CASPER based Readout for Microwave Kinetic Inductance Detectors (MKID)

Ran Duan & MKID group

CFA, Harvard
20 Aug 2010
MKID Group

• Caltech
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• JPL
  – Jack Sayers, Bruce Bumble, Peter Day, Rick Leduc, Hien Nguyen, Phil Wilson

• University of Colorado
  – James Schlaerth, Phil Maloney, Jason Glenn

• UCSB
  – Sean McHugh, Ben Mazin & group

• NIST
  – Jiansong Gao

• UC Berkeley
  – Bruno Serfass

+ collaborators
Open Source MKID Readout Outline

- Introduction of MKID and MKID readout
- Hardware and IF system
- Software and Firmware
- Results of MKIDs Readout Demonstration at CSO
- Discussion and Future Plans
Principle of Operation

- Photons break Cooper pairs creating quasiparticle excitations
- The quasiparticles changes the surface impedance of a thin film superconductor
- monitor the instantaneous resonance frequency and dissipation on feedline

Device Layout

- Antenna cover 100GHz – 500GHz (submm);
- MKID Resonator coupled to feedline at 2-6GHz (microwave)
How to Readout MKIDs

One of the most important advantages of MKIDs: Resonators can be frequency domain multiplexed (FDMUX).

1. Lithographically tune each detector to a slightly different frequency
2. Use a single HEMT amplifier to simultaneously read out many detectors
3. Move the complexity and challenge of readout to room temperature electronics
History and overview of Readout

Digital Mixing using specialist DSP chips:
MKID group DemoCam run 2006\(^1\): \(~10\) resonators

Many groups work on\(^2-5\):
mm/submm; IR; Optical-UV; X-Ray
Dark Matter; MSQUID; Quantum Computing

CASPERS\(^6\): Signal process hardware and software library

Open Source MKID Readout

6. Collaboration for Astronomy Signal processing and Electronics

MKID Group, Caltech
Readout system

0.5-4.5GHz Synthesizer
Baseband Clock Synthesizer

IF System

DAC & DAC board
ROACH Board
DAQ PC

Cryostat
MarkID Group, Caltech
Hardware: ADC and DAC

ADC:
550 msps, 12 bit
SNR: 64 dB

DAC:
1000 msps, 16 bit
NSD: 75 dBc

HEMT Noise
2-5K Require
ADC to have:
SNR > 55-59 dB
Readout system

0.5-4.5GHz Synthesizer
Baseband Clock Synthesizer

IF System

ADC & DAC board

ROACH

DAQ PC

Cryostat

MKID Group, Caltech
IF system design

Each component in the IF system are selected and configured carefully so that:

1. all the amplifier and mixer are working in the optimal range;
2. noise level reach ADC will dominate by the HEMT noise;
   (other component e.g. LNA, ADC won’t add additional noise)
3. two synthesizer, FPGA and DAC/ADC are all locked with same GPS locked frequency standard to avoid frequency drift;
4. DAC and ADC dynamic range are fully used;
5. the comb signal level reach MKID device are optimized for each individual resonator across the whole bandwidth.
MKID Readout Firmware design

12 bit ADC

2^11 complex PFB

QDR transpose

2^6 complex FFT

126 resonator Bin Selection

126 channel complex FIR filter & Decimation

GPS locked Timestamp & Header

10Gb Ethernet

131 K bins
Complex Channelizing

16 bit DAC

126 Channel DAC LUT
MKID Readout Firmware design

Select the 126 resonator bins
* Automatically change with DAC LUT
MKID Readout Firmware design

12 bit ADC

I_1
Q_1
I_2
Q_2

2^11 complex PFB

QDR transpose

2^6 complex FFT

126 resonator Bin Selection

126 channel complex FIR filter & Decimation

2^11 complex PFB

QDR transpose

126 channel complex FIR filter & Decimation

126 channel complex FIR Filter & Decimation

126 Channel DAC LUT

16 bit DAC

10Gb Ethernet

GPS locked Timestamp & Header

timestamp header

126 channel complex FIR Filter & Decimation
MKID Readout Firmware design

Add Timestamp and Header to data
Pack data as package, send out through 10GbE at 100Hz
## Test Results in CSO

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/C Ratio per channel</td>
<td>Require $&lt;-123$ dBc/Hz</td>
<td>Achieve: 5-9 dB better</td>
</tr>
<tr>
<td>Number of tones</td>
<td>126</td>
<td>Scalable;</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>340Mhz</td>
<td>Up to 550Mhz</td>
</tr>
<tr>
<td>DAC frequency step size</td>
<td>2600Hz</td>
<td>Scalable</td>
</tr>
<tr>
<td>DAC waveform buffer</td>
<td>Continuous; Fast reprogram</td>
<td>on fly fast reload</td>
</tr>
<tr>
<td>Channelizer Resolution</td>
<td>2600Hz</td>
<td>Scalable</td>
</tr>
<tr>
<td>Channelizer Size</td>
<td>131072 Bins;</td>
<td>Scalable</td>
</tr>
<tr>
<td>Output data format</td>
<td>Complex Output with 2*32 bit word</td>
<td></td>
</tr>
<tr>
<td>Channelizing Speed</td>
<td>Real time;</td>
<td></td>
</tr>
<tr>
<td>Output data rate</td>
<td>100 Hz / channel</td>
<td>FIR decimation; 10Gbit Ethernet</td>
</tr>
</tbody>
</table>
## Summarized Results: Readout of MKIDs

<table>
<thead>
<tr>
<th>Test Results in CSO</th>
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<tbody>
<tr>
<td><strong>Timestamp</strong></td>
</tr>
<tr>
<td>Synchronization</td>
</tr>
<tr>
<td>FPGA:</td>
</tr>
<tr>
<td>- Channelizing Mode</td>
</tr>
<tr>
<td>- Network Analyzer Mode</td>
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<tr>
<td></td>
</tr>
<tr>
<td>More Advantage offered by Open Source CAPSER</td>
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<tr>
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</tbody>
</table>
MKID DemoCam Run 2010

Successful demonstration at CSO on 2010 June

Readout 126 complex tones   DAQ pipeline

Photo: CSO Summit, June 2010

Make a clear path to built full MKID Camera
Dewar and Readout Setup
Future of MKID Readout

MKID Readout was successfully tested at CSO for 2 weeks; Almost all readout requirements were achieved and tested

Next step and current works:

• 2\textsuperscript{nd} generation of ADC/DAC: Better chip; Better design
• IF board
• New Power Supply, Cooling & Enclosure
• Full Camera Integration
  - 16 units of ROACH +DAC+ADC + IF board + Switch
Collaboration For Astronomy Signal Processing and Electronics (CASPER):

Jason Manley and David George  
*University of Cape Town and SKA, South Africa*

Henry Chen, Rick Raffanti and Dan Werthimer  
*UC Berkeley*

Glenn Jones, Matthew Stevenson  
*Caltech*

Collaboration For Open Source MKID Readout:

UCSB, UC Berkeley, NIST, UK ATC, etc

XILINX: Donation of all the FPGAs

Analog Device: Donation of all the ADC chips
Questions?

More questions on MKID Readout: rduan@caltech.edu

Find out more:  www.submm.caltech.edu

Most recently results in SPIE, astronomy and instrument conference:

•Paper 7741-8 :  MKID multicolor array status and results from DemoCam
•Paper 7741-15:  MUSIC for sub/millimeter astrophysics
•Paper 7741-26:  Optimization of MKID noise performance via readout technique for astronomical applications
•Paper 7741-32:  Optics for MUSIC: a new (sub)millimeter camera for the Caltech Submillimeter Observatory
•Paper 7741-80:  A slot array antenna for a millimeter/submillimeter-wave focal plane
•Paper 7741-56:  The cryomechanical design of MUSIC: a novel imaging instrument for millimeter-wave astrophysics at the Caltech Submillimeter Observatory
•Paper 7741-67:  An open-source readout for MKIDs