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

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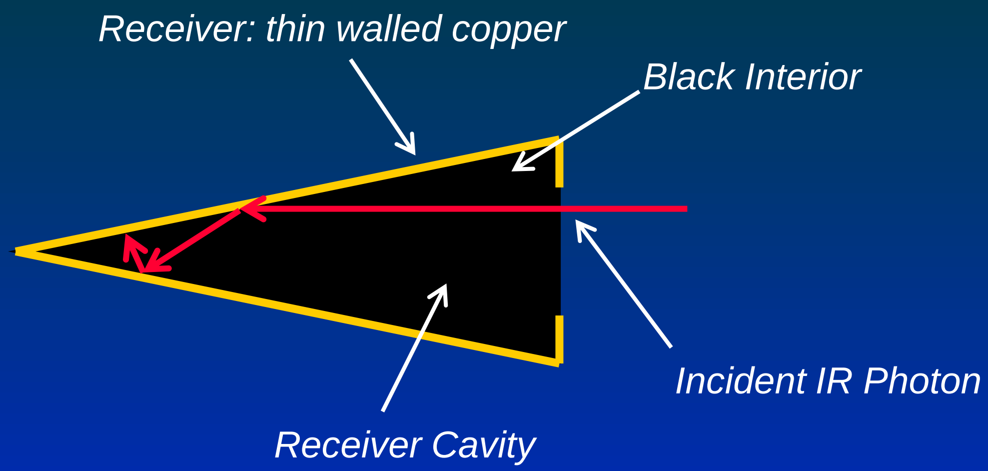
Outline

- *Introduction*
- *Absolute Cryogenic Radiometer Basics*
- *Targeted Improvements for LBIR Needs*
- *COTS electronics for ACR control*
- *Results: Comparison between “regular” and COTS electronics*
- *Conclusion*

Introduction

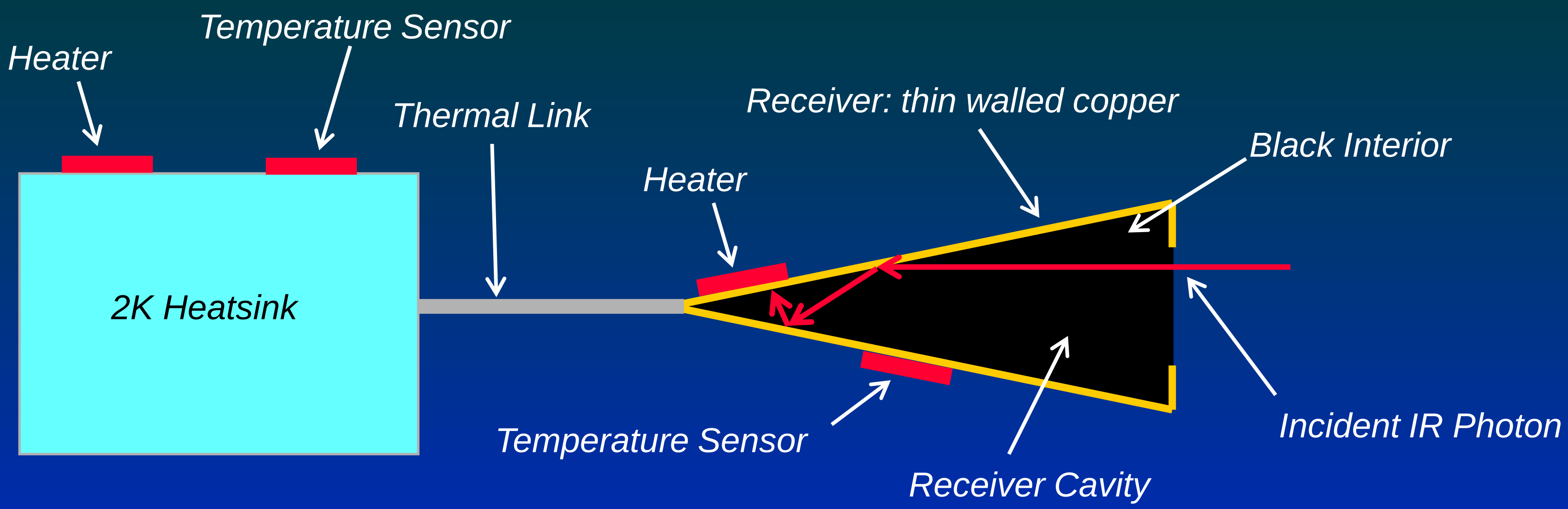
- *National Metrology Institutes around the world and others interested in highly precise (~±0.02% k=2), SI traceable radiance calibrations use Absolute Cryogenic Radiometers (ACRs) to set their optical power measurement scale.*
- *There are commercial electronics specifically designed for ACR calibrations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



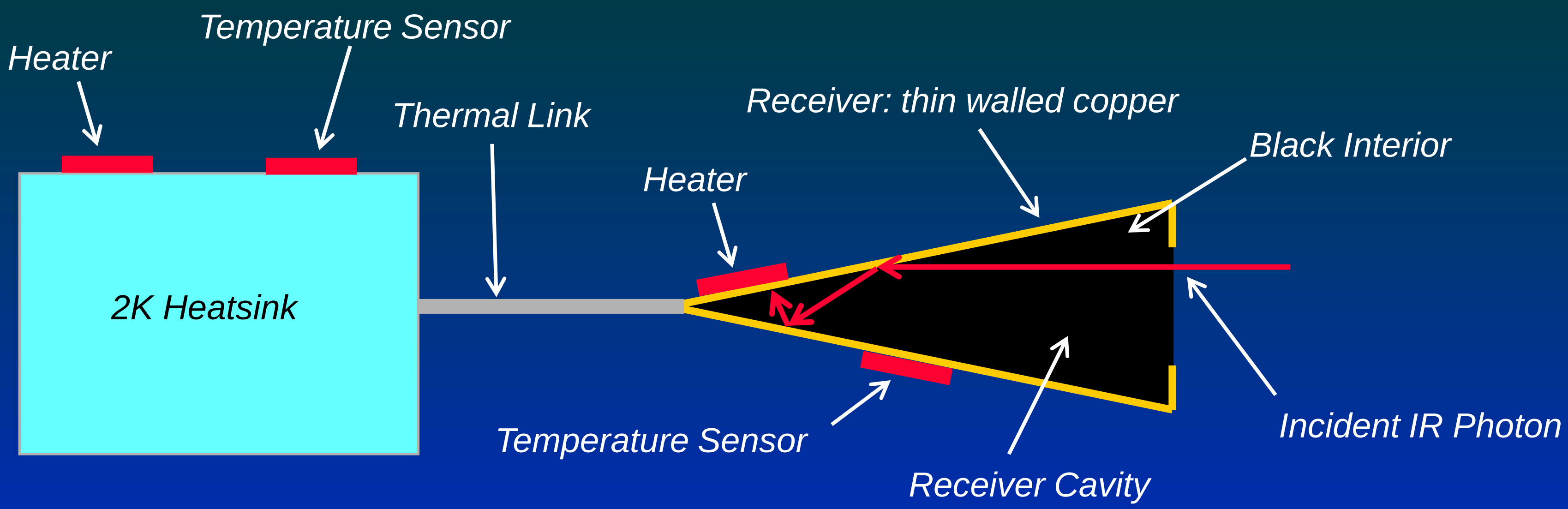
- *A typical Absolute Cryogenic Radiometer (ACR) cavity trap is approximately 5 cm long with an entrance aperture 2.5 cm in diameter.*
- *The conical shape and the specular black coating of an ACR traps 99.995 % of all photons entering its aperture.*
- *An ACR is a very efficient broadband absorber.*

ACR Basics: Temperature Control



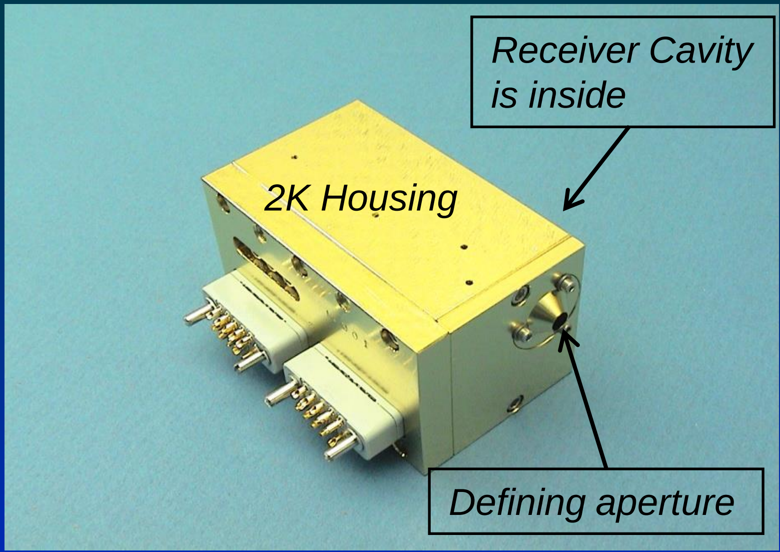
- *The receiver cavity is controlled to a precise temperature.*
- *The receiver cavity is thermally attached to a heat sink that is also precisely controlled in temperature.*
- *The ACR assembly is maintained in a low 2 K background.*
- *All changes in electrical power to maintain temperature are the result of changes in radiative power into the ACR defining aperture.*

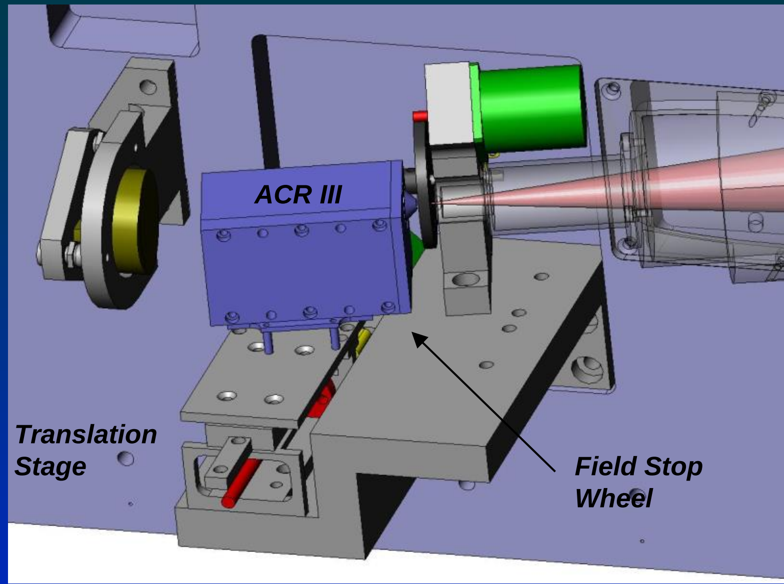
ACR Basics: Electrical-Optical Power Substitution



- *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.*

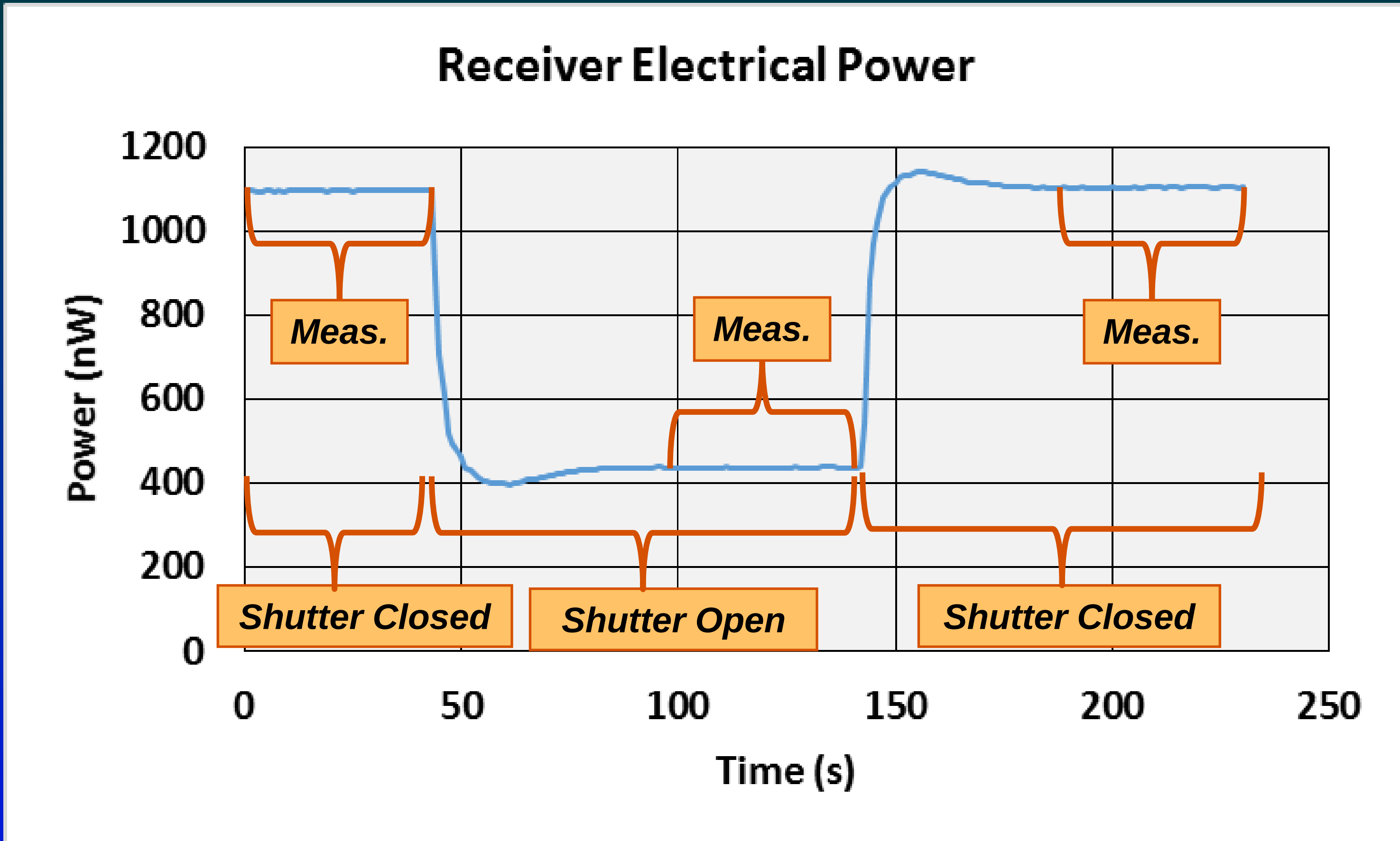
Absolute Cryogenic Radiometer in Practice





- *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).*

ACR Basics: Typical Power Measurement



- *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.*

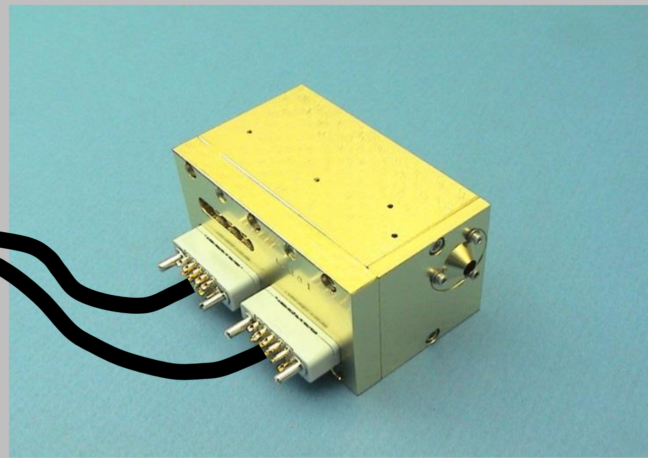
ACR Basics: Control Electronics

Heat Sink Temp Controller

Heat Sink Power Measurement

Receiver Temp Controller

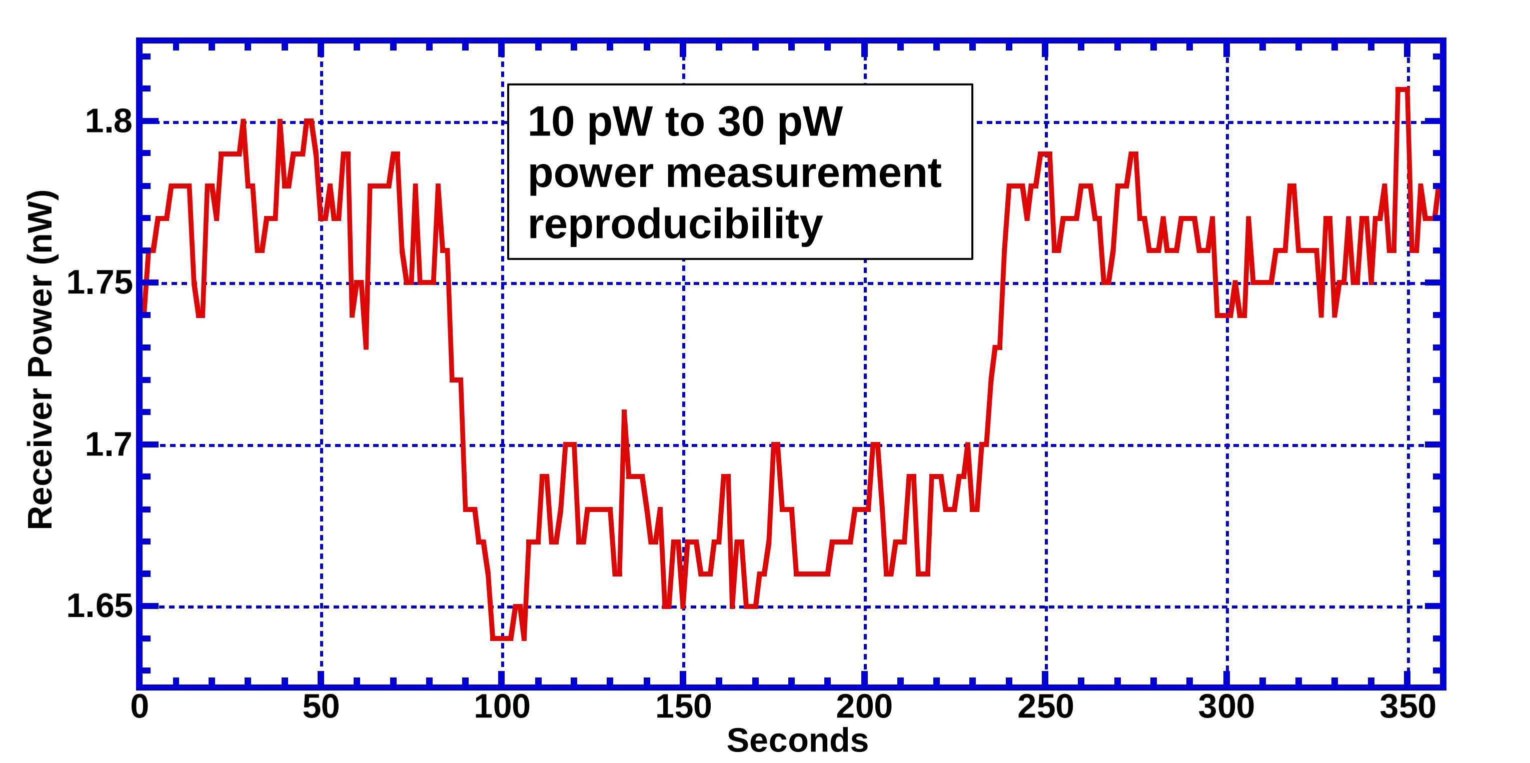
Receiver Power Measurement



Liquid He Cryostat at 2 K

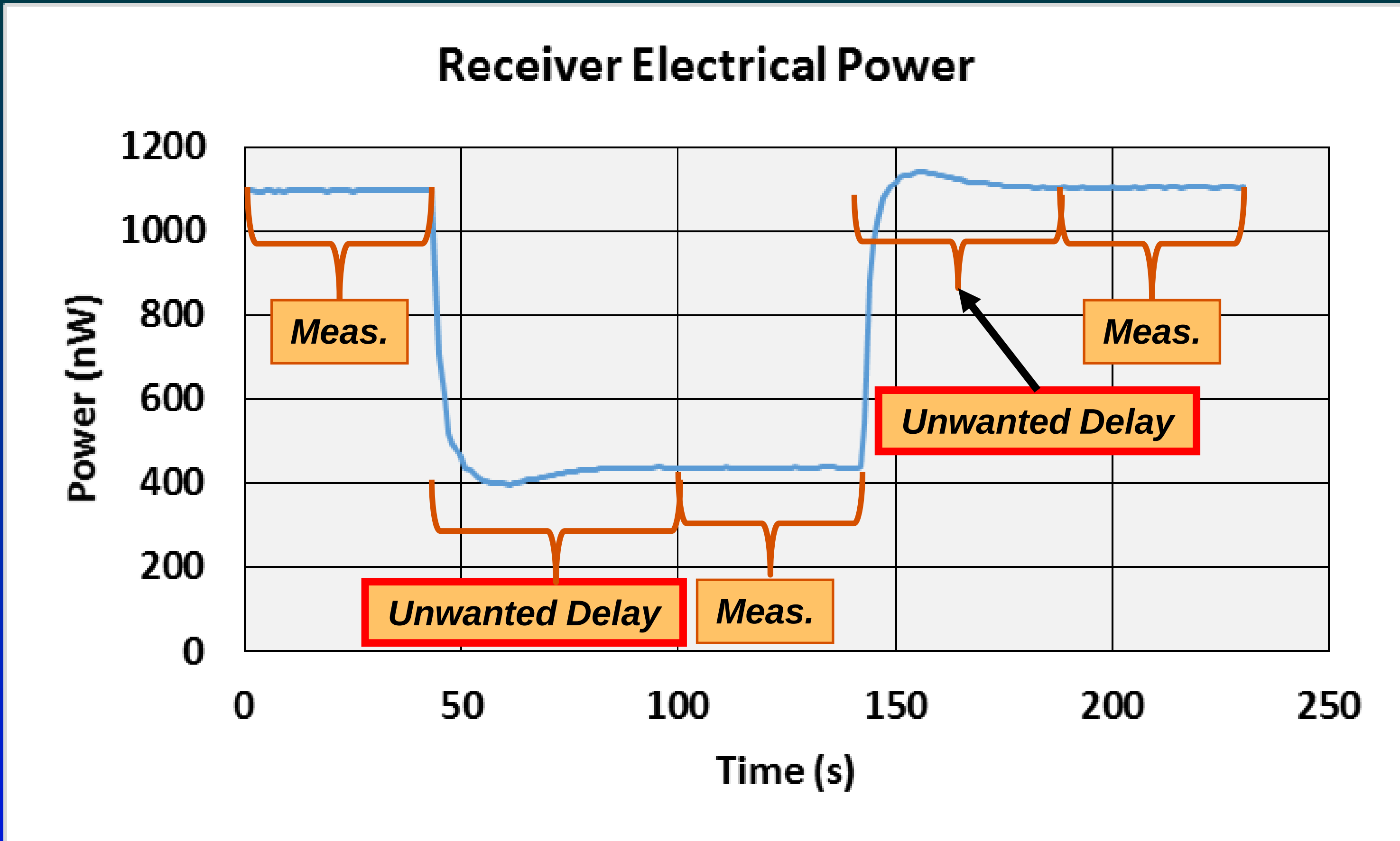
- *The temperature controllers must:*
  - ✓ *Measure temperature quickly (>10 Hz)*
  - ✓ *Control temperature precisely*
  - ✓ *Deliver high resolution and low noise heater power*
- *The volt meters that are used to measure power must be very accurate and have long term stability (~1 year).*
- *The COTS 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 .*

Goal #2: Reduce Measurement Time



- *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.*

"Standard" vs. COTS Control Electronics

Radiant Power Measurement Intercomparison

- *Blackbody radiant power measurements were made using both control systems under "identical" conditions.*
- *Relative Difference = (COTS – Standard)/Standard*

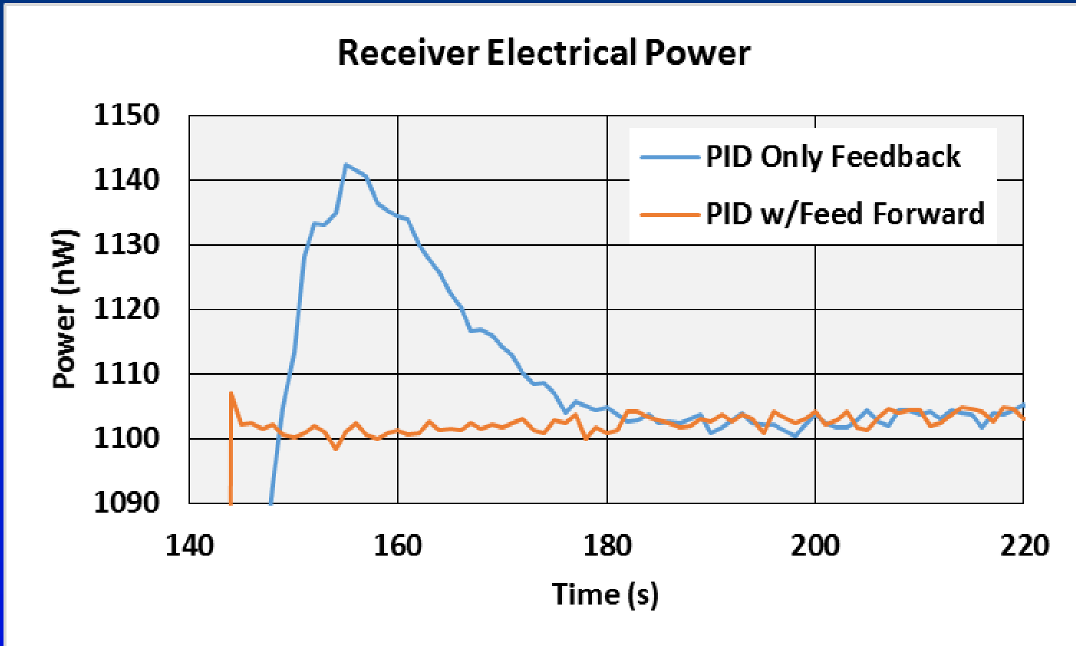
Power (nW)	Relative Difference (%)	Type A Uncertainty (%)
10.9189	0.1164%	0.1449%
777.7655	0.0011%	0.0117%
3092.5938	0.0007%	0.0017%

- *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.*



- *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.*

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