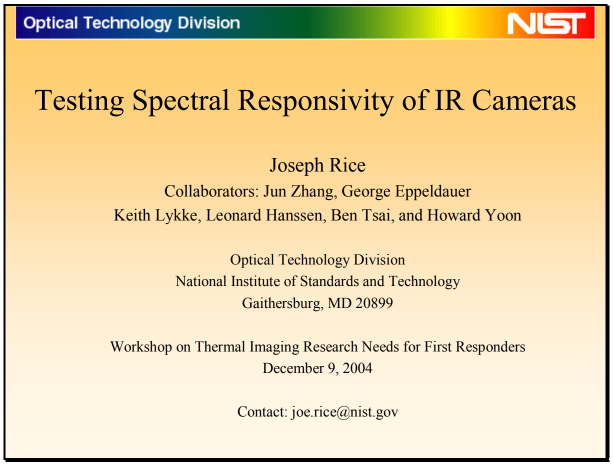
APPENDIX 3.K-

Testing Spectral Responsivity of IR Cameras

Joseph Rice, Optical Technology Division, NIST

We discuss current measurement capabilities and new testing techniques being developed in the Optical Technology Division of NIST that may be applicable to testing device models used by designers of thermal imaging cameras such as those in use by first responders. Existing capabilities include calibration of customer blackbody sources, calibration of customer IR cameras using NIST standard blackbody sources, and spectral measurement of reflectance, transmittance, and emittance of customer supplied samples of IR materials. We describe a new capability, the measurement of spectral responsivity, which has recently been developed from near-IR out to 5 micrometers and applied to single pixel radiometers. We are extending this technique and generalizing it to enable testing of infrared cameras. We present preliminary results for uniform scenes where tunable infrared lasers illuminate an integrating sphere, diffusing the light to fill the imaging system optics. Results from these tests show that signal-to-noise ratio, uniformity, stability, and other characteristics are favorable for use of this technique in the characterization of infrared imaging systems. We also describe a proposed generalization of this technique, to include scenes with arbitrary, controlled spatial content such as bar patterns or even real scenes, by illuminating a commercially available digital micro-mirror device.


Optical Technology Division NIST

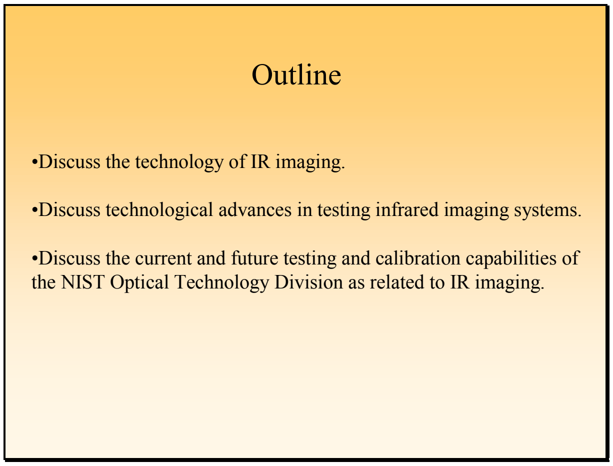
Testing Spectral Responsivity of IR Cameras

Joseph Rice
Collaborators: Jun Zhang, George Eppeldauer
Keith Lykke, Leonard Hanssen, Ben Tsai, and Howard Yoon

Optical Technology Division
National Institute of Standards and Technology
Gaithersburg, MD 20899

Workshop on Thermal Imaging Research Needs for First Responders
December 9, 2004

Contact: joe.rice@nist.gov


Outline

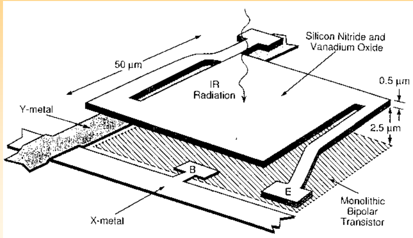
•Discuss the technology of IR imaging.

•Discuss technological advances in testing infrared imaging systems.

•Discuss the current and future testing and calibration capabilities of the NIST Optical Technology Division as related to IR imaging.

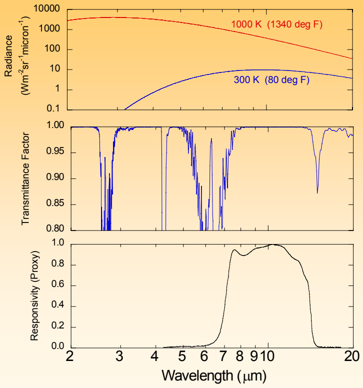
Technology Example: Microbolometer Pixel

- •IR radiation is absorbed in microbridge, heating it.
- •Supporting legs provide electrical contact and thermal isolation.
- •Vanadium Oxide microbridge electrical resistance changes when heated.
- •Monolithic pixel readout circuitry converts resistance change into electrical signal.
- •Has been developed into 320 x 240 arrays for uncooled thermal imaging applications.



From: R. A. Wood, "Monolithic silicon microbolometer arrays," Chapter 3 of *Uncooled Infrared Imaging Arrays and Systems, Semiconductors and Semimetals 47*, P. W. Kruse and D. D. Skatrud, eds. Academic Press, San Diego (1997).

Signal = Radiance * Transmittance * Responsivity + Background



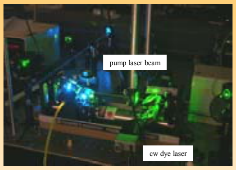
Radiance
- •Depends on scene (what we want to see).
- •Shown is blackbody.

Transmittance
- •Depends on environment.
- •Can be very complex.
- •Objects in path absorb IR and re-emit at other temperatures.
- •Shown is effect of 1 meter of air at 48% relative humidity.

Relative Spectral Responsivity
- •Depends on camera design.
- •Not flat-topped.
- •Usually there is out-of-band.
- •Data not often available.

Basic Principles behind the SIRCUS Technique

A variety of tunable lasers



fiber-coupled into an integrating sphere

Producing a source that is
- **Spatially uniform (Lambertian)**
- **Monochromatic**
- **Tunable continuously over a broad range**
- **high radiance,**
- ***of (known) radiance***

Ideally suited for measurements of
- **In-band relative spectral responsivity.**
- **Out-of-band-spectral responsivity.**
- **Spatial characterization.**
- **Absolute radiometric calibration.**

Goal: Measurements at the 0.1 % level

SIRCUS = Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources

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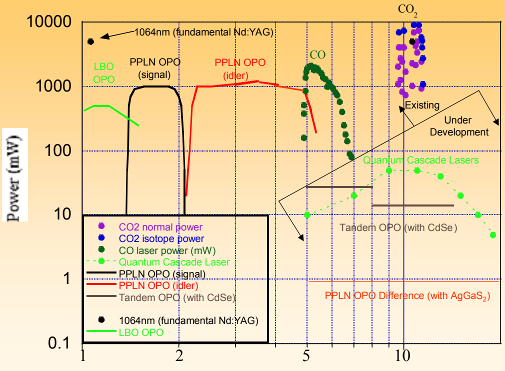
Wavelengths and Powers for SIRCUS IR

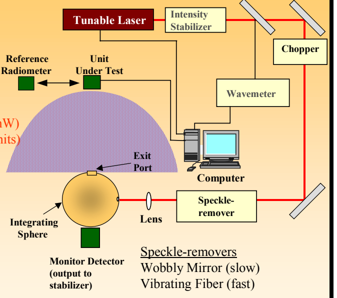


IR SIRCUS: Infrared Spectral Irradiance and Radiance Responsivity Calibrations with Uniform Sources

Wavelengths (microns)
- 1.064 YAG (10 W)
- 1.4 - 4.9 OPO (continuous, 0.5 to 1 W)
- 9 – 11 CO_2 (discrete 10 lines, W)
- 9-11 Isotopic CO_2 (discrete 10 lines, W)
- 4.8 - >6 CO (discrete, lots of lines, W)
- 5-12 OPO difference (continuous, mW)
- 4-12 OPO pumped OPO (continuous 10-100 mW)
- 8-12 Quantum Cascade (continuous, several units)

Reference Radiometers
- Electrically Substituted Bolometer (ESB)
- InGaAs (working standard)
- Extended InGaAs (working standard)
- Germanium, InSb, MCT (working standard)

Intensity Stabilizers
- Fresnel Attenuator (broadband, slow response)
- EOM (medium bandwidth, fast response, 1-5 µm)
- AOM (narrow bandwidth, fast response)



Speckle-removers
- Wobbly Mirror (slow)
- Vibrating Fiber (fast)

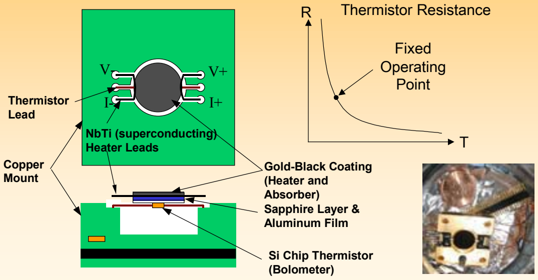
Black: Existing

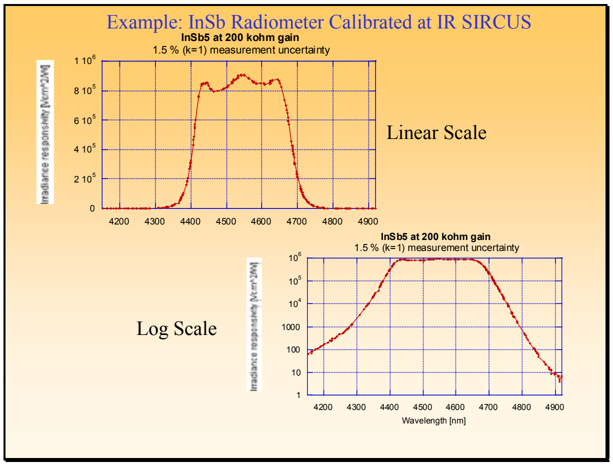
Red: Under development

Acknowledgement The IR-SIRCUS facility at NIST is being developed with the support of the United States Air Force through the Calibration Coordination Group (CCG03-511). Development of the SIRCUS facility was also supported by the CCG.

Electrically Substituted Bolometer (ESB): Reference Detector at IR SIRCUS

- •A liquid-helium-cooled bolometer stabilized with electrical substitution
- •NEP = 30 $pW/Hz^{1/2}$ @ 15 Hz for 1 cm diameter detector @ 5 Kelvin





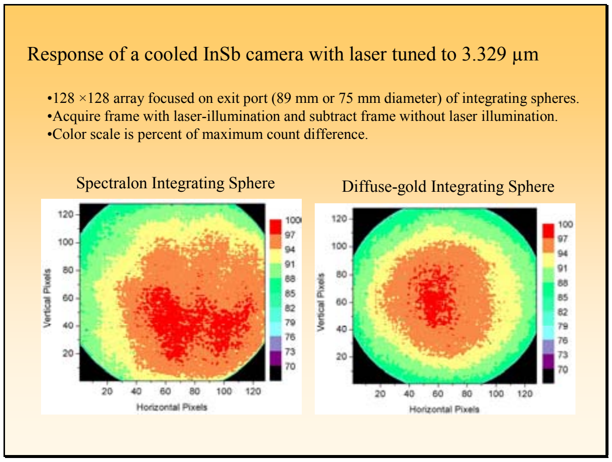
Example: InSb Radiometer Calibrated at IR SIRCUS

InSb5 at 200 kohm gain
1.5 % (k=1) measurement uncertainty

Linear Scale

InSb5 at 200 kohm gain
1.5 % (k=1) measurement uncertainty

Log Scale

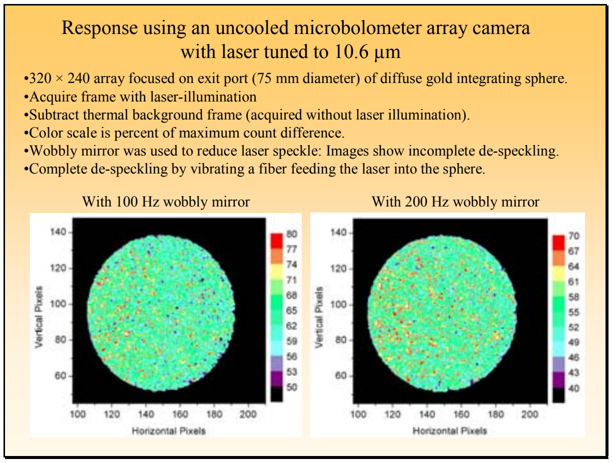


Response of a cooled InSb camera with laser tuned to 3.329 µm

- •128 ×128 array focused on exit port (89 mm or 75 mm diameter) of integrating spheres.
- •Acquire frame with laser-illumination and subtract frame without laser illumination.
- •Color scale is percent of maximum count difference.

Spectralon Integrating Sphere

Diffuse-gold Integrating Sphere

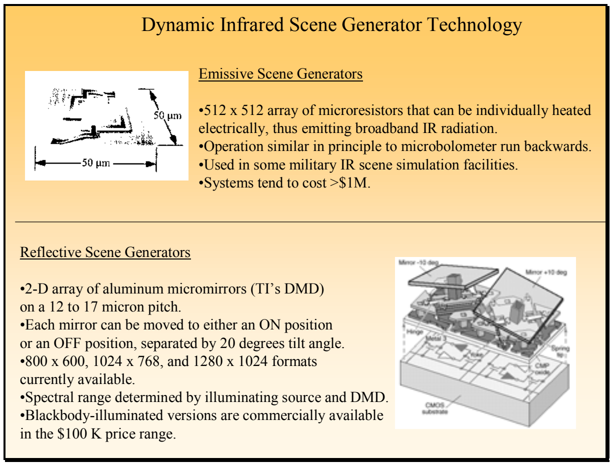


Response using an uncooled microbolometer array camera with laser tuned to 10.6 µm

- •320 × 240 array focused on exit port (75 mm diameter) of diffuse gold integrating sphere.
- •Acquire frame with laser-illumination
- •Subtract thermal background frame (acquired without laser illumination).
- •Color scale is percent of maximum count difference.
- •Wobbly mirror was used to reduce laser speckle: Images show incomplete de-speckling.
- •Complete de-speckling by vibrating a fiber feeding the laser into the sphere.

With 100 Hz wobbly mirror

With 200 Hz wobbly mirror



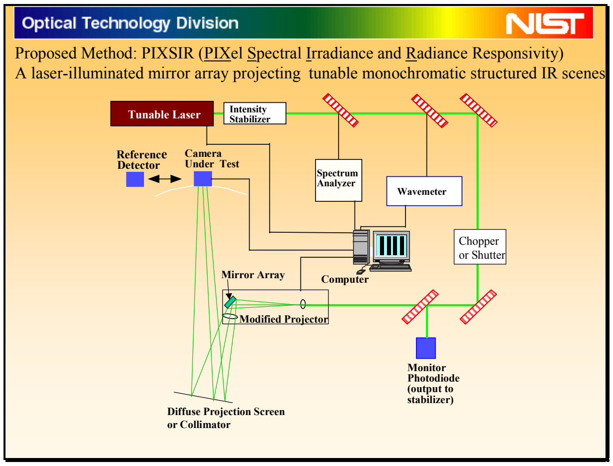
Dynamic Infrared Scene Generator Technology

Emissive Scene Generators

- •512 x 512 array of microresistors that can be individually heated electrically, thus emitting broadband IR radiation.
- •Operation similar in principle to microbolometer run backwards.
- •Used in some military IR scene simulation facilities.
- •Systems tend to cost >$1M.

Reflective Scene Generators

- •2-D array of aluminum micromirrors (TI’s DMD) on a 12 to 17 micron pitch.
- •Each mirror can be moved to either an ON position or an OFF position, separated by 20 degrees tilt angle.
- •800 x 600, 1024 x 768, and 1280 x 1024 formats currently available.
- •Spectral range determined by illuminating source and DMD.
- •Blackbody-illuminated versions are commercially available in the $100 K price range.



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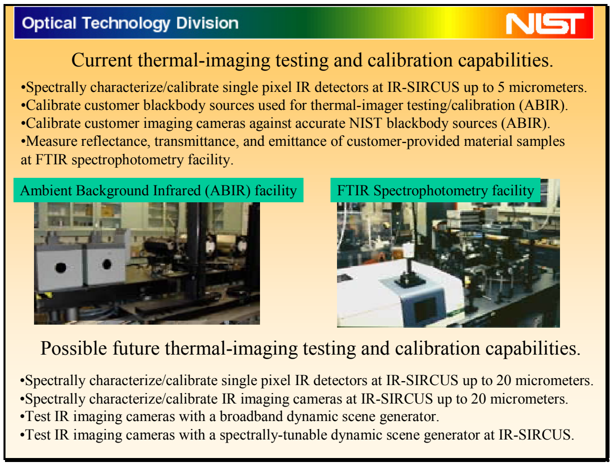
Proposed Method: PIXSIR (PIXel Spectral Irradiance and Radiance Responsivity)
A laser-illuminated mirror array projecting tunable monochromatic structured IR scenes



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Current thermal-imaging testing and calibration capabilities.

- •Spectrally characterize/calibrate single pixel IR detectors at IR-SIRCUS up to 5 micrometers.
- •Calibrate customer blackbody sources used for thermal-imager testing/calibration (ABIR).
- •Calibrate customer imaging cameras against accurate NIST blackbody sources (ABIR).
- •Measure reflectance, transmittance, and emittance of customer-provided material samples at FTIR spectrophotometry facility.

Ambient Background Infrared (ABIR) facility

FTIR Spectrophotometry facility

Possible future thermal-imaging testing and calibration capabilities.

- •Spectrally characterize/calibrate single pixel IR detectors at IR-SIRCUS up to 20 micrometers.
- •Spectrally characterize/calibrate IR imaging cameras at IR-SIRCUS up to 20 micrometers.
- •Test IR imaging cameras with a broadband dynamic scene generator.
- •Test IR imaging cameras with a spectrally-tunable dynamic scene generator at IR-SIRCUS.