Application of Cryogenic Radiometry to Inter-comparison Measurements Related to TSI

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Introduction

- Description of a proposed liquid helium cooled cryogenic radiometer suitable for a direct inter-comparison with a TSI flight instrument.
  - Operating temperature from 2 K to 9 K.
  - Optimized for both POWER and IRRADIANCE measurement modes.
  - This instrument will provide the first **direct** inter-comparison of TSI flight hardware to a standard optical watt at solar flux levels.

Why Go Cryogenic?

- A cryogenic system allows for the removal of most systematic effects.
- Superconductors!
  - No Joule heating
  - Accurate power measurement and delivery
  - Minimal thermal conduction down the leads
- High responsivity thermometry
- Very High Thermal Diffusivity
- Greatly reduced blackbody issues
  - 300K 50 mW/cm^2
  - 4 K 1.6 nW/cm^2

CryoRad-TSI Requirements

- Similar absolute scale as NIST's L-1 CryoRad or POWR
  - No reduction in any requirement
- Measure from 10 nW noise floor to 65 mW (1365 W/m^2)
- Capable of measuring both irradiance and power.
- An 8-mm diameter limiting aperture
- Single Vacuum Window!
  - The window transmittance would be the largest uncertainty! (~100 ppm)
  - Share a single vacuum with a flight/spare instrument. (Only concern is out-gassing of flight instrument)
  - Wide range of wavelengths would be possible for the inter-comparison, but not necessary, stick to 532 nm.

CryoRad-TSI Performance

- Active Heat Sink and Receiver Temp Control
- New TC-03 electronics will be ready and can be modified for use with this radiometer.
- Temperature Range 2 K to 9 K
- 1/e Time Constant < 3 s at 100 mW
- Cavity Absorptance > 0.999995
- Noise Floor < 100 nW out of 100 mW
- Elect./Optical Non-Eq. 0 +/- 5 ppm
- Elect./Thermal Non-Eq. 0 +/- 5ppm
- Temperature Sensors GRTs
- Heaters 1000 Ohms
- Responsivity 80 K/W

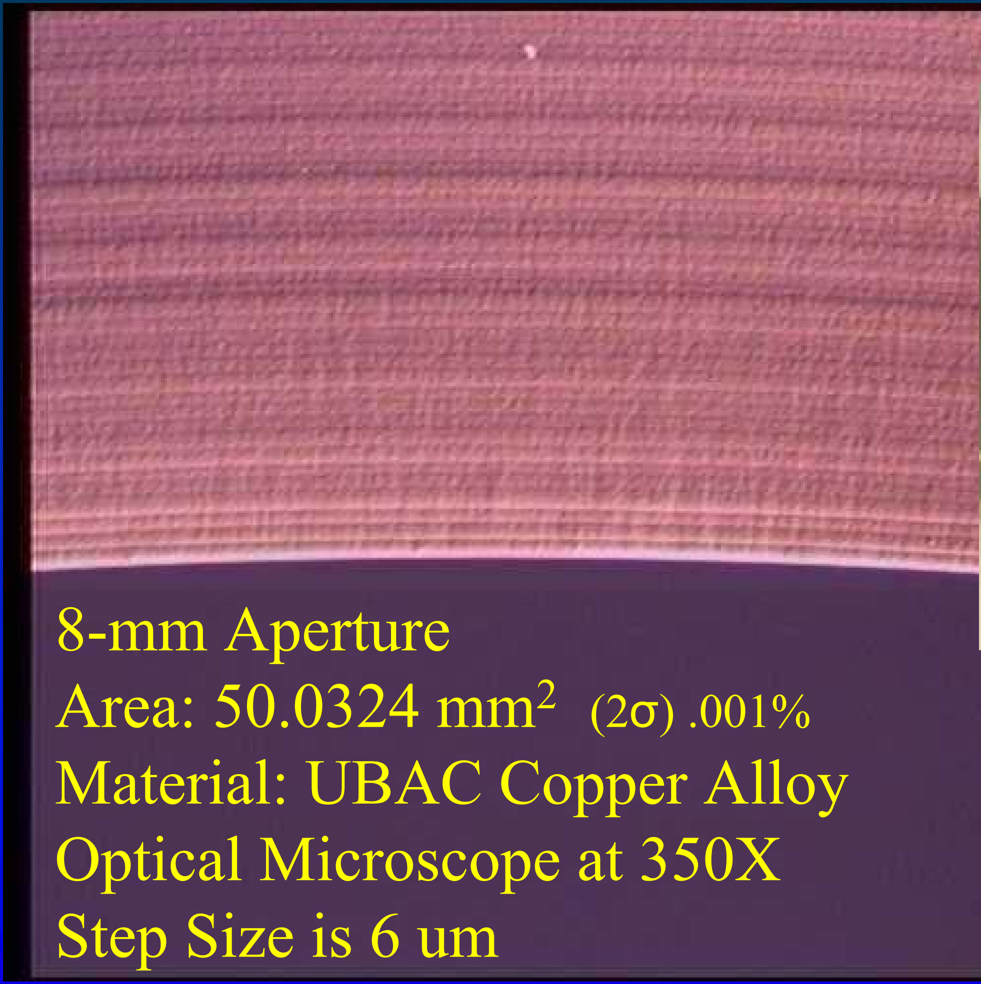
CryoRad-TSI Noise Predictions

- Assumptions:

Thermal impedance	12.5	mW/K
Sensor Resistance	1000	Ohms
Sensor Bias	31.6	µA
Sensor Power	1	µW
Amp Noise	1.9	nV/Hz$^{1/2}$
Johnson Noise	2.1	nV/Hz$^{1/2}$
Shot Noise	3.2	nV/Hz$^{1/2}$

- Intrinsic Thermal 66.5 pW/Hz$^{1/2}$
- Total NEP with V-Bias on Sensor 1123 pW/Hz$^{1/2}$

Diamond Turned Apertures



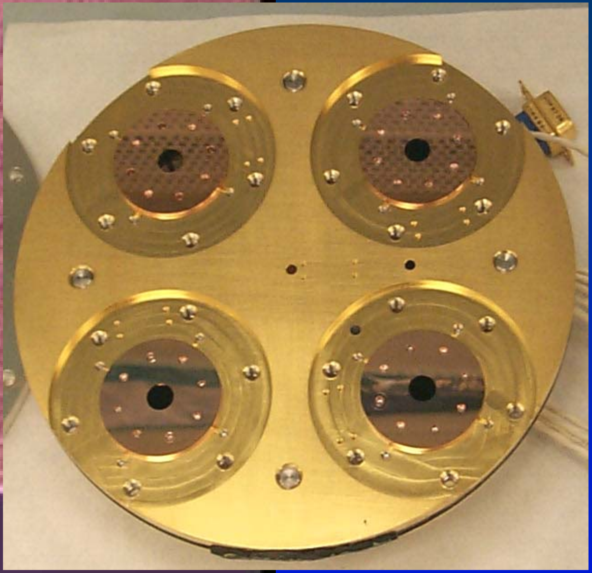
8-mm Aperture

Area: 50.0324 mm^2 (2σ) .001%

Material: UBAC Copper Alloy

Optical Microscope at 350X

Step Size is 6 um

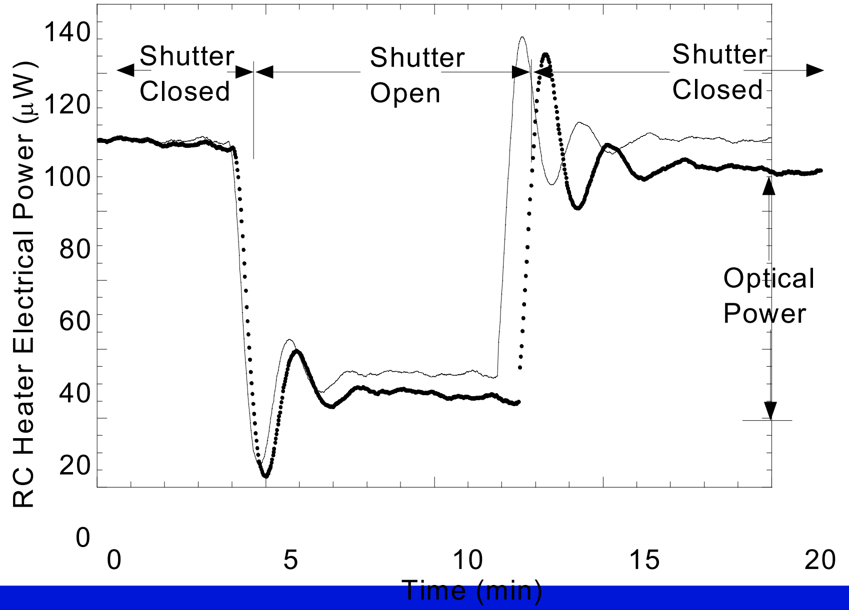


NISTAR
Heat Sink Assembly
with Defining Apertures

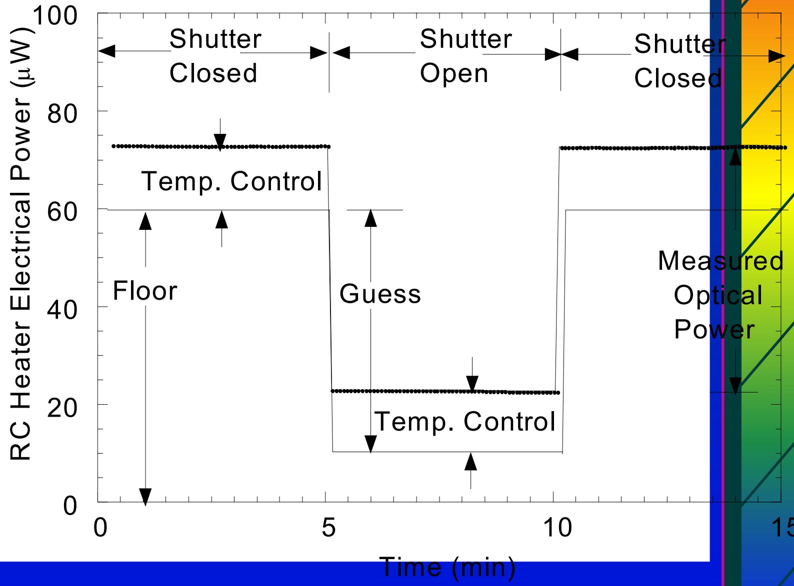
Feed-Forward Active Cavity Control Algorithm

(Example data from 300 K prototype built before NISTAR)

Without



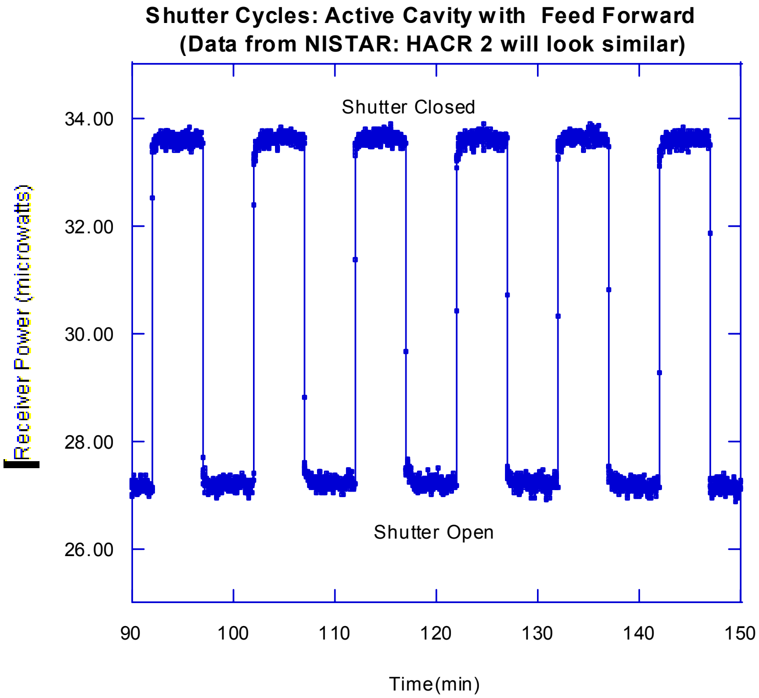
With

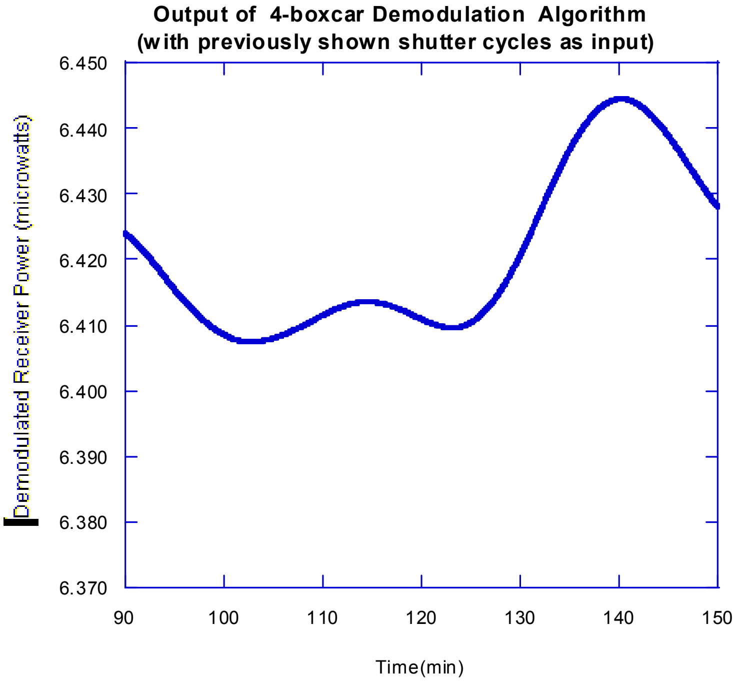


Phase-Sensitive Detection Algorithm used for Demodulation

$$r_J = real\left[\frac{\sum_{M=J-N+1}^{J}\sum_{L=M}^{M+N-1}\sum_{K=L-N+1}^{L}\sum_{I=K}^{K+N-1} e^{i2\pi I/N}\phi_I}{\sum_{M=J-N+1}^{J}\sum_{L=M}^{M+N-1}\sum_{K=L-N+1}^{L}\sum_{I=K}^{K+N-1} e^{i2\pi I/N}\psi_I}\right]$$

ϕ_I = sequence of measured values
ψ_I = sequence of shutter position values
I = raw index
J = processed index
N = number of points per shutter cycle
r_J = demodulated response


Shutter Cycles: Active Cavity with Feed Forward
(Data from NISTAR: HACR 2 will look similar)

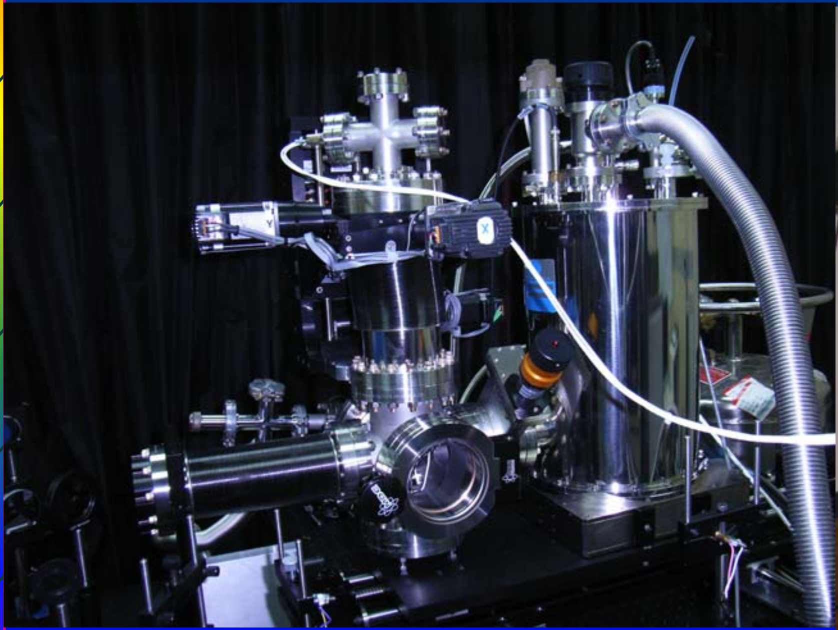

Output of 4-boxcar Demodulation Algorithm
(with previously shown shutter cycles as input)

CryoRad-TSI Radiometer Uncertainty Budget for Inter-comparison at 532 nm and 65 mW

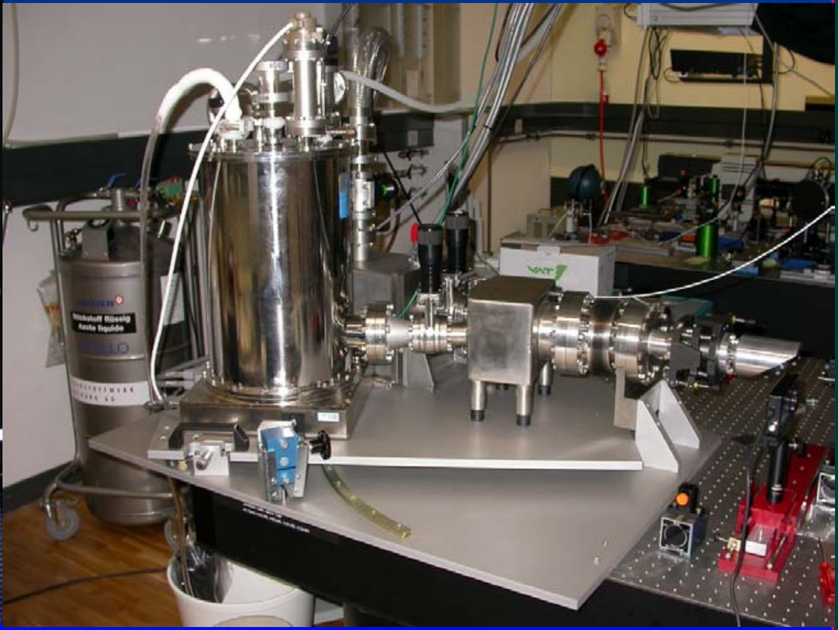
Measurement	Value (Units)	Value (ppm)	Component of Uncertainty (ppm, k=1)	Type
Aperture Area	50 mm^2	1 000 000	30	B
Thermal Contraction (4K)	24 µm (diam.)	6000	50	B/A
Diffraction		<400	40	B
Cavity Reflectance		5	1	A
Electrical Power Linearity	1mW to 65 mW	1 000 000	5	A
Electrical Power Cal	at 65 mW	1 000 000	5	A
Heater Lead Losses		0.0	5	B
E/O Non-Equivalence		0.0	5	A
Scattered Light		100	10	B
Repeatability (Noise)		1 000 000	2	A
		RSS Total	72	

Single Window

- The use of a common window removes a major uncertainty in modern cryogenic inter-comparisons.



ITRI



METAS

- CryoRad-TSI – a significant new capability for mission assurance.

- What Next?
  - #1) Power mode inter-comparison with silicon trap. (1 month)
  - #2) Direct inter-comparison at 65 mW. (1 year)

- Then what?
  - RETURNABLE cryogenic radiometer!
  - On-orbit | Aircraft | Balloon
  - $$$ | $$ | $
  - 5-10 yrs? | 3 yrs? | 1-2 yrs

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