Instrumentation for Kinetic Inductance Detector Based Submillimeter Radio Astronomy

Ran DUAN

30 Oct, 2013

研究经历

2008 – 2013 Caltech

Research Interests:

70%： 望远镜接收机相关技术（Readout Electronics/ Receiver)
30%： 亚毫米波器件 （Submm Device: Antenna; Filter etc)

例如于毫米波、亚毫米波、远红外 及暗物质探测等等
For Submm, MM, FIR, Dark Matter detection etc.

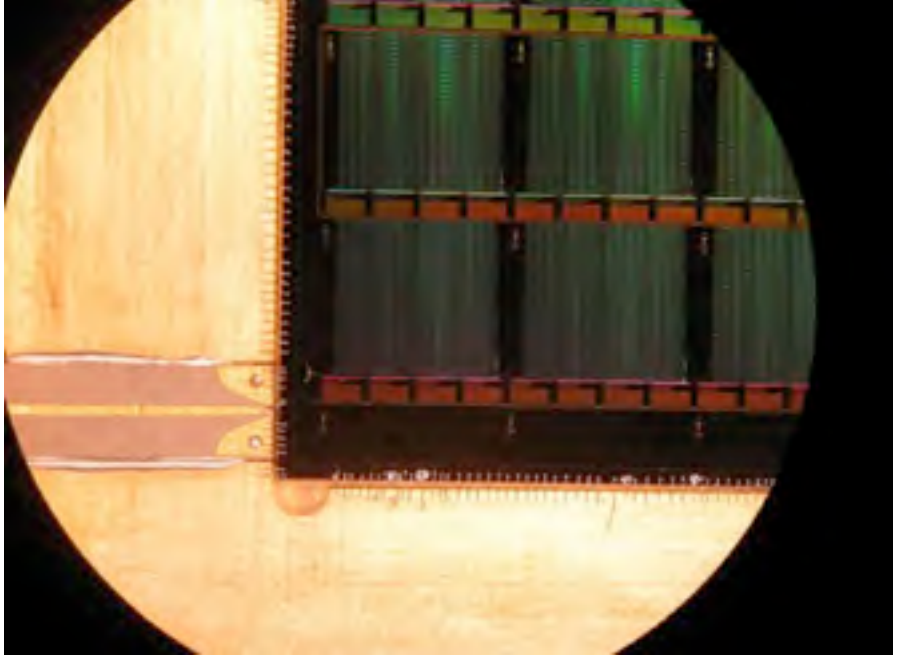
Projects I involved:

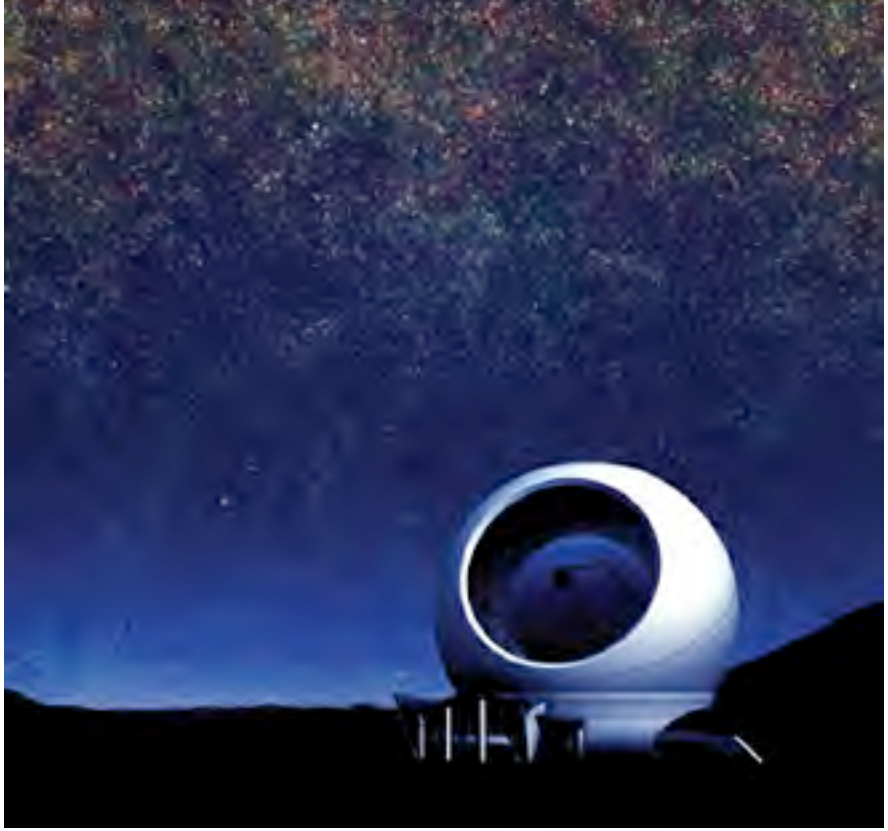
- MUSIC: First Sub-mm Camera based on KIDs Technology (In 2013, it becomes the permanent Instrument for CSO, Hawaii)
- SPIDER： South Pole, Balloon-borne Project, 宇宙微波背景（CMB）
- CCAT： New Sub-mm Telescope, Chile

MKID Group

- **Caltech**
  - Ran Duan, Nicole Czakon, Seth Siegel, David Moore, Omid Noroozian, Tasos Vayonakis, Tom Downes, Jack Sayers, Chris McKinney, Larry Beirich, Sunil Golwala, Jonas Zmuidzinas
- **JPL**
  - Matt Hollister, Bruce Bumble, Peter Day, Loren Swenson, Rick Leduc, Hien Nguyen, Phil Wilson
- **University of Colorado**
  - James Schlaerth, Phil Maloney, Clint Bockstiegel, Amandeep Gill, Spencer Brugger, Jason Glenn
- **UCSB**
  - Sean McHugh, Ben Mazin
- **NIST**
  - Jiansong Gao

+ collaborators



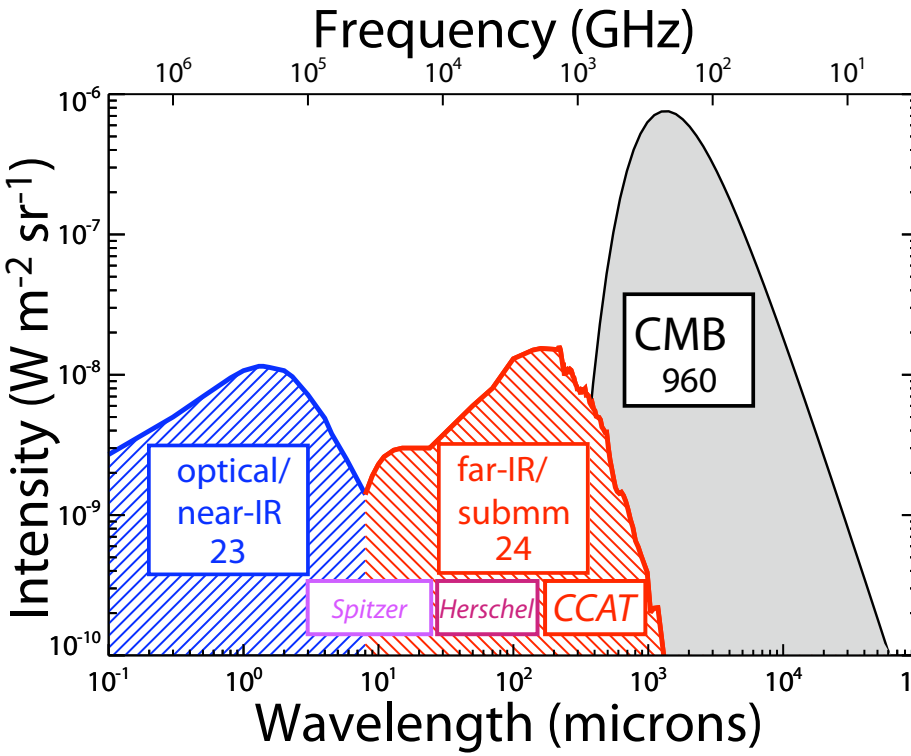



MKID Group - Caltech

Scientific Motivation

Submm and Far-IR wavelength:

"High priority in coming decade….. Undertake large and detailed surveys of galaxies…" – NRC's Astro2010 Decadal Report, p2-18



- formation and evolution of galaxies.
- structure in the universe;
- Dark matter halos in which they form.
- Help study of galaxy clusters.

Dole et al. 2006

Outline

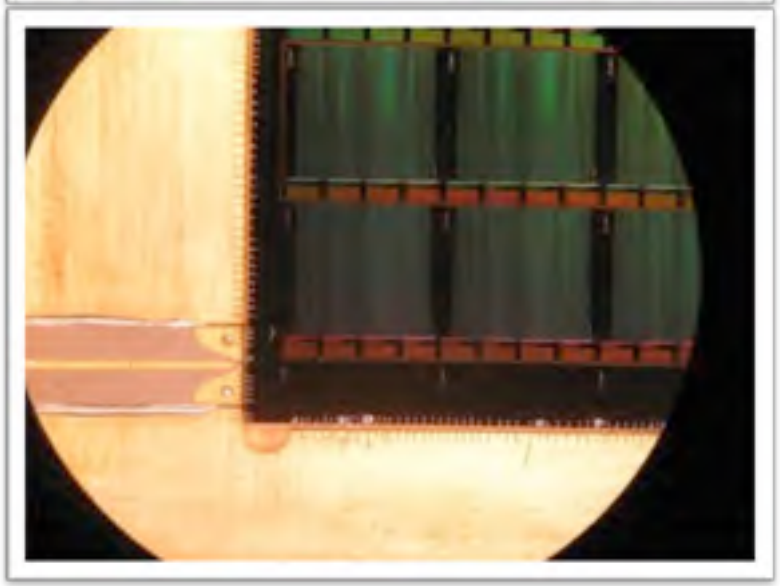
MKID Background

On Wafer

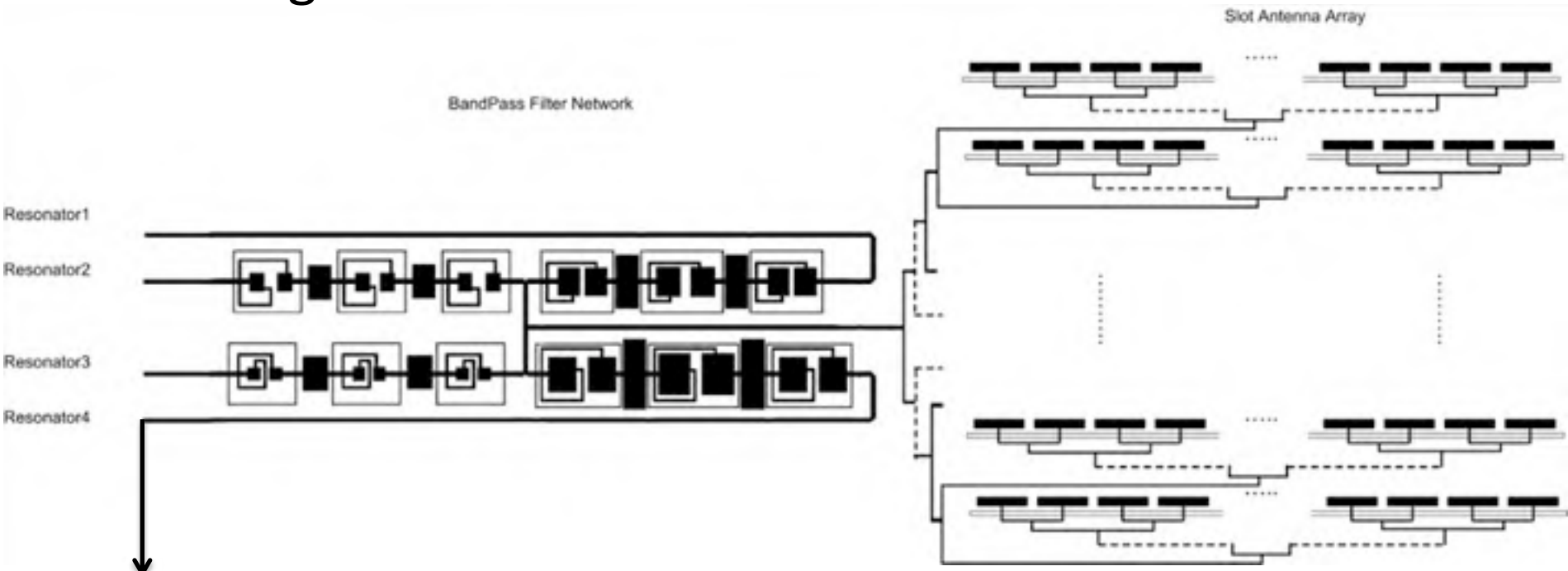
Open Source KIDs Readout:

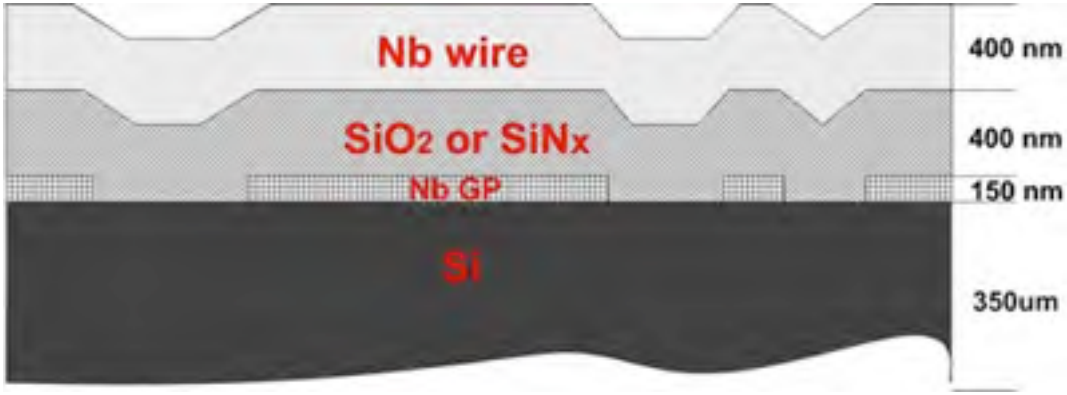
- Introduction of MKID
- Readout Design and Hardware
- Software and Firmware
- Telescope DAQ

Summary of 2 telescope engineering run



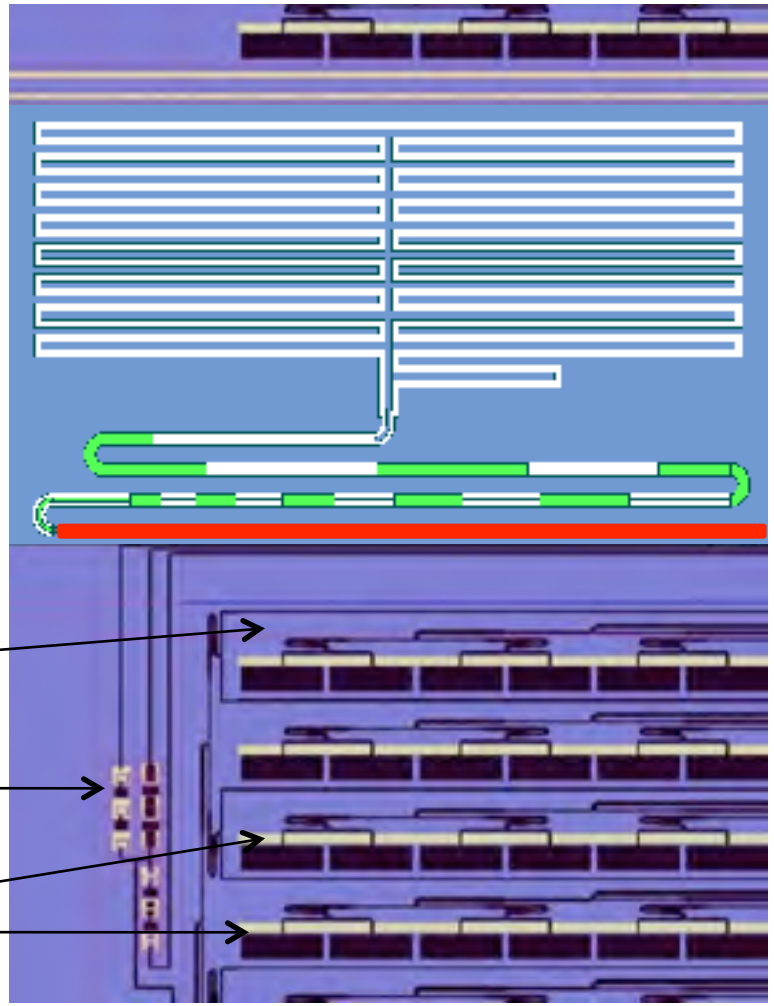
Wafer Design Overview





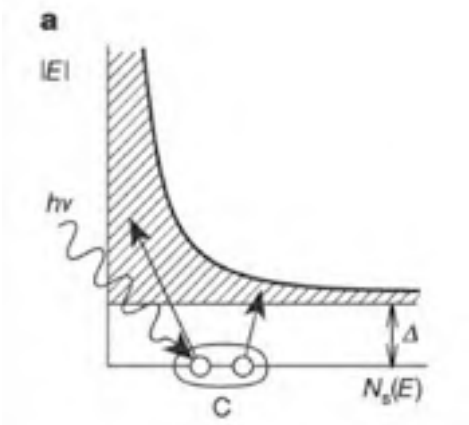
Device Layout

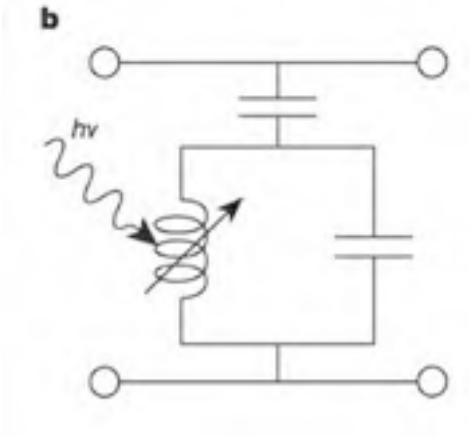
- Antenna & BPF cover 100GHz – 400GHz (mm/submm);
- LC Resonator & Electronics coupled to feedline at 2-6GHz (microwave)

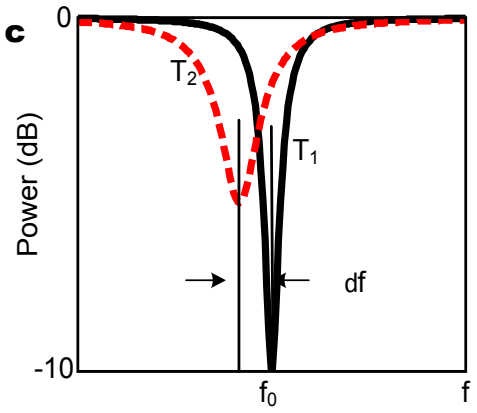


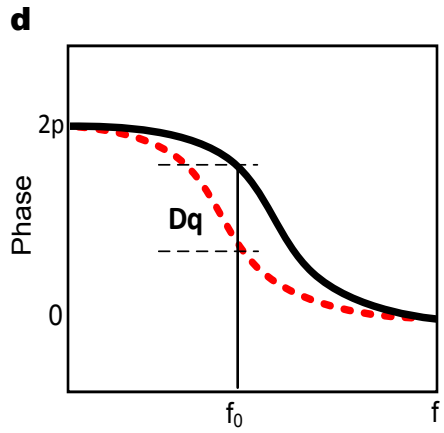
Principle of Operation

- 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
- Microwave Kinetic Indutance Detector (MKID)

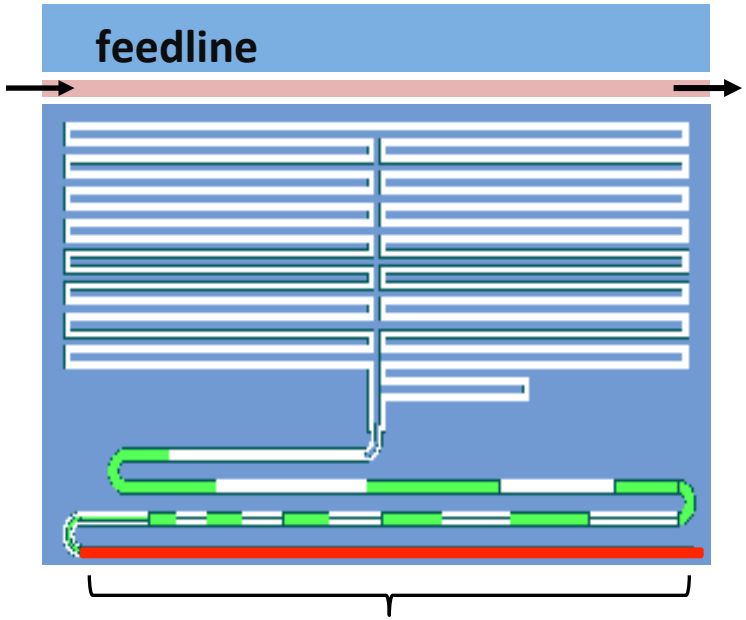








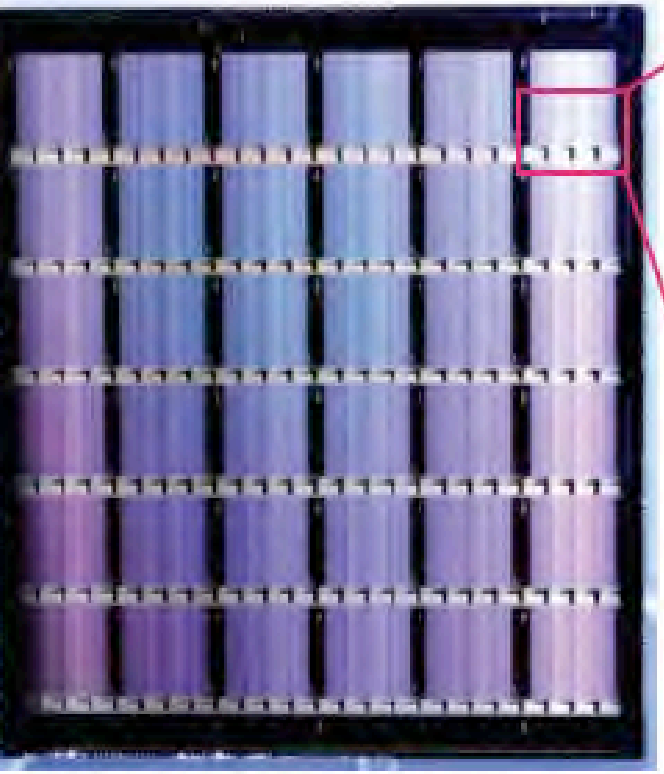
MKID Resonator Design:

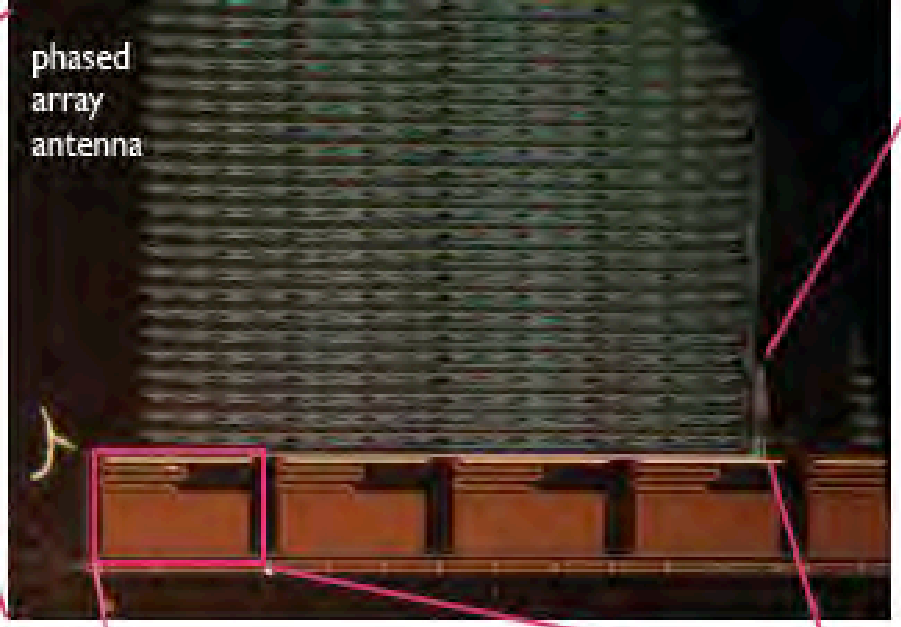


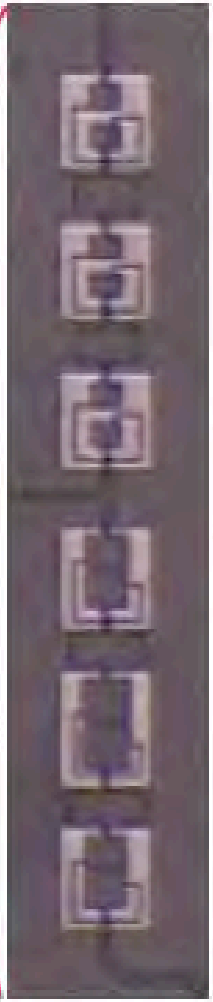
Al section:
part of the inductor

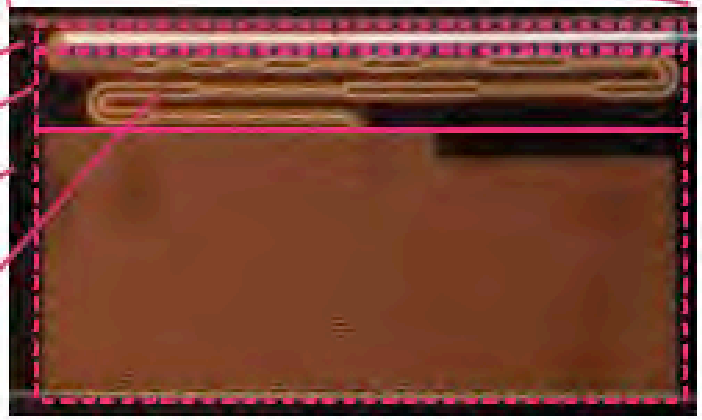
* P. Day et al, Nature, Vol 425, 2004

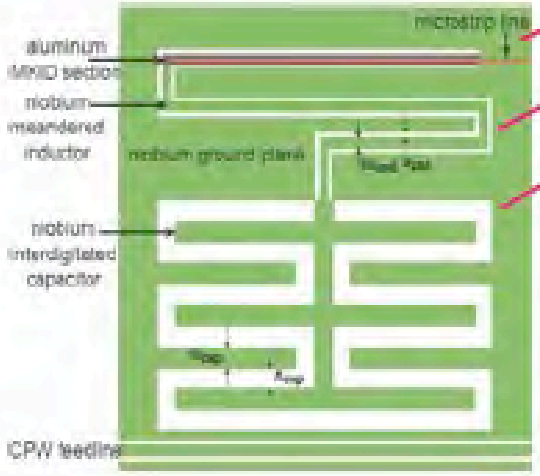
Open-Source Readout











stepped impedance filter to block power absorbed in IDC

MKIDs (four, one per color)

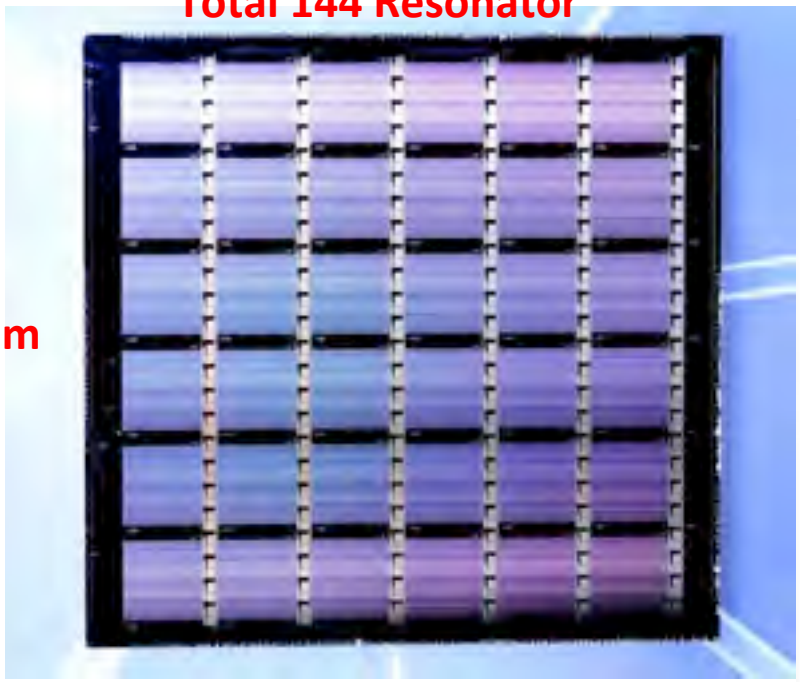
bandpass filters (2 colors)

Detector development funded by JPL RTD, NASA APRA, Moore Foundation

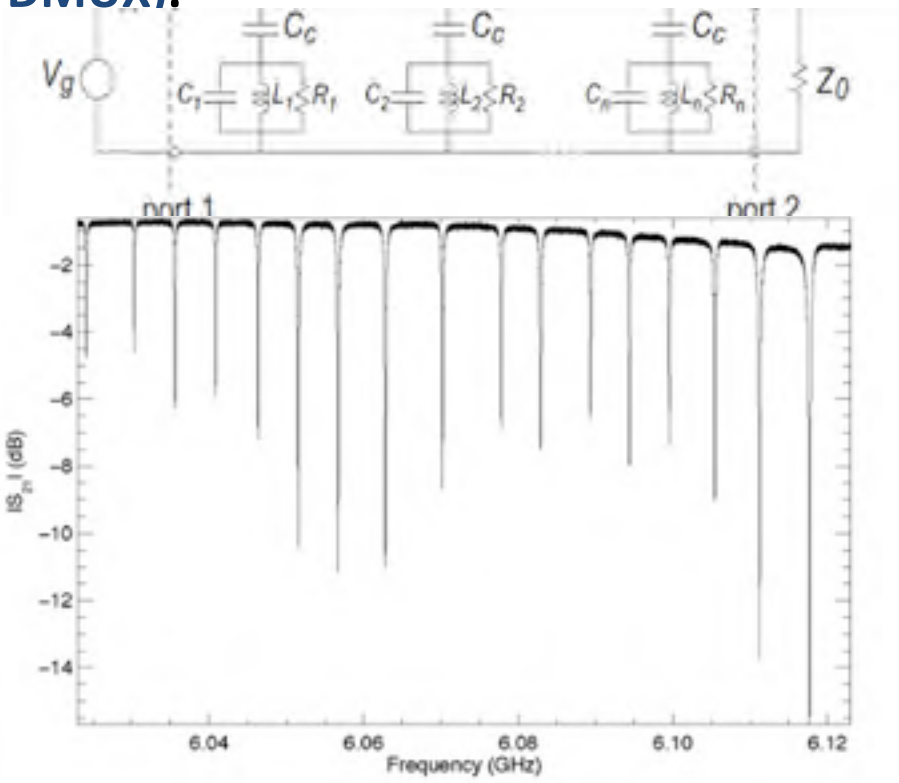
How to Readout MKIDs

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

Total 144 Resonator



30 mm



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:

MUSIC group DemoCam run 2006[1]: ~10 resonators

Using off the shelf components and FPGA board:

MUSIC group DemoCam run 2010: ~128resonators

Many groups work on[2-5]:

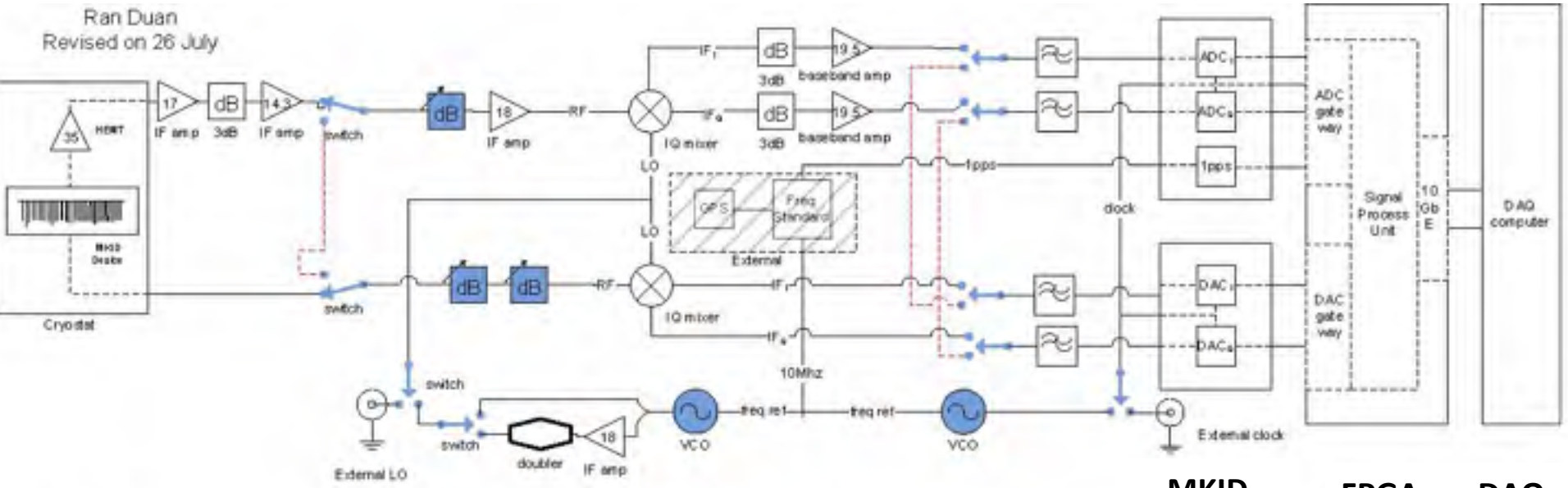
mm/submm; IR; Optical-UV; X-Ray

Dark Matter; MSQUID; Quantum Computing; Bioinformatics

CASPER[6] : Signal process hardware and software library

Open Source MKID Readout (OSR)

1. Mazin, B. A. et al. "Digital readous for large microwave low-temperature detector arrays," Nuclear Instruments and Methods in Physics Research A 599,2006 799{801 (2006)
2. Yates, S. J. C. et al Applied Physics Letter 95, 042504 (2009).
3. Benz, A. O. et al,Astronomy and Astrophysics 442, 767773(2005).
4. Irwin, K. D. et al and Halpern, M., \Time-division squid multiplexers," TDM white paper (2008).
5. Dobbs, M. and Lee, A., \Mhz freuqency domain multiplexed readout," CMBpol Instrument Technologies Whitepaper (2008).
6. Collaboration for Astronomy Signal processing and Electronics



Dewar

MKID IF Board

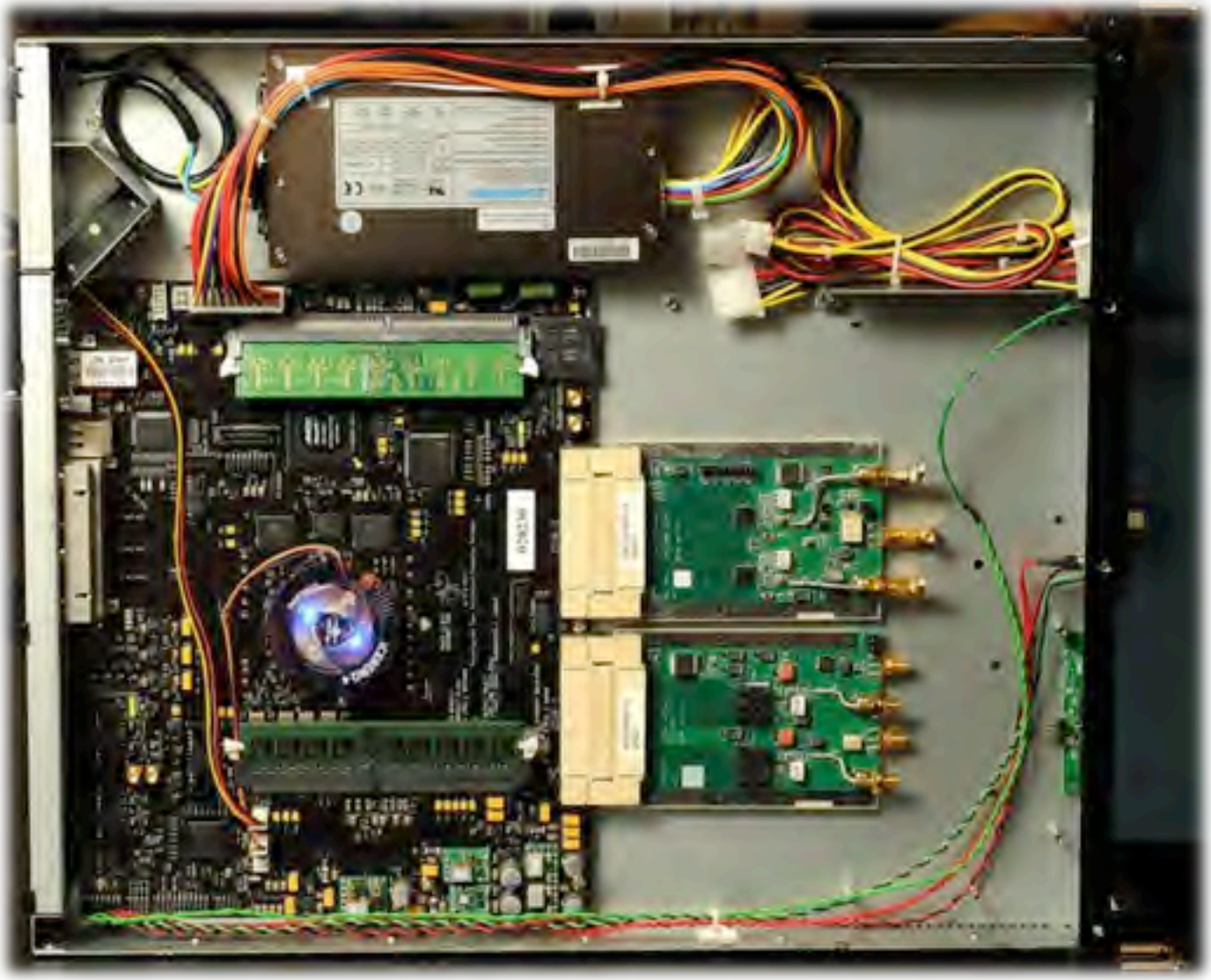
MKID ADC/DAC Board

FPGA Board

DAQ PC

Hardware: Signal Process Unit

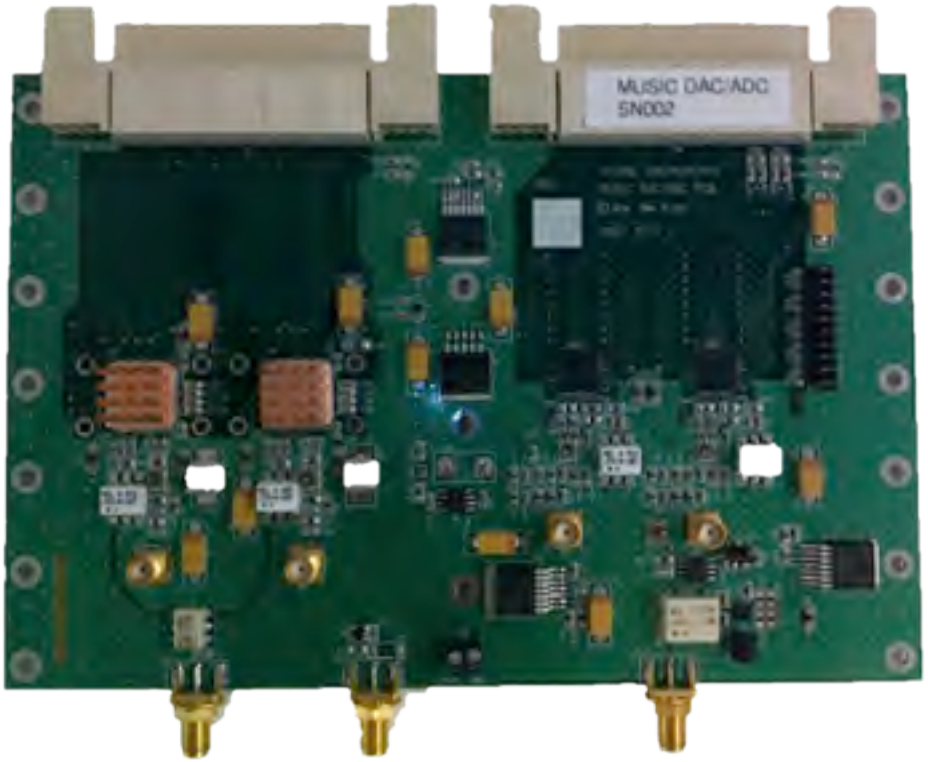
Reconfigurable Open Architecture Computing Hardware

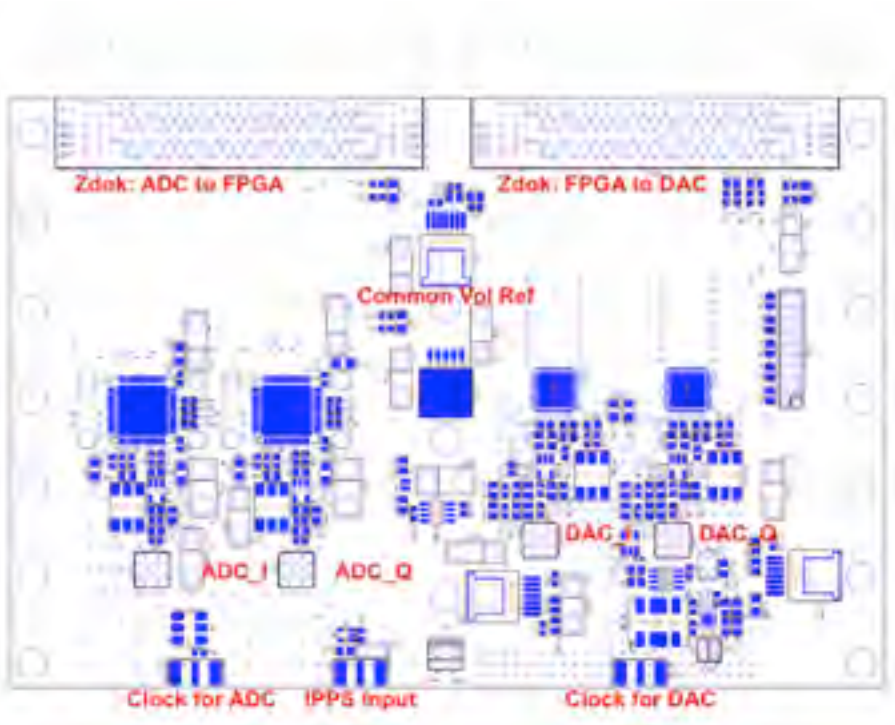


Important ROACH Components:

1. Xilinx Virtex 5 FGPA
2. Power PC
3. External Memory:
   DDR DRAM;
   2 QDR SRAM
4. 2 Zdok connector
5. 4 CX4: 40Gbit
6. 1 1Gbps Ethernet

Hardware: ADC/DAC Board





Two ADC: 550 msps, 12 bit

SNR: 64 dB

Two DAC: 1000 msps,16 bit

NSD: 75 dBc

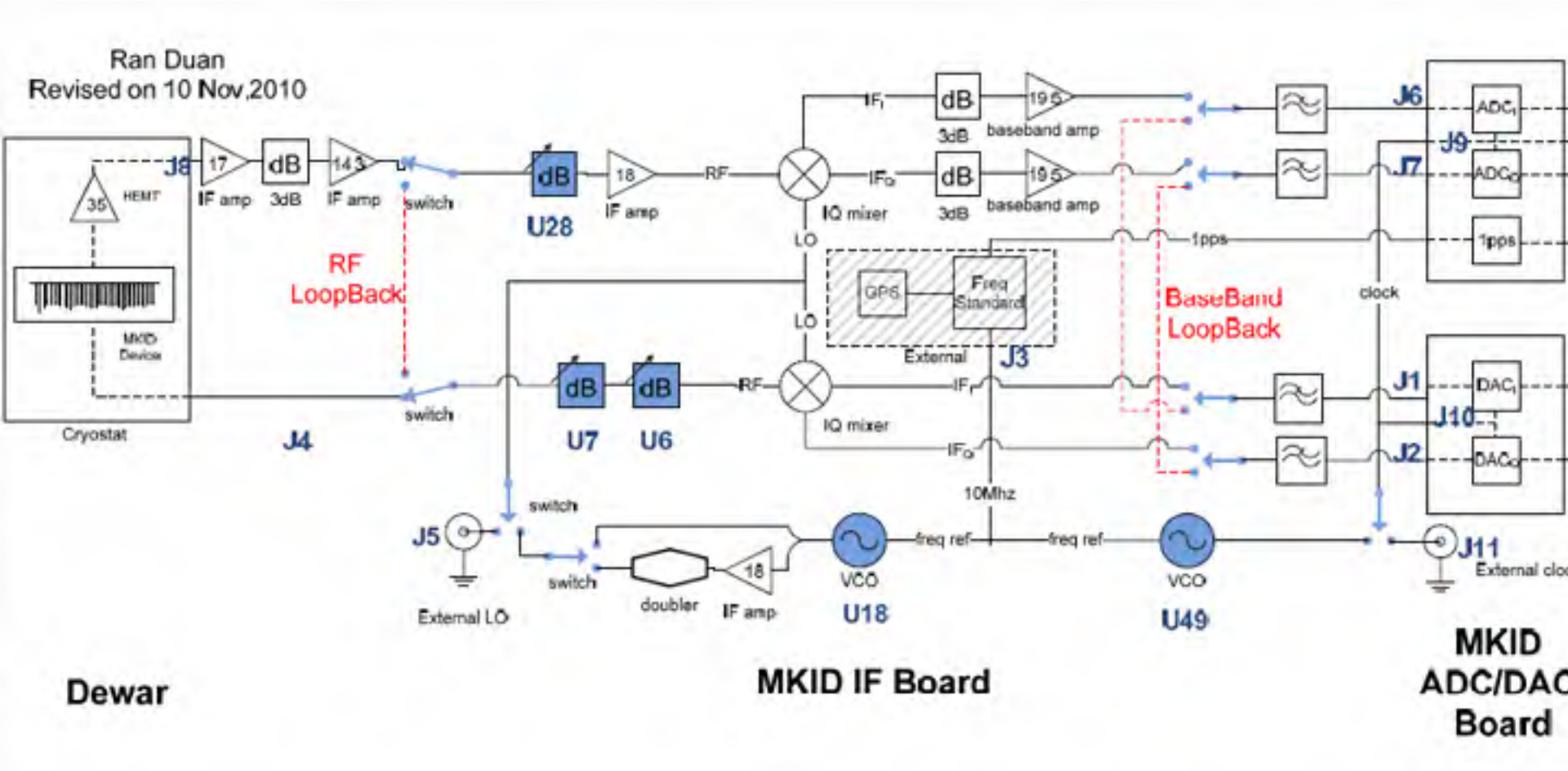
2nd Generation Board:

Common Voltage Reference

External/OnBoard

Power option

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


Ran Duan
Revised on 10 Nov,2010
HEMT
MKID Device
Cryostat
J8
17
IF amp
dB
3dB
14.3
IF amp
switch
J4
RF LoopBack
switch
dB
U28
18
IF amp
RF
IQ mixer
LO
IF
IF
dB
3dB
19.5
baseband amp
dB
3dB
19.5
baseband amp
J6
J9
J7
ADC
ADC
1pps
1pps
clock
BaseBand LoopBack
GPS
Freq Standard
External
J3
LO
dB
dB
U7
U6
RF
IQ mixer
IF
IF
J1
J10
J2
DAC
DAC
10Mhz
switch
J5
External LO
switch
doubler
18
IF amp
U18
VCO
freq ref
freq ref
U49
VCO
J11
External clo
Dewar
MKID IF Board
MKID ADC/DAC Board

Hardware: IF Board

1. Control the VCO for LO from 2.2 to 4.4 GHz and from 4.4 to 5GHz or higher with doubler.

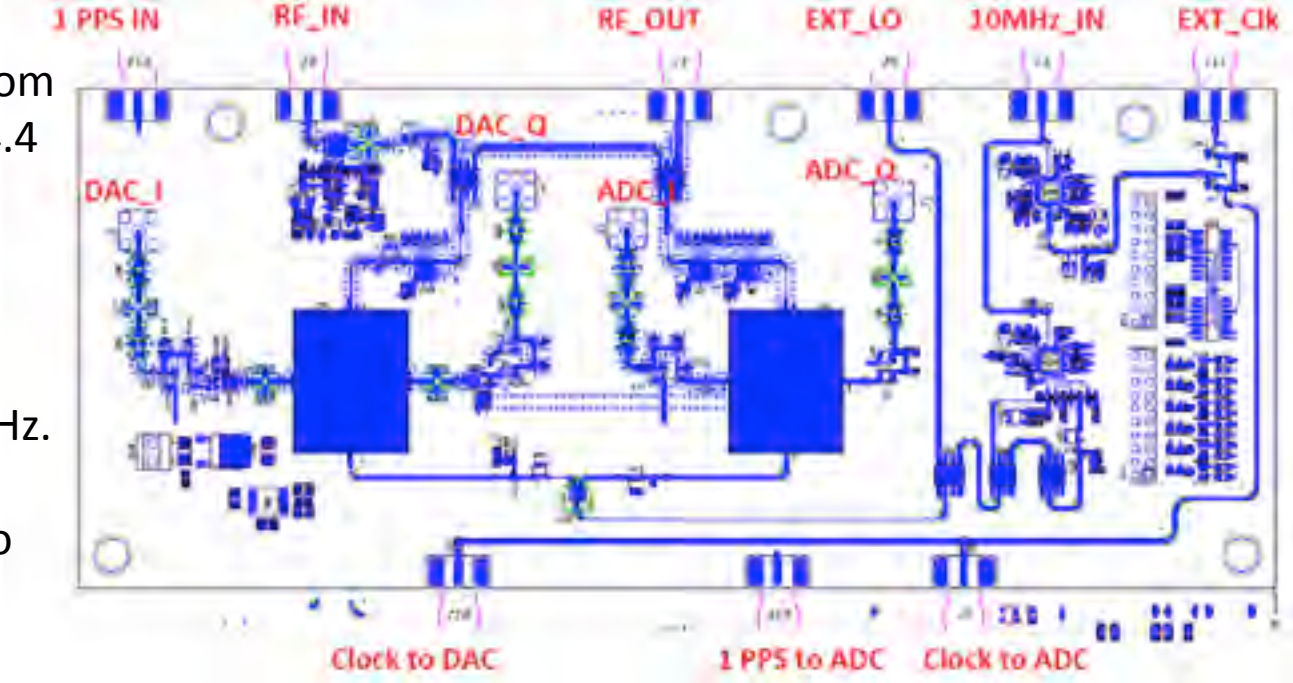
2. Control the VCO for Clock from 137.5 MHz to 4400MHz.

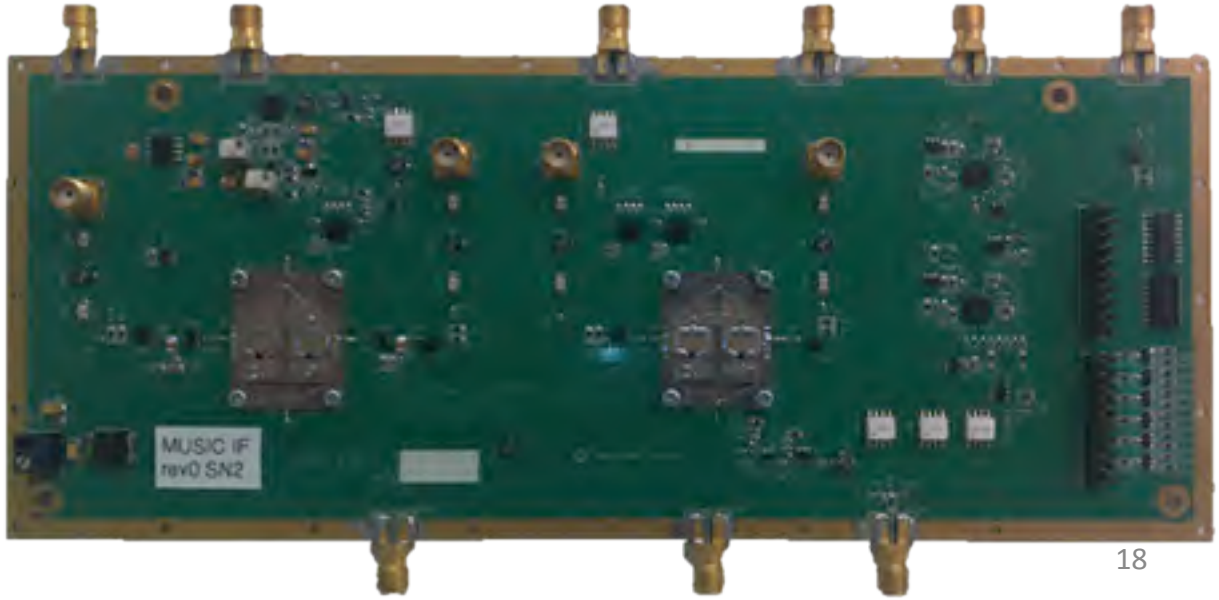
3. Control Baseband switch to do BB loop back test

4. Control RF switch to do RF loop back test.

5. Control 3 variable attenuator, each with attenuation from 0-31.5 dB.

6. Control to use External LO or External Clock.





IF board design

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

1.all the amplifier and mixer are working in the optimal range;

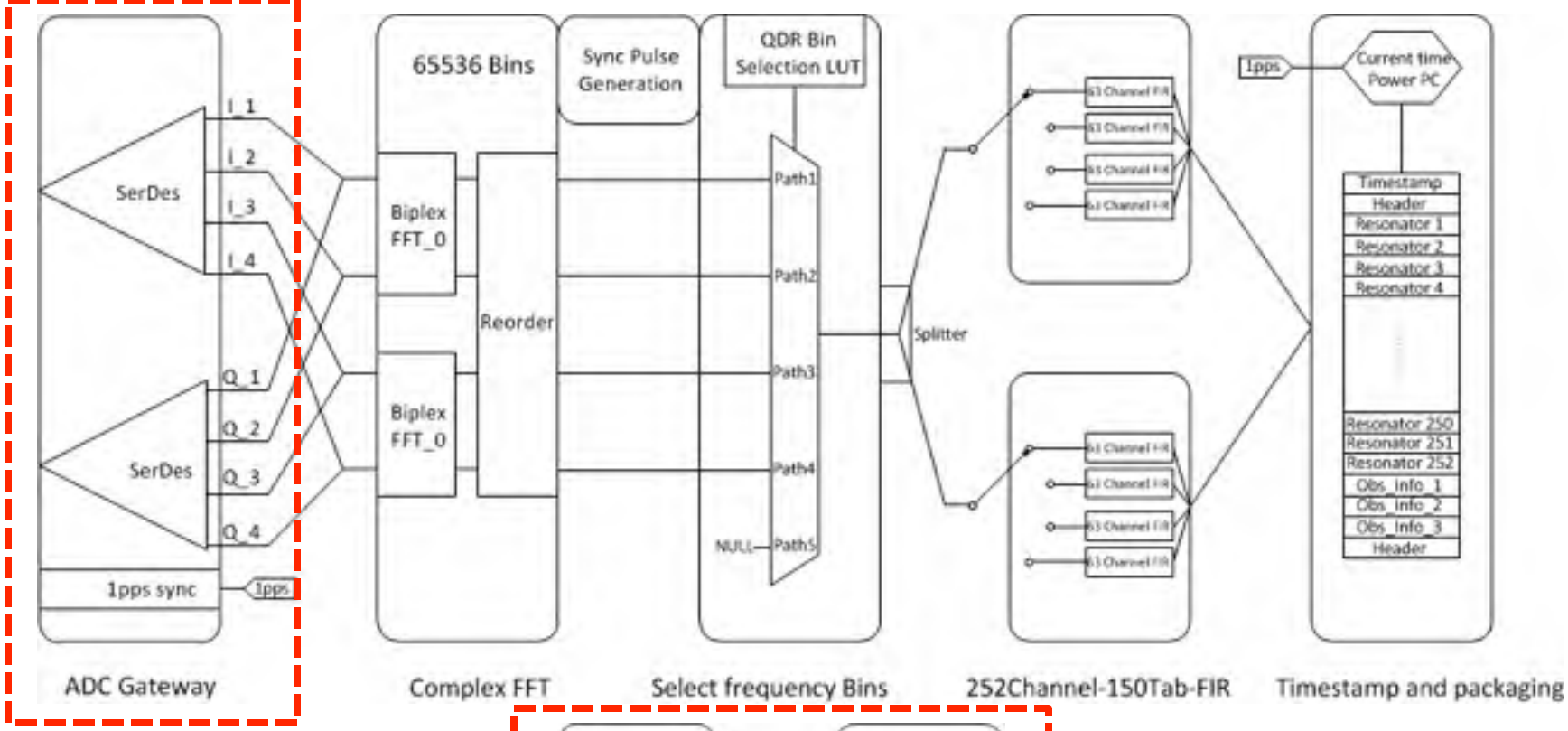
2. noise level reach ADC will dominate by the HEMT noise;

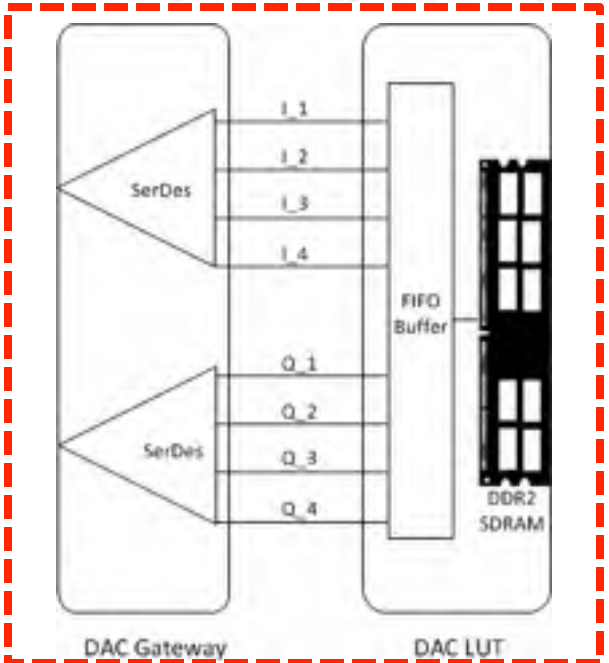
(other component e.g. LNA, ADC won't add additional noise)

3. two VCO, 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;

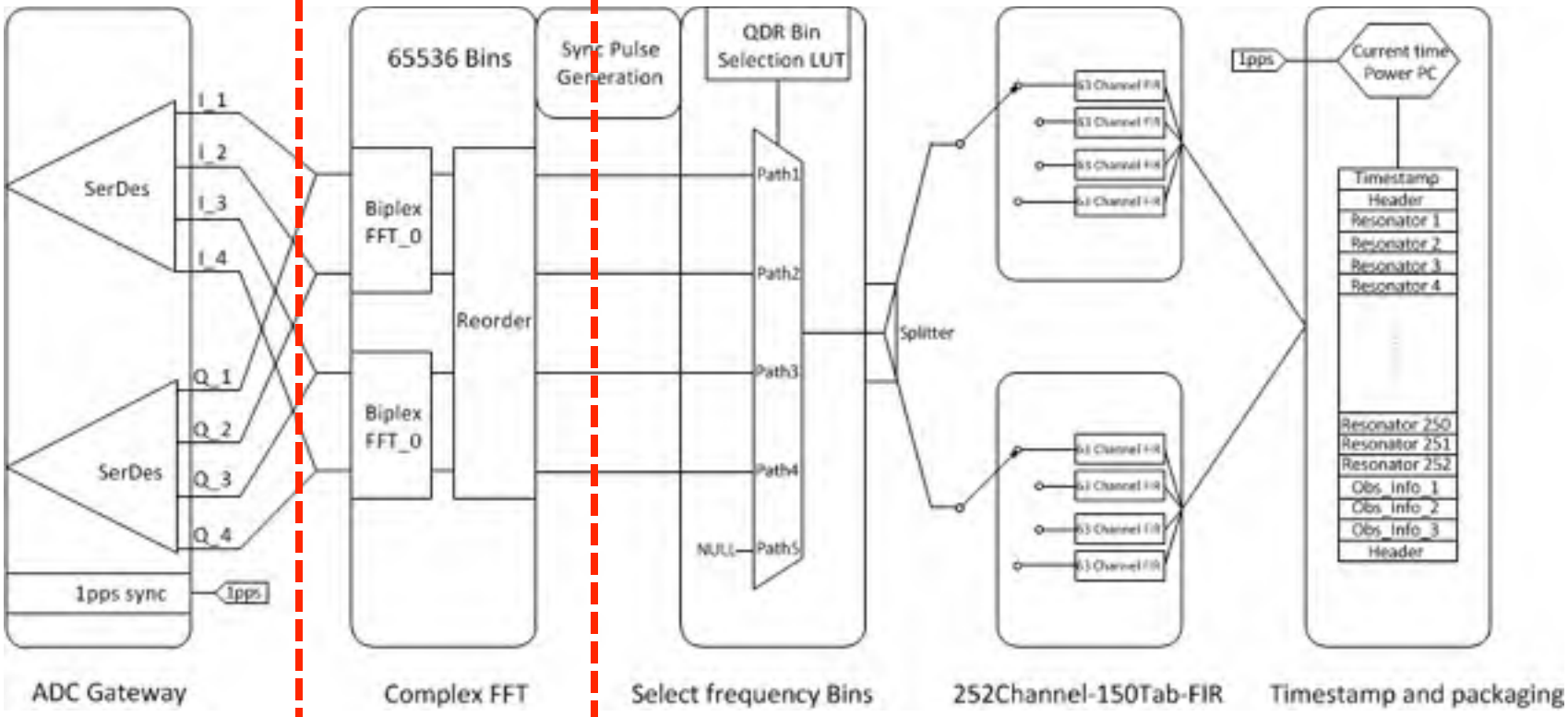
5. the probe signal level reach MKID device are optimized for each individual resonator.



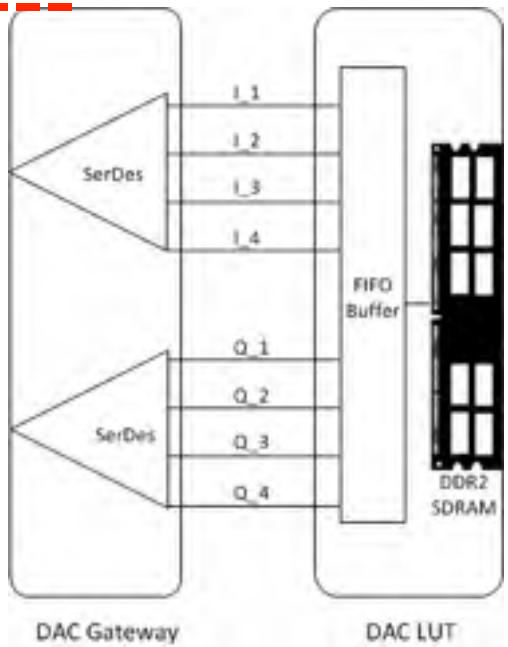


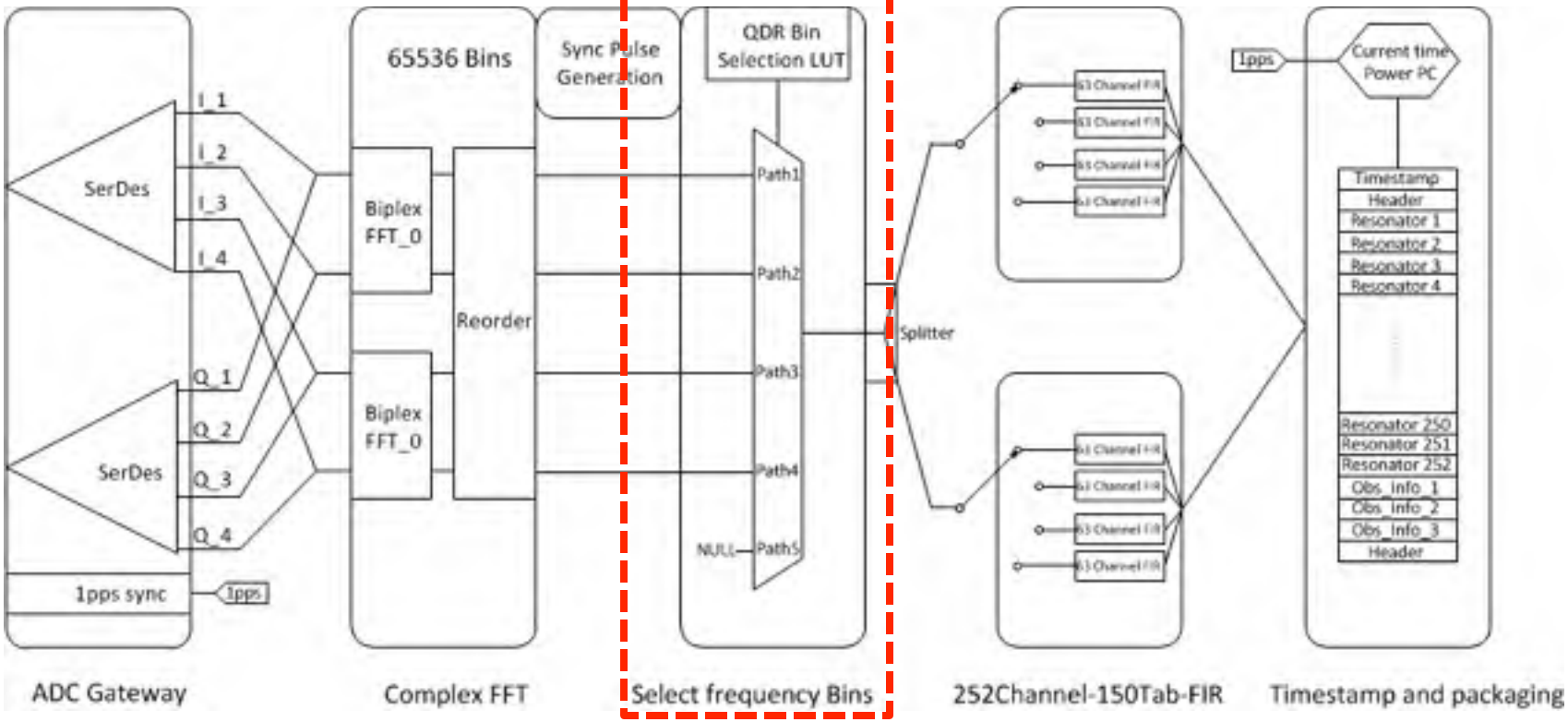
ADC

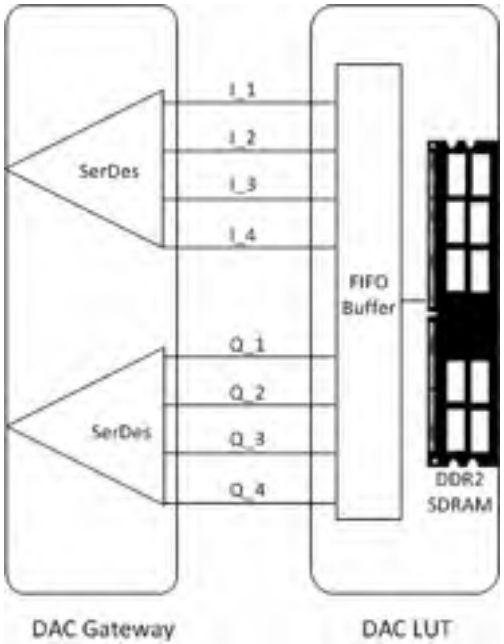
DAC LUT Buffer & DAC



65536 bins Complex Channelizing

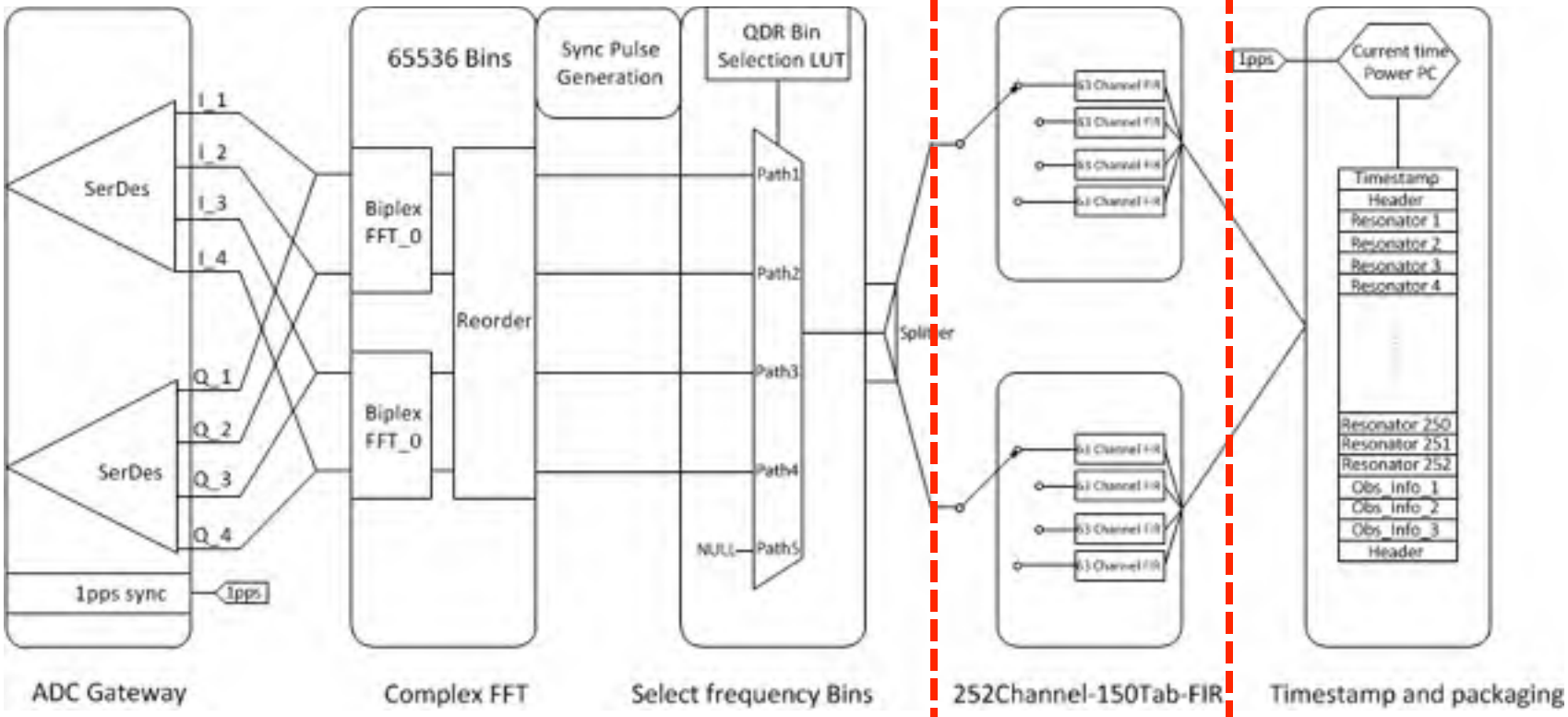


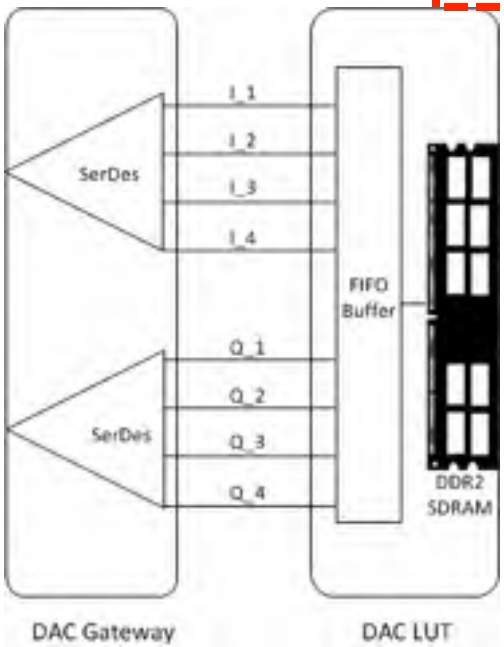




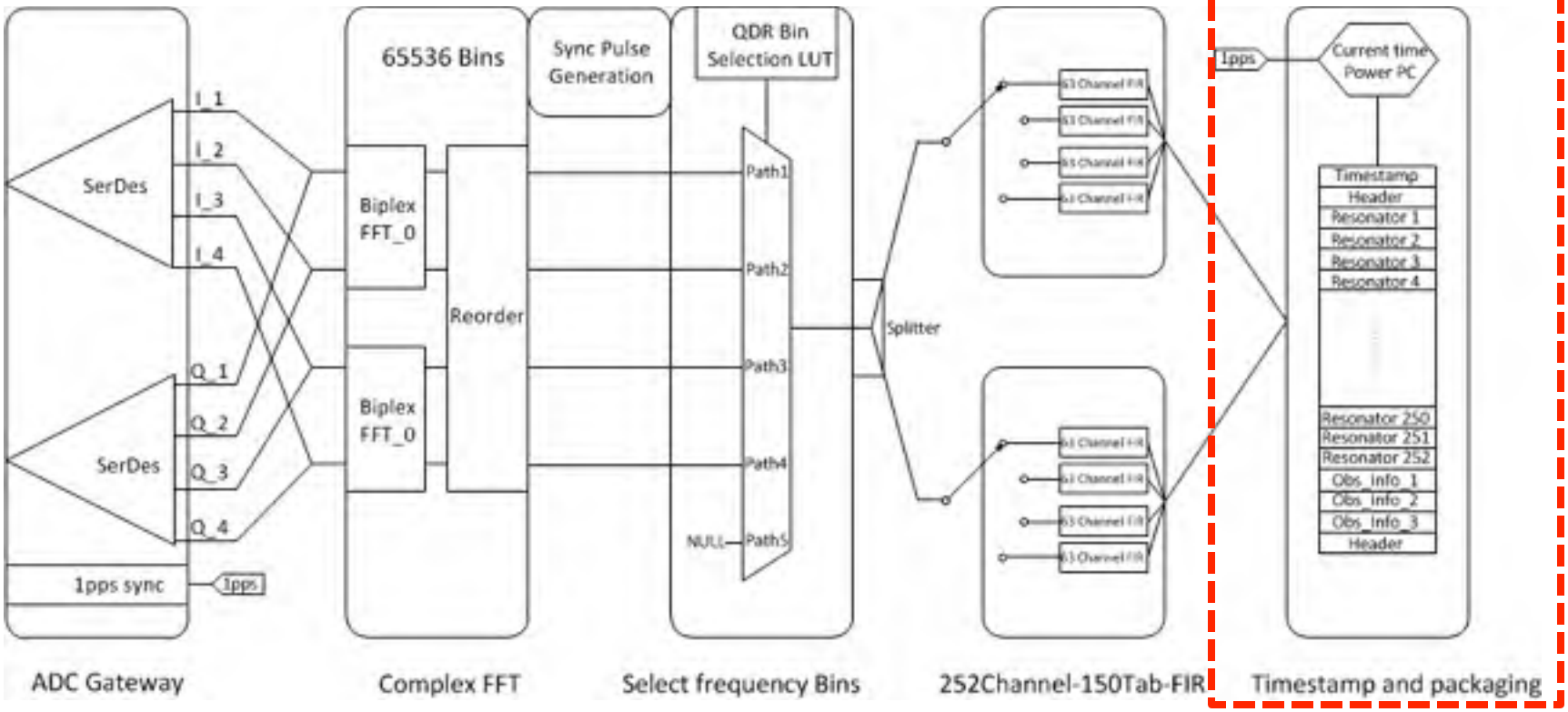
Select the 192 resonator bins

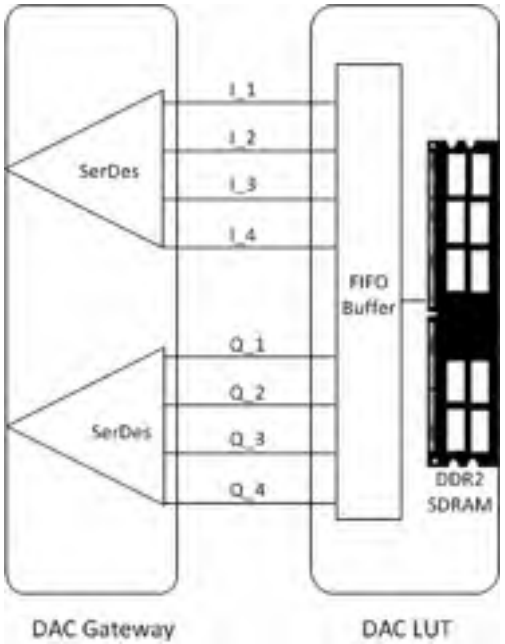
*** Automatically change with DAC LUT**





192 channel complex FIR Filter & Decimation

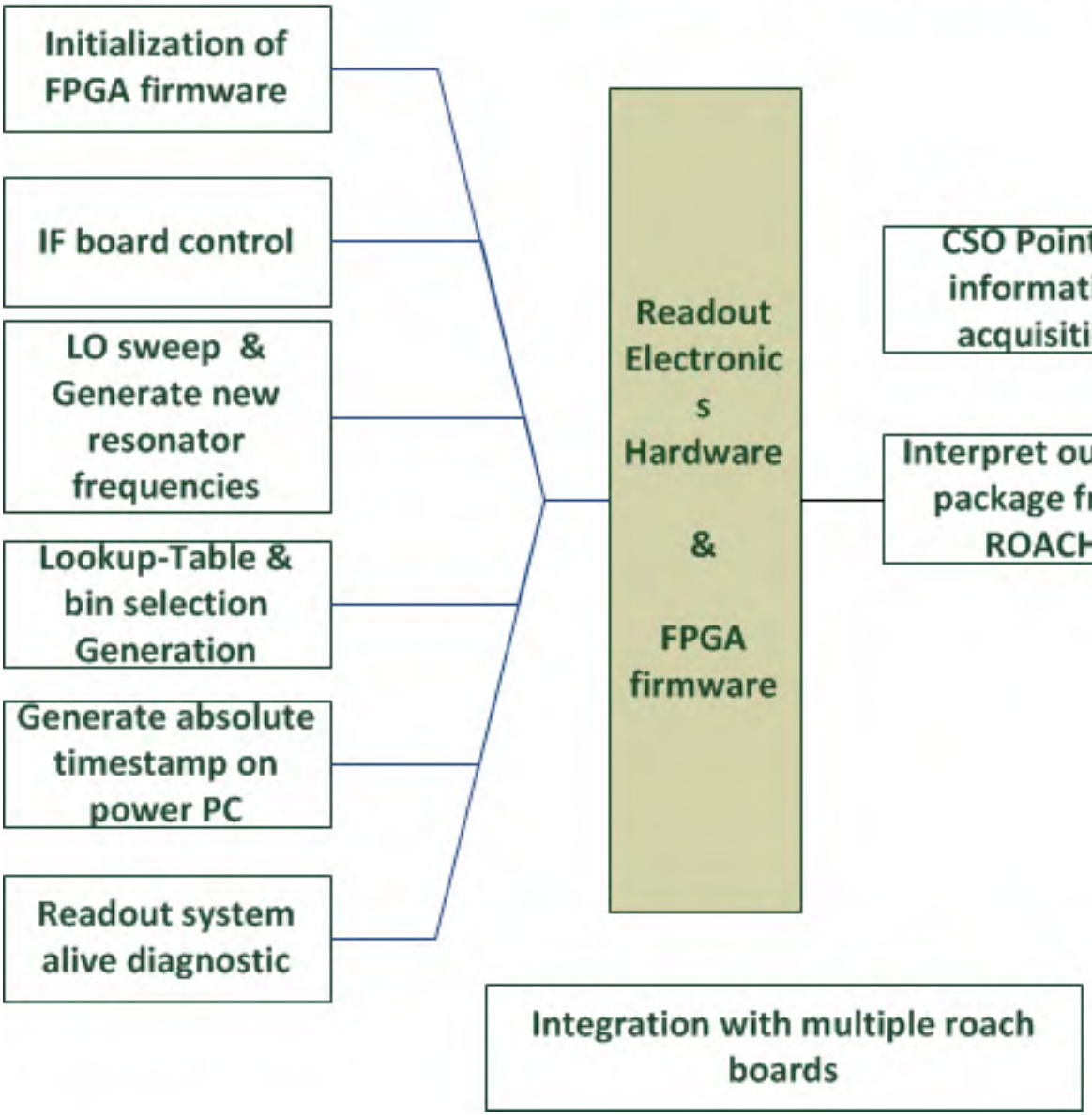




Add Timestamp and Header to data

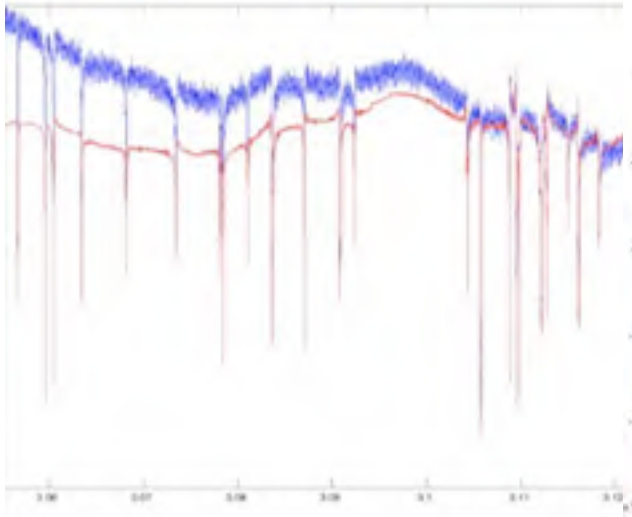
Pack data as TCP package, send out through normal 1G Ethernet at 100Hz

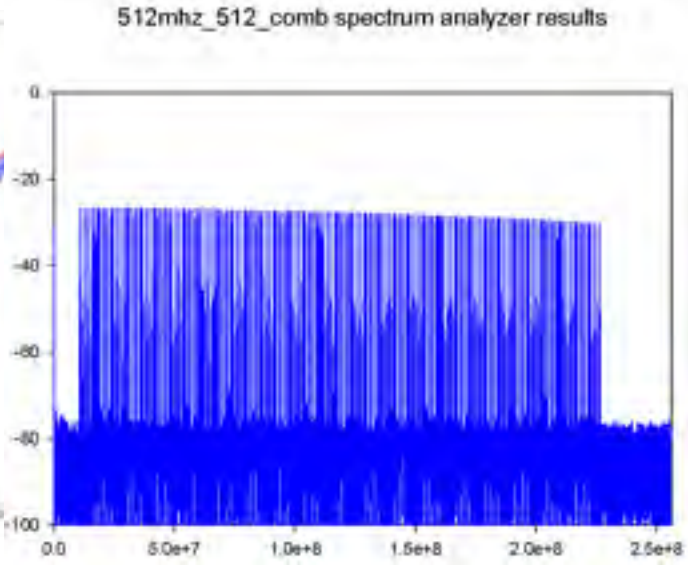
DAQ Implementation :

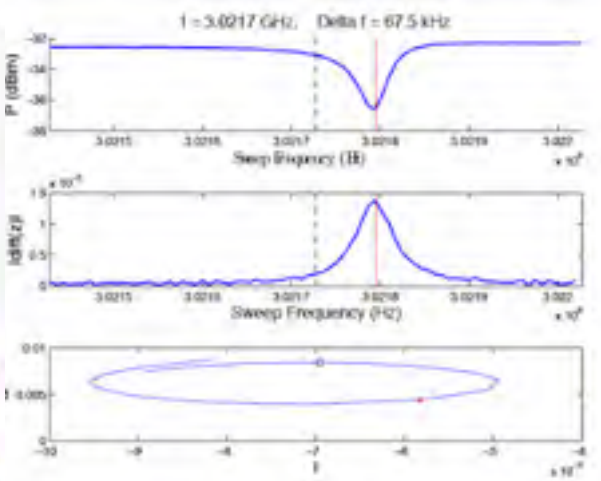


Operation Modes:

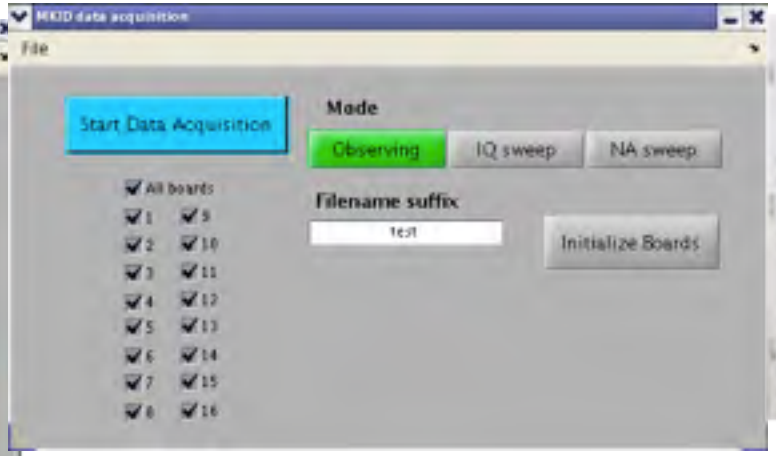
1. **Telescope data taking**
2. **FTS data taking and analysis**
3. **Network Analyzer sweep**
4. **Beam Map data taking and analysis**
5. **Multiple readout board selection**

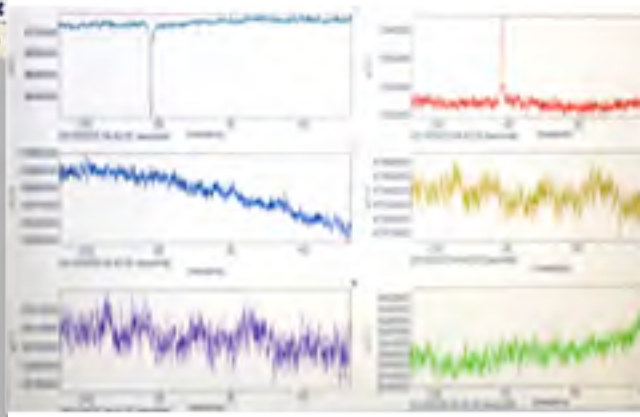



512mhz_512_comb spectrum analyzer results
0
-20
-40
-60
-80
-100
0.0
5.0e+7
1.0e+8
1.5e+8
2.0e+8
2.5e+8


f = 3.0217 GHz, Delta f = 67.5 kHz
P (dBm)
Sweep Frequency (Hz)
Sweep Frequency (Hz)


File
DAQ mode
Filename root
Start Data Acquisition
Resonator characterization
ROACH configuration
Network Analyzer
Standard FFT
Time domain co-add
Find resonators
Configure ROACH


MKID data acquisition
File
Start Data Acquisition
Mode
Observing
IQ sweep
NA sweep
All boards
Filename suffix
test
Initialize Boards



Summary of Telescope Run

MKID DemoCam Run 2010

Successful demonstration at CSO on 2010 June

Readout 126 complex tones

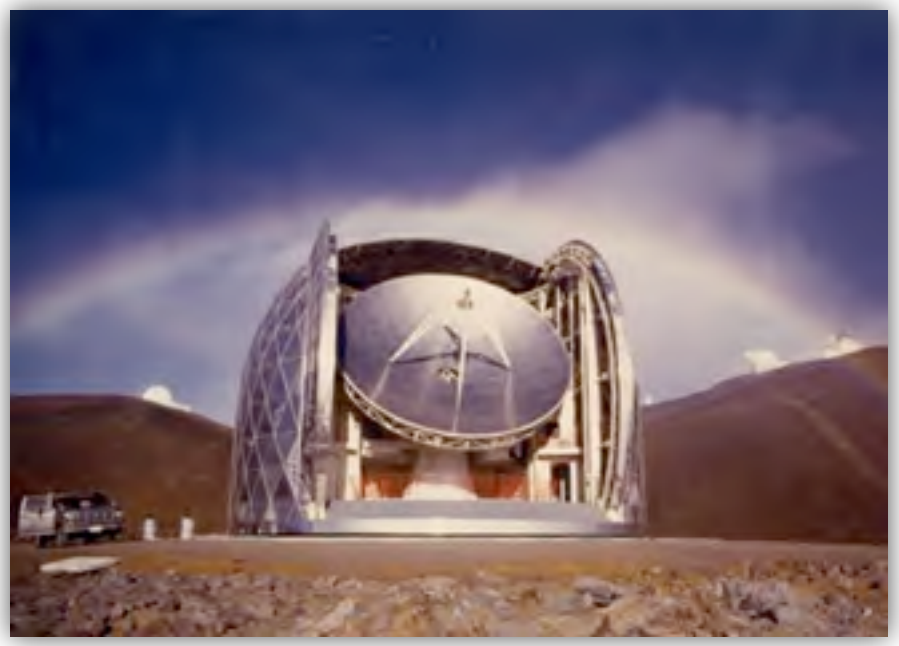
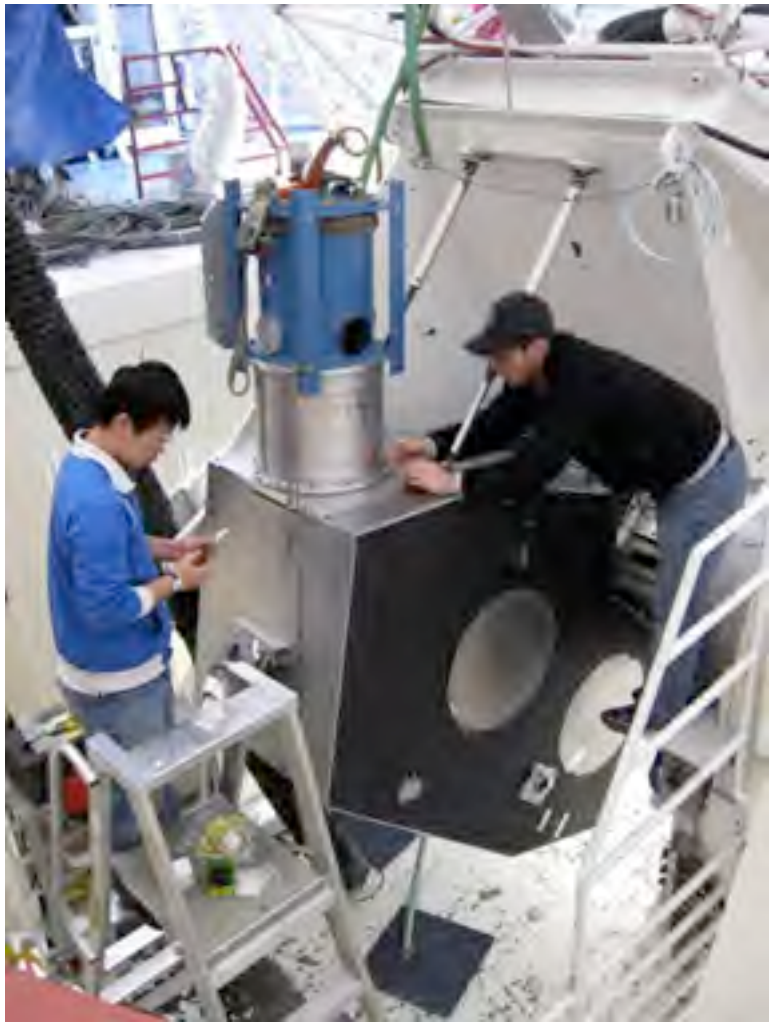


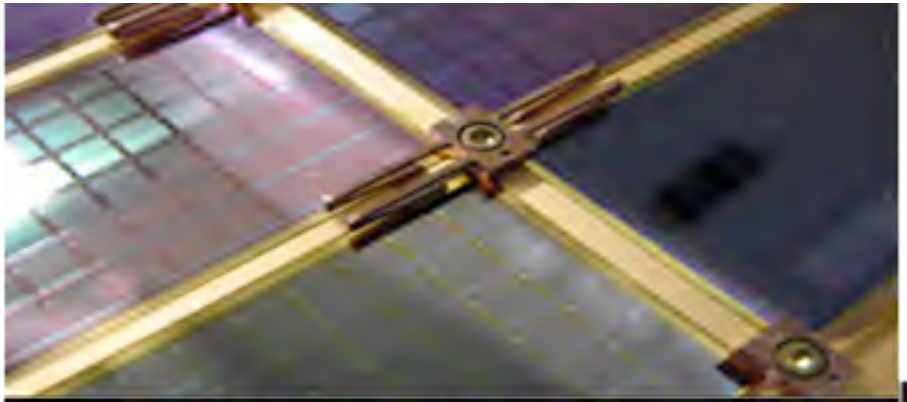
Photo: CSO Summit, June 2010

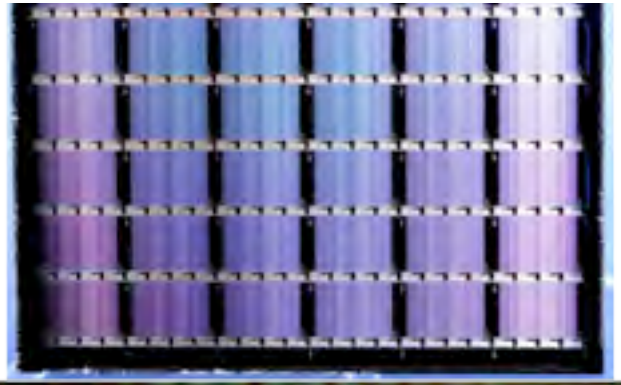
Make a clear path to built full MKID Camera

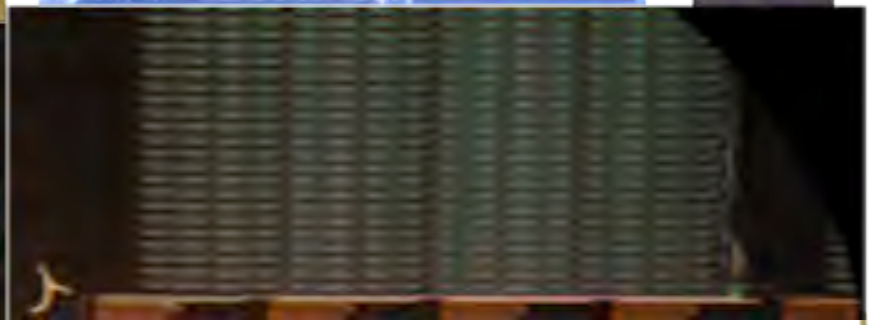
Dewar and Readout Setup 2010

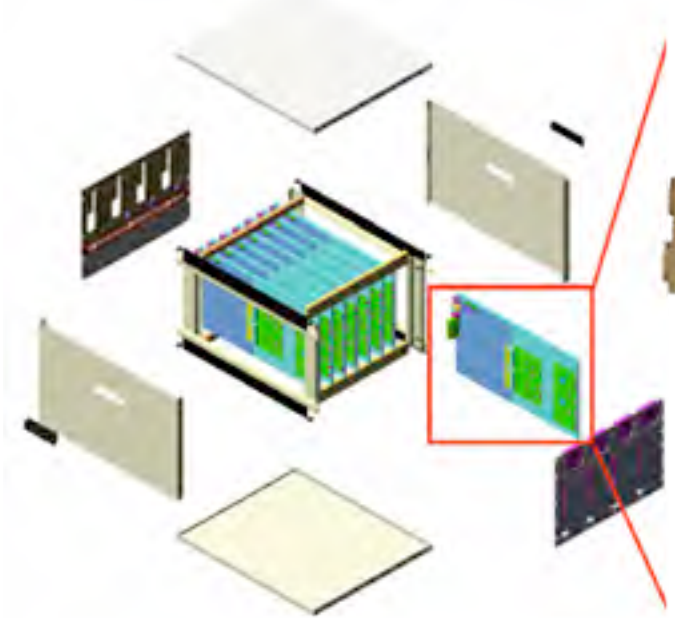


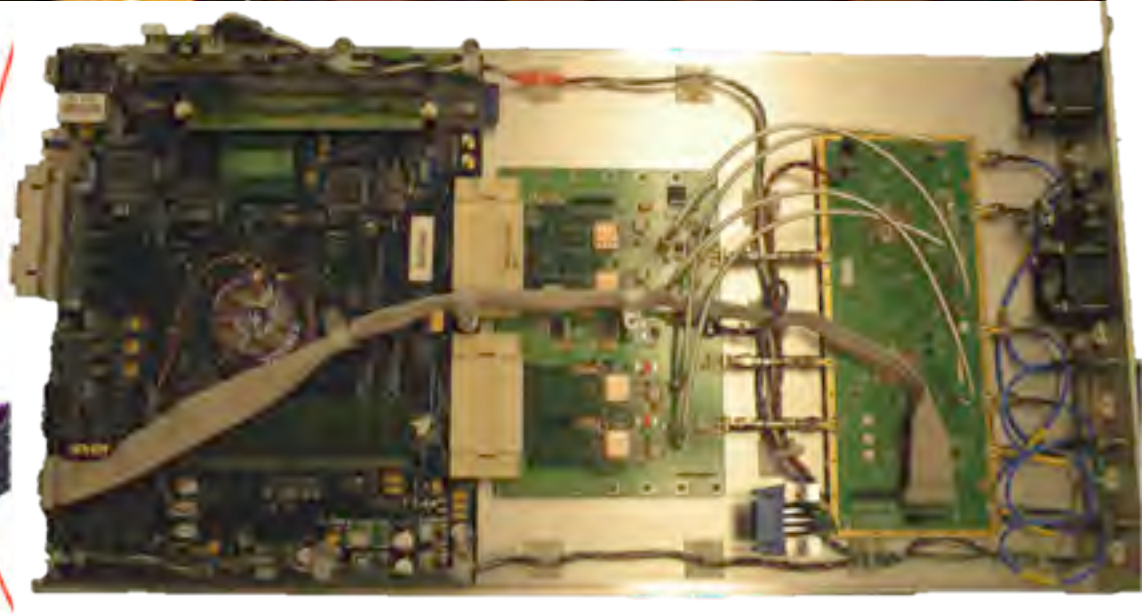
MUSIC



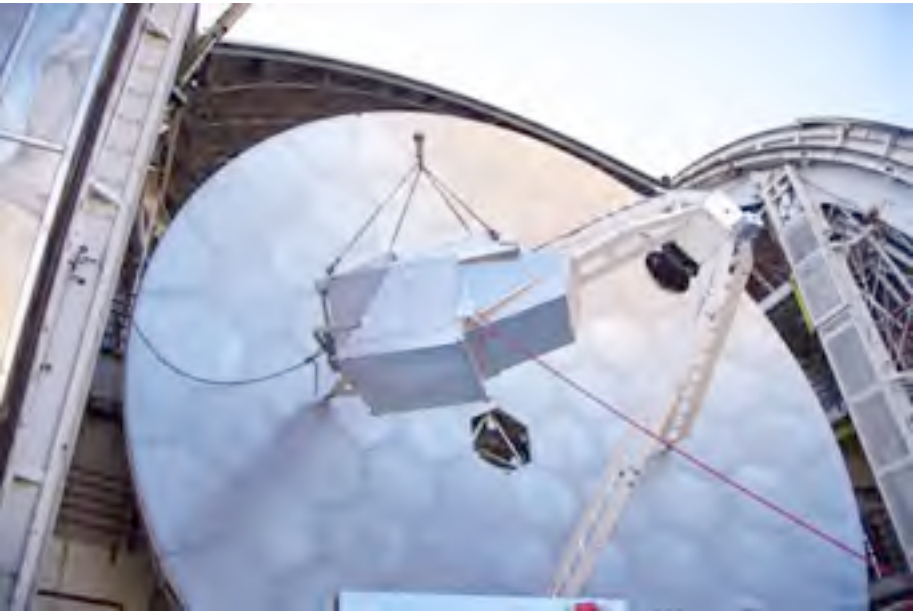


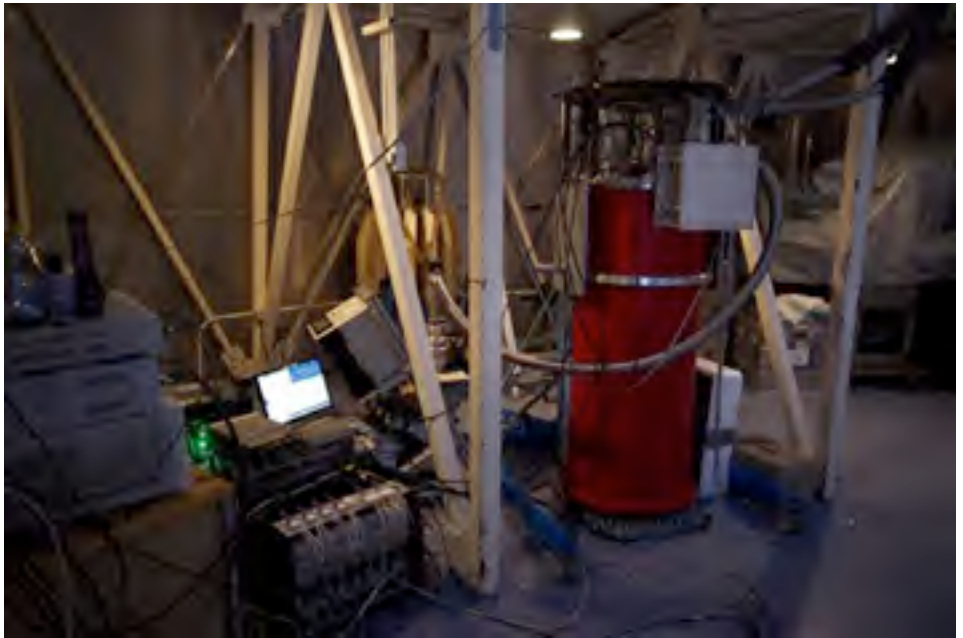






Installation: Optical box --- > Cryostat --- > Readout





MUSIC Camera Run 2012

Open Source KIDs Based Readout Platform

http://www.its.caltech.edu/~rduan/Readout.html

Thanks to MUSIC Group, OSR Group, Casper Group and Techne Instr, Omnisys Support!

- 400+ Report and Notes
- All aspect of Kinetic Inductance Detector Readout
- Development process since 2009

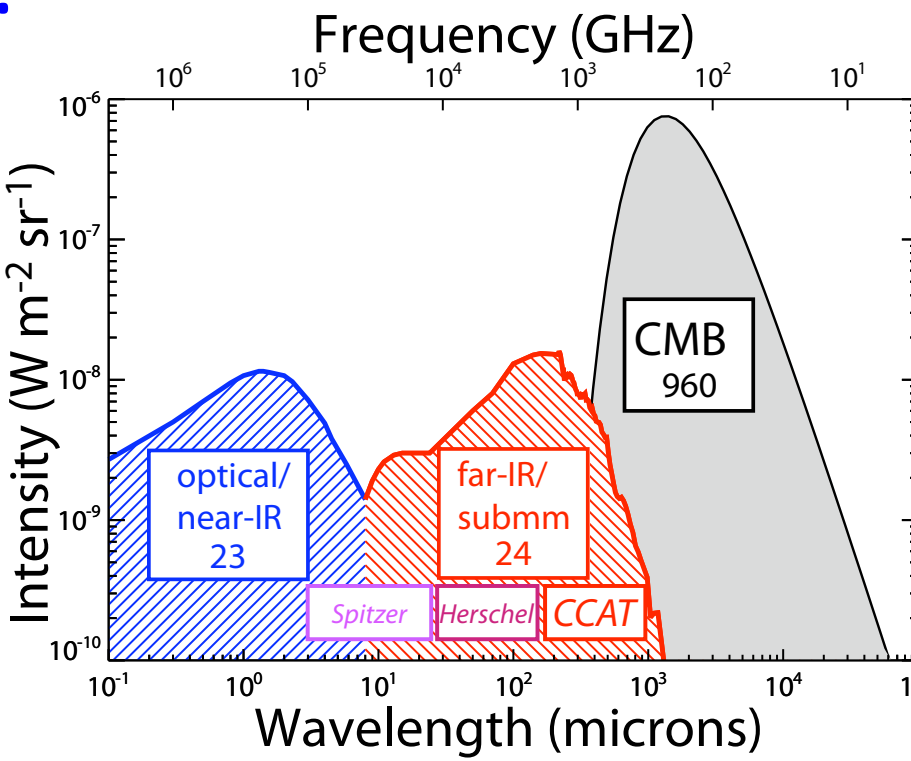
1. NASA JPL: Jet Propulsion Laboratory, US
2. NASA GSFC: Goddard Space Flight Center, US
3. NIST : National Institute of Standards and Technology, US
4. NRAO: National Radio Astronomy Observatory, US
5. SRON: Space Research Organiation Netherlands, Netherland
6. CNRS/CSNSM: Centre National de la Recherche scientifique, France
7. NAO: National Astronomical Observatories, Chinese Academy of Sciences, China
8. Fermi Lab, US
9. Argonne National Lab, US
10. Durham University, UK
11. UBC, Canada
12. Standford U, US
13. UCSB, US
14. UC Berkeley, US
15. UC Colorado, US
16. U of Penn, US
17. U Paris, France
18. U of Seoul, South Korea
19. Columbia U, US

Scientific Motivation

Submm and Far-IR wavelength:

- Half of the luminosity of the universe;
- 98% of photon emitted since Big Band

"High priority in coming decade….. Undertake large and detailed surveys of galaxies…" – NRC's Astro2010 Decadal Report, p2-18



- formation and evolution of galaxies.
- structure in the universe;
- Dark matter halos in which they form.
- Help study of galaxy clusters.

Dole et al. 2006

Motivation?

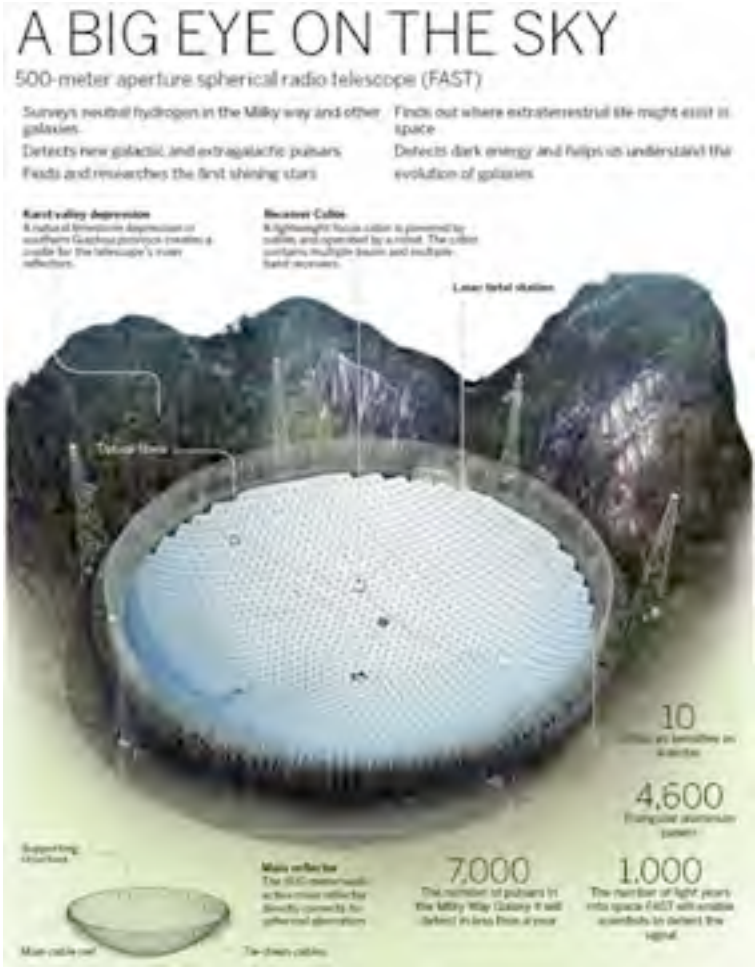
Astronomical Instrument:

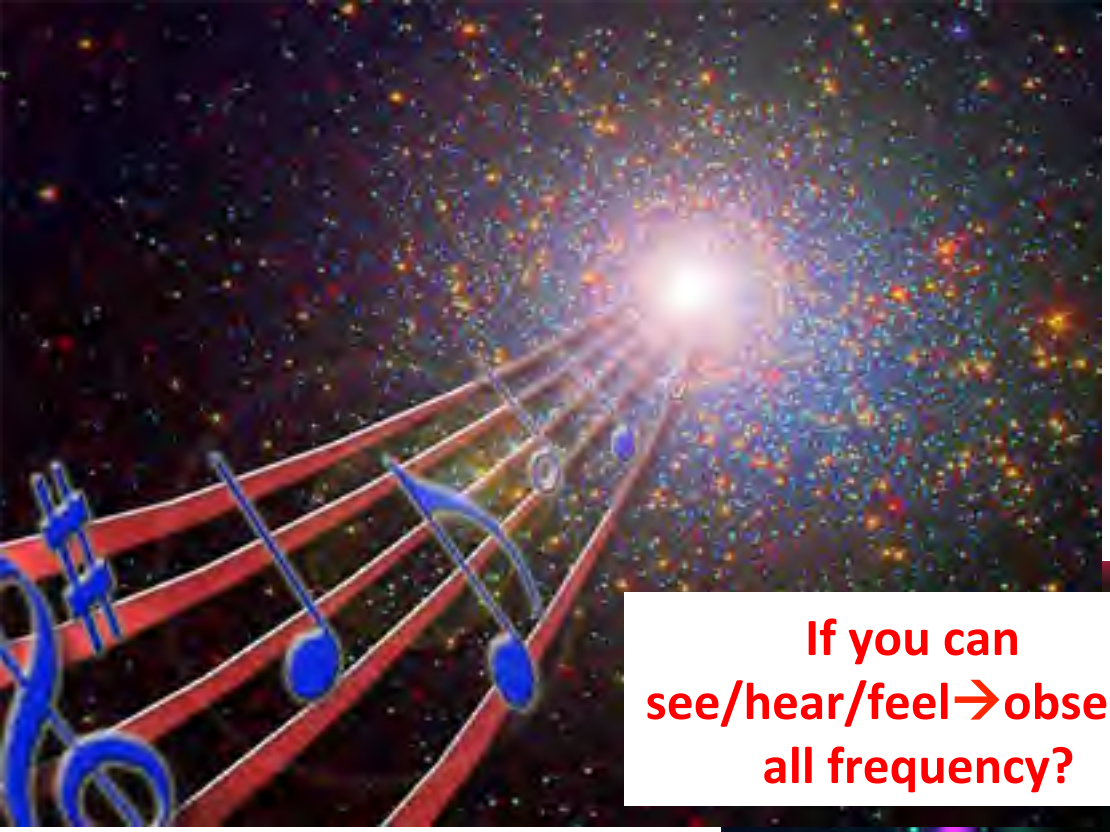
To see universe in the view never see before;

To see things people never see before.

Universe is trying to show us what is it truly looks like

Open the eyes





Universe is an symphony of “sound”

If you can see/hear/feel→observe all frequency?

Universe is painting of “color”

Spirit of Discover

Stand on any point in history, we make mistakes all the time, even some basic ones

Light; Matter; Human; Universe

We could easily make mistakes, especially in this young area we are working on.

There must be exciting discovers with all kinds of possibility, without limit!

Reference:

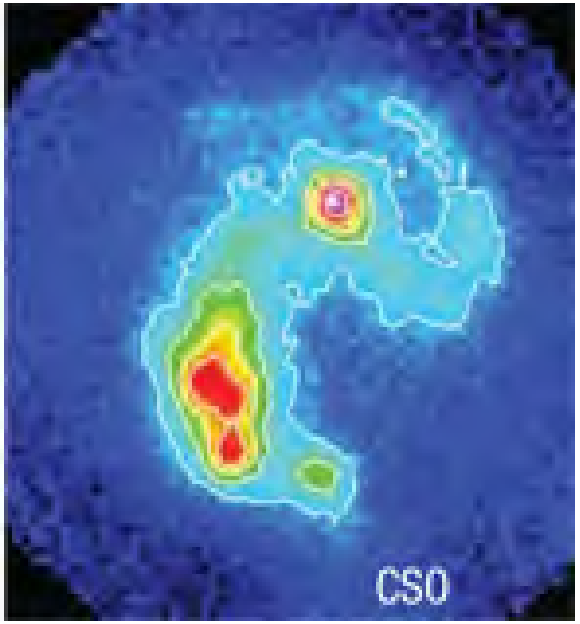
The Tao of Physics, Fritjof Capra, 2000

Rainbow of human body, ChangLin Zhang, 2002

Research Interests:

- Receiver/Readout Development
- Antenna/Feed
- Sub-mm Detection

THE END



Visible **infrared** **submillimeter**

Email: **duan.ran.naoc@gmail.com**