Design of a scientific CCD camera with a large focal plane of 4k x 4k pixels

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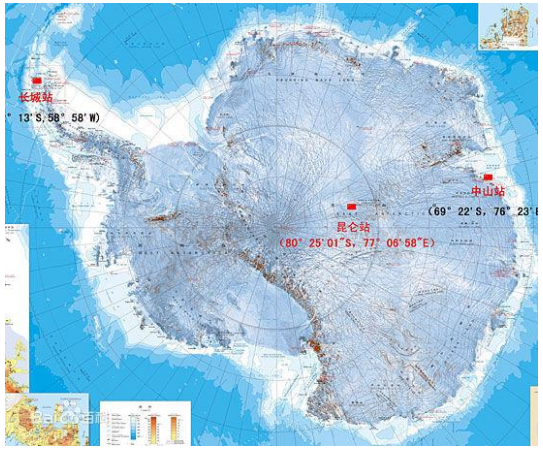
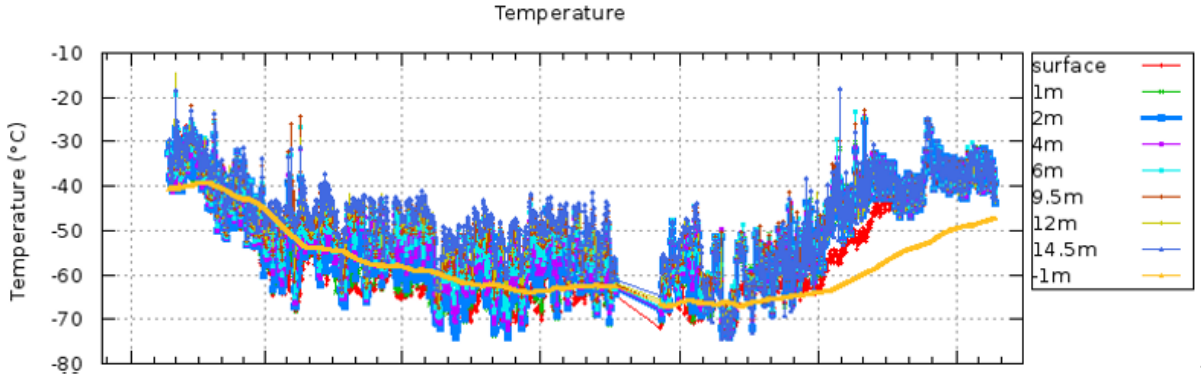
Advantages of the Antarctic observatory site

- Astronomical seeing is the best of all the sites on earth.
- low perceptible water vapor, weak infrared background radiation are conducive to infrared and sub-millimeter wave astronomical observation.
- Continuous darkness and the abundant clear-sky nights.

Kunlun Station at Dome A

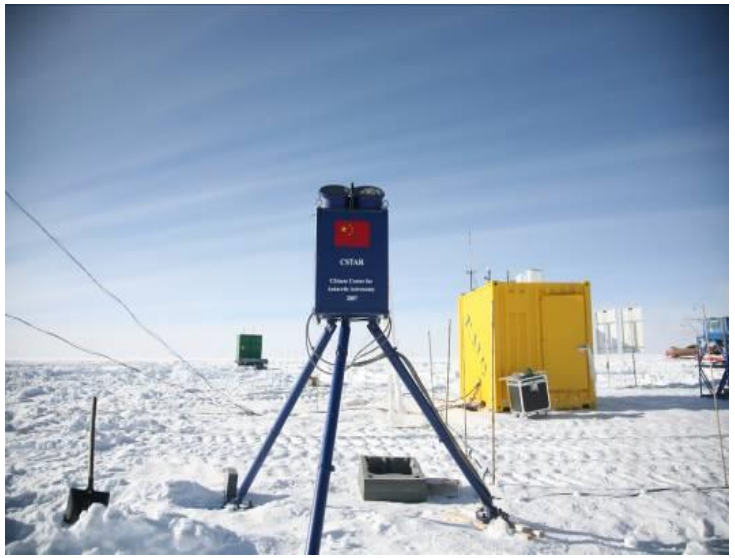
- The average annual temperature: -25 ℃, the lowest: -88 ℃.
- Dry climate, low precipitation
- Windy, with wind speeds averaging 17m/s



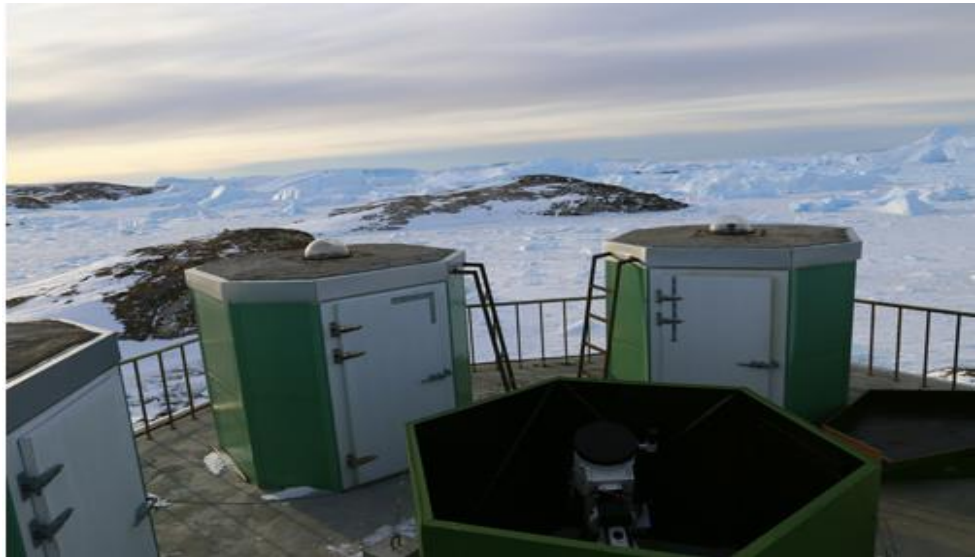


China's Astronomical Projects in Antarctica

- CSTAR(Chinese Small Telescope Array)



- BSST(Bright Star Survey Telescope)

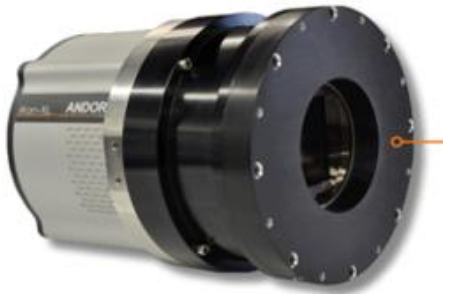


- Sites testing
  - Cloud cover
  - Sky background
  - Seeing
- Exoplanet surveys
  - Ongoing planetary transit survey
  - Planetary compositions, internal structures and atmospheres beyond our solar system

- AST3(Antarctic Survey Telescope)

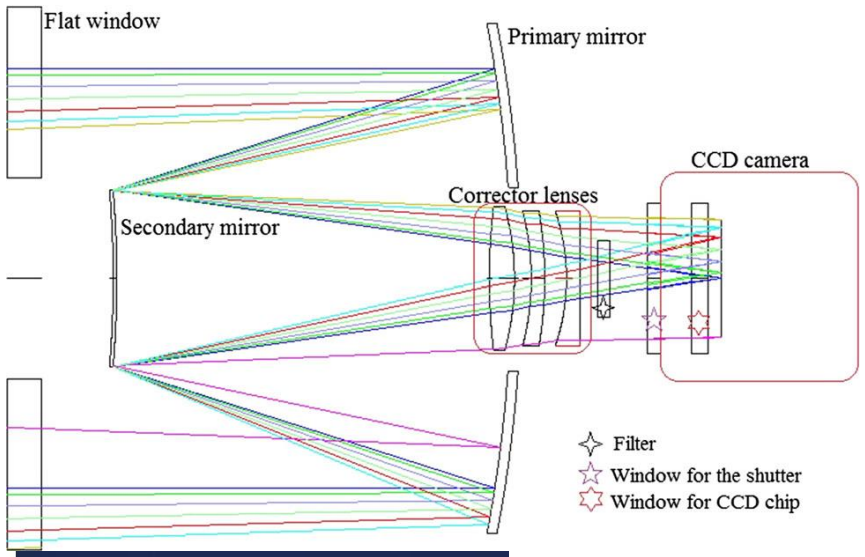
China's Astronomical Projects in Antarctica

- CCD Cameras



Telescope	CSTAR	BSST	AST3
Camera model	DV435	iKon-XL	STA
CCD model	CCD47-20	CCD303-88	STA1600-FT
Number of pixels	1024 x 1024pixels	4096 x 4136pixels	10560 x 10560 pixels
Pixel size	13 micron pixel	12 micron pixel	9 micron pixel
Type	Back Illuminated	Back Illuminated	Back Illuminated
Maximum data rate	1 MHz	3 MHz	1 frame/second
Outputs	1	4	16
Readout noise	7.5 e^- at 1 MHz; 6.9 e^- at 500 kHz	7.5 e^- at 1 MHz; 4.2 e^- at 100 kHz	7-9 e- at 1 MHz; 5 e- at 100 kHz
Charge storage	80,000 e-	350,000 e-	80,000 e-
Quantum Efficiency	> 90%	> 95%	> 90%
Dark signal	0.06 e^-/pixel/second (at -40℃)	0.3 e^-/pixel/second (at -25℃)	0.3 e-/pixel/second (at -100℃)

BSST(Bright Star Survey Telescope)



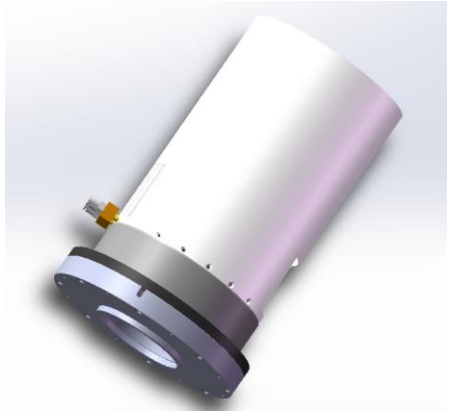
Technical Specifications of the BSST

Parameter	Specification
Telescope aperture	300 mm
Field of view	3.4°
CCD pixel	12 um
Image scale	3” per pixel
Image quality	1.5-3 pixel FWHM over entire field
Maximum speed	2° s^{-1}
Pointing accuracy	<3’
Tracking accuracy	1.5” in 5 min (RMS)
Operation temperature	-80℃ ~ 40℃

- Problems with commercial CCD cameras
  - Extremely low temperature operation environment
  - Not adequately tested at extremely low temperatures
  - Expensive
- Requirements of larger telescope in future
- Self-designed, customized

Main technical parameters

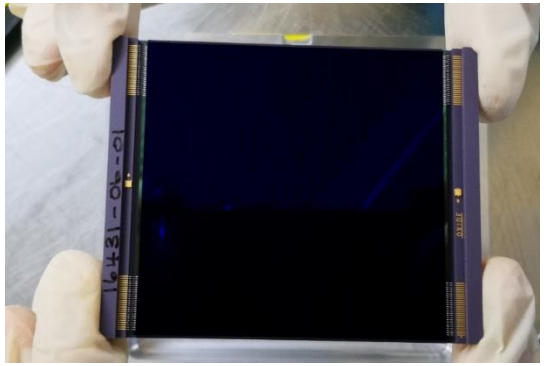
- Refrigeration: Thermoelectric Cooler (TEC)
  - Operation temperature: -80 to 40 ℃
  - Air cooling: 50 ℃ below room temperature
  - Water cooling: 70 ℃ below room temperature
- Vacuum: Vacuum maintainability
- Readout: two readout modes
  - ACDS mode: 100KHz and 500KHz data rate, noise < 10 e^-
  - DCDS mode: 3MHz max data rate, noise < 10 e^- at 1MHz
  - High gain or high dynamic range mode are optional
  - Dark signal: 0.08 e^-/pixel/second (at -40℃)
- Dimension:
  - Image size: 61.4 mm x 61.4 mm

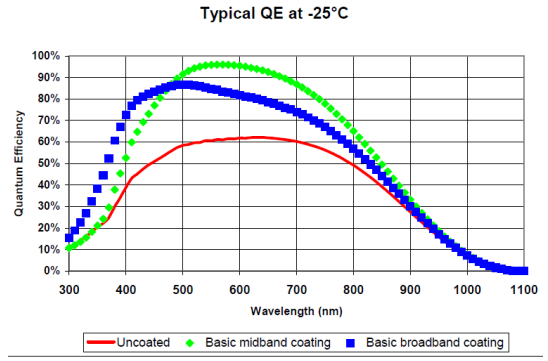


Ø165×275mm

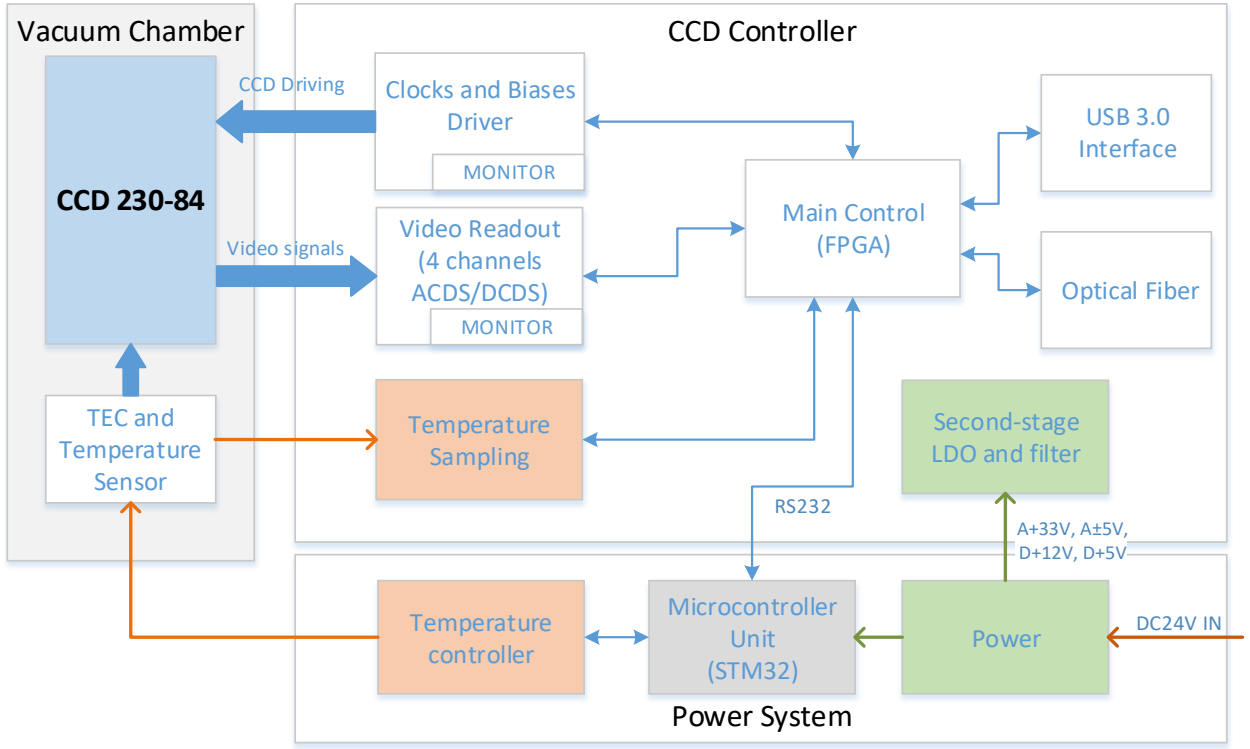
CCD230-84 Scientific CCD Sensor

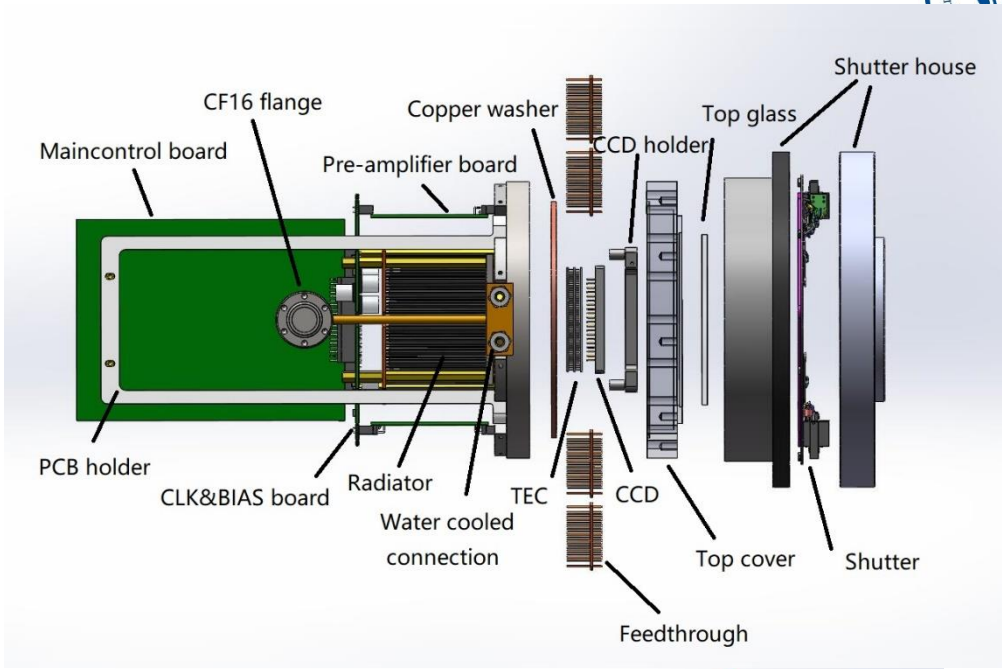
Number of pixels	4096(H) x 4112(V)
Pixel size	15 µm square
Image area	61.4 mm x 61.4 mm
Outputs	4
Package size	63.80 mm x 79.60 mm
Package format	aluminium oxide PGA
Flatness	<20 µm (peak to valley)
Amplifier sensitivity	2.5 µV/e^-
Readout noise	8 e^- at 1 MHz; 4 e^- at 50 kHz
Maximum data rate	5 MHz
Charge storage	150,000 e^-
Dark signal	0.2 e^-/pixel/second (at -25℃)
Spectral range	300-1060nm
Type	Back Illuminated, Full-frame

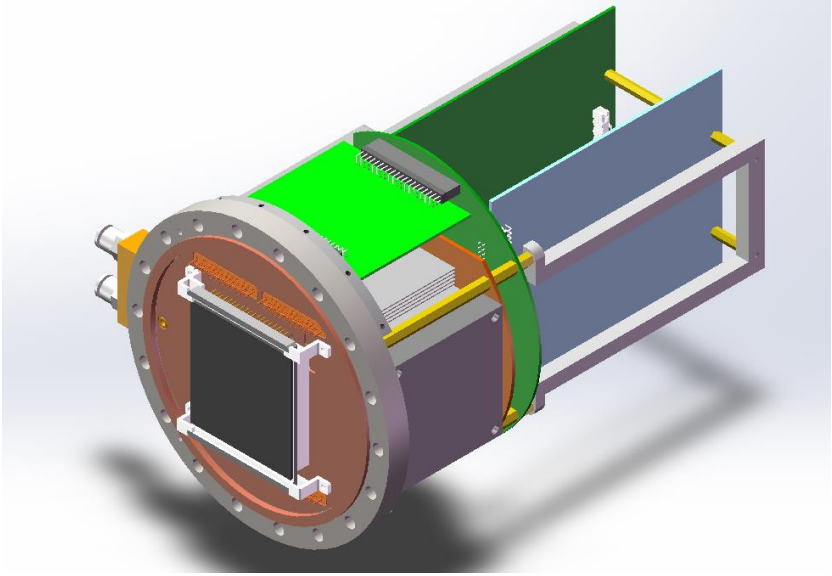




Hardware Structure



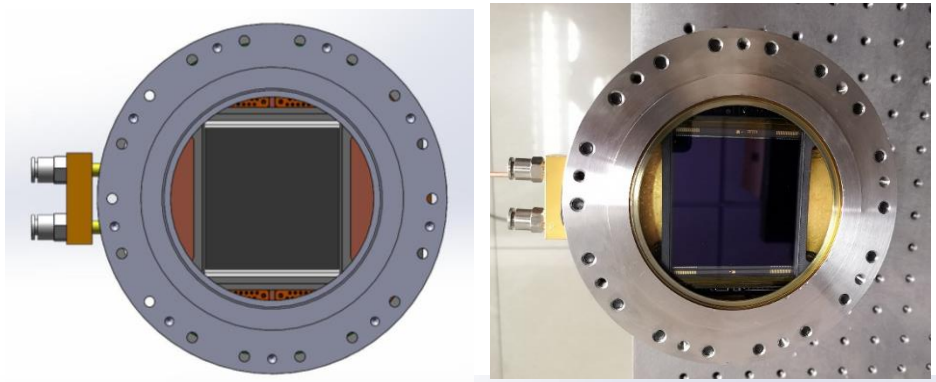




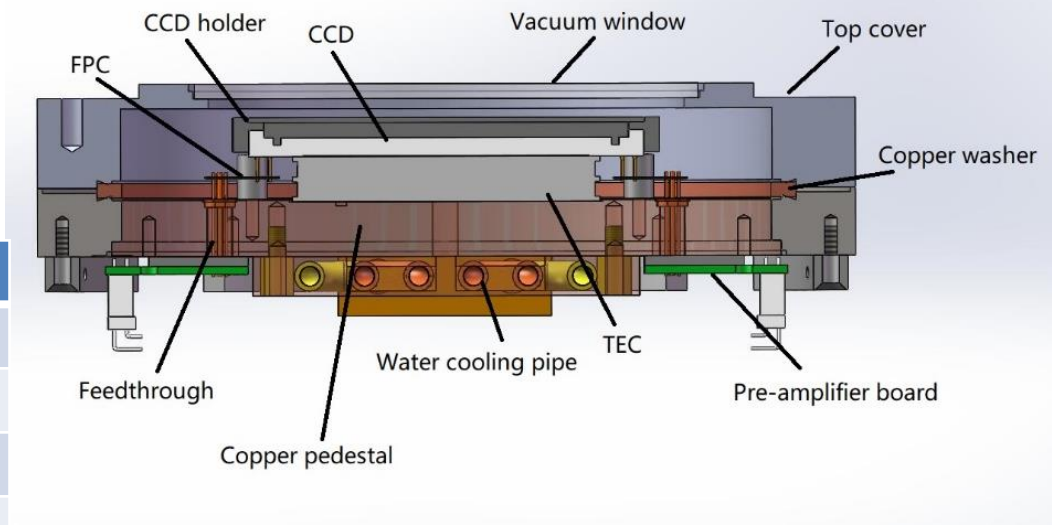
- Vacuum acquisition and long-term maintenance
- Low noise electronics
- Complex readout and control circuit of large focal plane CCD

Low Temperature Vacuum Chamber

Methods	Advantages	Disadvantages
Liquid Nitrogen	Low refrigeration temperature	Liquid nitrogen difficult to supply; The Dewar is large
Cryocooler	Low refrigeration temperature; maintenance free	Vibration; High cost
TEC	Flexible; Vibrationless; Low cost	Limited refrigerating capacity

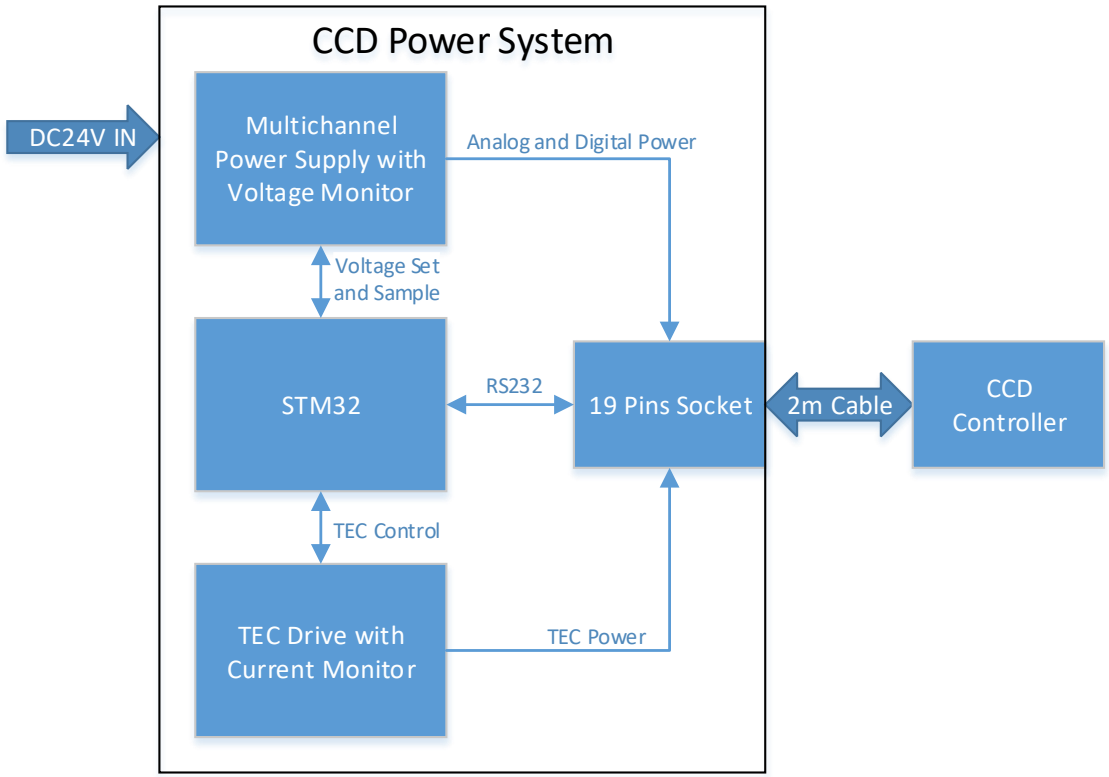


- Key points and Difficulties
  - Vacuum acquisition and vacuum maintenance
  - Refrigeration effect
  - Miniaturization
  - Low temperature resistance



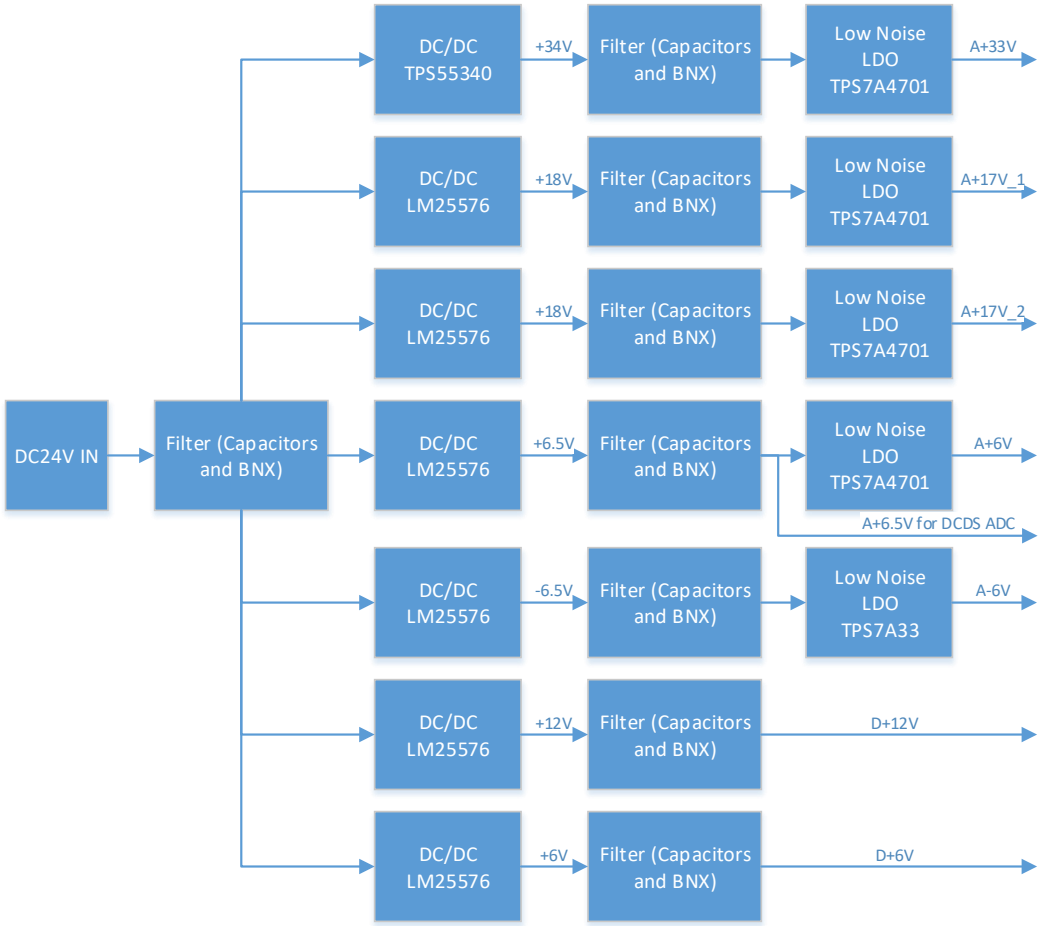
	Air cooling	Water cooling
Room temperature	31℃	31℃
Cold side temperature	-26.8℃	-44.7℃
Hot side temperature	43.0℃	20.6℃
Temperature difference between cold side and room temperature	57.8℃	**75.7℃**
Temperature difference between cold and hot sides	69.8℃	65.3℃

CCD Power System



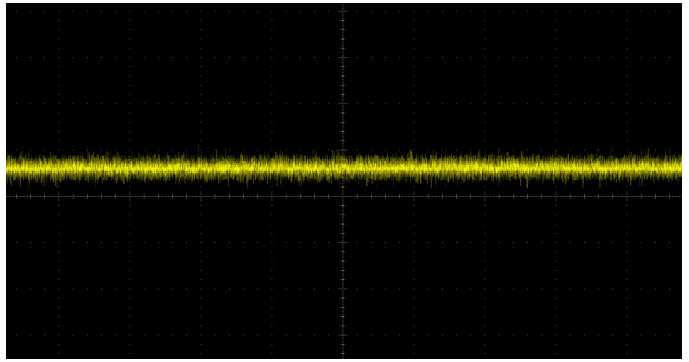
CCD Power Box

- Multichannel Ultralow Noise Power Supply
- TEC Controller

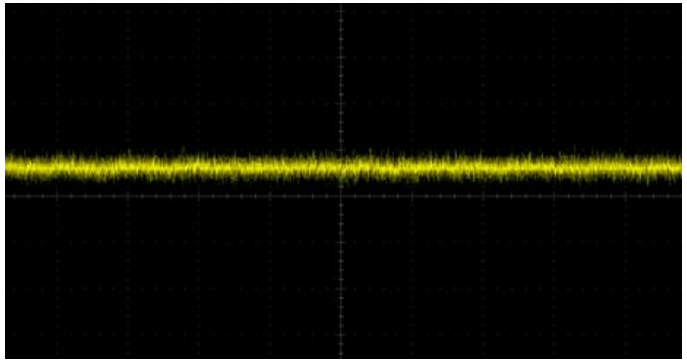


Multichannel Power Supply - Performance Tests

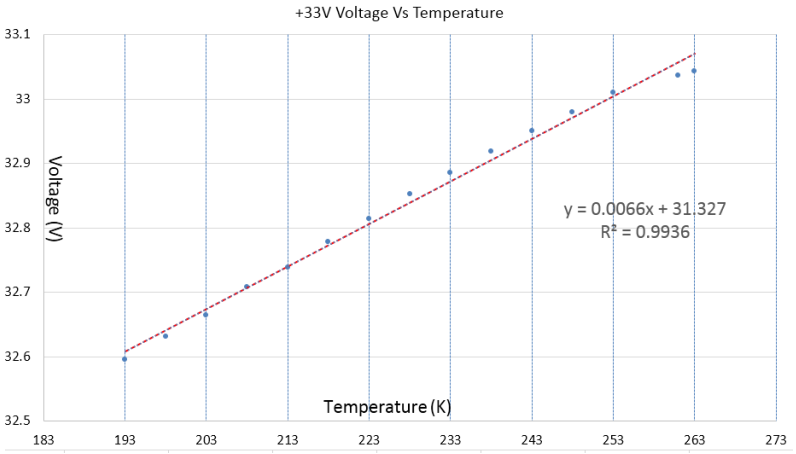
Voltage	RMS Noise	Max Current
Analog +33V	31.0uV	1A
Analog +17V	64.8uV	1A
Analog +17V	64.8uV	1A
Analog +6V	40.7uV	1A
Analog -6V	40.7uV	1A



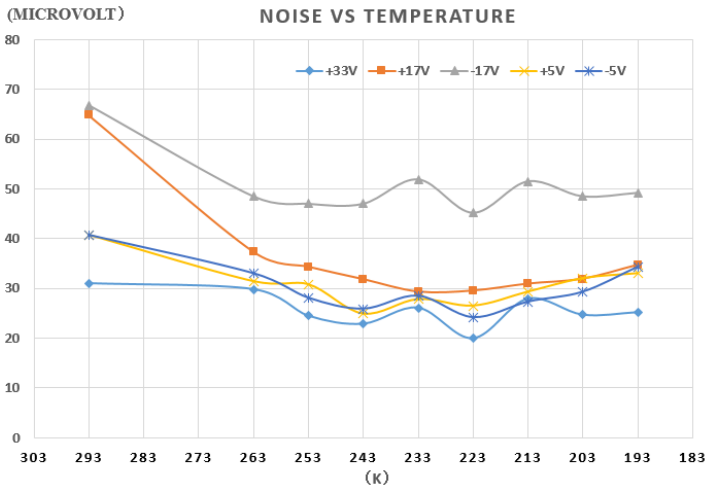
Background noise of oscilloscope



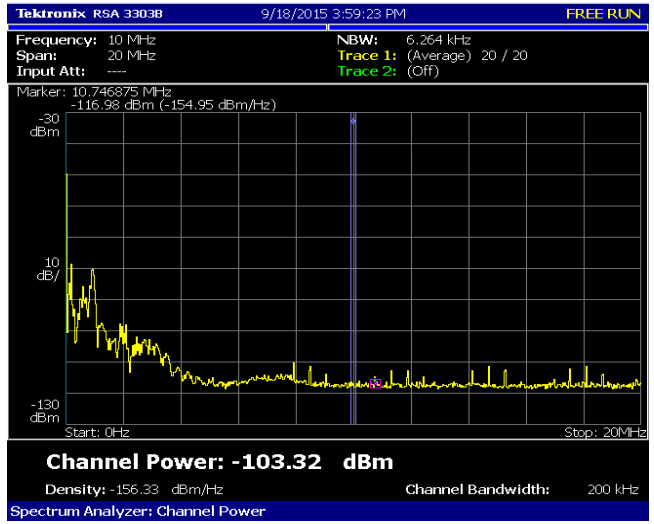
Total noise of power output



+33V Output Voltage vs Temperature

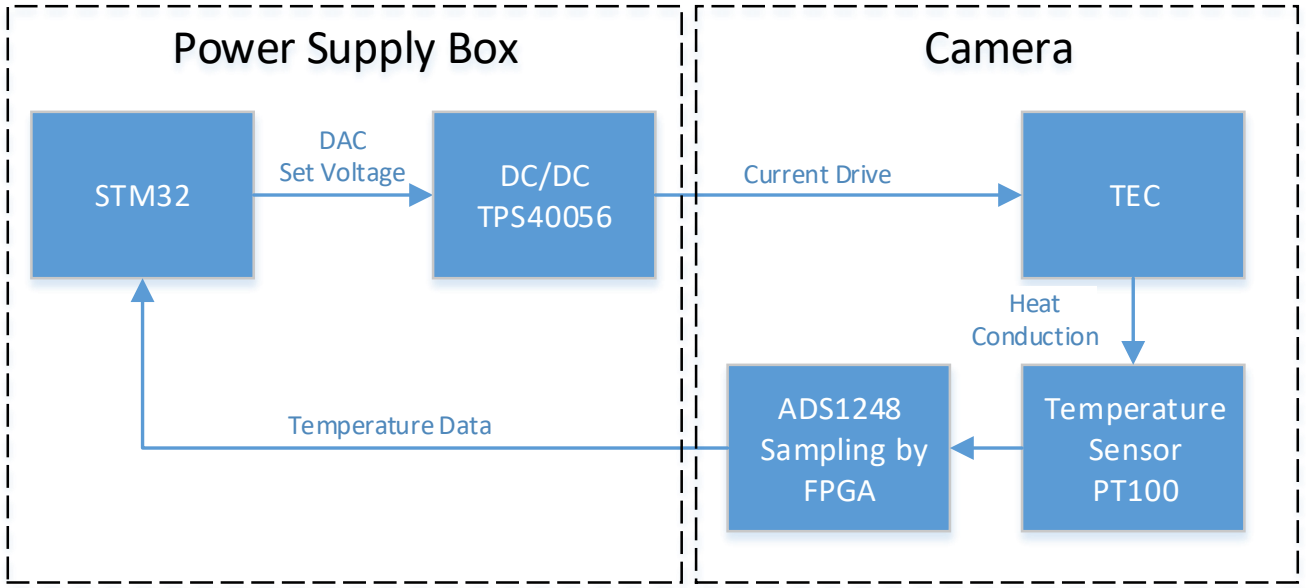


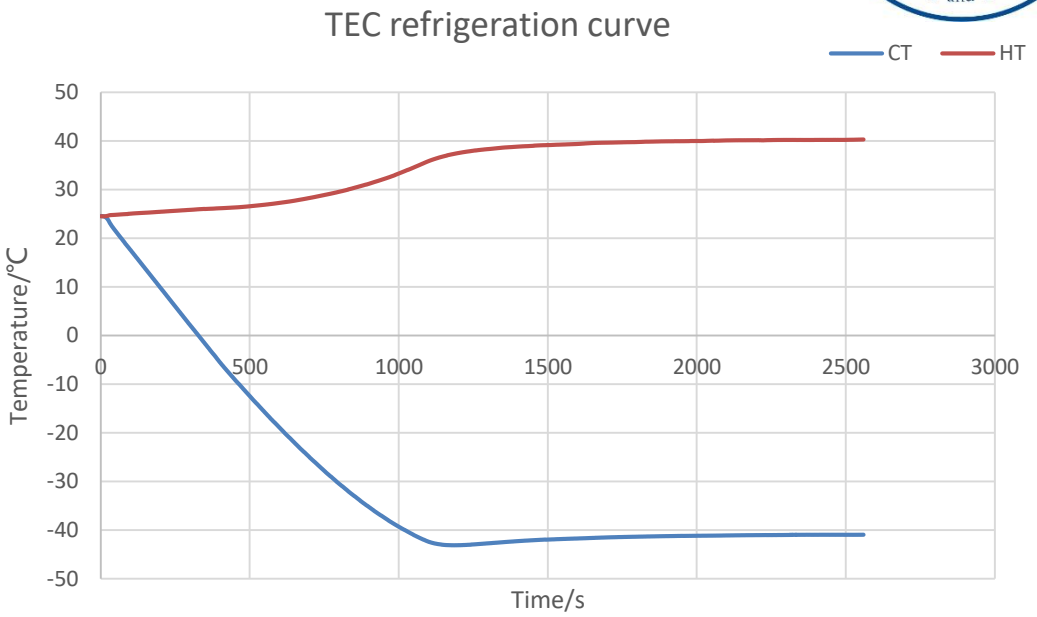
Noise vs Temperature



Spectrum of +33V output

TEC Controller

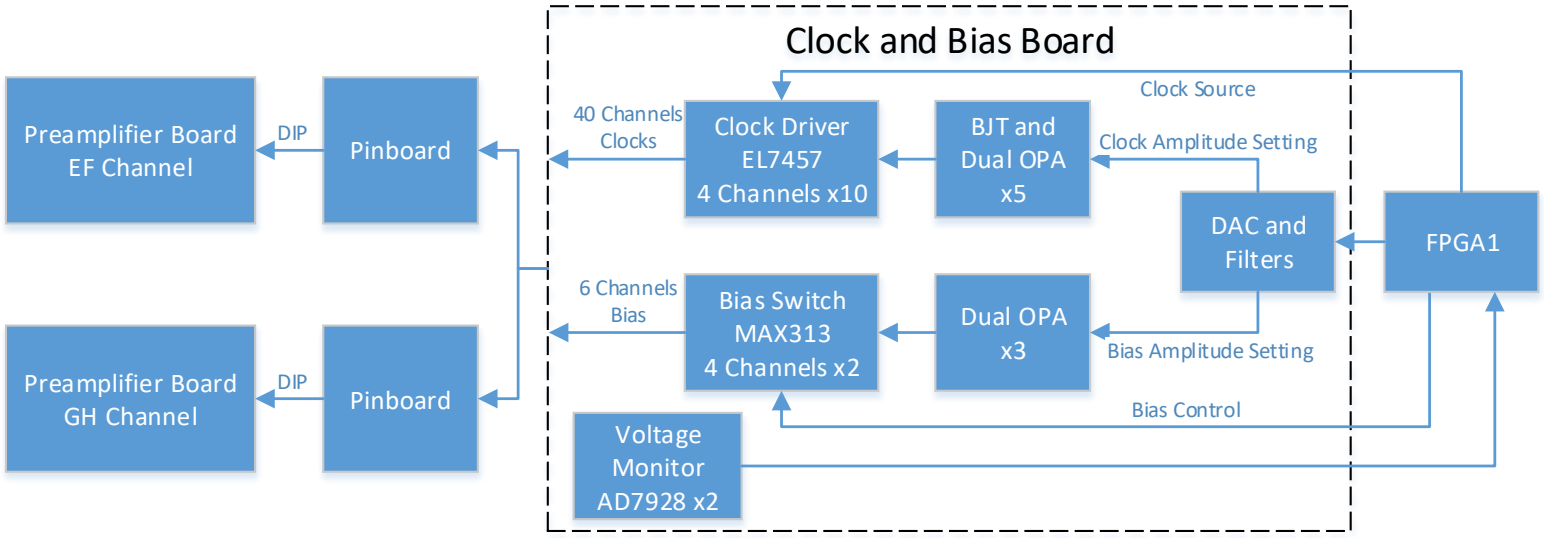




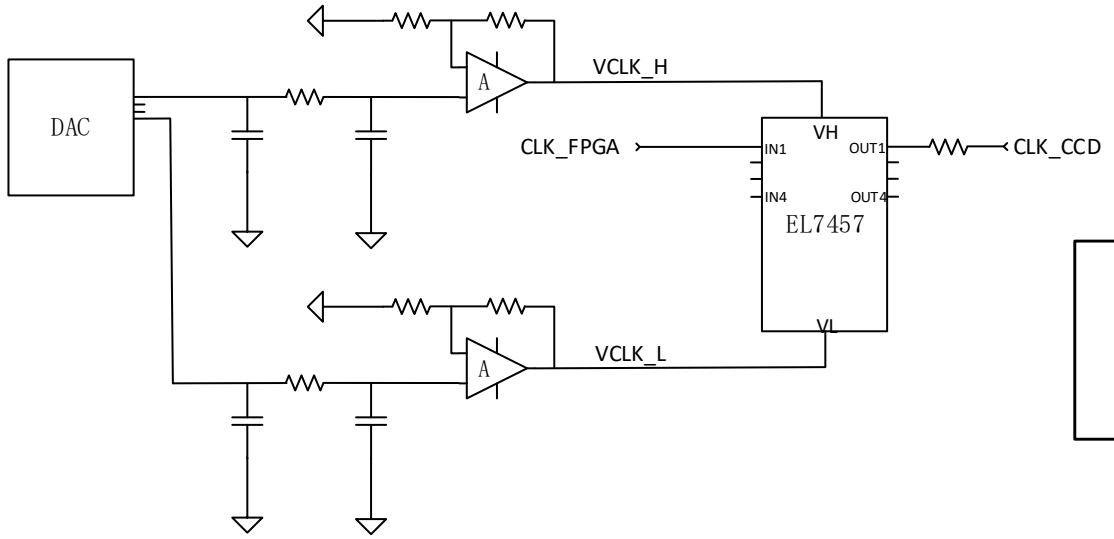
- Voltage controlled voltage source
- High driving capability: 20V, 10A Max
- Low output ripple
- Digital PID control algorithm

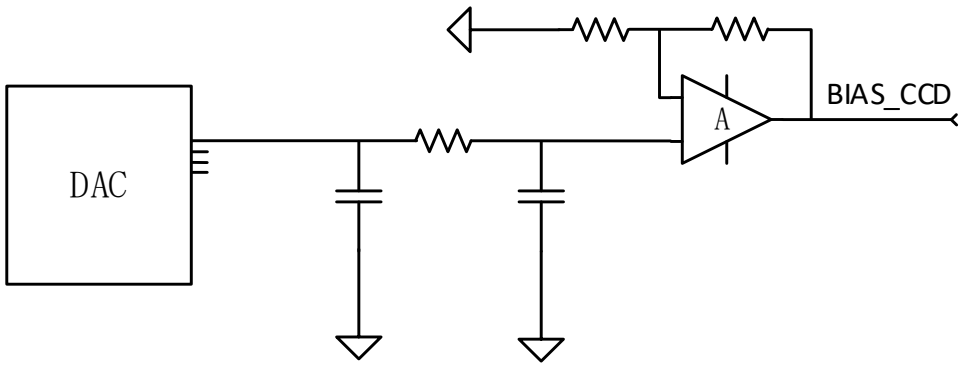
- Temperature Sensor: 4-wire PT100
- High Temperature measurement accuracy: 0.002℃
- Temperature stability < 0.01℃
- Temperature stabilization time < 30 minutes
- Cooling rate < 5 ℃/minute

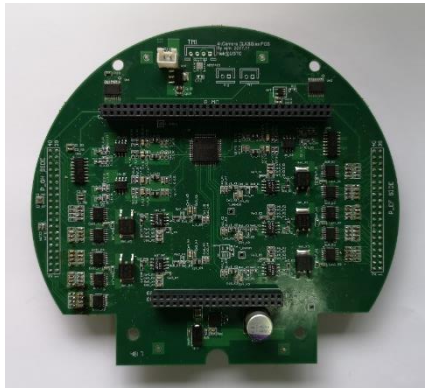
CCD Controller - Driving solution



- Clock: 40 Channels
- Bias: 6 kinds of amplitude
- Amplitude setting:
  - AD5391, 16-channel, 12-bit
- Voltage Monitor:
  - AD7928, 8-channel 12-bit
- Clock Power Supply:
  - OPA + BJT
- Clock Drive:
  - EL7457, 40MHz Quad CMOS Driver
- Bias Power Supply:
  - OPA ADA4075, 2.8 nV/√Hz

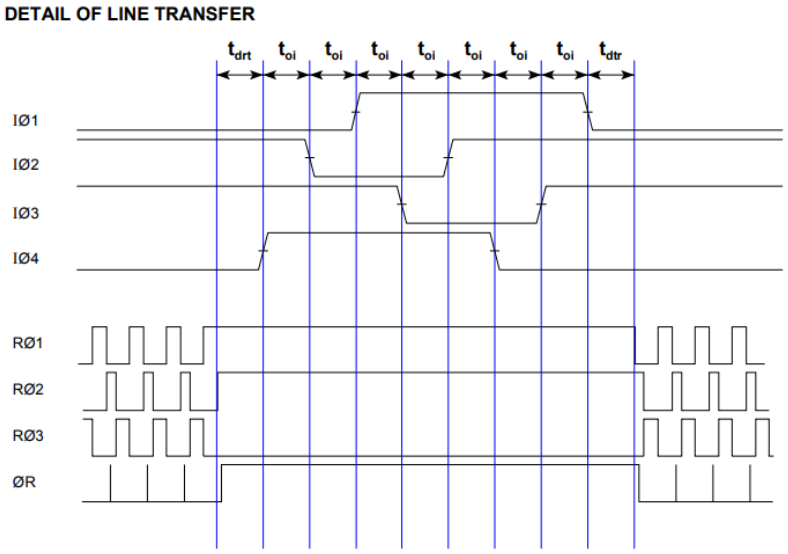




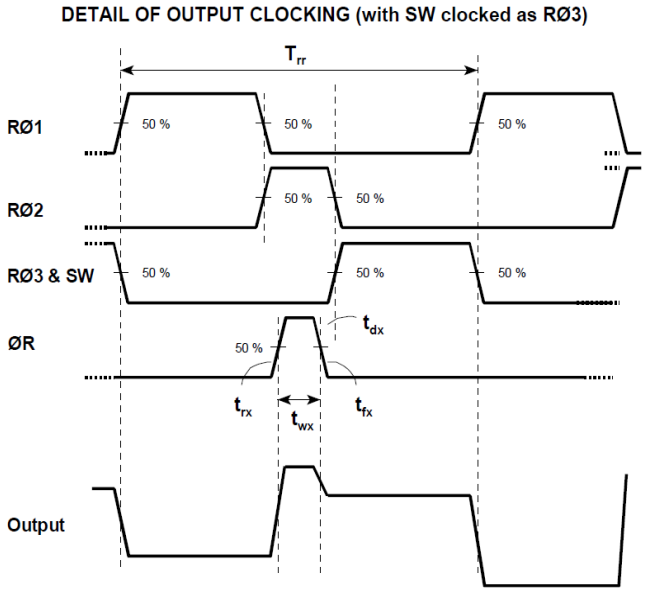


CCD Controller - Driving solution

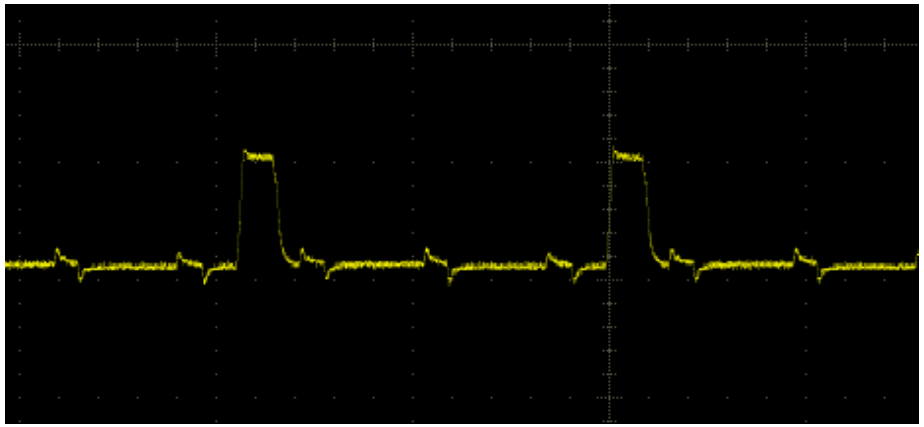
- Clock edge adjustment
- Reduce crosstalk by optimizing clock timing



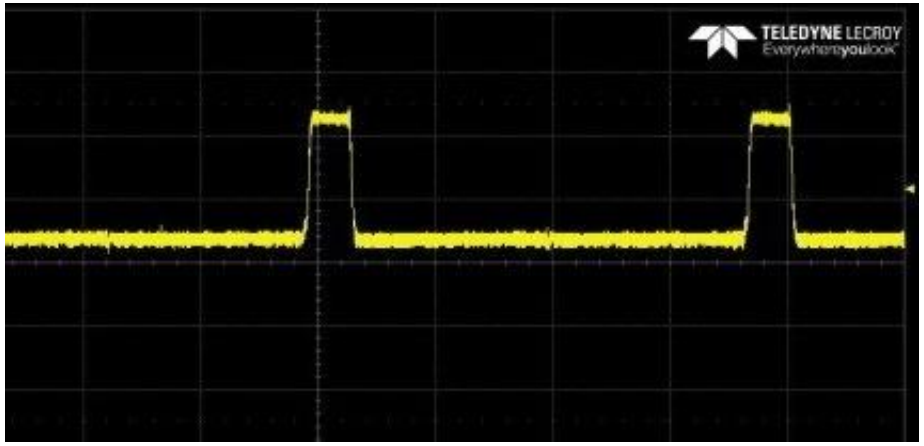
Line Transfer Clock



Readout Clock



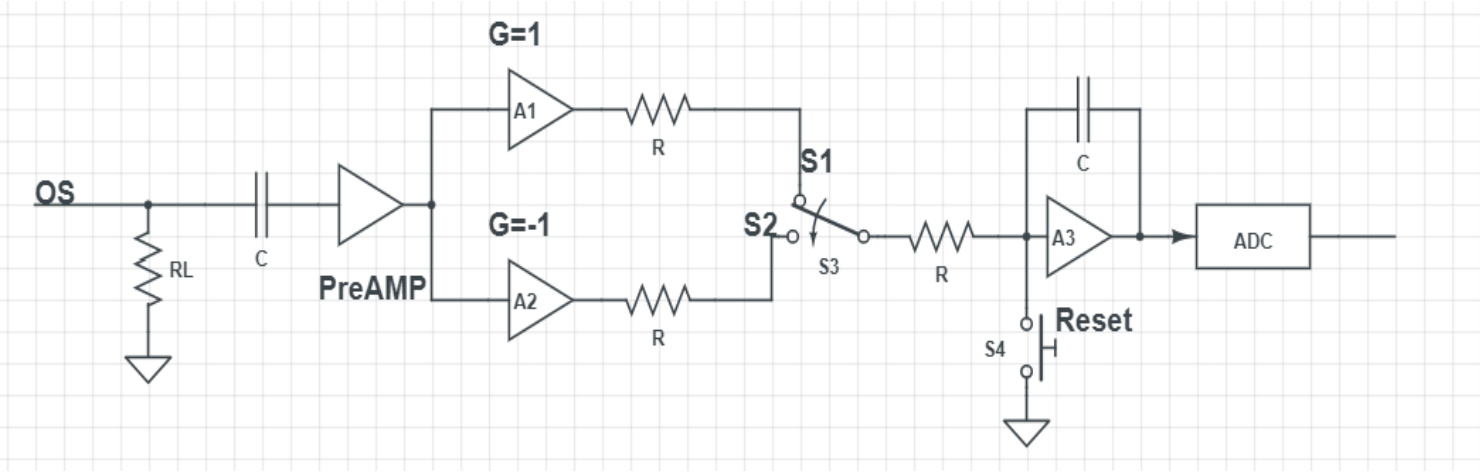
Clock waveform without processing

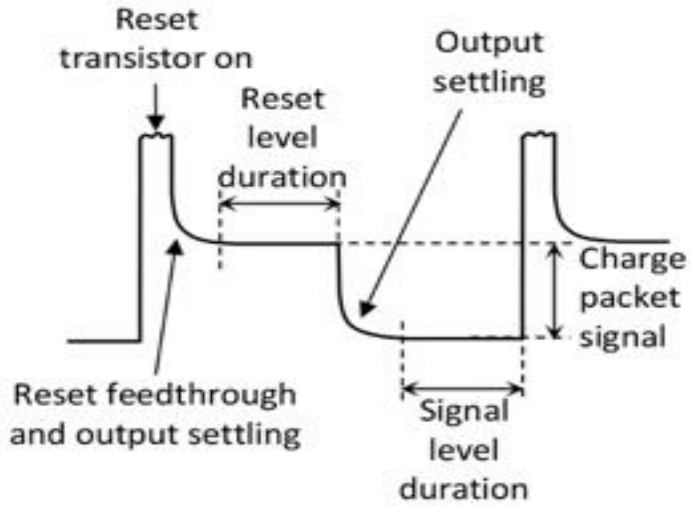


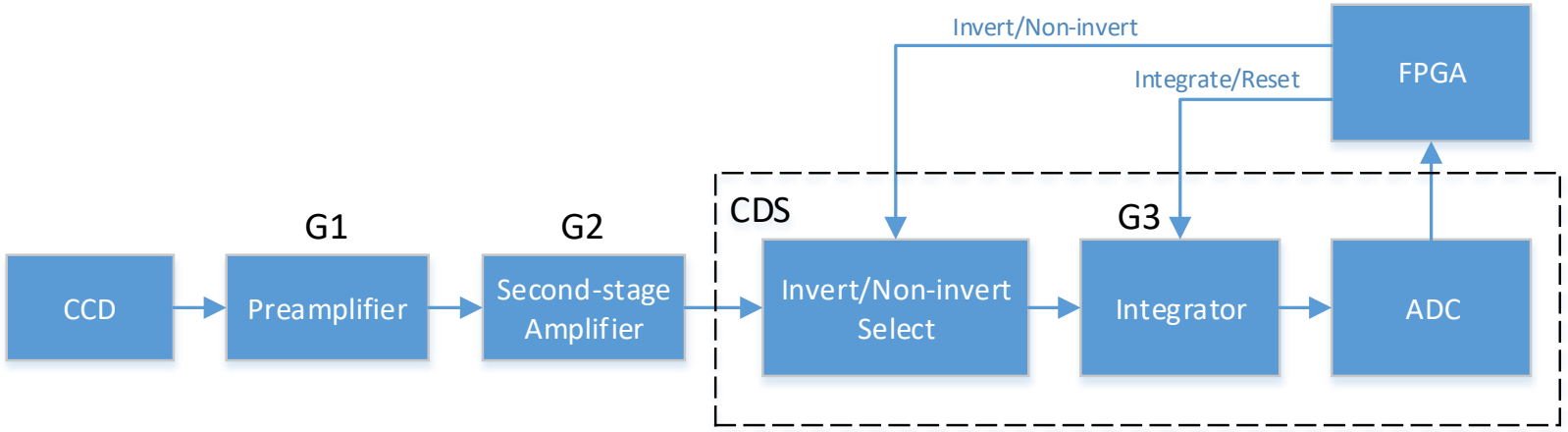
Clock waveform with processing

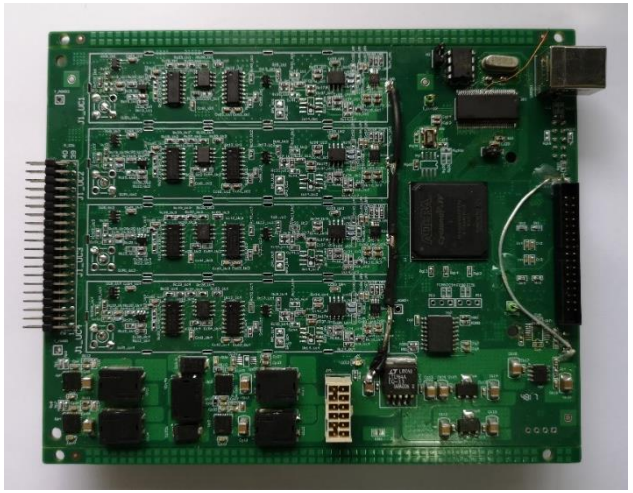
CCD Controller - Readout solution (ACDS)

- ACDS: Analog Correlated Double Sampling
- Dual Slope Integration



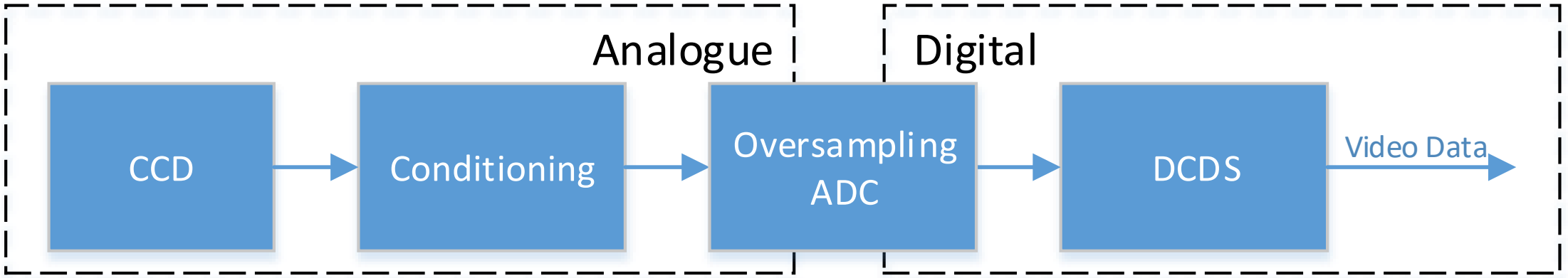






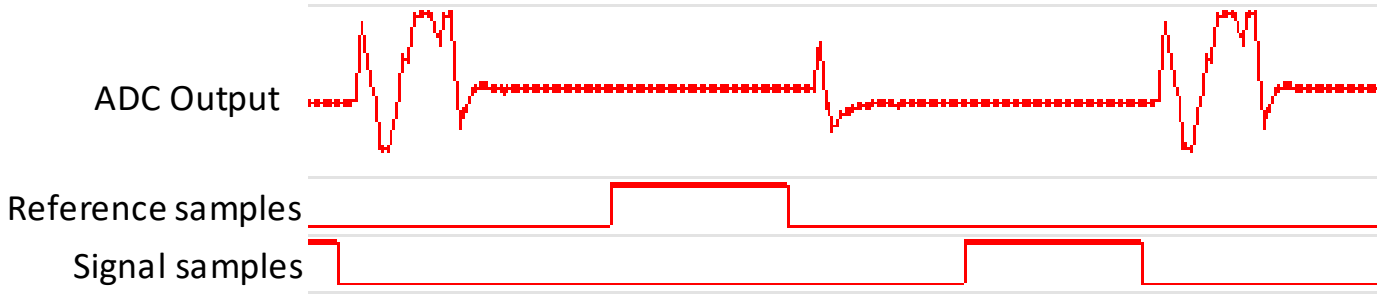
CCD Controller - Readout solution (DCDS)

- DCDS: Digital Correlated Double Sampling

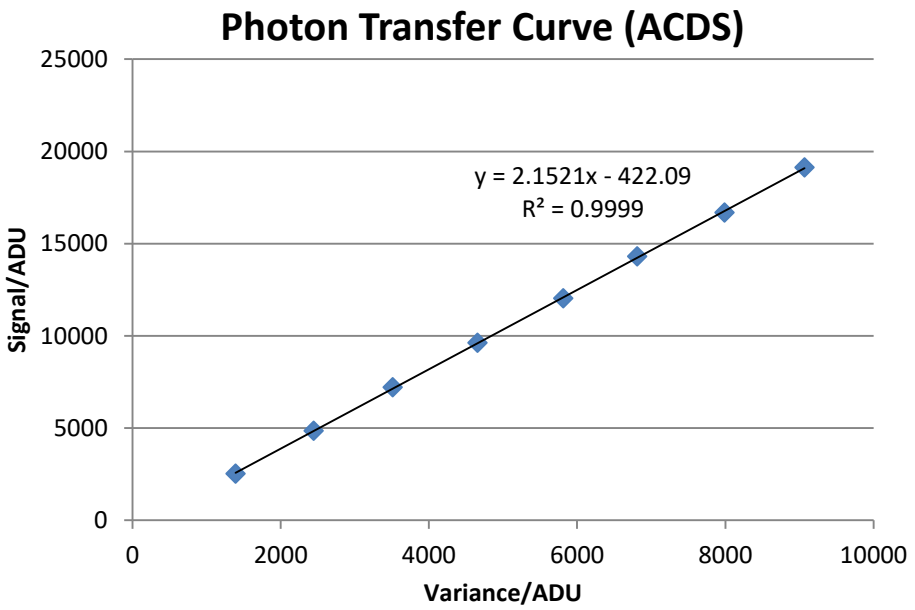


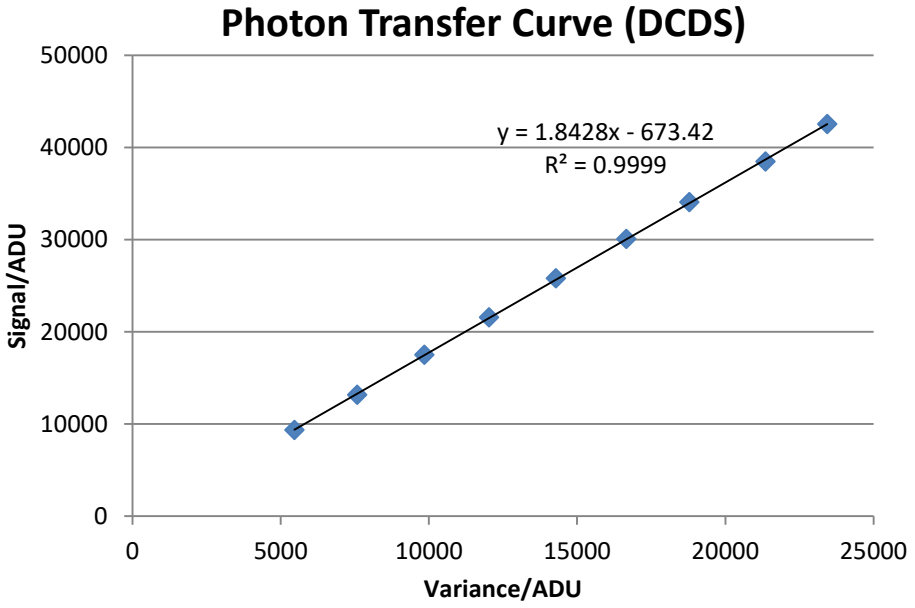
- DC restore
- Anti-alias filter

- Digital low pass filter
- correlated double sampling
- Precise adjustment of sampling point position
- 105Msps, sampling 16-Bit A/D converters



Gain measurement





Mode	Readout Speed	Integration Time	Gain
ACDS	100kHz	2000ns	1.2176 e^-/ADU
ACDS	500kHz	680ns	2.1521 e^-/ADU
DCDS	500kHz	35points/467ns	1.8428 e^-/ADU

- The gain of ACDS mode is inversely proportional to the integration time.
- The gain of DCDS mode is independent of the number of signal samples.

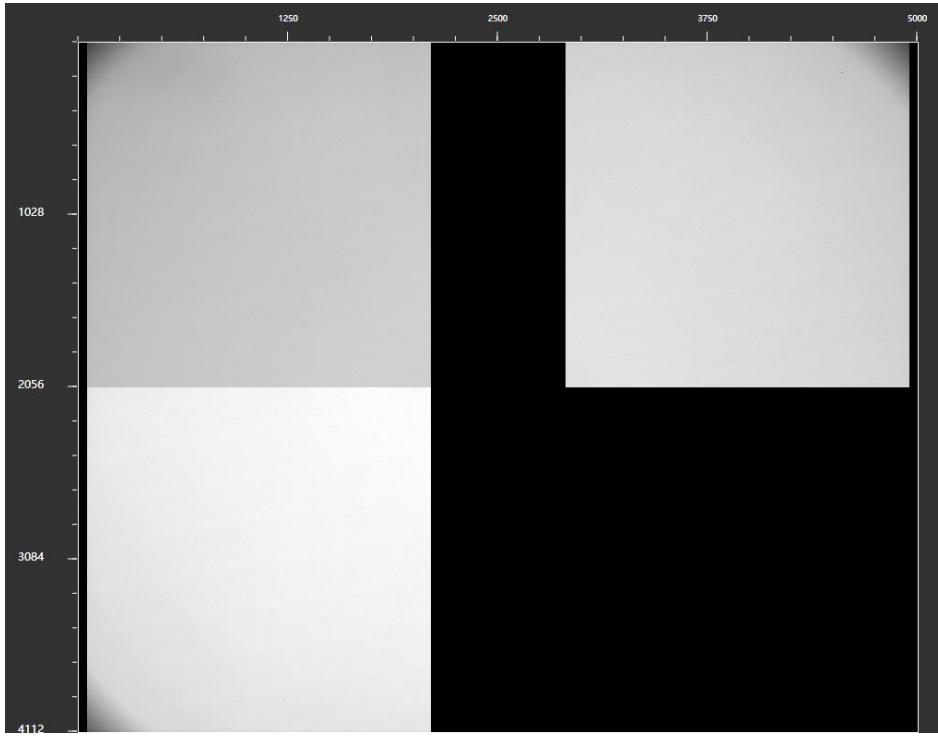
Noise Performance

- ACDS

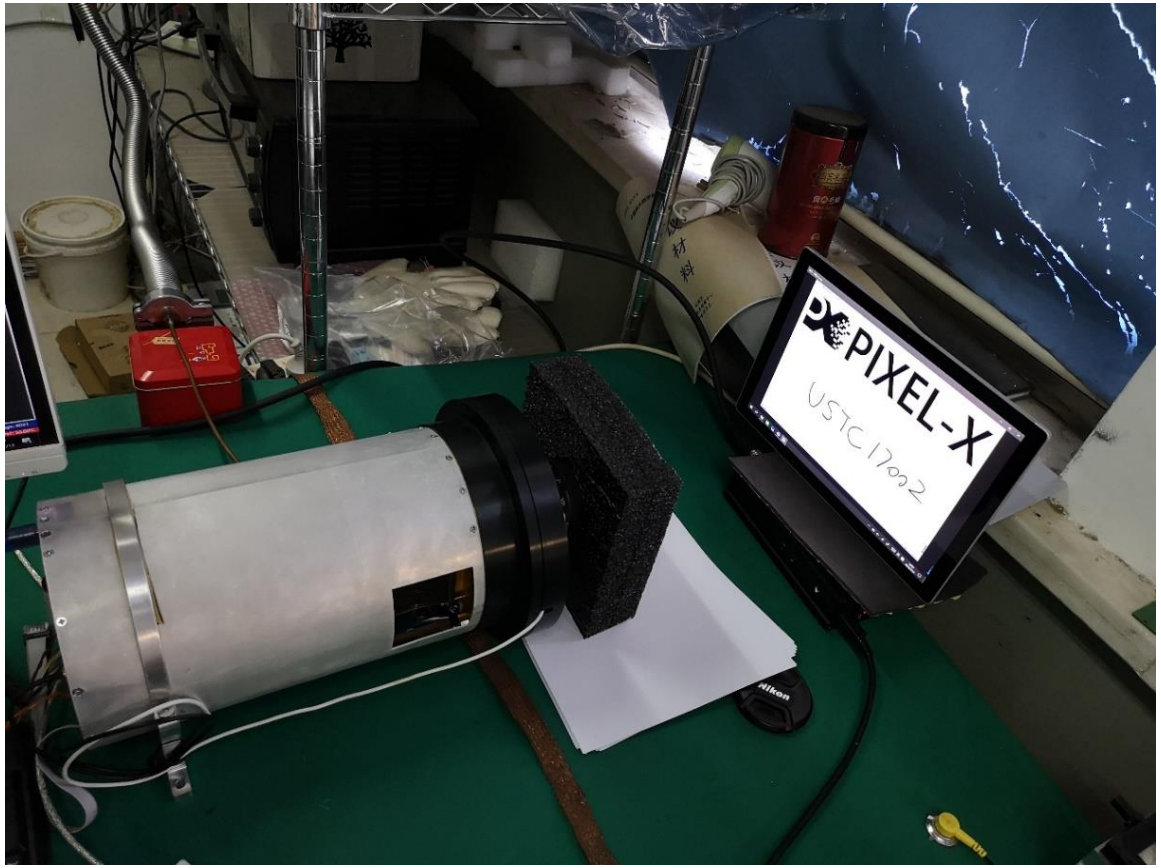
Temperature	100kHz; 3500ns	100kHz; 2000ns	500kHz; 680ns
25℃	8.78 e^-	10.79 e^-	9.15 e^-
-25℃	6.73 e^-	7.79 e^-	8.59 e^-
-40℃	6.75 e^-	7.69 e^-	9.06 e^-

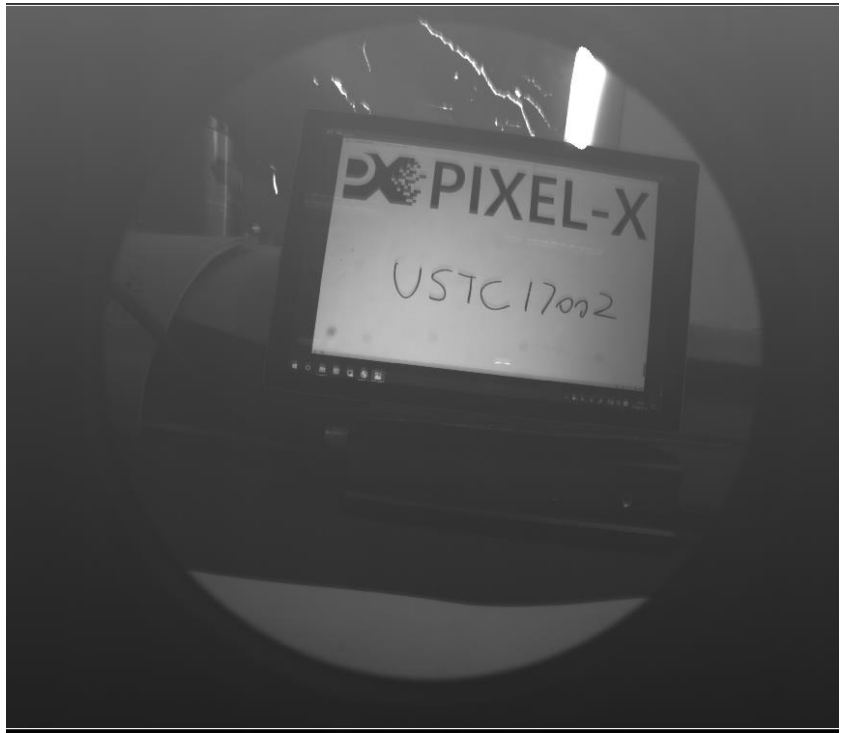
- DCDS

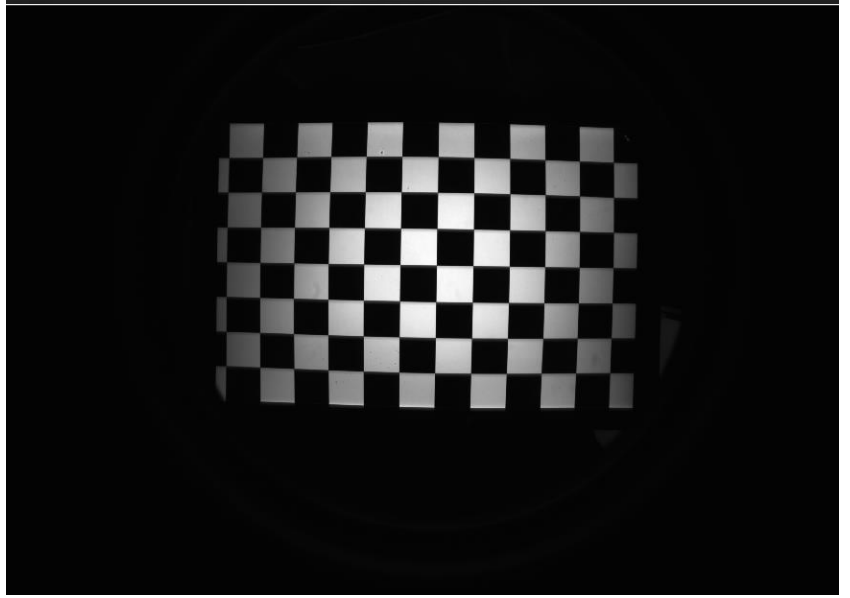
Temperature	500kHz; 46 points	500kHz; 35 points	1000kHz; 21 points
25℃	9.32 e^-	10.49 e^-	14.28 e^-



Imaging Tests







Conclusions

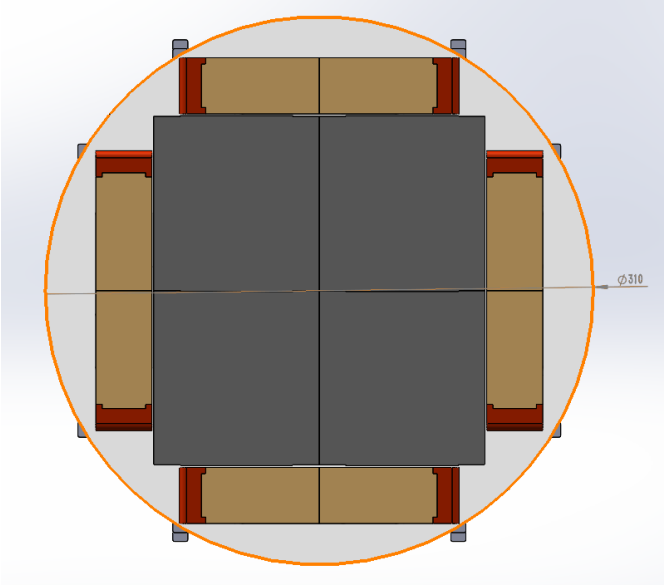
- Completed the development of the 4k x 4k pixels CCD camera
- Vacuum maintenance, miniaturization, cooling capacity and low temperature resistant

  75℃ below room temperature
- Low noise clock and bias driver
- low noise high precision readout system, ACDS and DCDS
- The readout noise reaches the advanced level

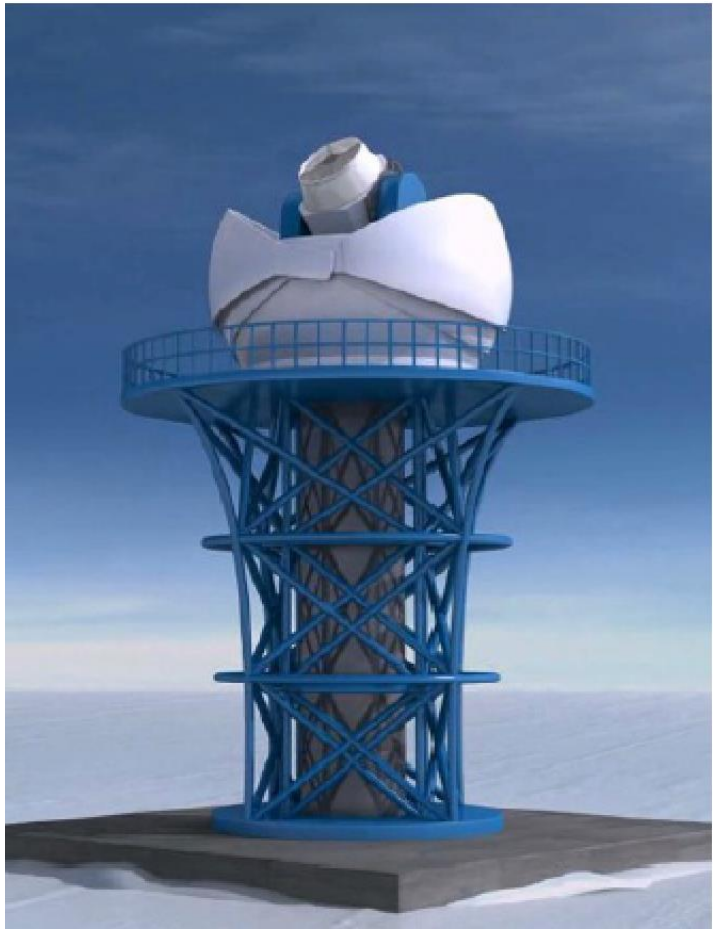
  < 10 e^- at 500KHz

Future outlook

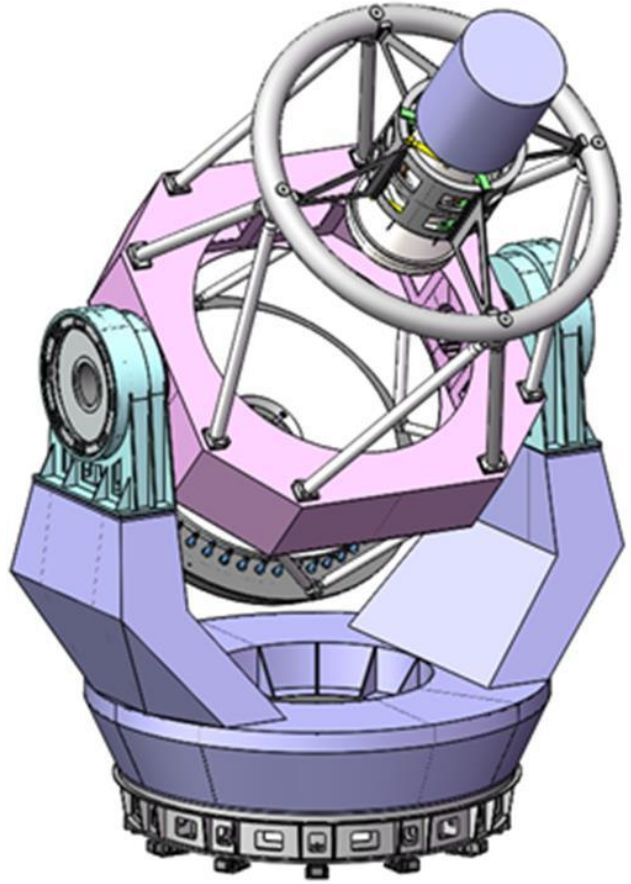
- Mephisto: Multi-channel Photometric Survey Telescope
  - Aperture: 1.6m
  - 4 pieces of 9K x 9K CCD spliced



- KDUST: Kunlun Dark Universe Survey Telescope
  - Aperture: 2.5m
  - 25 pieces of 8K x 8K CCD spliced



- WFST: Wide Field Survey Telescope
  - Aperture: 2.5m
  - 9 pieces of 9K x 9K CCD spliced



Future outlook

- Higher requirements for the development of the large focal plane splicing CCD detector system
- Modularization , ASIC
- The reduction of readout noise of CCD detector system

Thanks for your attention!