Absolute Cryogenic Radiometer Control Using Commercial Off-the-Shelf Electronics

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Outline

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• Targeted Improvements for LBIR Needs
• COTS electronics for ACR control
• Results: Comparison between “regular” and COTS electronics
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Introduction

- National Metrology Institutes around the world and others interested in highly precise (~±0.02% k=2), SI traceable radiance calibrations use Absolute Cryogenic Radiometers (ACRs) to set their optical power measurement scale.

- There are commercial electronics specifically designed for ACR calibrations currently available, but these complete systems can be difficult for the end-user to modify, upgrade, and calibrate.

- The Low Background Infrared Facility (LBIR) is interested in:
  1. Operating the ACRs at lower powers,
  2. Shortening measurement time,
  3. And making SI traceability easier to maintain.

- LBIR developed a research calibration system using commercial off-the-shelf (COTS) components such as AC resistance bridges and tabletop voltmeters to build up a system for ACR radiative power calibrations.
ACR Basics: The Receiver Cavity

• A typical Absolute Cryogenic Radiometer (ACR) cavity trap is approximately 5 cm long with an entrance aperture 2.5 cm in diameter.

• The conical shape and the specular black coating of an ACR traps 99.995 % of all photons entering its aperture.

• An ACR is a very efficient broadband absorber.
The receiver cavity is controlled to a precise temperature.

The receiver cavity is thermally attached to a heat sink that is also precisely controlled in temperature.

The ACR assembly is maintained in a low 2 K background.

All changes in electrical power to maintain temperature are the result of changes in radiative power into the ACR defining aperture.
• Changes in absorbed radiance are converted into changes in thermal power that work to change the receiver cavity temperature.

• The electrical power to control the receiver cavity to a constant temperature is measured accurately.

• The change in electrical power is then equal to the negative of the change in radiative power.
This is an image of the ACR assembly that is used in the Missile Defense Transfer Radiometer.

For power measurements around 5 nW the peak-to-peak noise is around 200 pW.

Reproducibility of lowest power measurements (5 nW to 1 nW) is approximately 11 pW (k=1).
Power measurements are only made when steady state is achieved.

The difference between shutter open and shutter closed electrical power measurements is your radiative power signal.
The temperature controllers must:

- Measure temperature quickly (>10 Hz)
- Control temperature precisely
- Deliver high resolution and low noise heater power

The volt meters that are used to measure power must be very accurate and have long term stability (~1 year).

The COTS electronics must be high quality.
Goal #1: Lower Measurement Power Limit

- For standard system the current low power measurement limit is set by both the ACR assembly and control electronics.
- Standard control electronics have a digitization noise floor as well as a rumored “~100 pW” measurement accuracy.
Test time and cost would be significantly reduced if settling time were reduced.
Goal #3: Simplify Calibration Procedure

- **Current standard control electronics require:**
  - The use of a calibration procedure that is a bit long.
  - Starts with the calibration of your favorite high-quality Digital Volt Meter.

- **So why not just use the Digital Volt Meter directly!**
“Standard” vs. COTS Control Electronics

“Standard” Electronics

- Receiver Temp Controller
- Receiver Power Measurement

COTS Electronics

- Temp Controller
  - Receiver Temp Controller
  - Fast AC resistance bridge
  - Low-noise temperature control

- 2 x Digital Volt Meter
  - Receiver Power Measurement
  - Accurate voltage measurement
  - Easily calibrated

- Function of “Standard” control electronics can easily be broken out into separate components.
Blackbody radiant power measurements were made using both control systems under “identical” conditions.

Relative Difference = (COTS – Standard)/Standard

<table>
<thead>
<tr>
<th>Power (nW)</th>
<th>Relative Difference (%)</th>
<th>Type A Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.9189</td>
<td>0.1164%</td>
<td>0.1449%</td>
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<tr>
<td>777.7655</td>
<td>0.0011%</td>
<td>0.0117%</td>
</tr>
<tr>
<td>3092.5938</td>
<td>0.0007%</td>
<td>0.0017%</td>
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Compared to uncertainty, radiant power measurements are indistinguishable between the two control electronics systems.

Nice surprise: Agreement at 10 nW is 10 times lower than “rumored” accuracy of “Standard” electronics.
“Standard” vs. COTS Control Electronics

Time Response Intercomparison

- **COTS temperature controller had similar temperature control performance as “Standard” controller.**
- **COTS temperature controller permits “feed-forward” capability.**

![Receiver Electrical Power Graph](chart.png)

- **For this particular power measurement COTS permits reduction of settling time from 50 s to 10 s.**
Conclusions

- **COTS ACR control electronics were successfully used to substitute for “Standard” control electronics.**
  - Power measurements are equally accurate.
- **COTS ACR provides instant improvements**
  - Shorter measurement times.
  - Easier calibration and shorter SI traceability chain.
  - Easier repair and maintenance.
- **COTS ACR provides avenue for further improvement in low power measurement.**
- **Future Direction: Reduce low power measurement limit 100 X.**