be changed from day to day
Multiplexing

- Worked on small blocks of up to 72 pixels
  - All pixels read out simultaneously using multiplexer
  - Shown here responding to modulation of detector bias (6 columns, 12 pixels in each row)
Load curves

• Measure detector current as a function of bias current in multiplexed mode in instrument

• Basic characterization method

• Curves have expected shape

• Good agreement between NIST hardware/MCE and between testbed/instrument
Load curves

• Take set of load curves at different pixel heater settings

• Normal state resistance in agreement with design values √
Load curves

- Also plot as power in detector vs voltage
- Power constant in superconducting transition
- Power proportional to $V^2$ in normal state
- Responsivity ($S$) in transition proportional to $1/V$
- $S = 5e5$ to $8e6$ A/W. Values agree with those from modulating bias
Power measurements

• For each load curve, plot electrical (heater+bias) power in transition

• Electrical power constant as heater power varies √

• Difference in power for shutter open and closed same for different pixels (NO calibration factor!) √
Consistency

• Also measured optical response in testbed
• Measured power in good agreement with calculation
  • using calibration for illuminator power and measured filter profiles

• So power from heaters, detector bias and illuminator in good agreement
  • Calibration is well understood
    • We can have confidence in NEP values
• Optical NEP measured in testbed
  • $1.4 \times 10^{-16}$ W/rtHz
  • Requirement: $2.9 \times 10^{-16}$ W/rtHz

• Measurement on single pixel device: $\sim 1 \times 10^{-16}$ W/rtHz

• (Note: lower NEP for 850 µm arrays)
**NEP**

- Electrical NEP measured in instrument
  - $2.5 \times 10^{-16}$ W/rtHz
  - Requirement: $2.1 \times 10^{-16}$ W/rtHz
  - BUT: frame rate currently limited – undersampling detectors; expect factor of 4 improvement following firmware upgrade

- Note: this is measured in instrument in operating configuration
  - Multiplexing
  - Pulse tube coolers
  - Long thermal paths between fridge and arrays
Conclusions

• Detectors and read-outs operate in a stable and reproducible fashion

• Testbed and instrument both function well

• Results from characterization measurements self-consistent and in agreement with expected values

• *Upper limit* on electrical NEP *in instrument* almost within specifications

• Optical NEP in testbed within specifications

• *We can go ahead and make the science grade arrays!*