Canadian Space Agency Agence spatiale canadienne

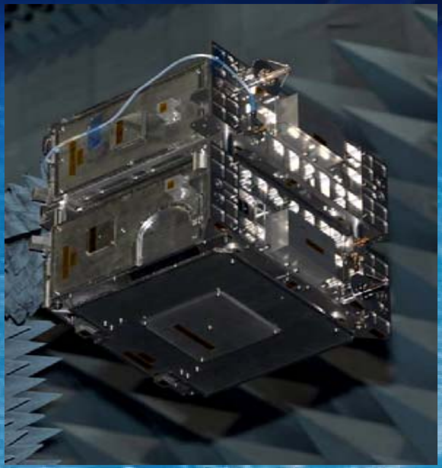
Microbolometers for mid, thermal, and far IR sensing

L. Ngo Phong, *Canadian Space Agency*
T. D. Pope and F. Chateauneuf, *INO*

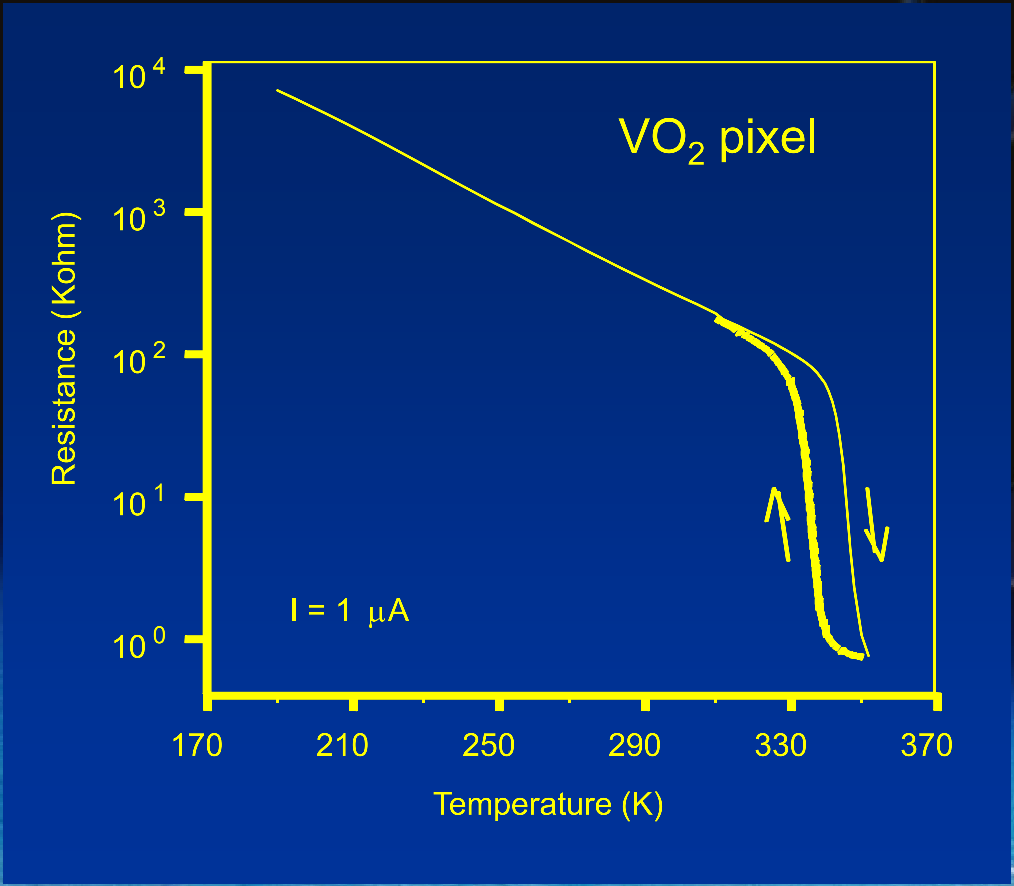
Canada

Introduction

- The advantage of microbolometer, beside the room temperature operation, is the absence of a cutoff wavelength
- Lately there have been requirements for coregistration in the MWIR, TIR, and FIR
- Technology development at the CSA has focused on *linear* arrays of microbolometers
- Sensors were developed for two missions: SAC-D Aquarius (MWIR / TIR) and JC2Sat (FIR)
- Details on these sensors are presented

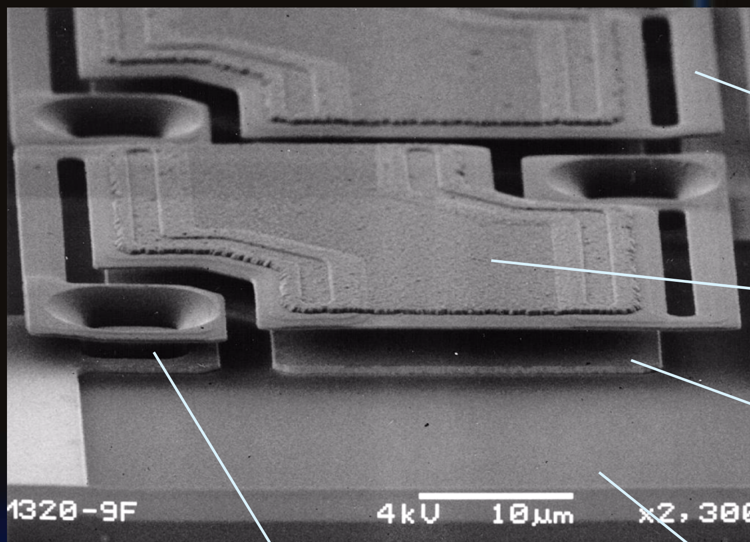


Bolometric sensing



- Thermal mechanism
- Spectral response defined by absorptance
- Absorptance can be adjusted using coating or cavity effect

Use of MNT



Si_3N_4 microbridge

Thin film bolometer and coating

Reflector

vias

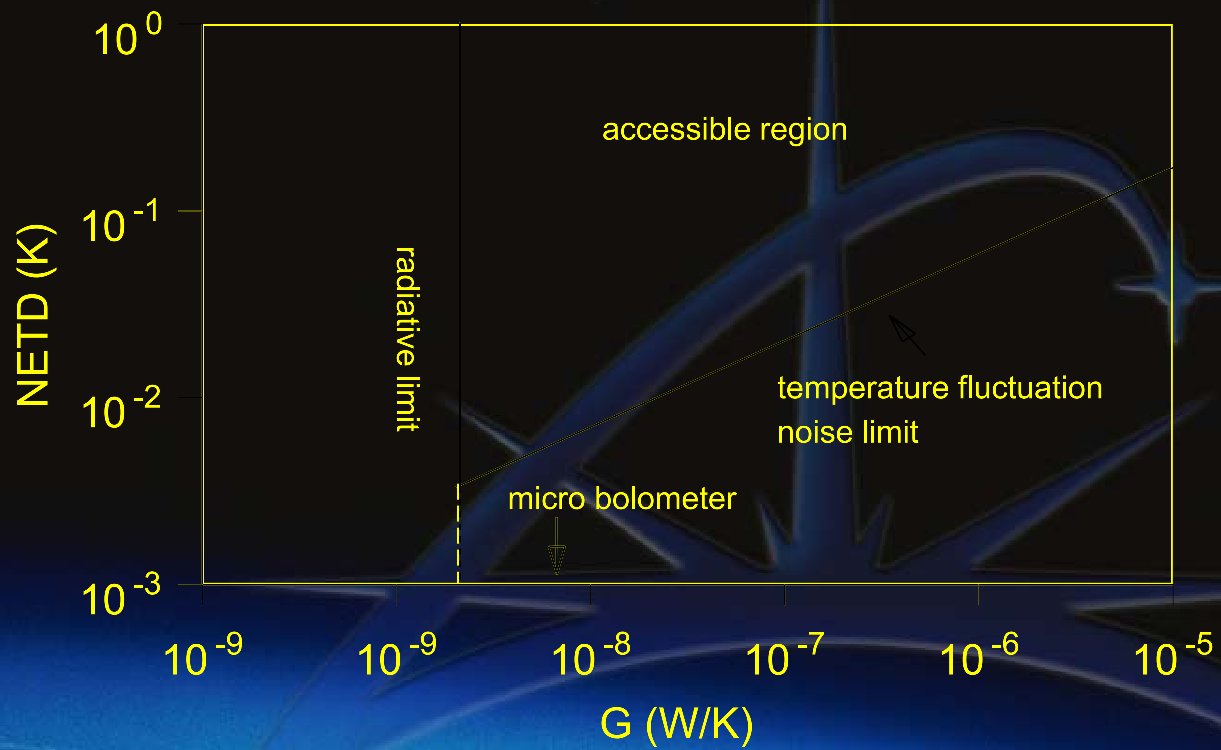
Monolithically embeded ROIC

$$r = \frac{I_b (dR / dT)\eta}{G(1+\omega^2\tau^2)^{1/2}}$$

▷ Vacuum gap provides cavity effect and thermal isolation

Canadian Space Agency / Agence spatiale canadienne

Performance limitations



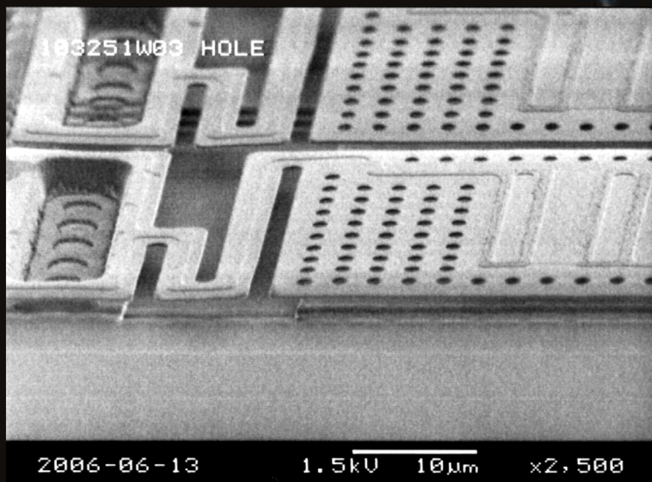
30 ms integration, F/1 optics, 90% transmission

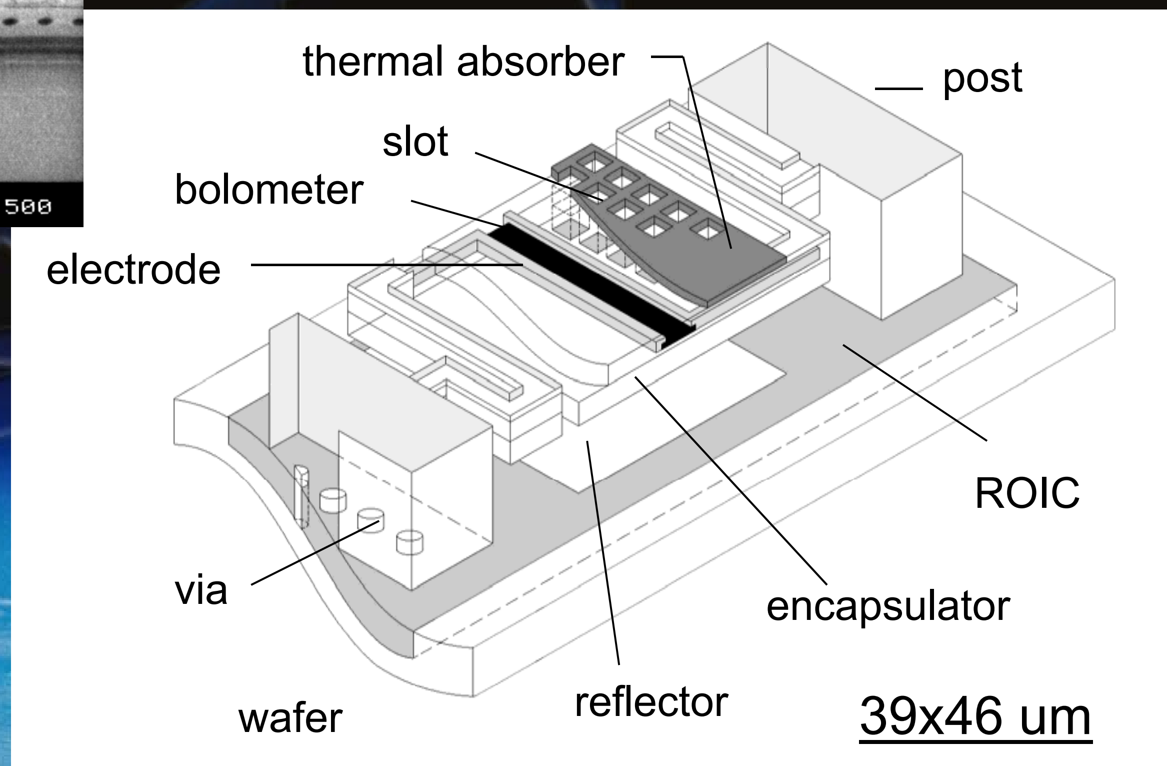
(*Kruse, SPIE* **2552**, *556*)

- Need for low *G*, lower limit of effective *G* ~ 10^{-8} W/K
- *C* must be kept to small values to ensure adequate speed (*C*/*G*)
- Designs with reduced *C* and *G* are structurally challenging

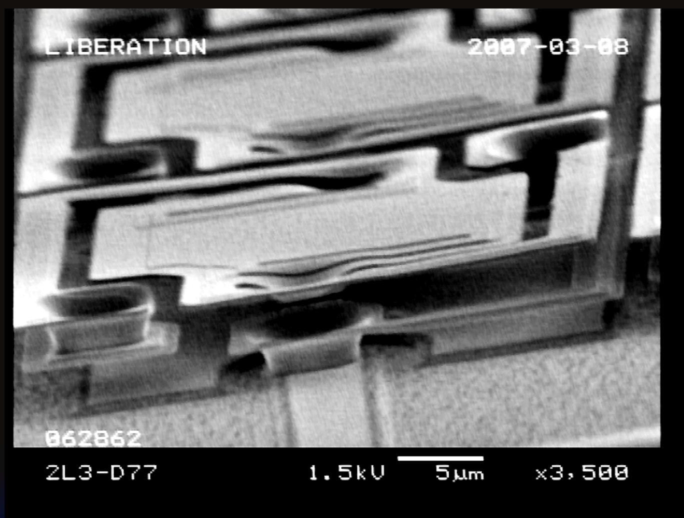
Canada

Single stage design

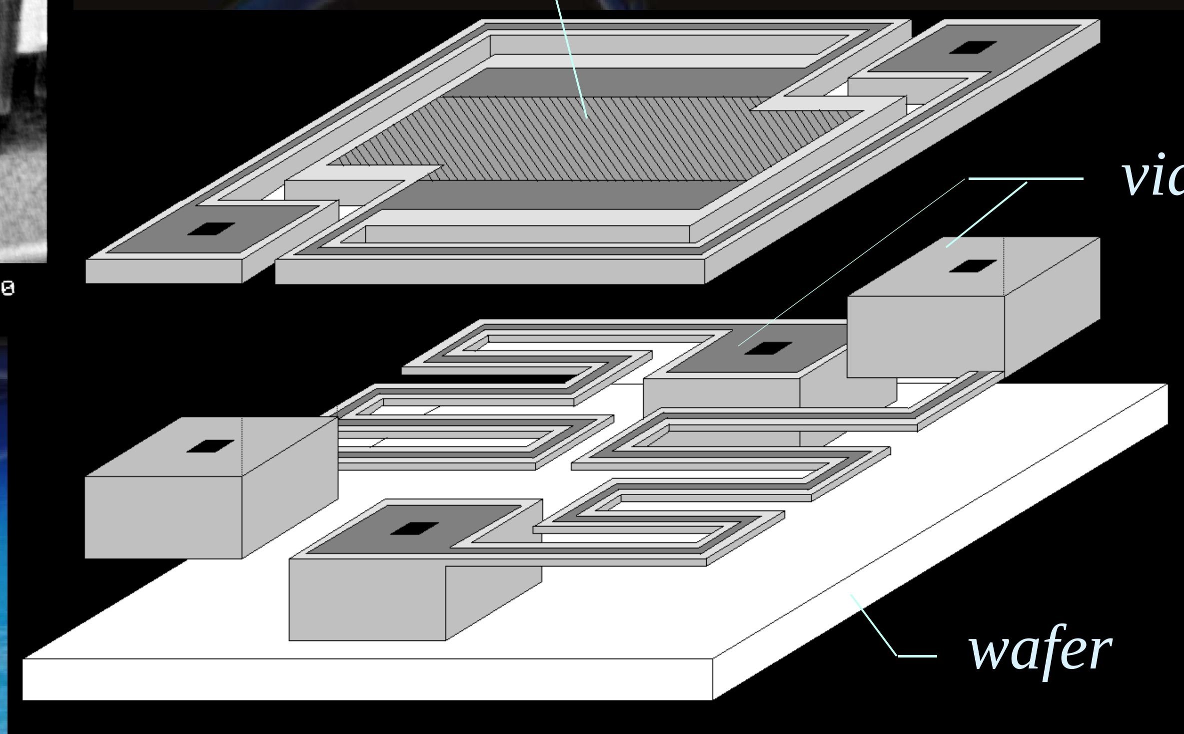




Double stage design

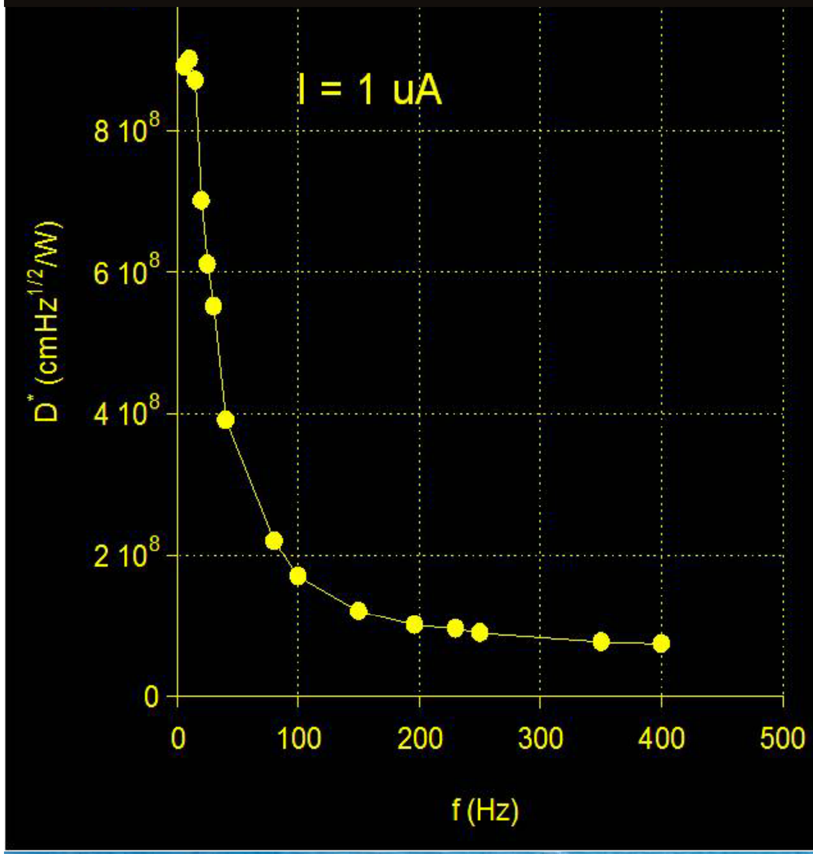


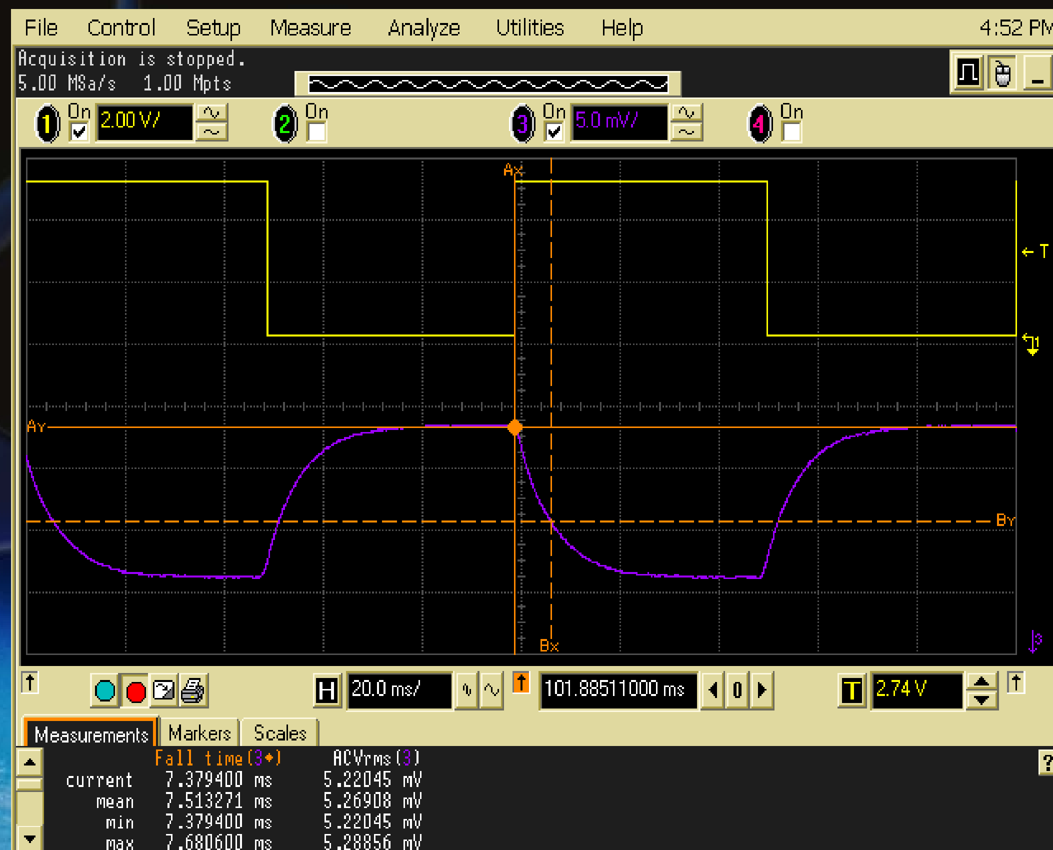
39x39 um



- Maintain *D** with an increased fill factor
- Avoid along track blurring

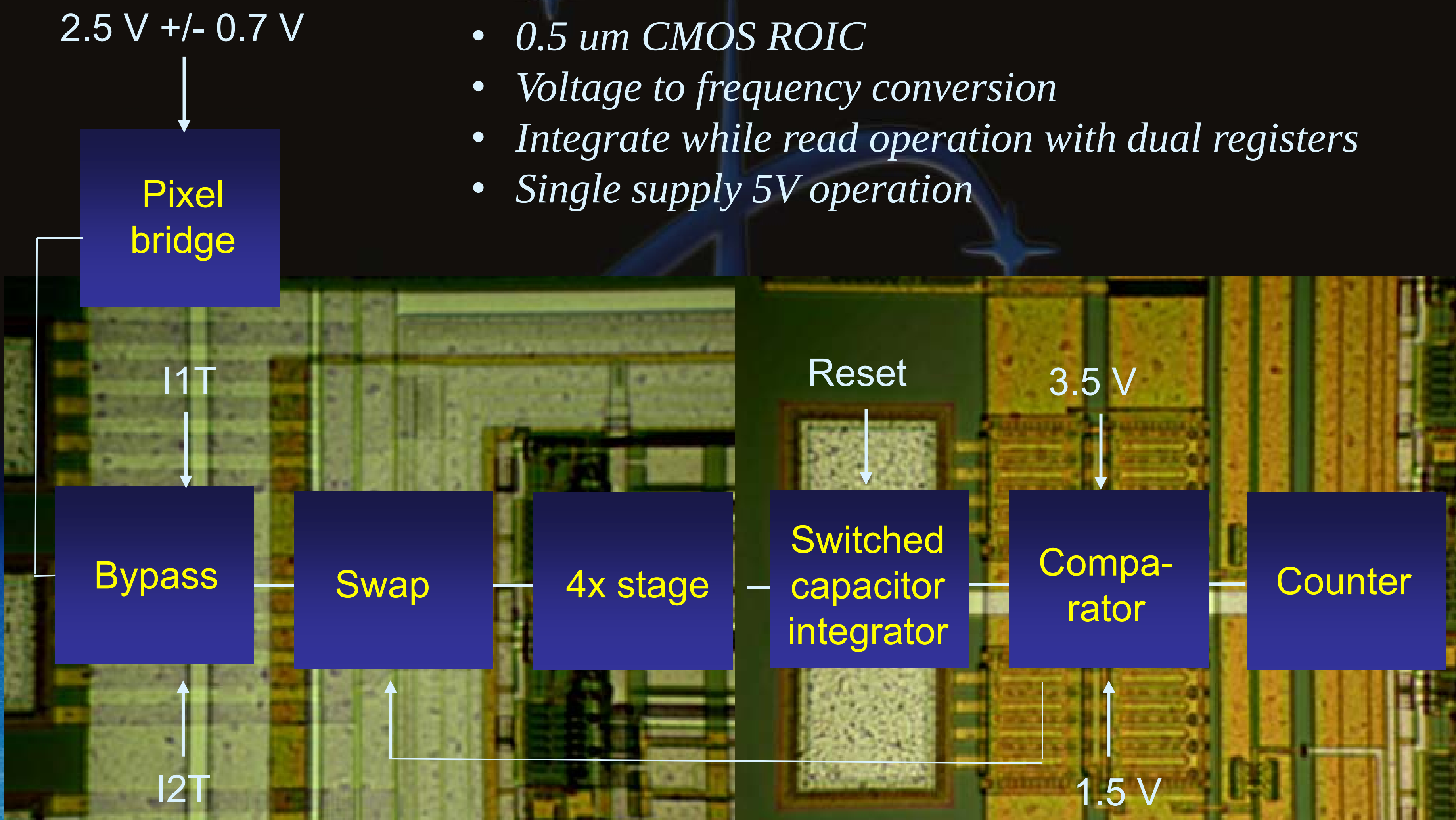
Typical characteristics





Pixel signal chain

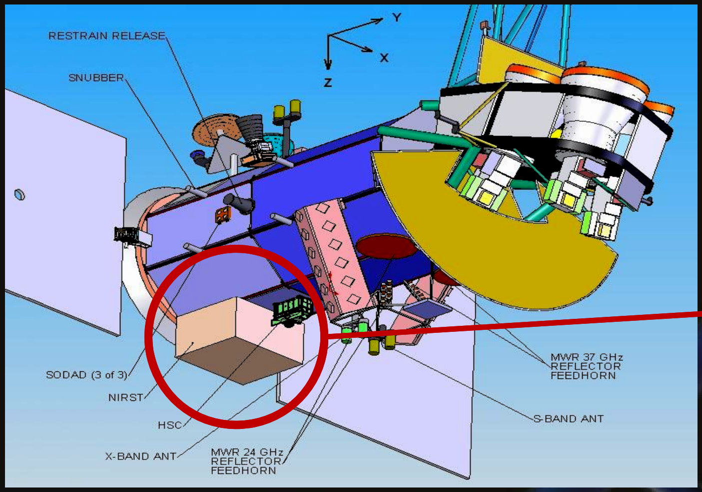
- *0.5 um CMOS ROIC*
- *Voltage to frequency conversion*
- *Integrate while read operation with dual registers*
- *Single supply 5V operation*



ROIC

Format	512 x 3
Line spacing	2.88 mm
Microbolometer pitch	39 μm
Supplied voltage	5 V +/- 10% all operating conditions
Power consumption	0.7 W / line
Integration / readout	parallel (dual register)
Integration time	10 - 140 ms
Master clock speed	0.8 - 2 MHz
Signal chain response	1.79 μV / lsb (3 mV input, 0.8 MHz, 140 ms integration time)

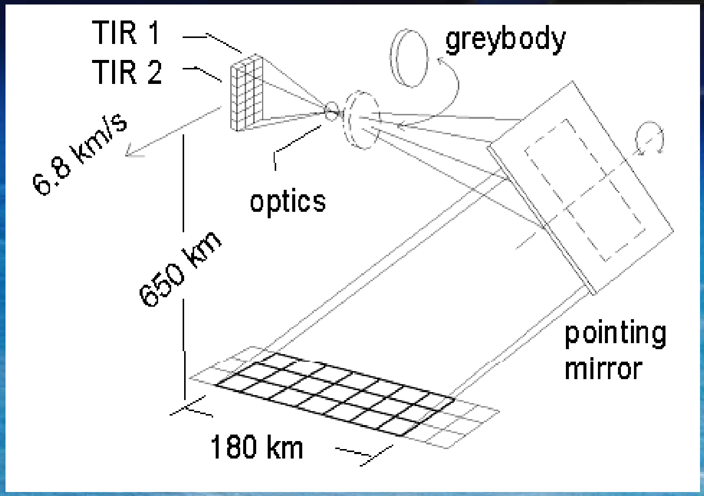
MWIR-LWIR sensing



Linear arrays of 512x3 microbolometers developed for SAC-D / NIRST

NIRST

- *is a pushbroom scan radiometer with boresight pointing and in-field spectral separation*
- *evolves on sun synchonous orbit @ 657 km alt, ascending node @ 6 pm*
- *retrieves temperatures of wildfire, volcanic activities, and sea surface*



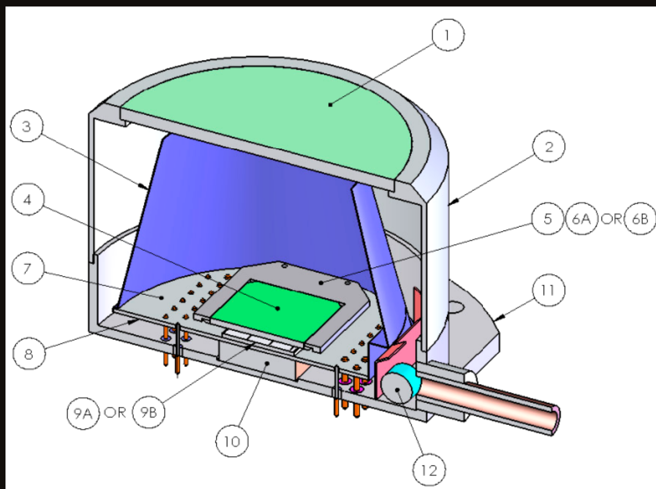
MWIR sensor

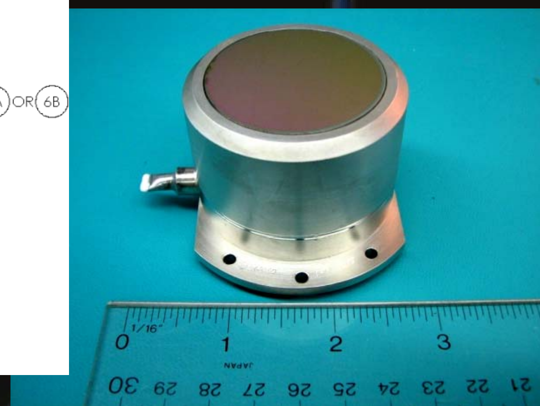
Format / pitch	512 x 3 / 39 um
Number of active lines	1
Spectral band 1	3.4 - 4.2 µm
Out-of-band transmission	< 4%
Operating temperature	283 - 291 K
Non-operating temperature	233 - 313 K
Time constant	12 ms
Responsivity	$2x10^4$ V/W
Detectivity	10^9 cm.$Hz^{1/2}$/W
NETD (f/1 optics, 39 um pixel, 4uA bias, 50 ms integration, 0.6 transmission)	2.3 K @ 400 K scene
Radiometric temperature range	300 - 700 K
Saturation temperature	> 600 K

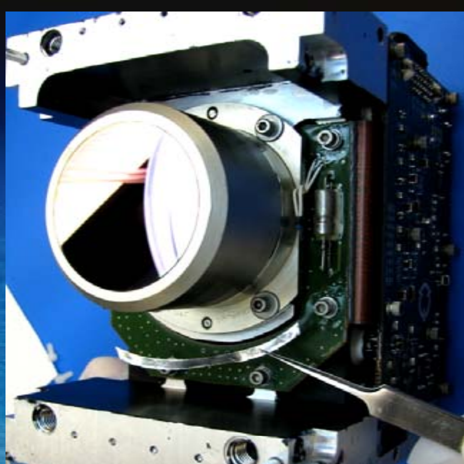
LWIR sensor

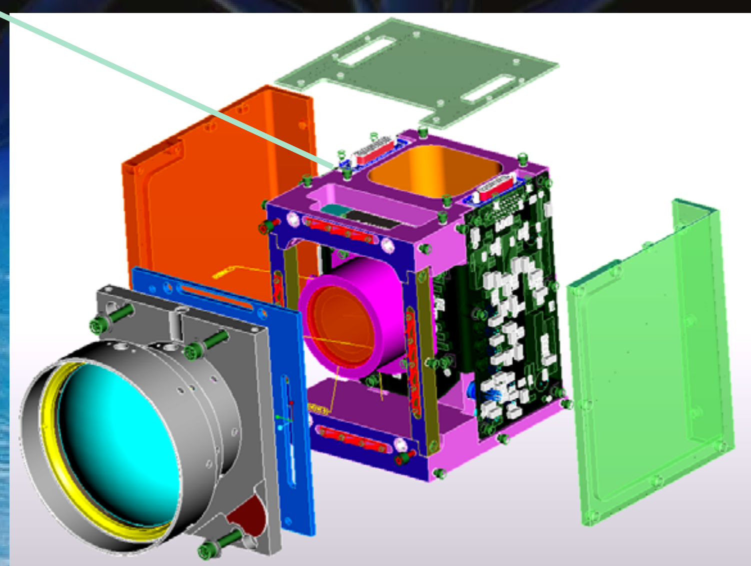
Format / pitch	512 x 3 / 39 um
Number of active lines	2
Spectral band 2	10.4 -11.3 µm
Spectral band 3	11.4 -12.3 µm
Operating temperature	283 - 291 K
Non-operating temperature	233 - 313 K
Out-of-band transmission	< 1%
Time constant	12 ms
Responsivity	4.2 - 5.8 x10^4 V/W
Detectivity	2.1 - 2.9 x 10^9 cm.$Hz^{1/2}$/W
NETD (f/1 optics, 39 um pixel, optimum current bias, 50 ms integration, 0.6 transmission, readout noise included)	< 0.4 K @ 300 K scene, band 2 < 0.5 K @ 300 K scene, band 3
Radiometric temperature range	200 - 400 K
Saturation temperature	> 600 K

Radiometric sensor





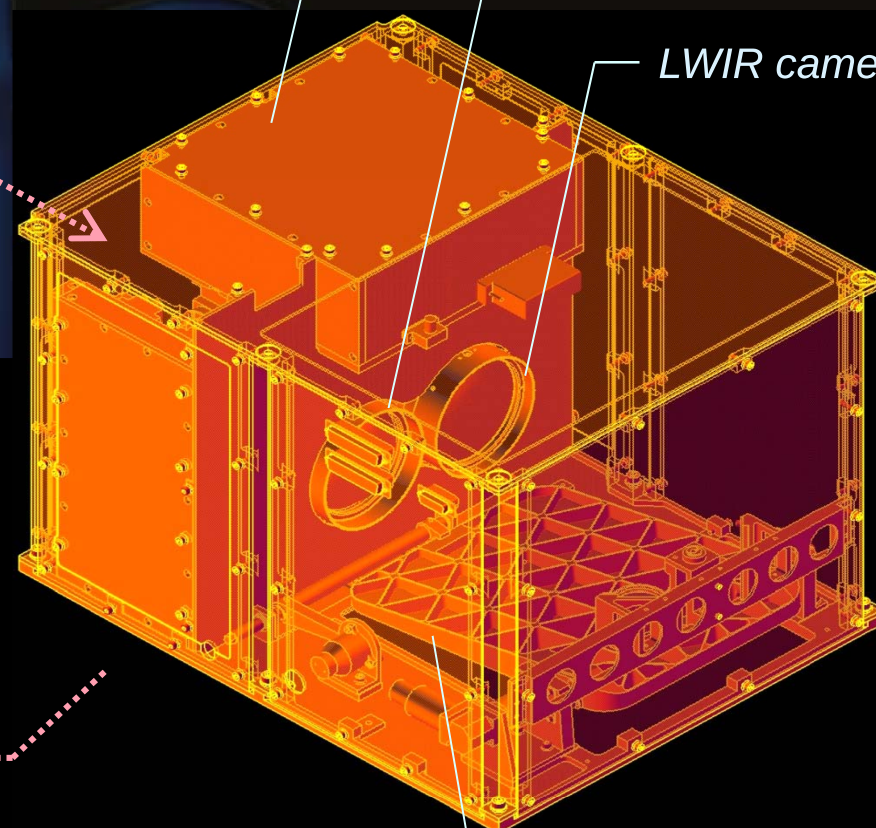


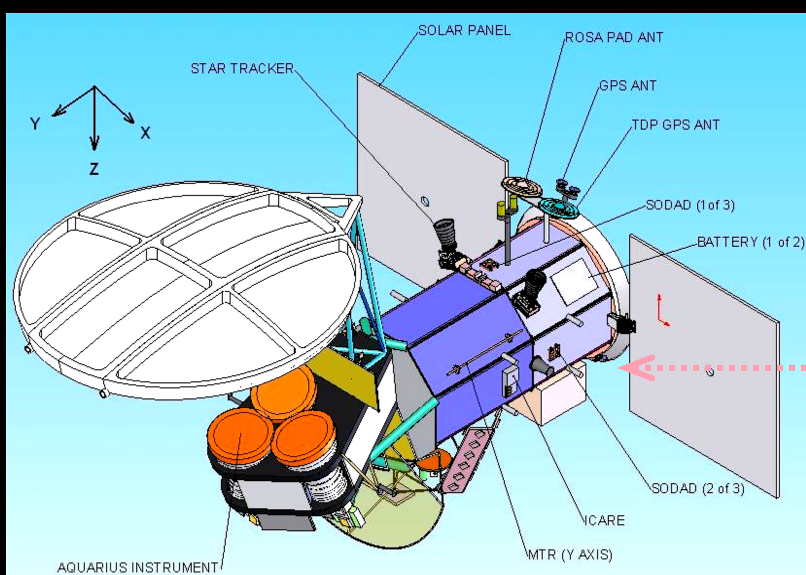


(1) IR window; (2) package cover; (3) cold shield; (4) spectral separation filter; (5) filter assembly; (8) routing circuit wafer; (9) 512x3 microbolometers with ROIC; (10) thermoelectric cooler; (11) assembly header with vacuum tube; and (12) vacuum stabilizing getter.

Canadian Space Agency   Agence spatiale canadienne

Instrument details

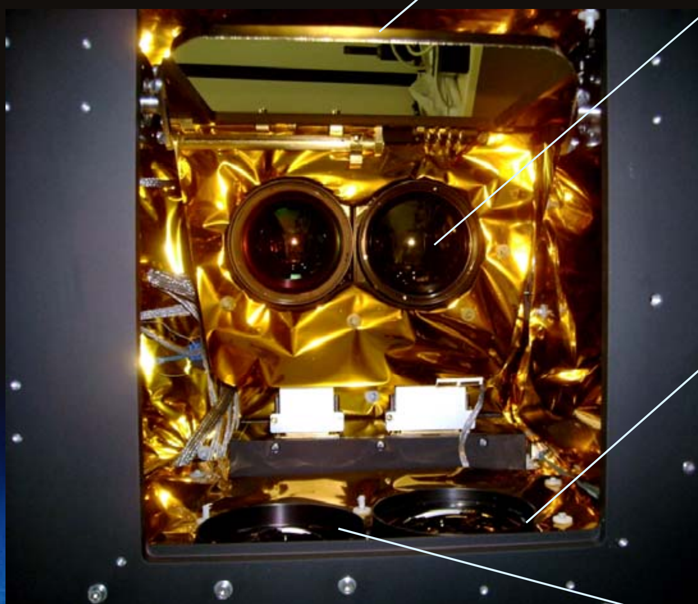




Instrument details

Pointing mirror

Reflection of cameras pointing to Earth surface



LWIR camera

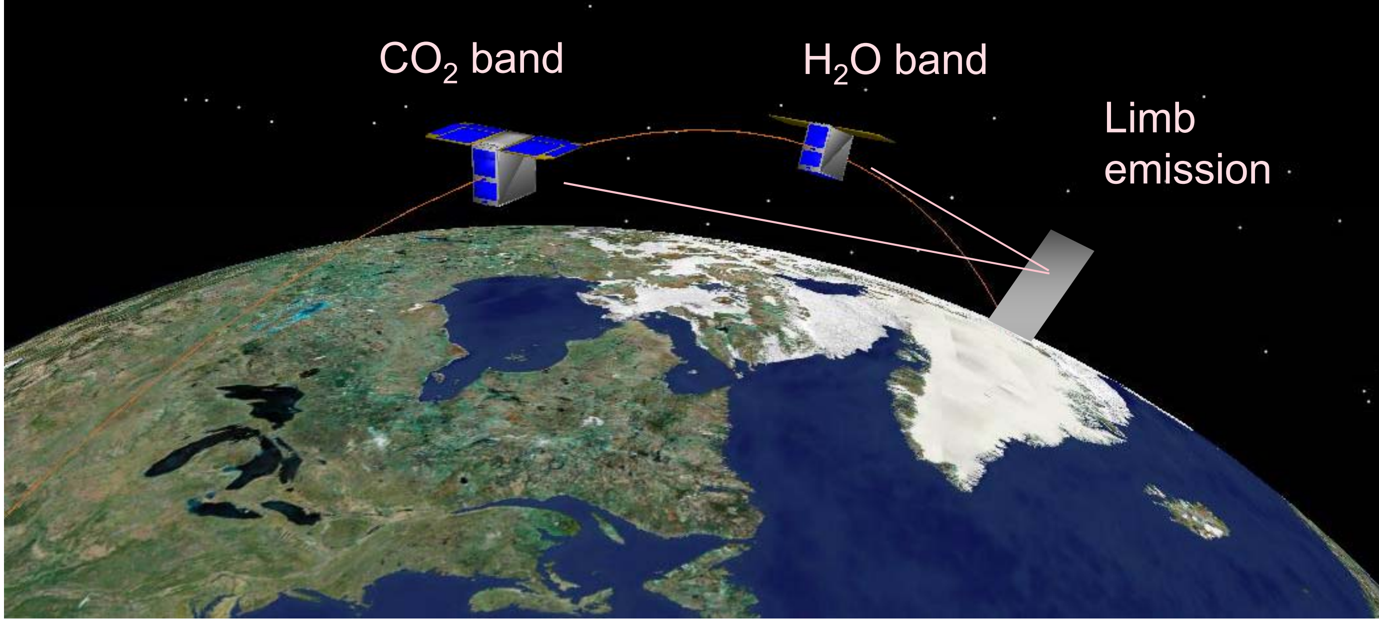
MWIR camera

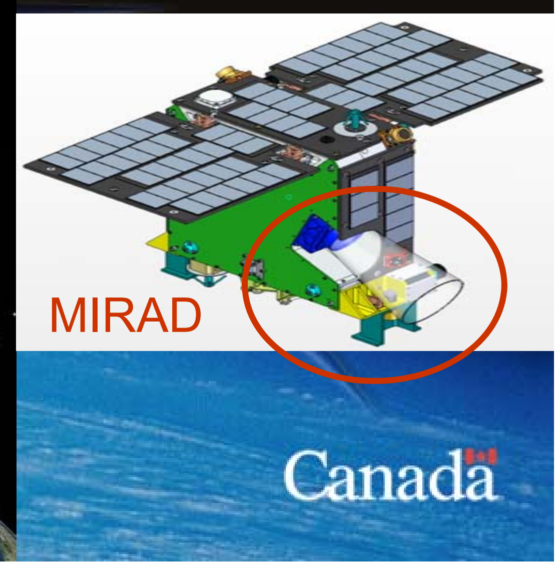
Canadian Space Agency   Agence spatiale canadienne

Far IR sensing

JC2Sat-FF

- Consist of two miniature far IR radiometers distributed on two FF nanosats
- Coregister limb radiances in the CO_2 15 um band (sat 1) and H_2O 25 um band (sat 2)
- Generate a database of limb radiance profiles with global, seasonal, day/night time variations
- Provide characteristics of navigational horizon and atmospheric OR in the far IR

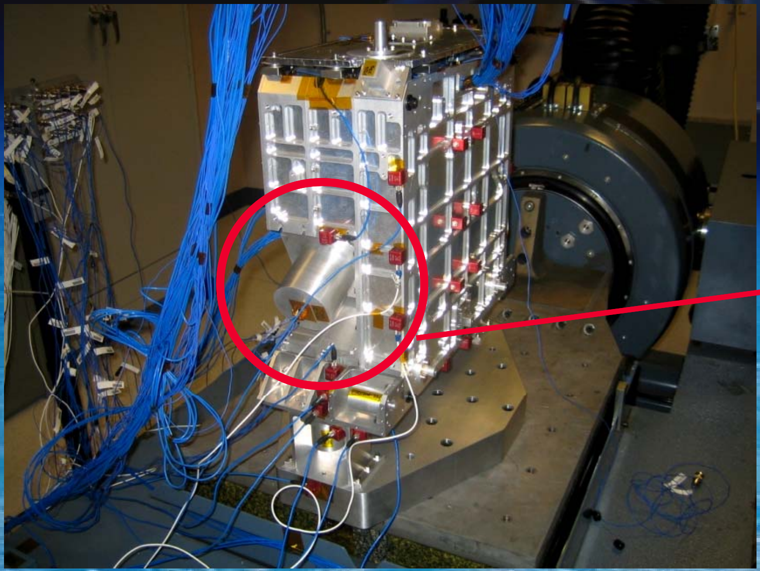


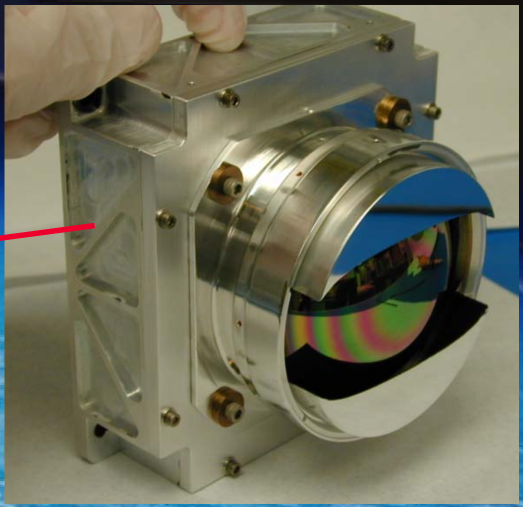


Canadian Space Agency Agence spatiale canadienne

Radiometers

- Miniaturized to fit in nanosats
- Differ in operating spectral band, one band per nanosat
  - *FIR1: 14-16 um*
  - *FIR2: 24.3-26.1 um*
- Coregister the radiance profiles of the Earth's limb
- Enable direct FIR measurement using microbolometers

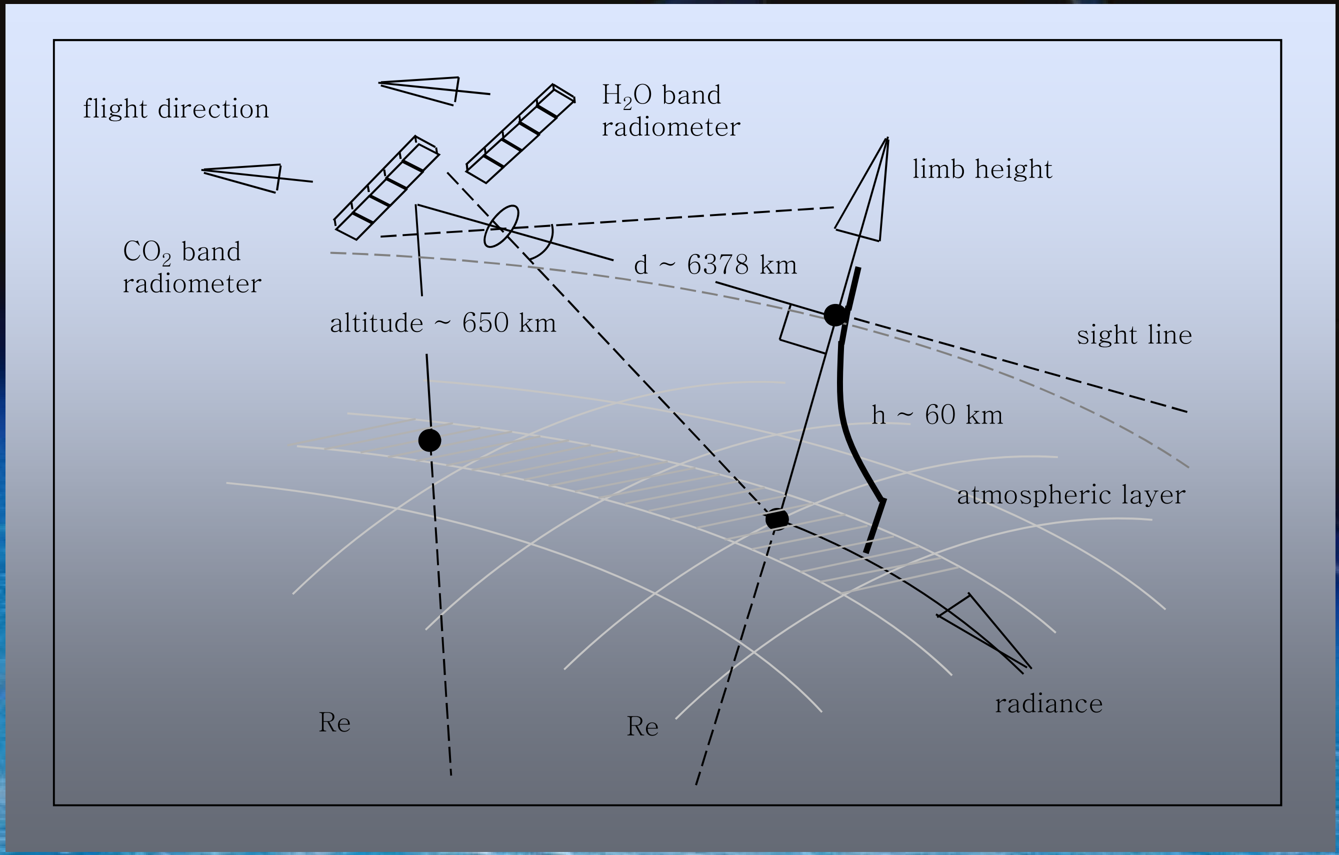




Canada

Operation

- Perform measurements during the formation keeping phase (30 days)
- Acquire and transmit data to CPU when powered
- Measure in sequences of 14 s with 1 orbital period between sequences (latitude coverage in 28.5 days)
- Downlink data to two ground stations (~ 15 min / station / sat / day)



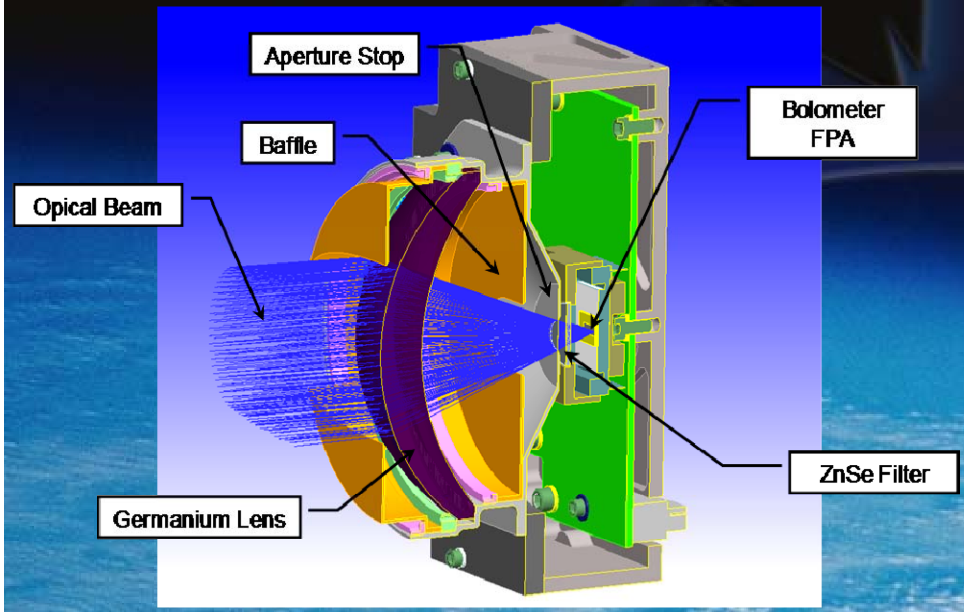
Budgets

	Spacecraft	*Radiometer (allocation)*	*Radiometer (design)*
Power (W)	14	1	0.39 (average) 0.58 (max)
Mass (kg)	20	0.50	0.48
Volume (mm^3)	350x350x150	105x105x100	105x105x100

Canadian Space Agency Agence spatiale canadienne

Optics

- Largest fraction of the volume and mass budgets
- Optics must be small but provides enough throughput for the sensor
- Optical materials must be compatible with the design of small optics
    - *Ge allows for diffraction limited single lens design in band 1*
    - *CdTe has an acceptable transmittance in band 2 and can be diamond turned into aspherical surfaces*



Canada

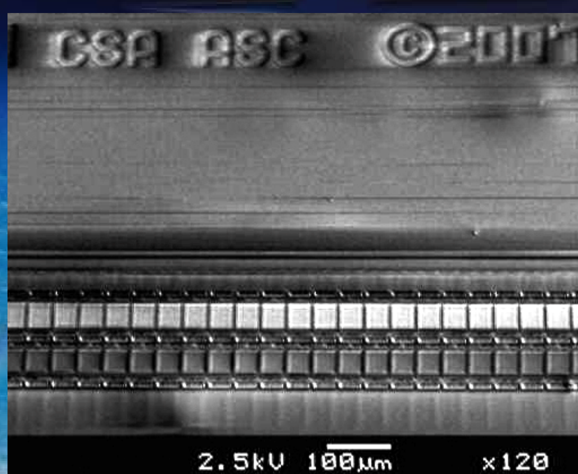
Optics

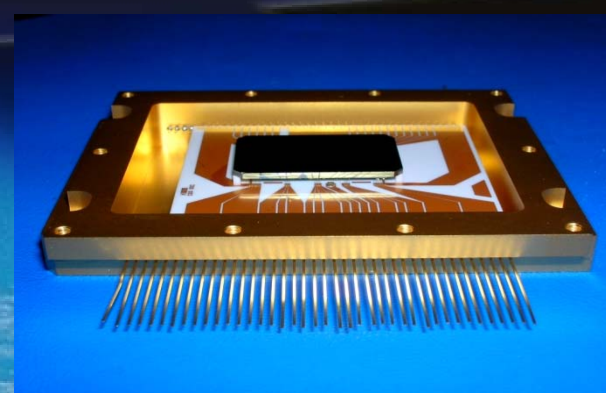
	Band 1	*Band 2*
Waveband	Corrected from 14 um to 16 um	Corrected from 24.2 um to 26.2 um
IFOV (per pixel)	0.98 mrad	0.98 mrad
F/# (Working)	F/1.47	F/1.3
Detector	1X256 pixels, 1D=13.312 mm (50 um/pl, 2 um gap)	1X256 pixels, 1D=13.312 mm (50 um/pl, 2 um gap)
EFL	51.02 mm	51.02 mm
Entrance Pupil Diameter	34.013 mm	39.246 mm
FFOV in 1D	14.87 degrees	14.87 degrees
Elements	1 aspherical lens (in Ge)	2 aspherical lenses (both in CdTe)
Optics mass	171.0 g	82 g
Dimension	71 mm diameter 52.1 mm length	67 mm diameter 84.4 mm length
Total transmittance	39%	34%
Athermal range	10^0C to 28^0 C	10^0 C to 28^0 C

Sensors

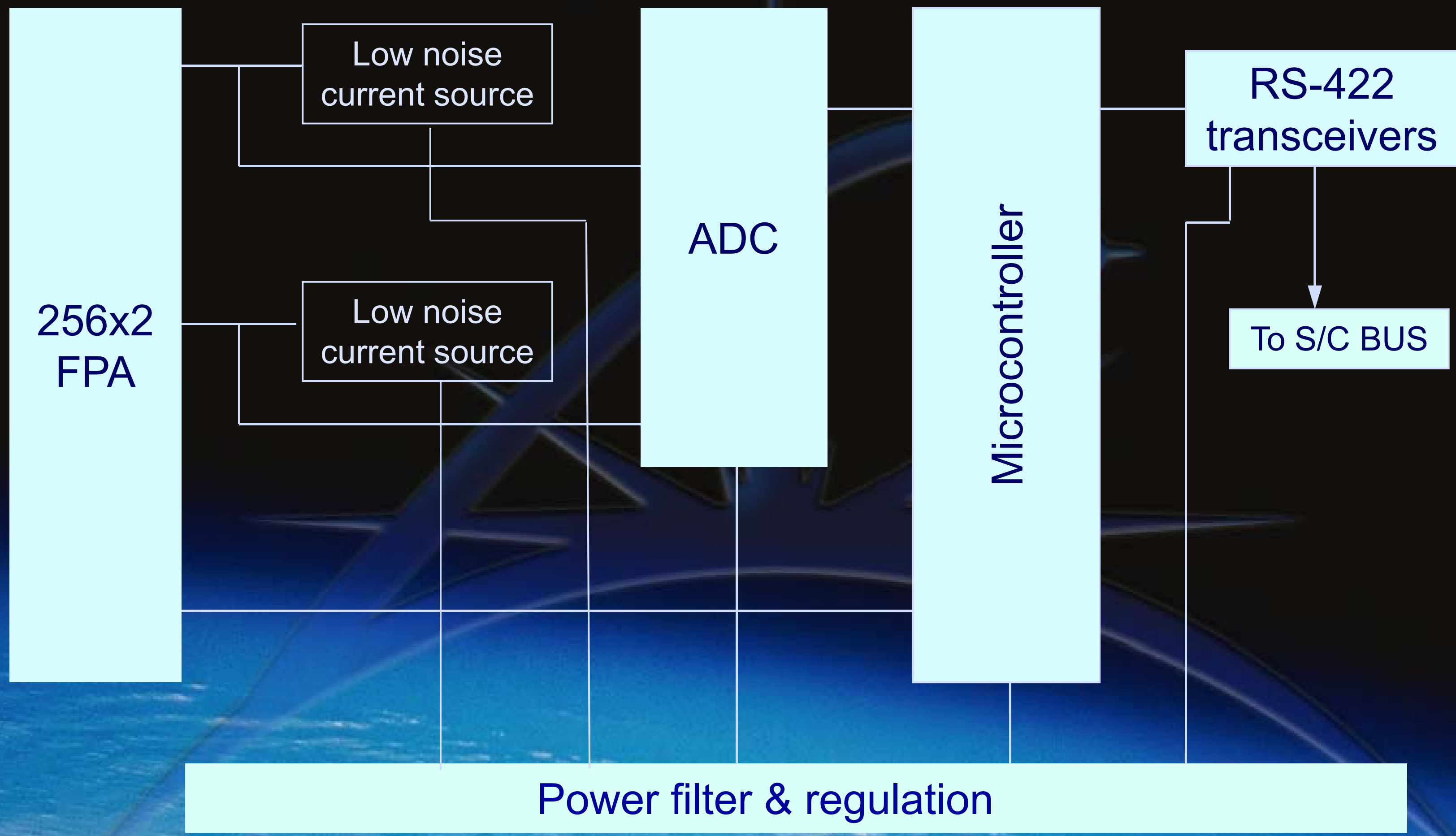
- *IFOV* ~ 1 mrad; resolution: *d* tan *IFOV* ~ 2.8 km
- No. of pixels needed to capture the limb: 2*h* / 2.8 km ~ 43 pixels
- Equivalence of +/- 5 deg error ~ 175 pixels
- A minimum of 218 pixels is required

Format selected: linear array of 256x2 pixels
One row of active pixels, one row of reference pixels



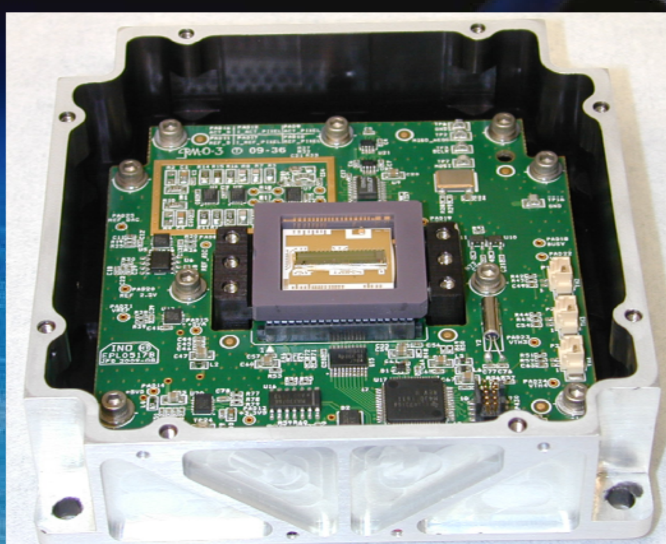


Electronics



Canadian Space Agency
Agence spatiale canadienne

Electronics



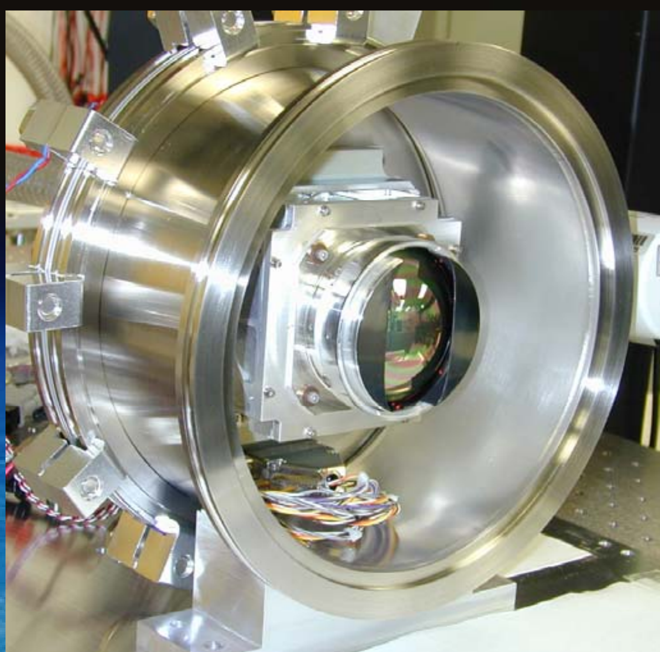
- Remove offset due to die temperature drifts
- Monitor average sensor resistance and adjust supplied current
- Monitor temperatures of lens assembly, sensor, and microcontroller for data interpretation
- Filter and regulate supplied power
- Control process of data acquisition and transmission

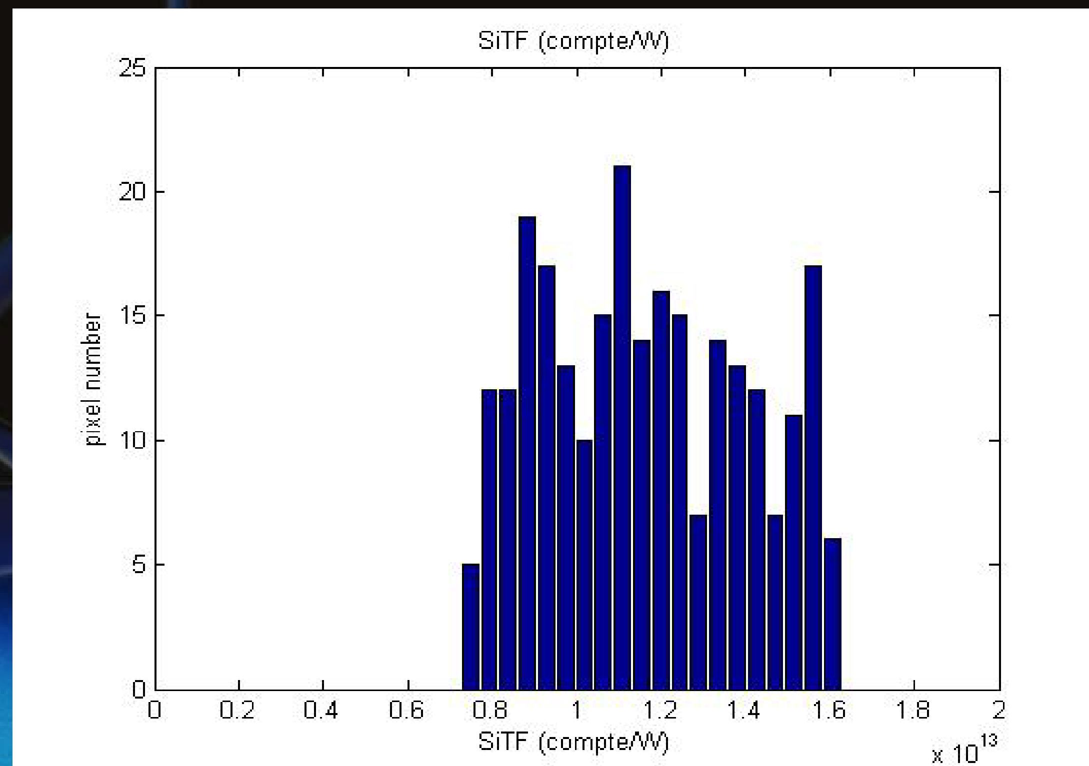
Canada

Canadian Space Agency
Agence spatiale canadienne

Tests

T cycling: -30 to 70 C
Vibration: 14.1 grms





Canada

Summary

- Technology development at the CSA has focused on linear arrays of resistive microbolometers
- Details on the developed sensors were presented
- The main challenge - monolithic ROIC - was successfully addressed
- Suitability of microbolometers for use in different infrared bands was confirmed
- Flight sensors were delivered to SAC-D Aquarius mission (MWIR / TIR) and JC2Sat mission (FIR)