Development of Microwave Brightness Temperature Standards at NIST

Dave Walker, Jim Randa, Chriss Grosvenor,
Dazhen Gu, Katie MacReynolds, Amanda Cox,

Electromagnetics Division
NIST-Boulder

NOAA/NESDIS Workshop on Climate Data Records
from Satellite Microwave Radiometry, 22 Mar 10

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OUTLINE

- History and Background
- Previous Activities
- Current Activities
  - Standard Radiometer
    - Free space radiometric measurements
    - Identifying and quantifying error sources
  - Standard Target
    - Target characterization
    - Materials measurements
- Additional Capabilities

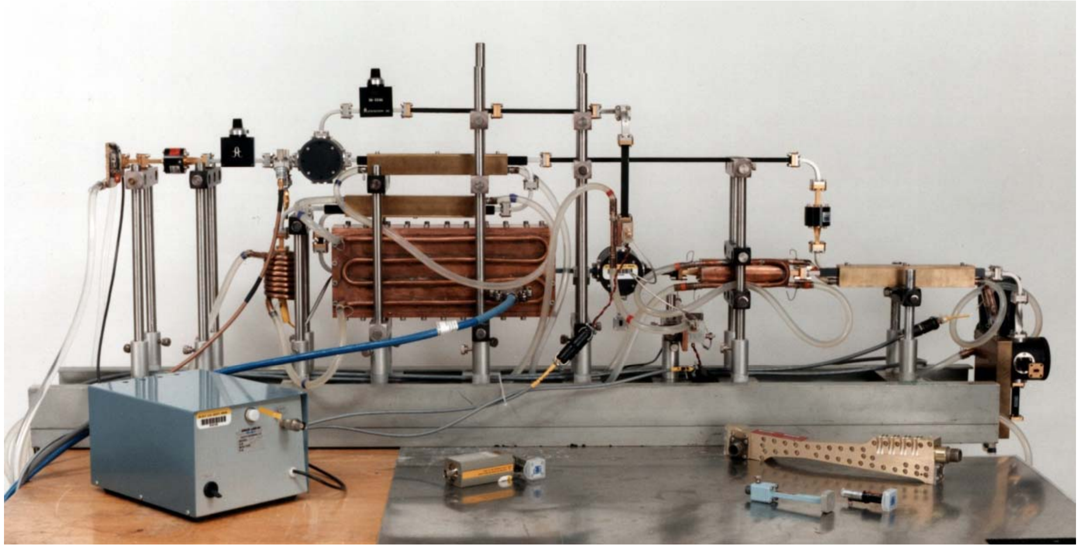
Traceability—Foundation for Accurate Measurements

Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

Based on the SI
(International System of Units)

NIST Noise Radiometers

- Coaxial radiometers: 30 MHz, 60 MHz, 1 – 18 GHz
  - N.B. Coaxial primary std. only up to 12.4 GHz
- Waveguide radiometers: 12.4 GHz – 18 GHz, 18 – 26.5, 26.5 – 40, 33 – 50, 50 – 65 GHz.
  - Each waveguide radiometer contains a full 6-port reflectometer & heterodyne receiver



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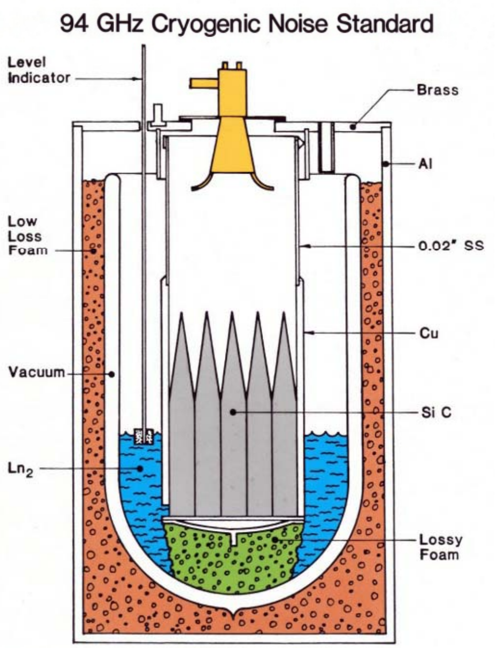
Thermal Noise Primary Standards

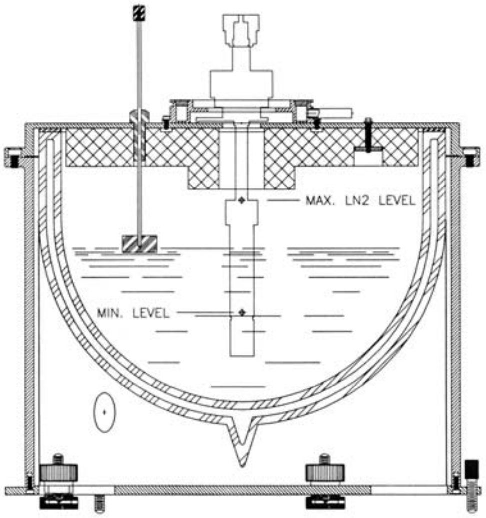
- Ambient & cryogenic (liquid nitrogen) standards.

$u_{TCry} \approx 0.65$ K

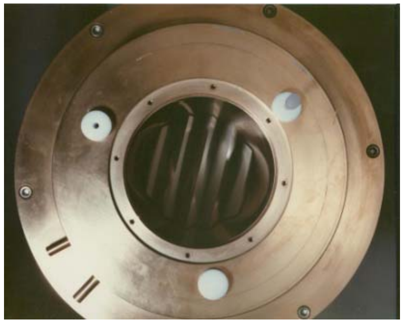
◄Coaxial

Waveguide►





$u_{TAmb} \approx 0.1$ K



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History

- Program to support microwave remote sensing initiated in 2001
  - Arose out of historical Microwave Thermal Noise Project with 30+ years' experience
  - Program ran until 2005, then canceled due to lack of funding
- Current program resurrected in June 2009
  - Funded through Congressional Climate Change Initiative
  - Essentially picked up where we left off

Previous Activities

- Concept for brightness temperature standard
  - Standard Radiometer
  - Standard Target
- Antenna Pattern Characterization
- Target Characterization
  - Absorber meas. in WR-90 (8-12.4 GHz) waveguide
  - Reflectivity measurements
  - Infrared imaging

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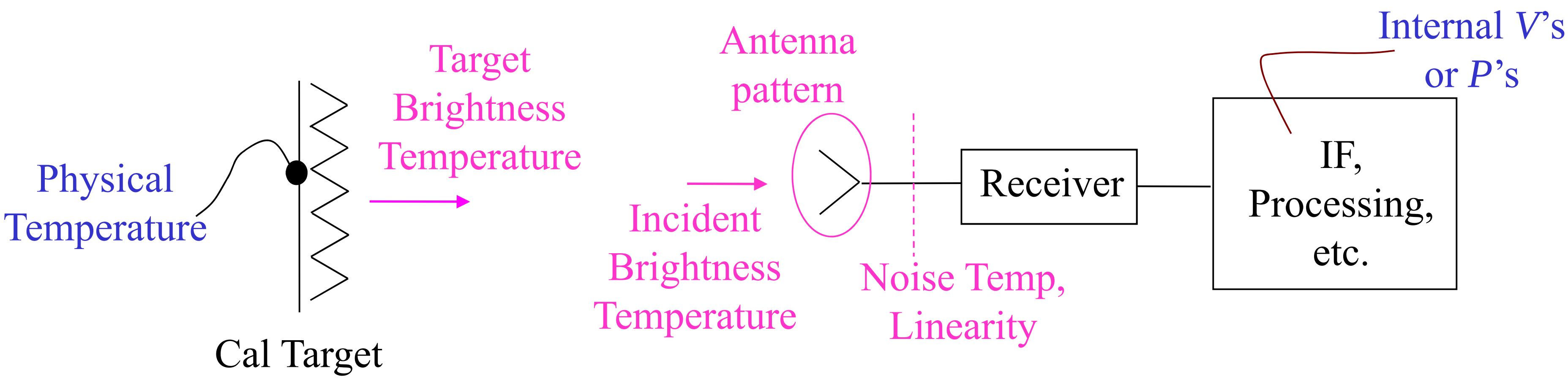
Previous Activities (cont'd)

- Near-ambient noise T measurements
- Radiometer free space measurements
- Modeling of target proximity effects
- Detector nonlinearity
- Standard Terminology Project
- Measurement of noise diode calibration sources for Aquarius instrument

Microwave Remote-Sensing Metrology

- Important question: what quantity is traceable?



- Want as much as possible included.
- Complications:
  – conditions & environment
  – absolute vs. relative “accuracy” (uncertainty)

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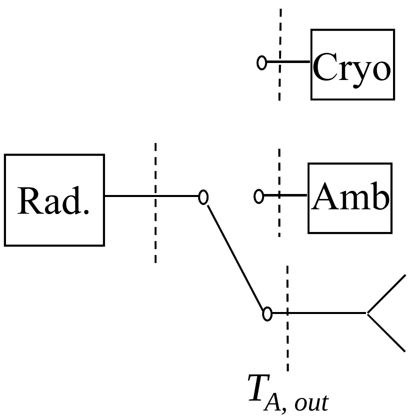
Brightness Temperature:

Framework for standard radiometers



$$T_{A,in} = \eta_M \overline{T_{ML}} + (1-\eta_M)\overline{T_{SL}}$$

$$\eta_M = \frac{\int_{main} F_n(\theta,\phi)d\Omega}{\int_{4\pi} F_n(\theta,\phi)d\Omega}$$

$$\overline{T_{ML}} = \frac{\int_{main} T_B(\theta,\phi)F_n(\theta,\phi)d\Omega}{\int_{main} F_n(\theta,\phi)d\Omega}$$

$$\overline{T_{SL}} = \frac{\int_{other} T_B(\theta,\phi)F_n(\theta,\phi)d\Omega}{\int_{other} F_n(\theta,\phi)d\Omega} \quad .$$

$$T_{A,out} = \alpha T_{A,in} + (1-\alpha)T_a$$

$$\alpha \approx 1/L$$

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Uncertainties

$$\overline{T_{ML}} = T_a + \frac{1}{\alpha \eta_M}\left(T_{A,out} - T_a\right)$$

T_a : ~ 0.2 K
$T_{A,\,out}$: ~ 0.3 – 0.5 K
α : ~ 0.5 %
η_M : ??

If $u_\eta \sim u_\alpha$, then at 20 GHz the uncertainty in $\overline{T_{ML}}$ is 0.3 K – 0.8 K for T_B between 200 K & 300 K.

So, plan to develop standard radio-meters for 18 – 26 GHz, 26.5 – 40 GHz, & 50 – 65 GHz.

Millimeter Wave Planar Near-field Range

Frequency Range - 1 to 75 GHz
currently expanding to 110 GHz

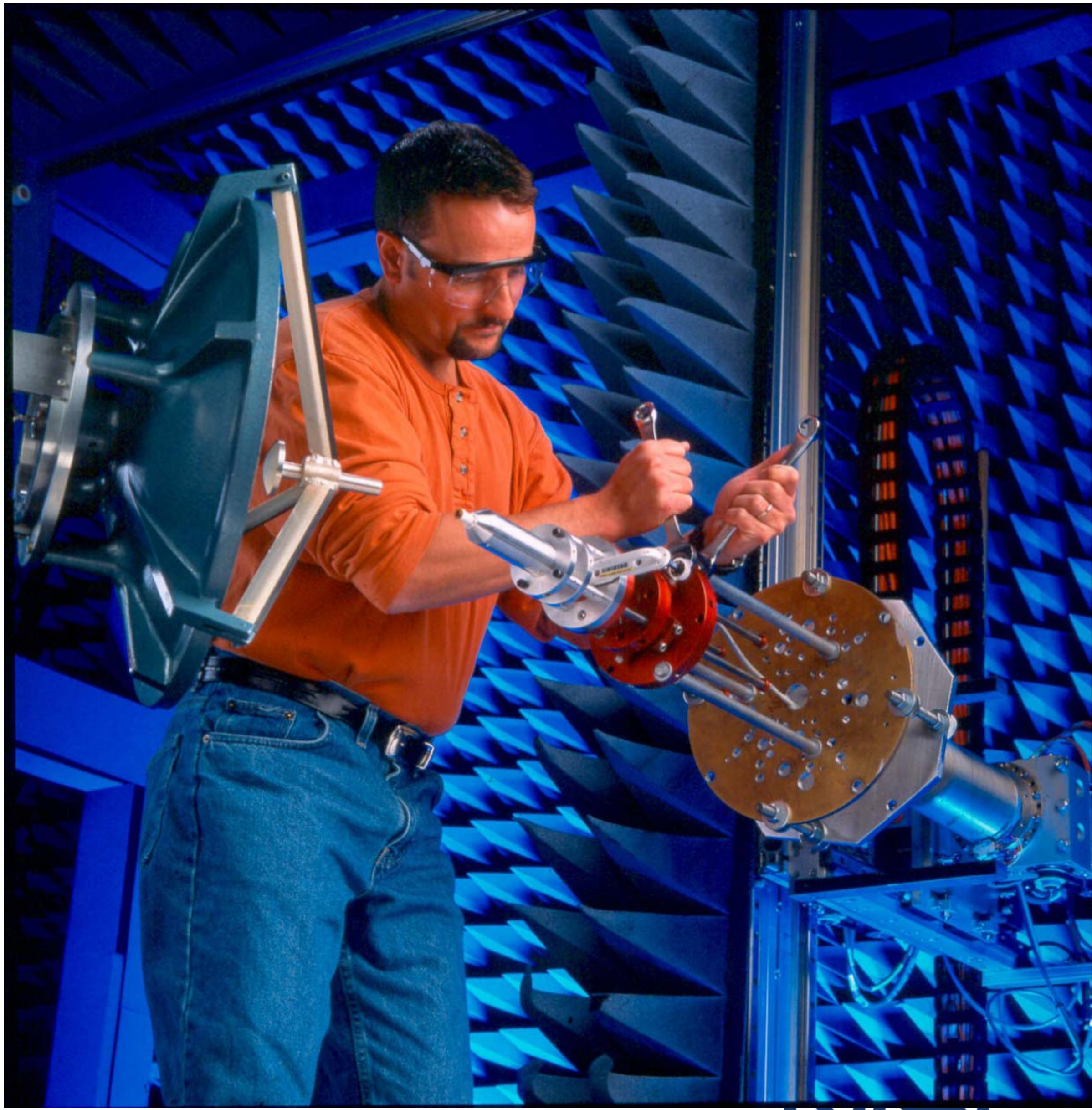
(Could be up graded to 220+ GHz Using NIST probe position error correction software and RF Equipment)

Typical Uncertainties:

1 - 26 GHz
gain ± 0.20 dB
patterns ± 0.05 dB/dB to -40 dB

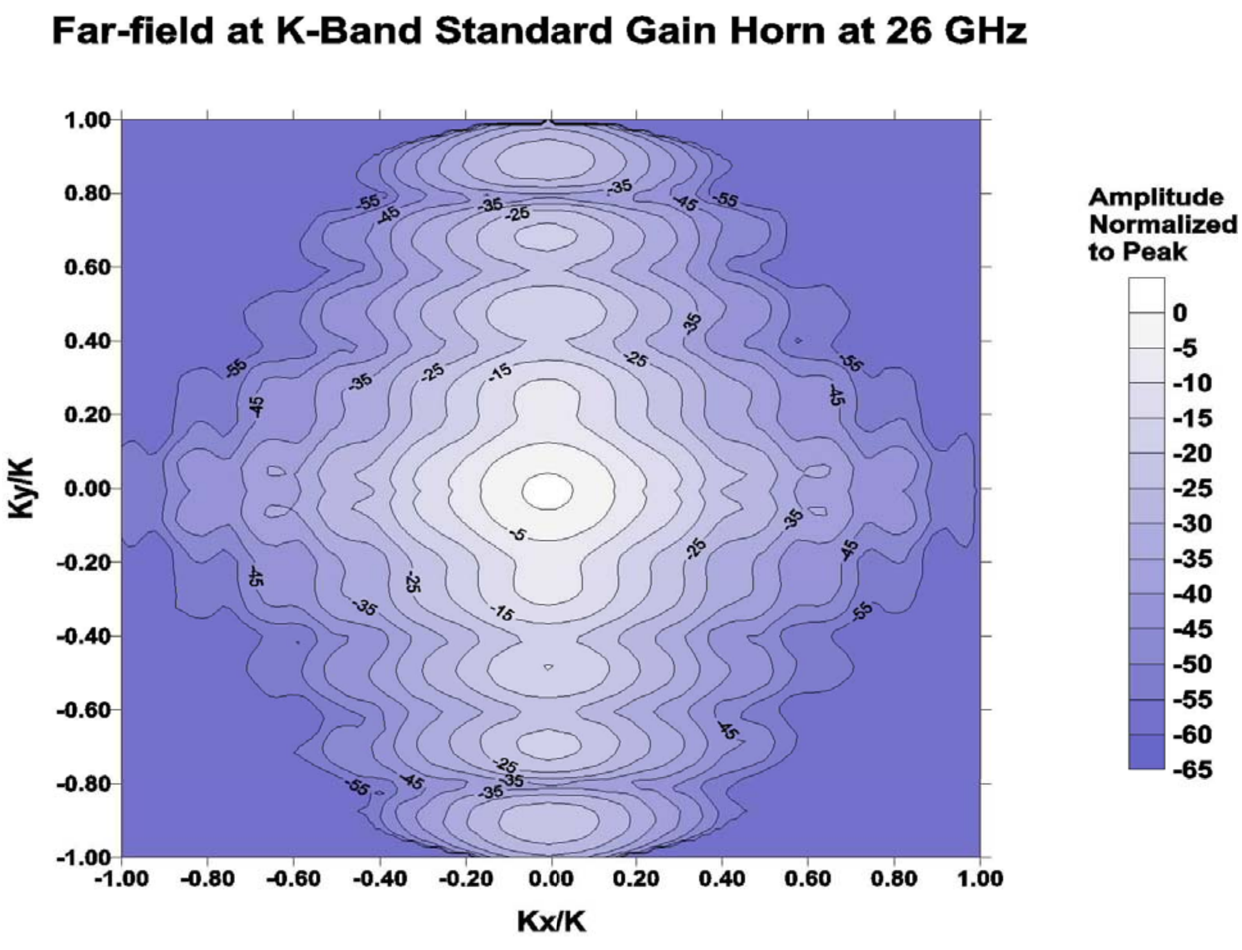
26 - 50 GHz
gain ± 0.25 dB
patterns ± 0.07 dB/dB to -40 dB

50 - 75 GHz
gain ± 0.30 dB
patterns ± 0.10 dB/dB to -40 dB



WR-42 Standard gain horn

Measured antenna pattern for a standard-gain horn (SGH) on the near-field range.



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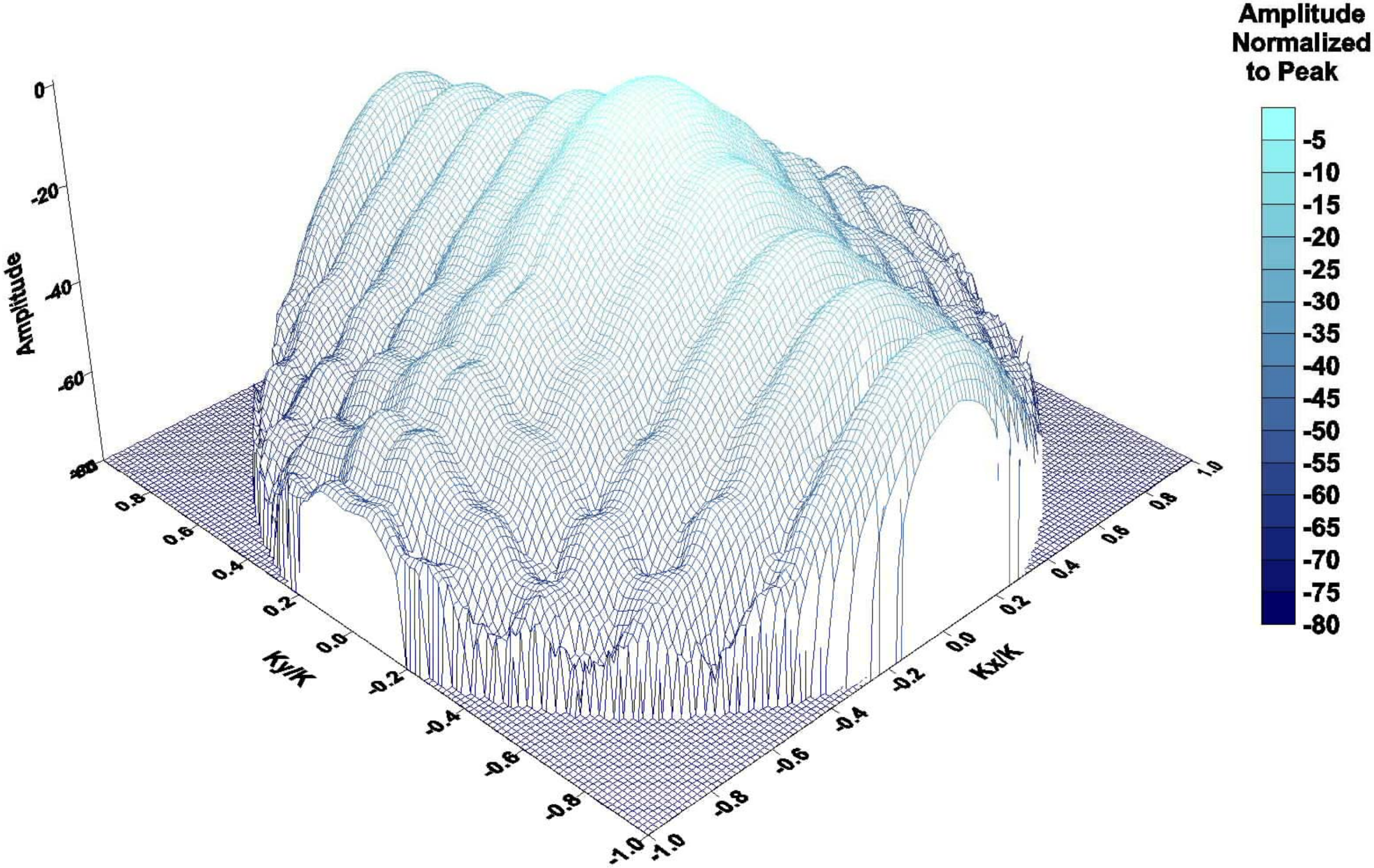
Far-field at K-Band Standard Gain Horn at 26 GHz



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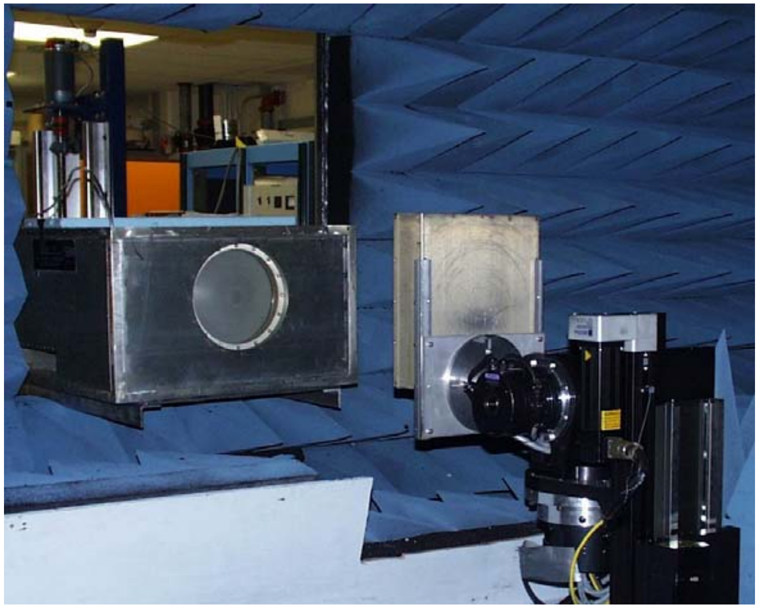
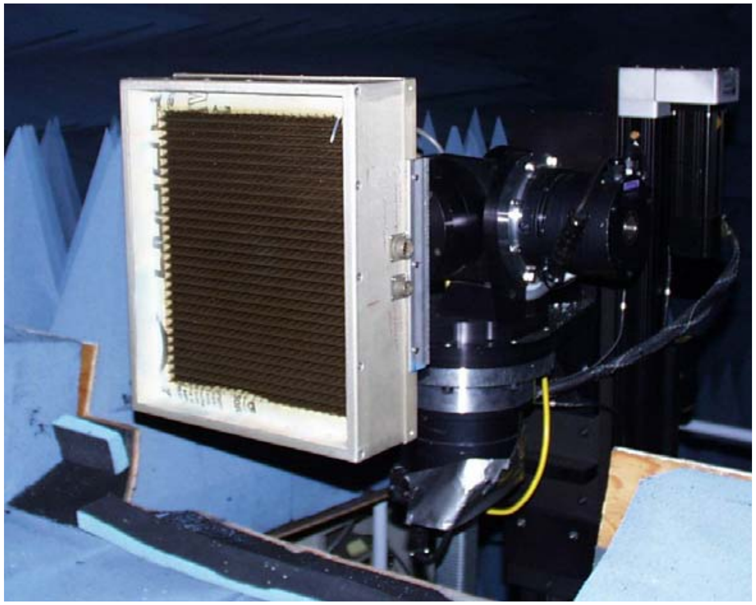
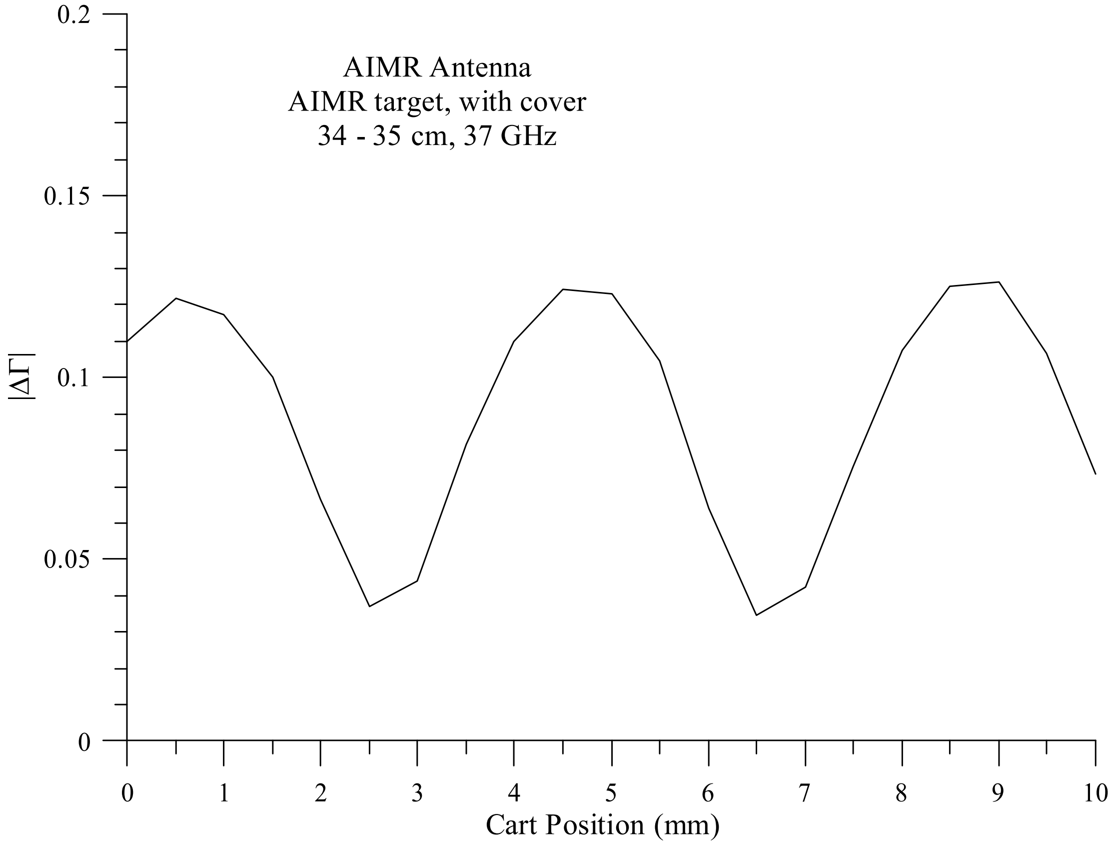
Target reflectivity effects







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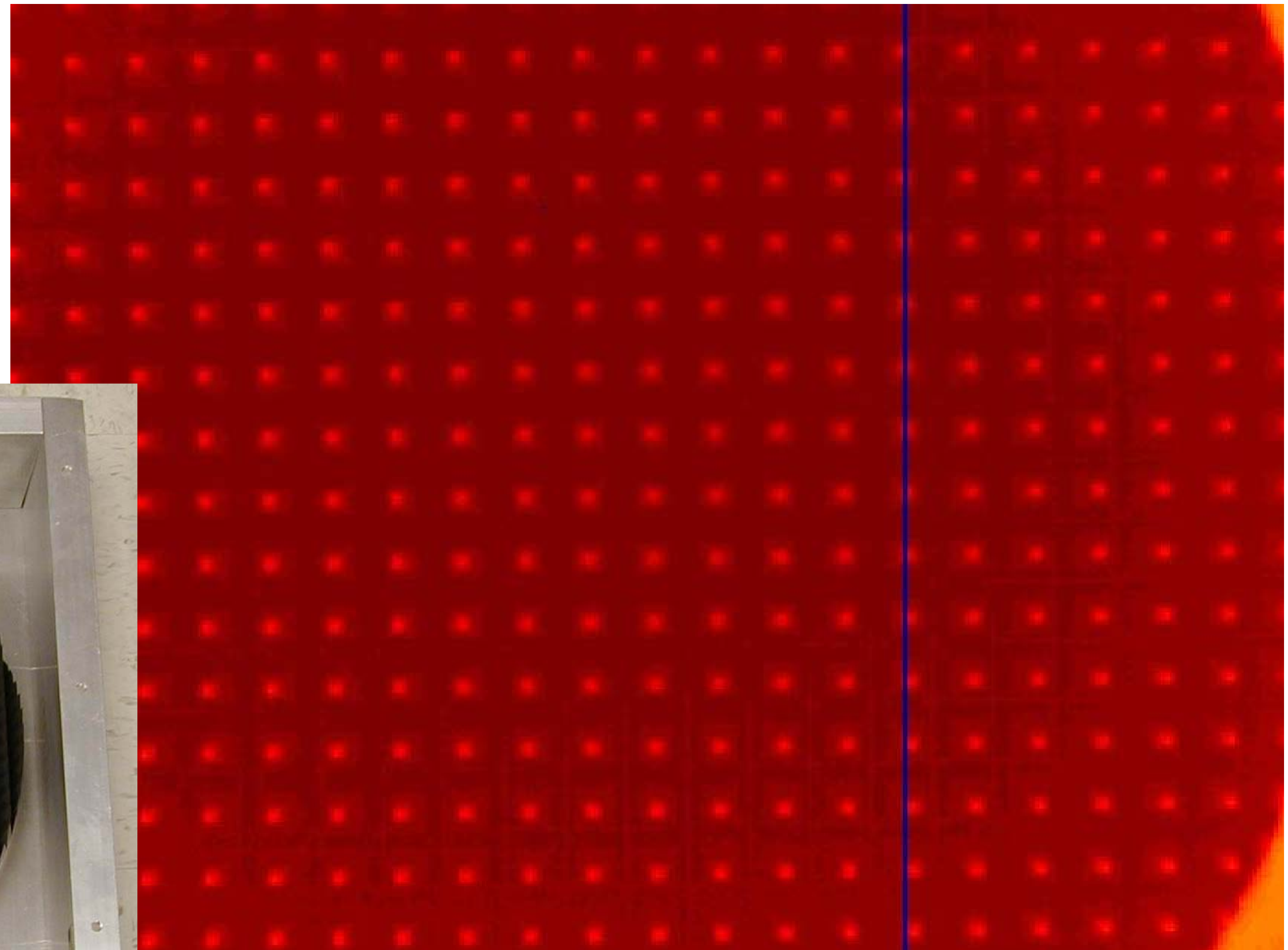
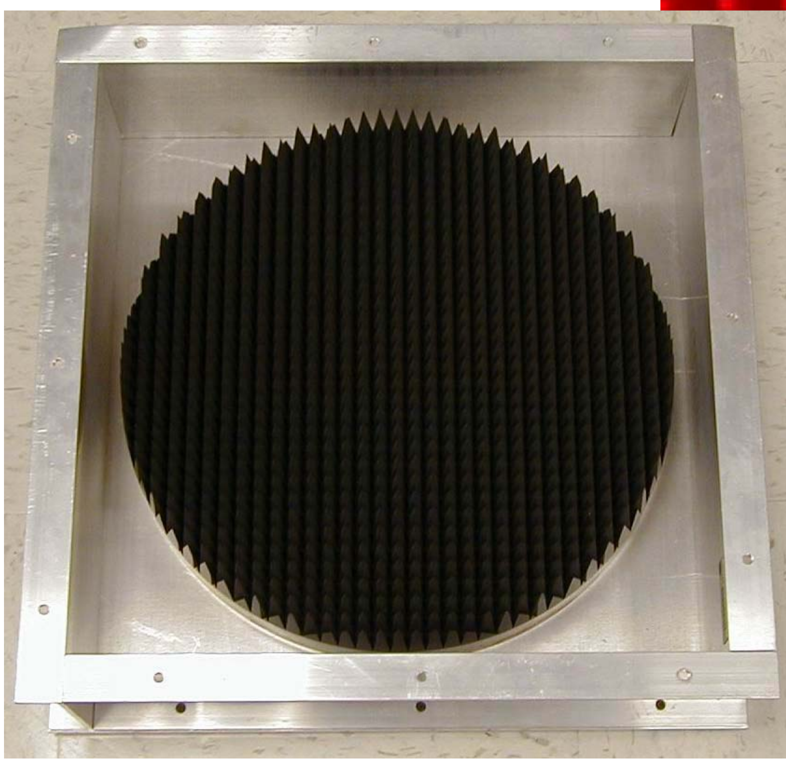
IR Thermal Image of Target





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Noise Temperature Measurements Near Ambient

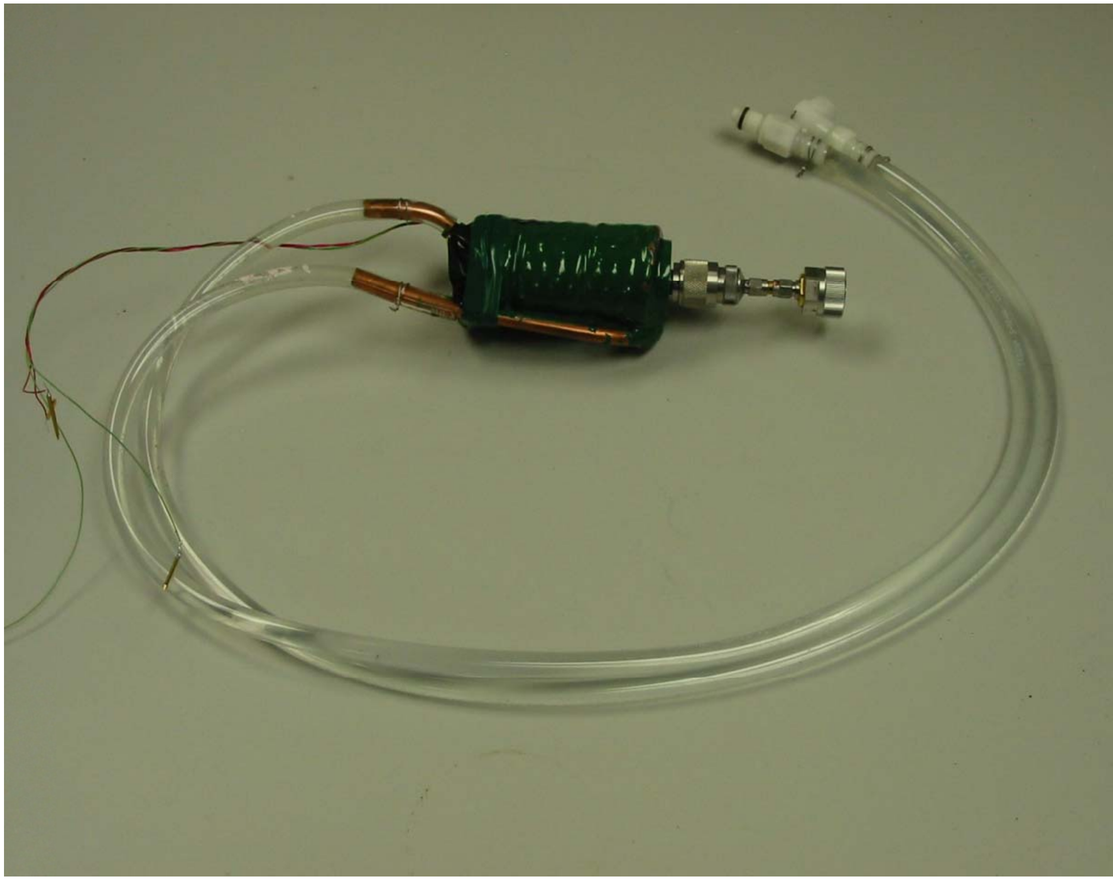
Don’t normally measure near ambient.

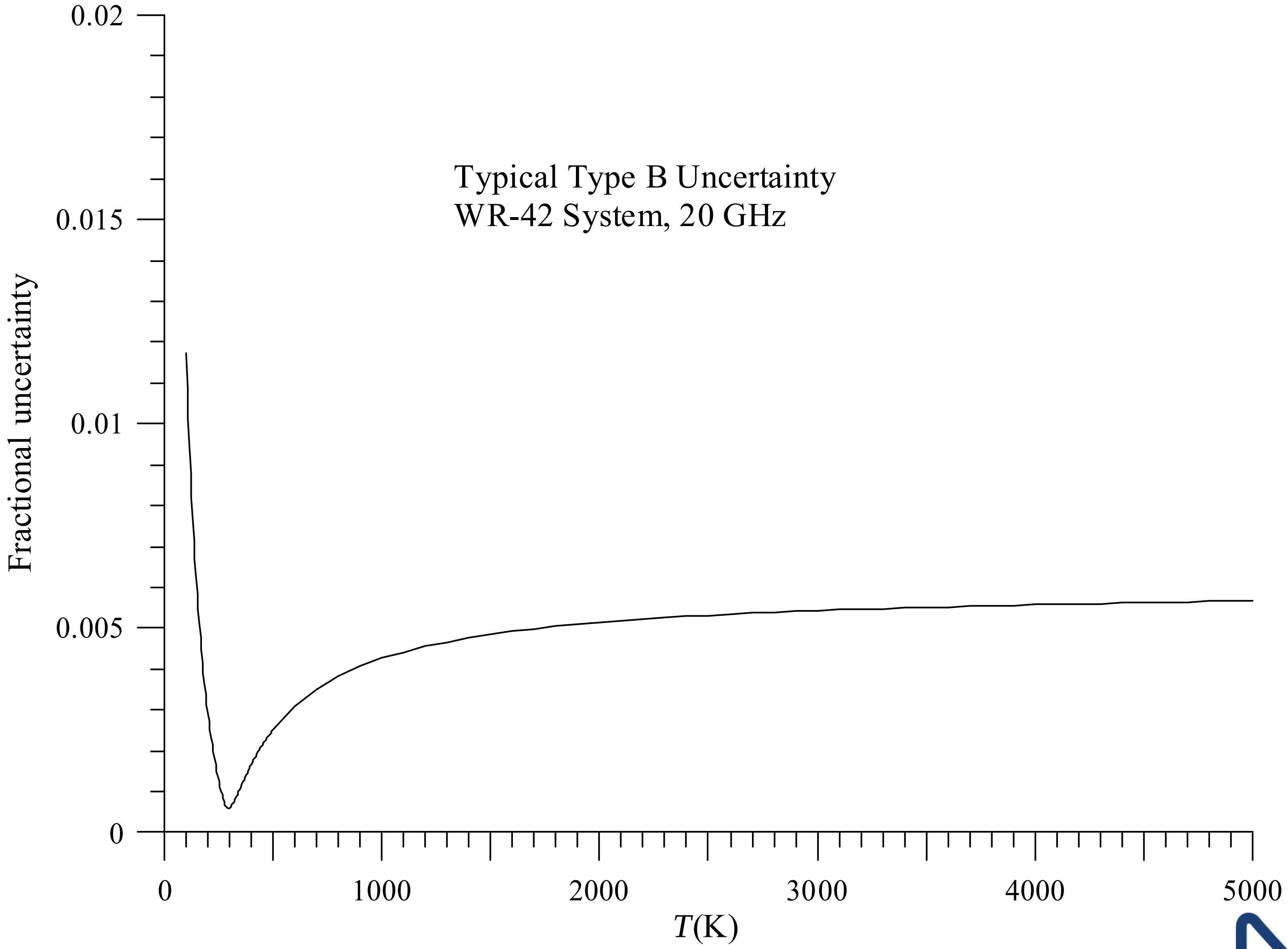
Check of uncertainty near ambient:

- Designed & built variable source with known noise temperature.

- Measured it.

- Tests entire system (except antenna)





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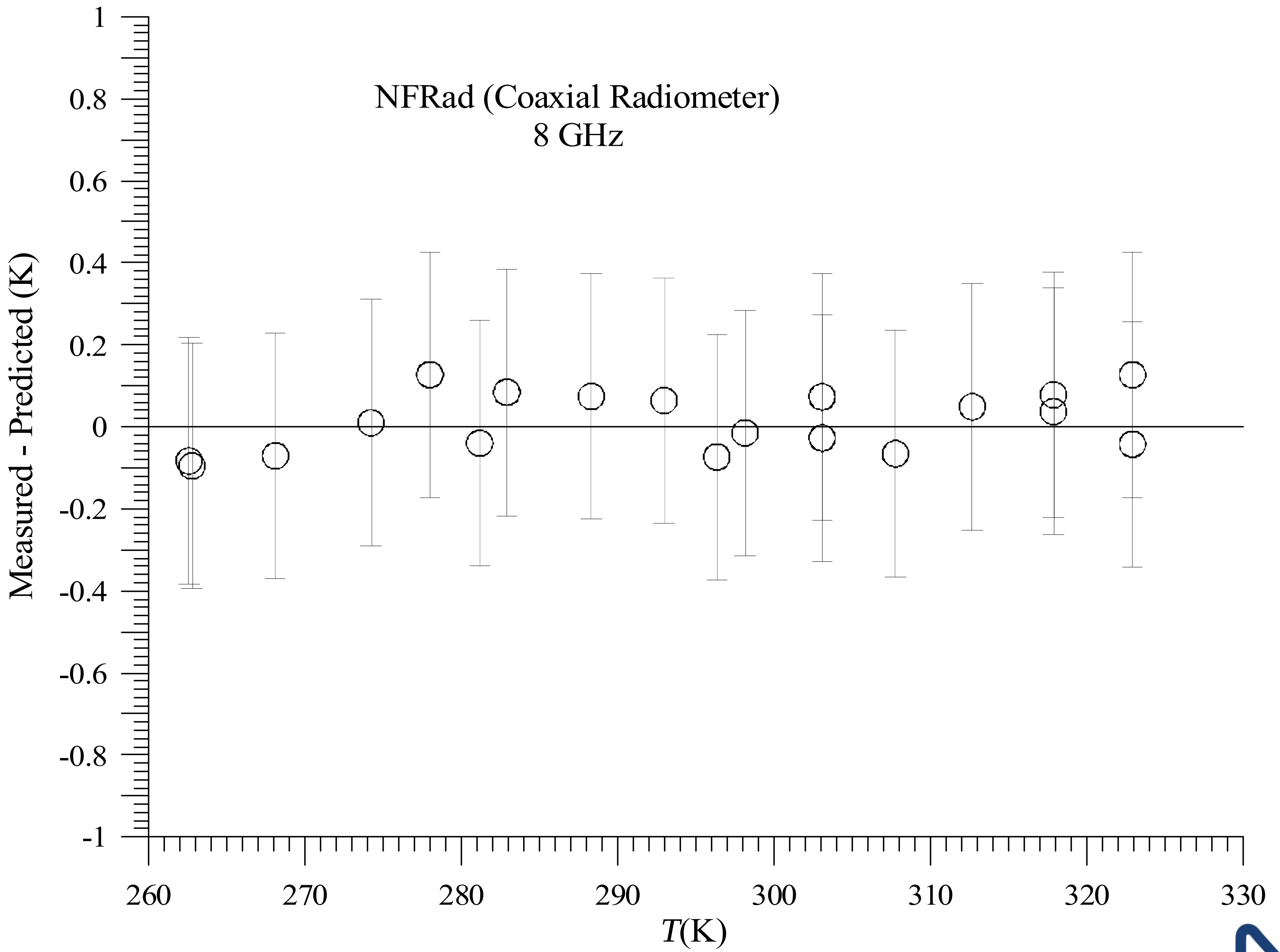
Noise measurements near ambient



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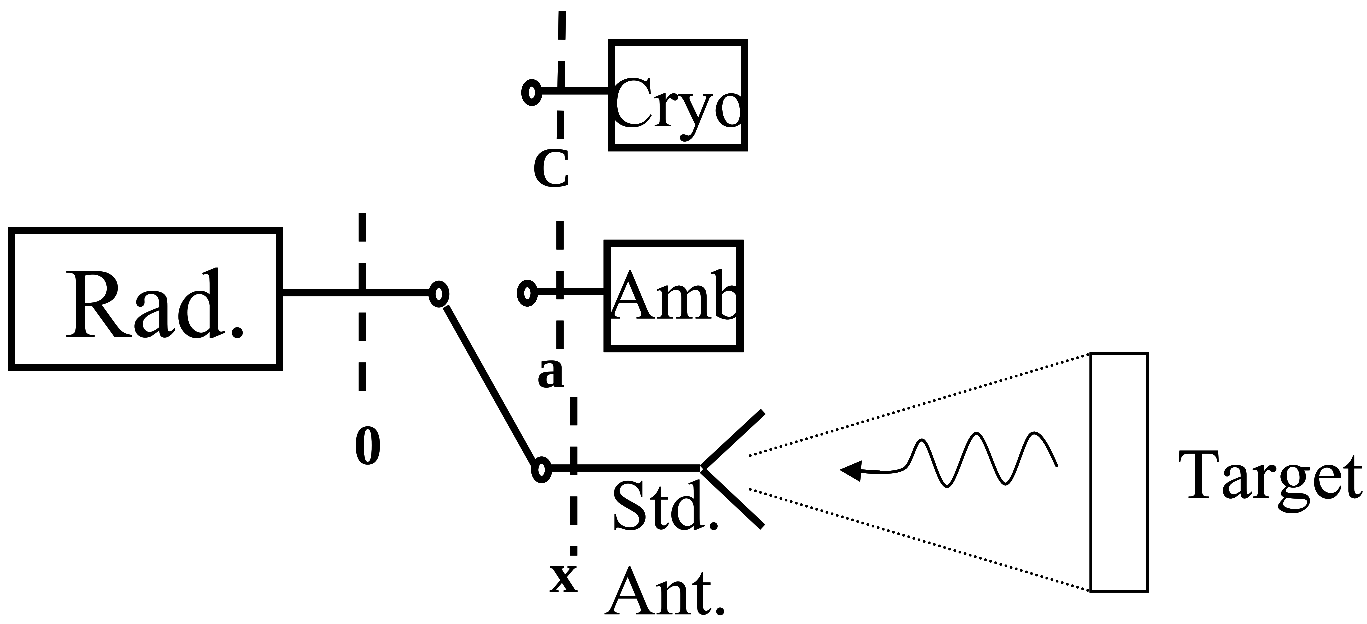
Radiometric Target Measurement

--Use existing NIST radiometer linked to primary noise standards:



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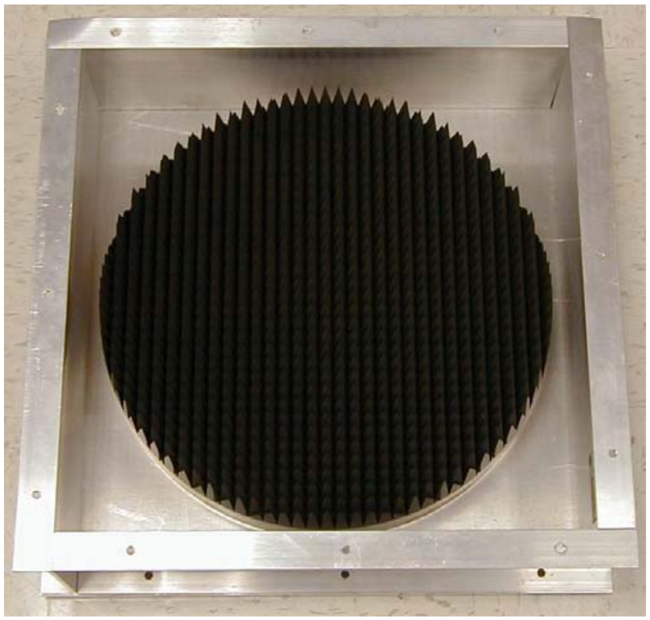
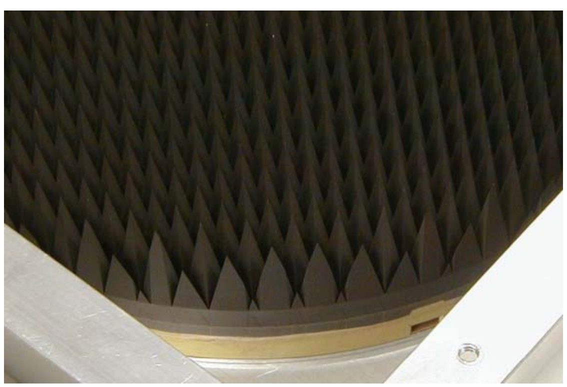
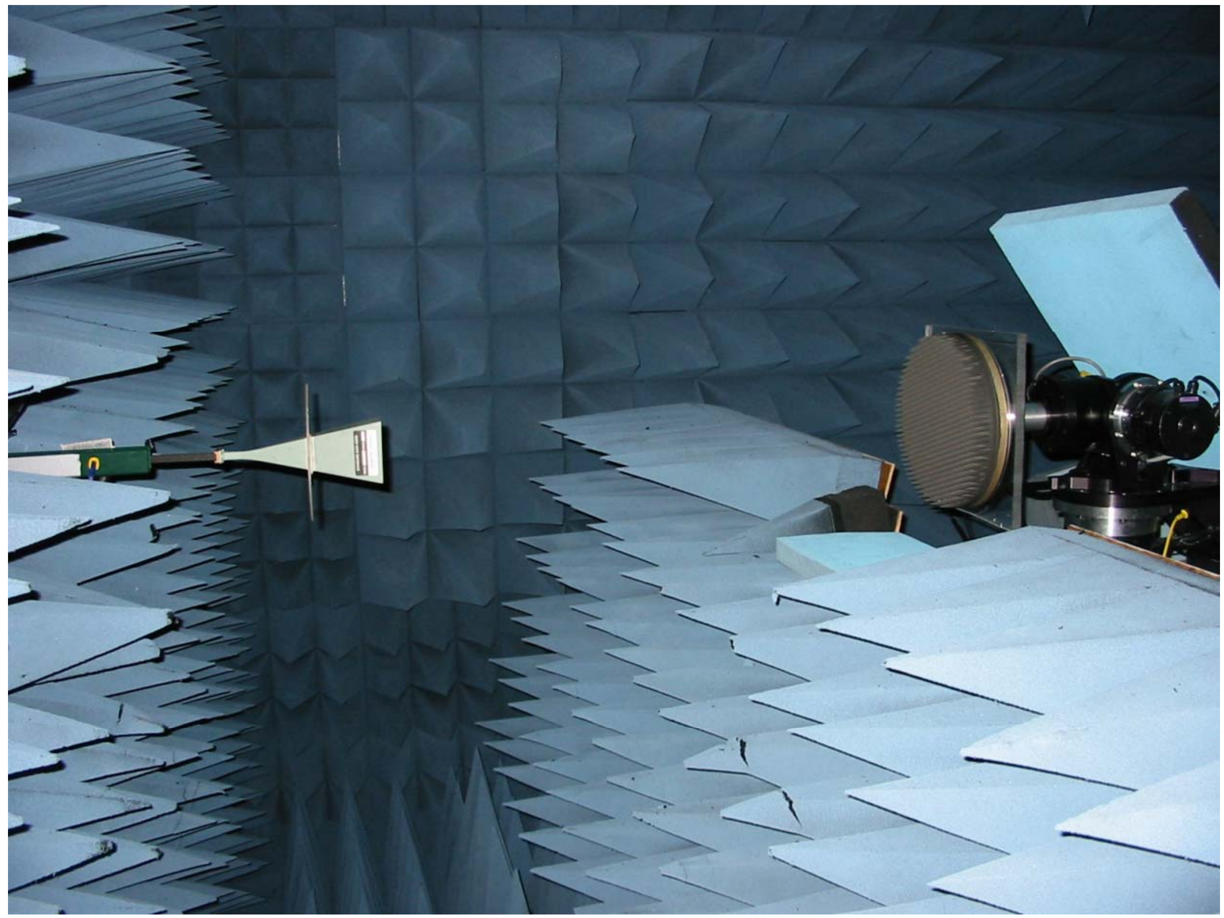
Standard radiometer with typical cal target

(NASA GSFC “Cryo” target shown)







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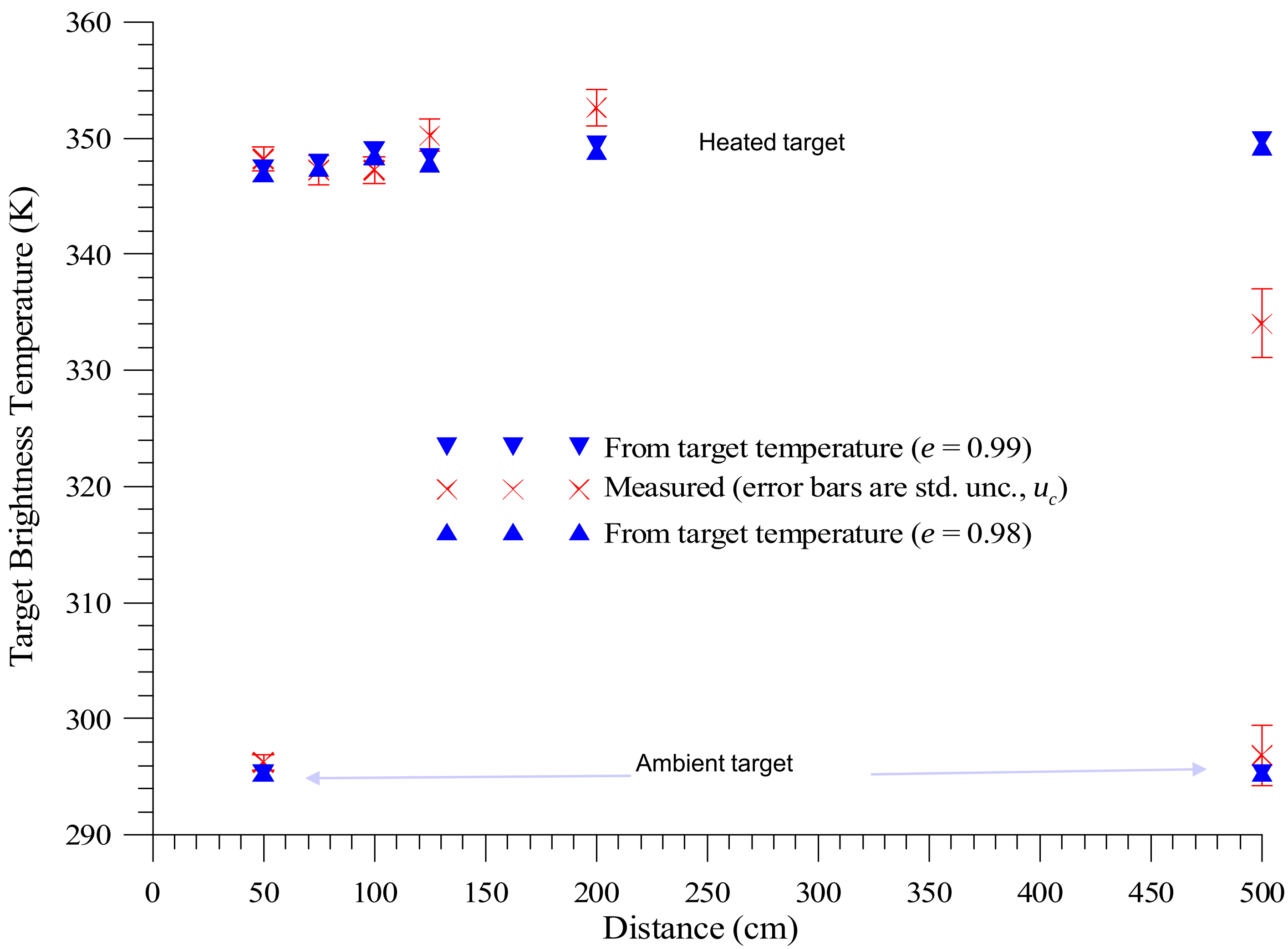
Radiometric Target Measurement
(NOAA GSR target)



Measured & predicted brightness temperatures vs. separation distance.

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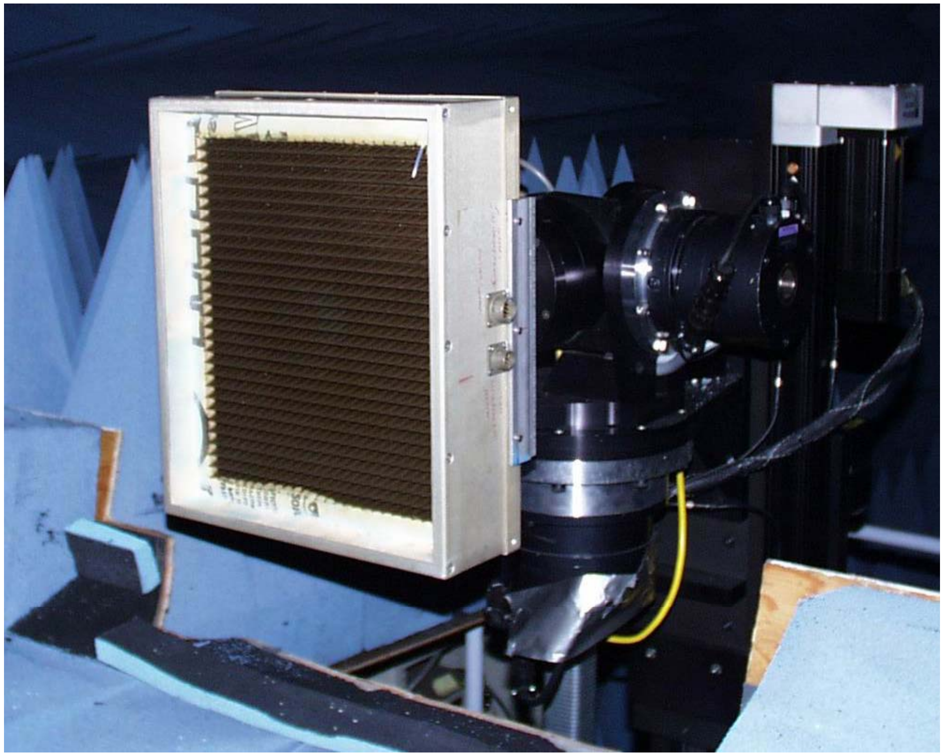
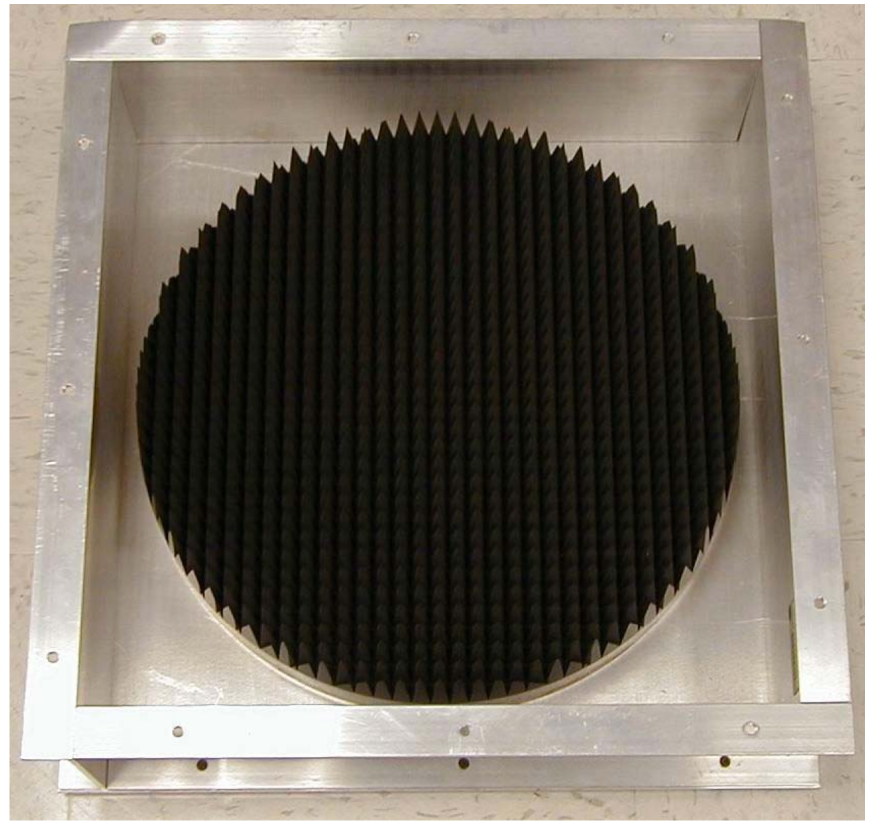
Alternative: Standard Target



AIMR Target

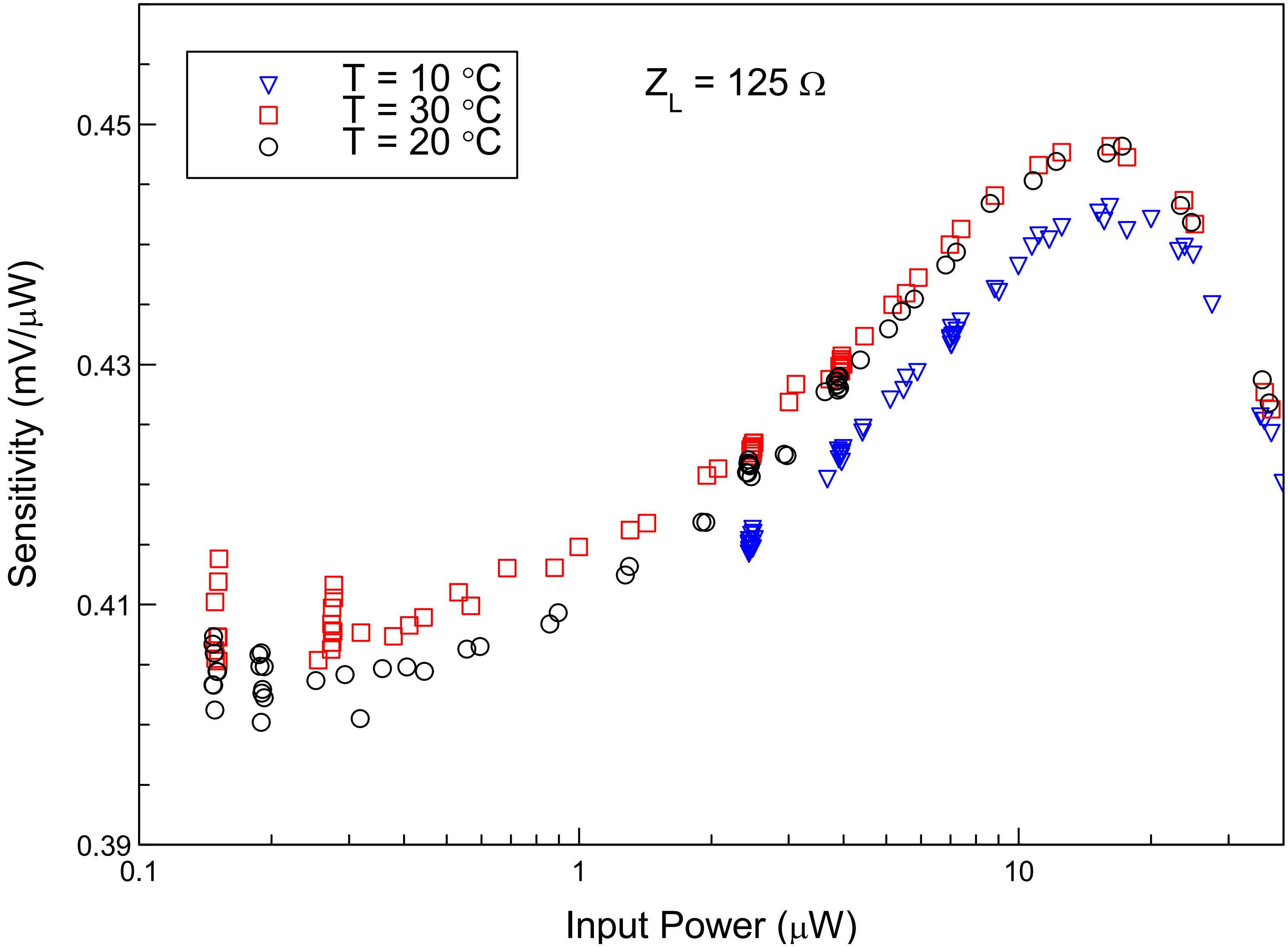


GSFC “Cryo” Target

Proposed Combined Standard Radiometer and Target

- Independent realizations of T_B
- Independent, full uncertainty analyses
- Combined (full) standard would be a weighted average of the two
  - Possible $\sqrt{2}$ uncertainty improvement vs. single std.
- Transfering the T_B standard would involve either:
  - A second (portable) target calibrated with the full standard
  - Measuring a customer’s target or radiometer at NIST with the full standard

Detector nonlinearity study



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Standard terminology for microwave radiometry (a.k.a. “Dictionary Project”)

Developed in cooperation with CEOS WGCV (Working Group on Cal-Val)

Link (including all relevant publications) at:

http://www.nist.gov/eeel/electromagnetics/rf_electronics/noise_project.cfm

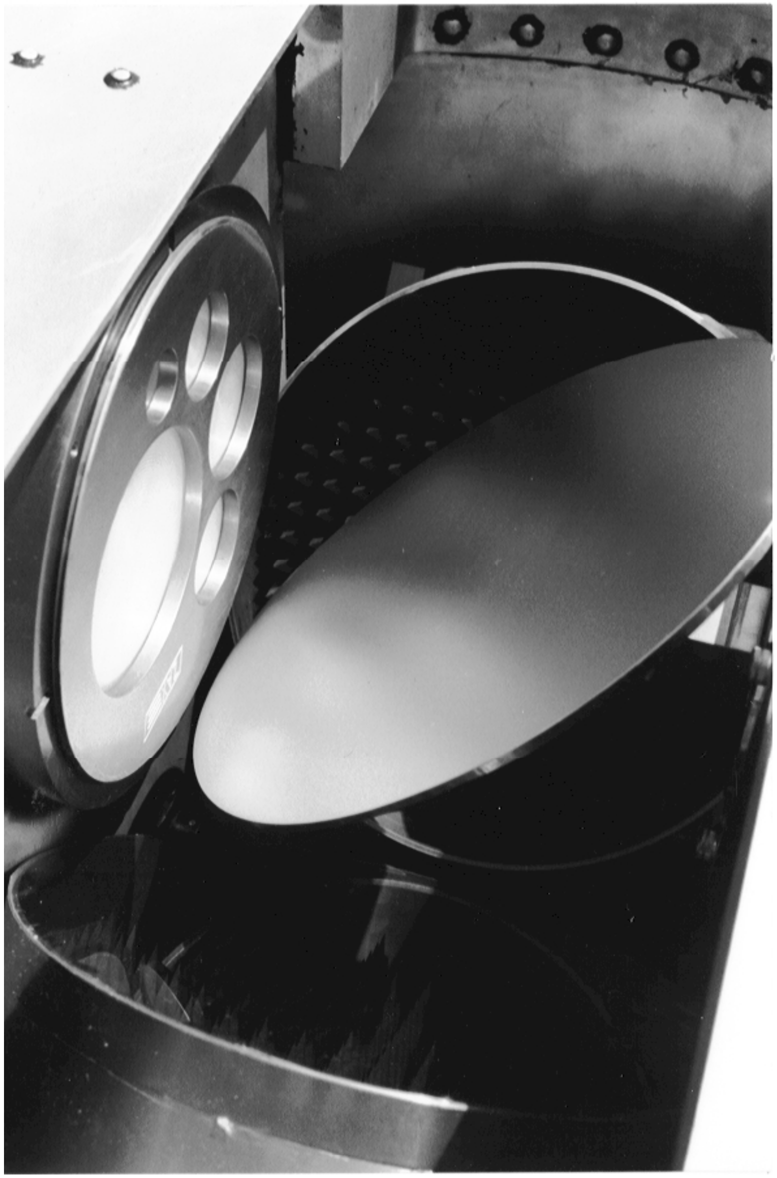
Current Activities

- Reflectivity Measurements
  - 2 horns, 3 targets, 2 temperatures
  - Additional absorber materials
- Expanded Radiometer Free-Space Measurements
  - Additional horns and targets
  - Better alignment (fixturing and surveyor's transit)

Current Activities

- Absorber measurements in waveguide
  - Three WG bands (WR -90, 62, 42)
  - Fixturing up to WR-10
  - Five concentrations of ferrous-doped epoxy (machinable)
  - Plans for measuring castable material
- Free-space absorber measurements
  - Multiple absorber samples
- Ensemble detection experiments with GSFC

MIR Calibration Targets (Courtesy P. Racette, GSFC)



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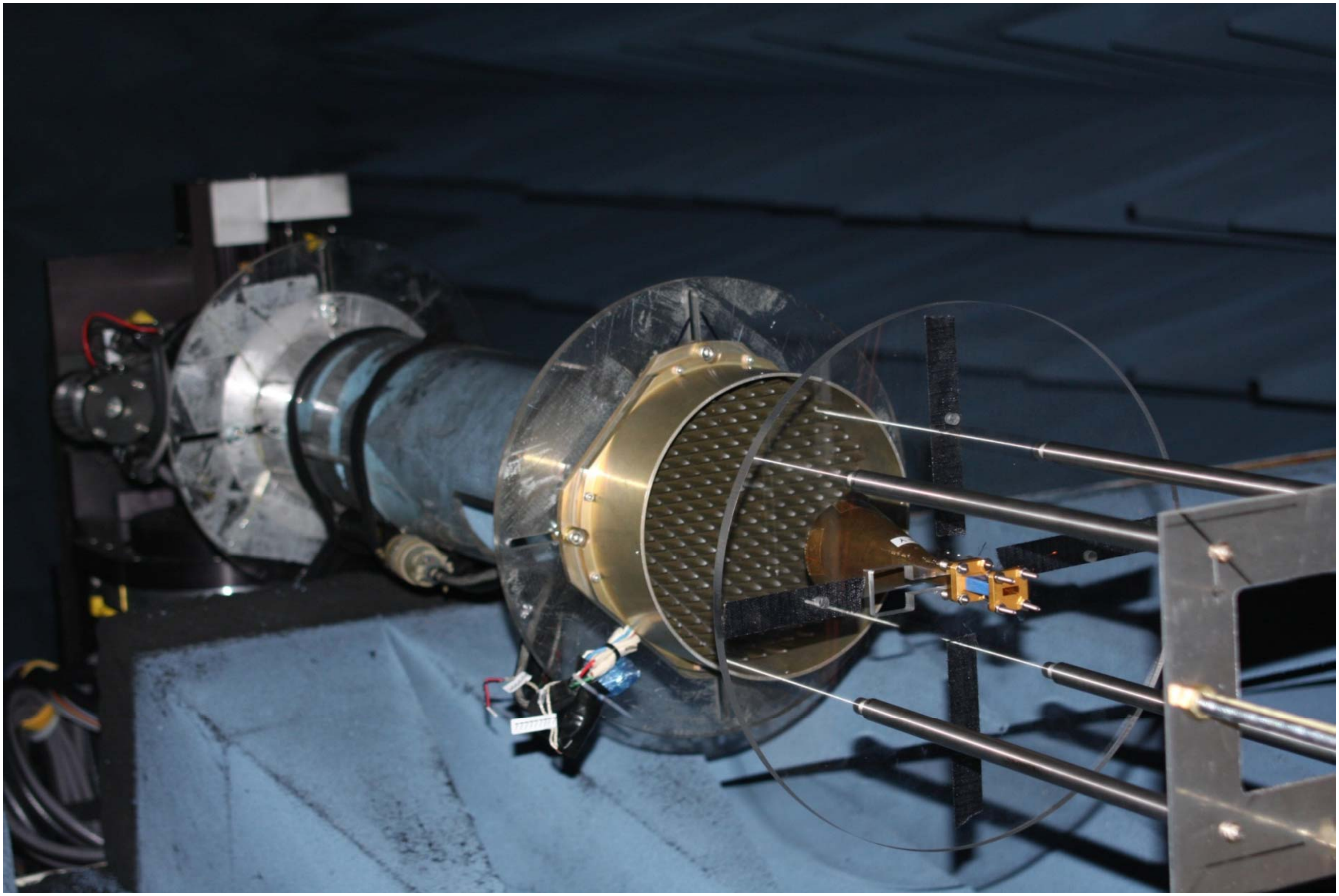
Radiometer / Reflectivity Measurements



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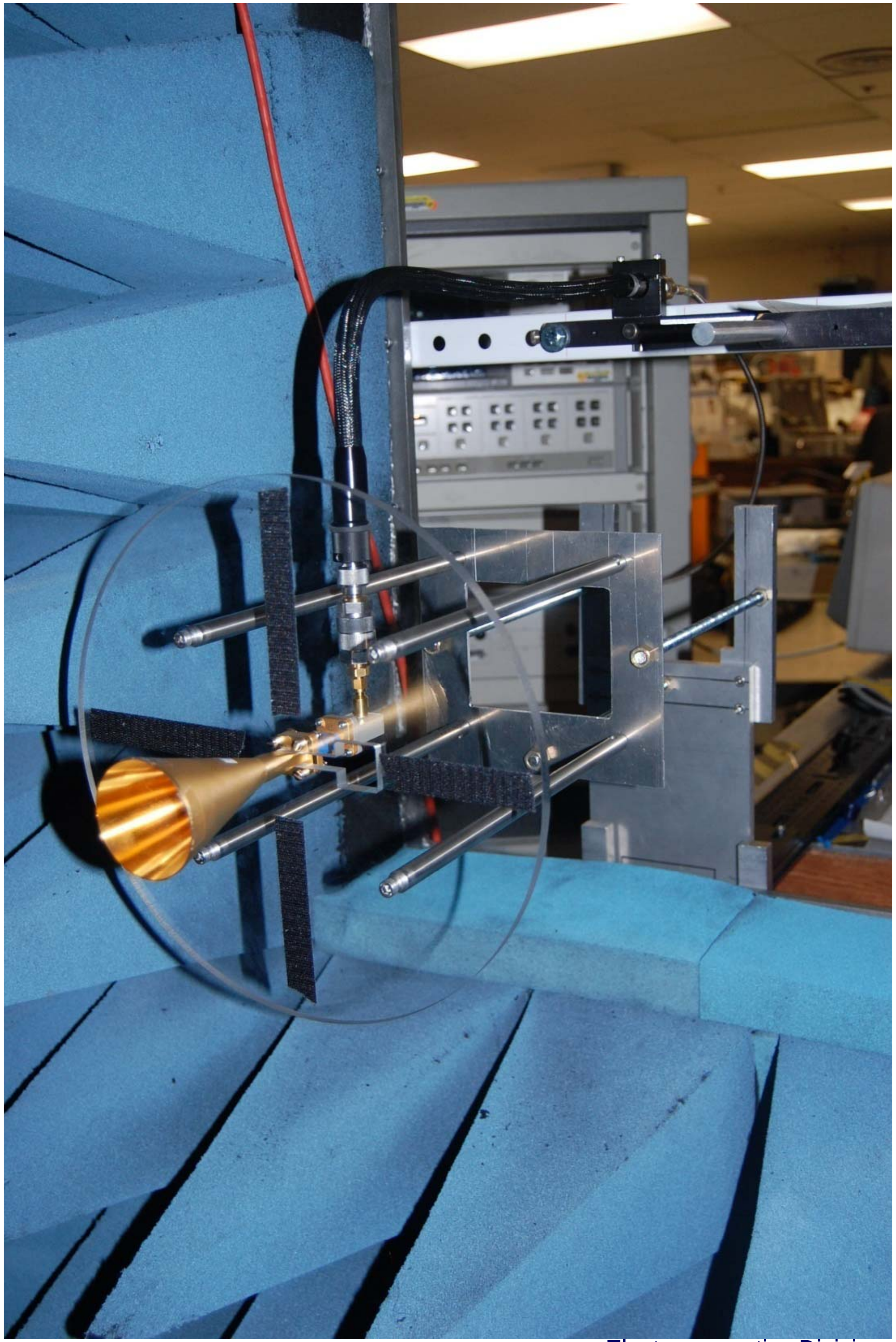
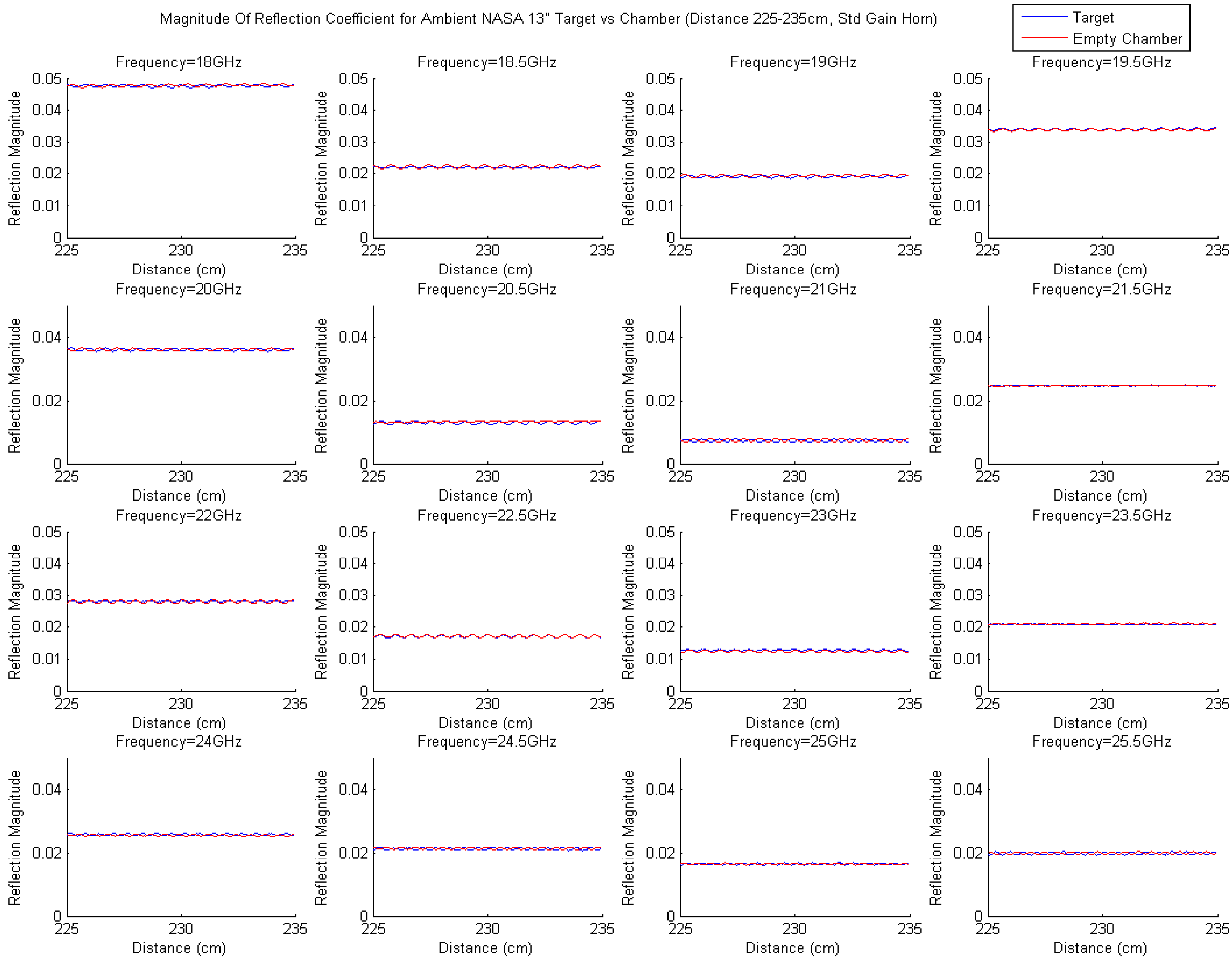
Reflectivity Measurements

- Conical and Pyramidal Standard Gain Horns
- Vector Network Analyzer
- Multiple Horn-to-target distances
- Ambient & heated
- Next: full emissivity

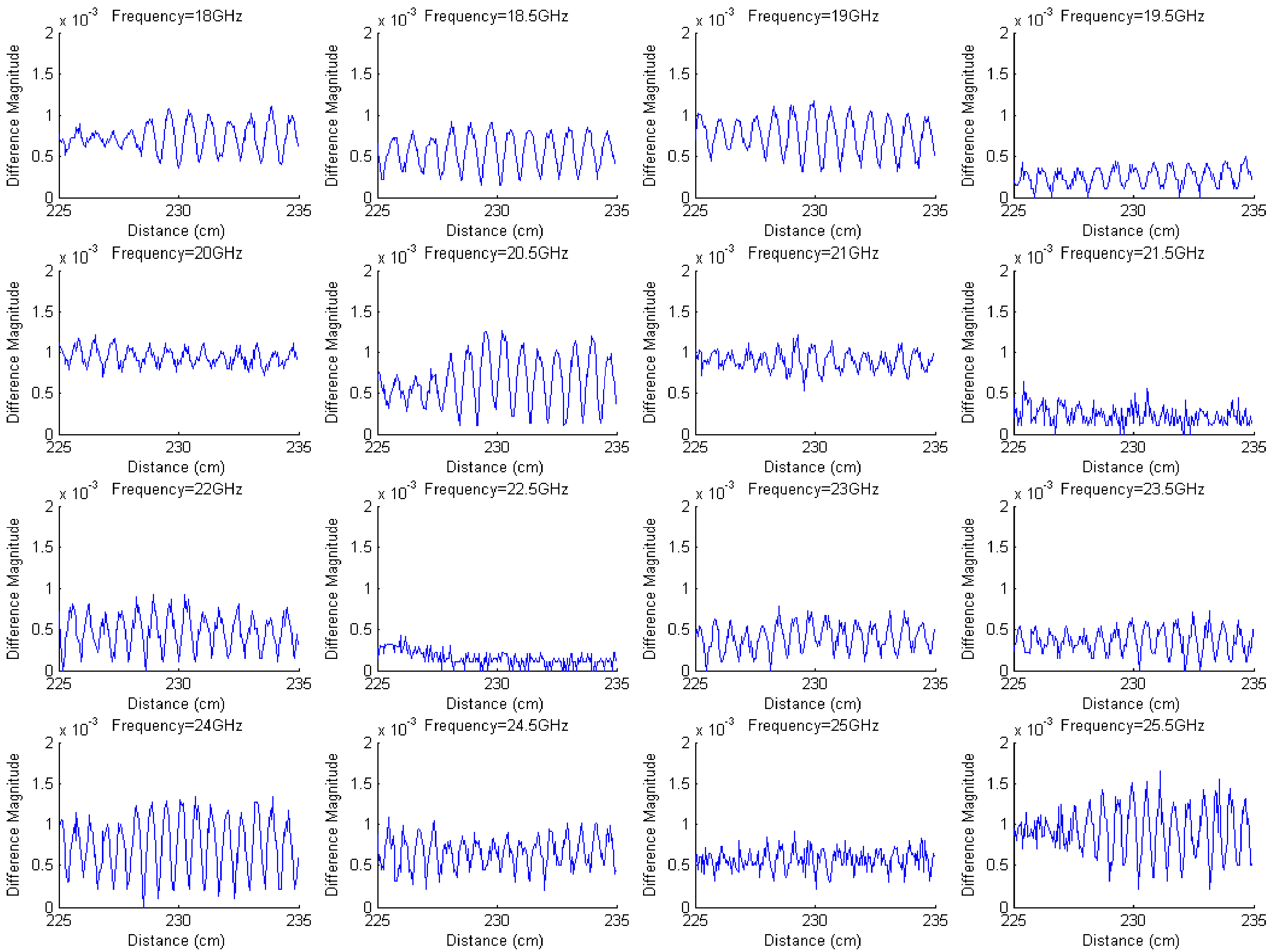


GSFC “Cryo” target |Γ|

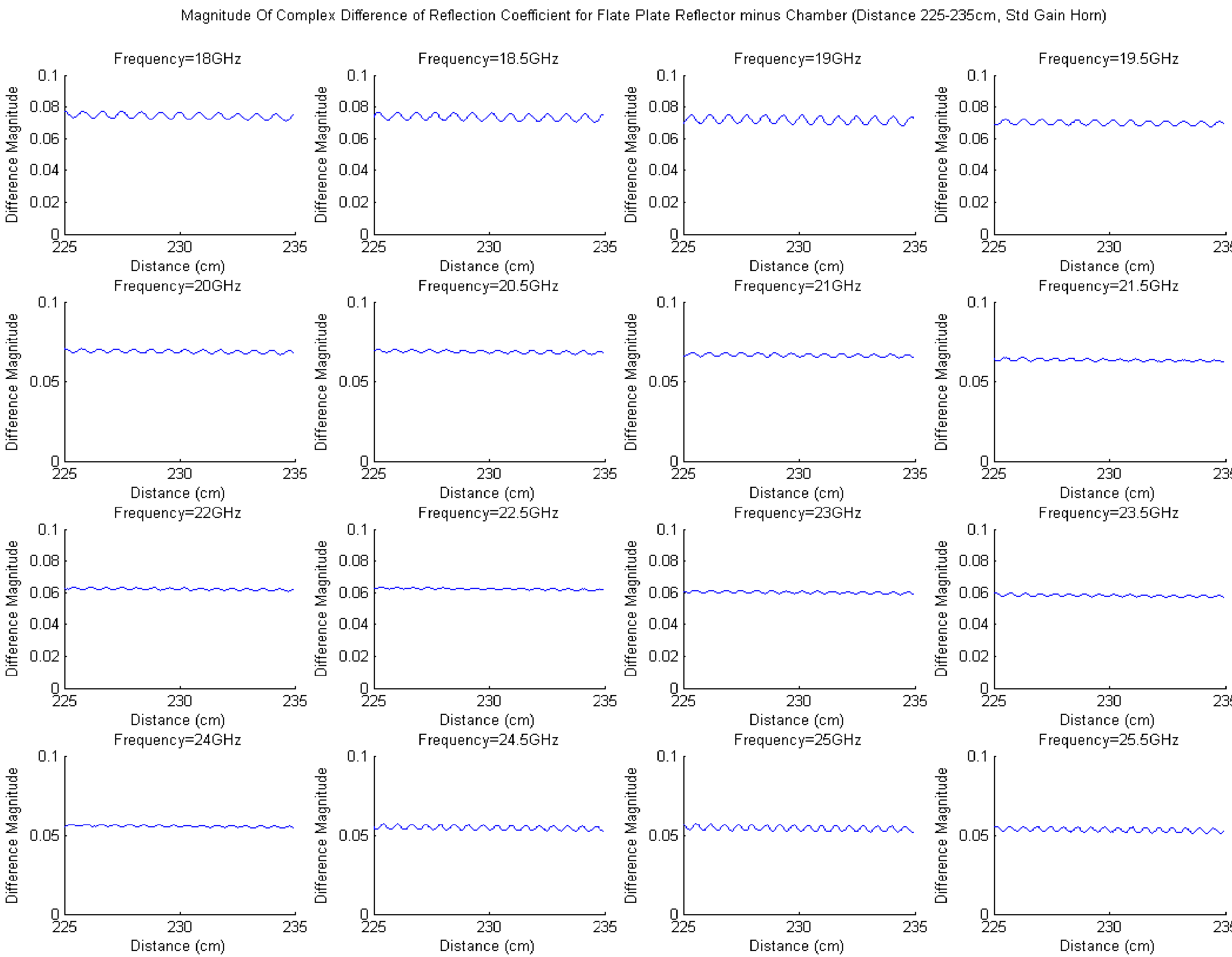


GSFC “Cryo” target |Γ|

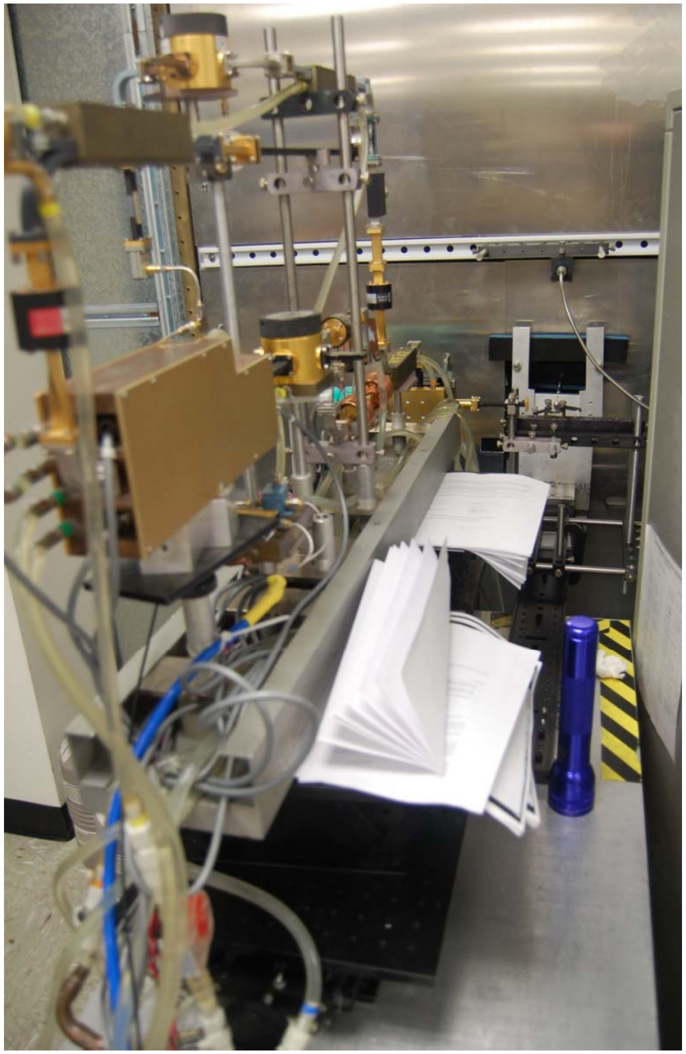
Magnitude Of Complex Difference of Reflection Coefficient for Ambient NASA 13" Target minus Chamber (Distance 225-235cm, Std Gain Horn)

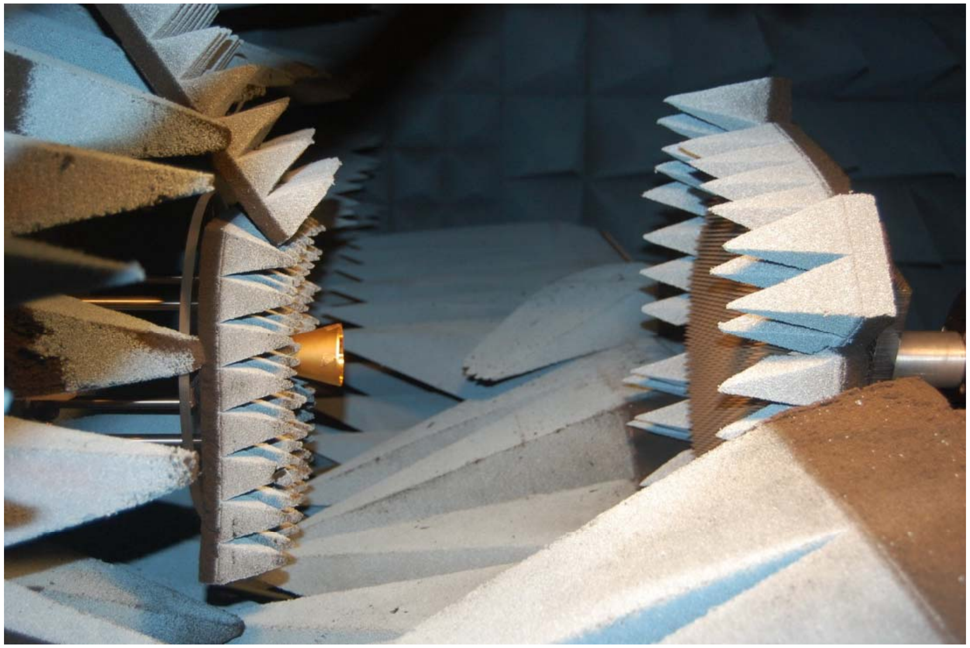


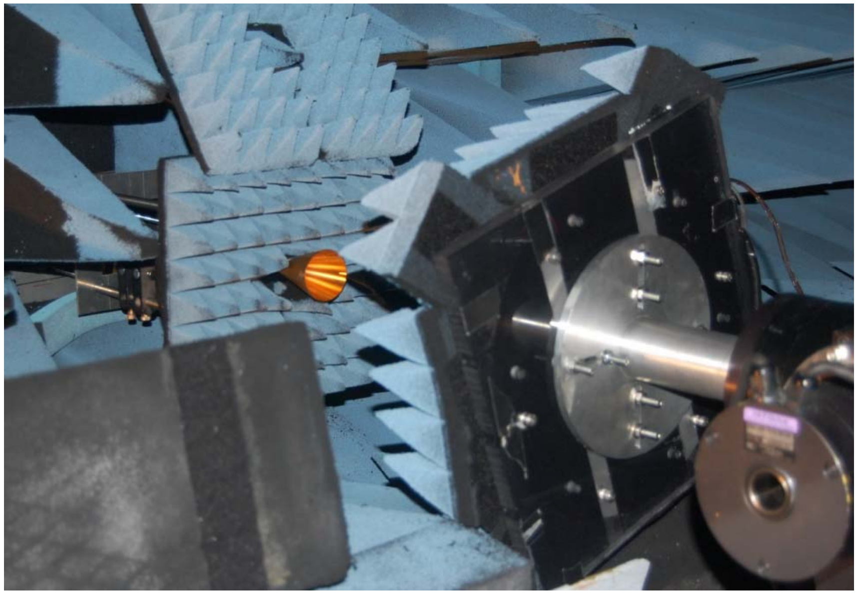
GSFC “Cryo” target: flat plate |Γ|



Radiometric setup – GSFC target







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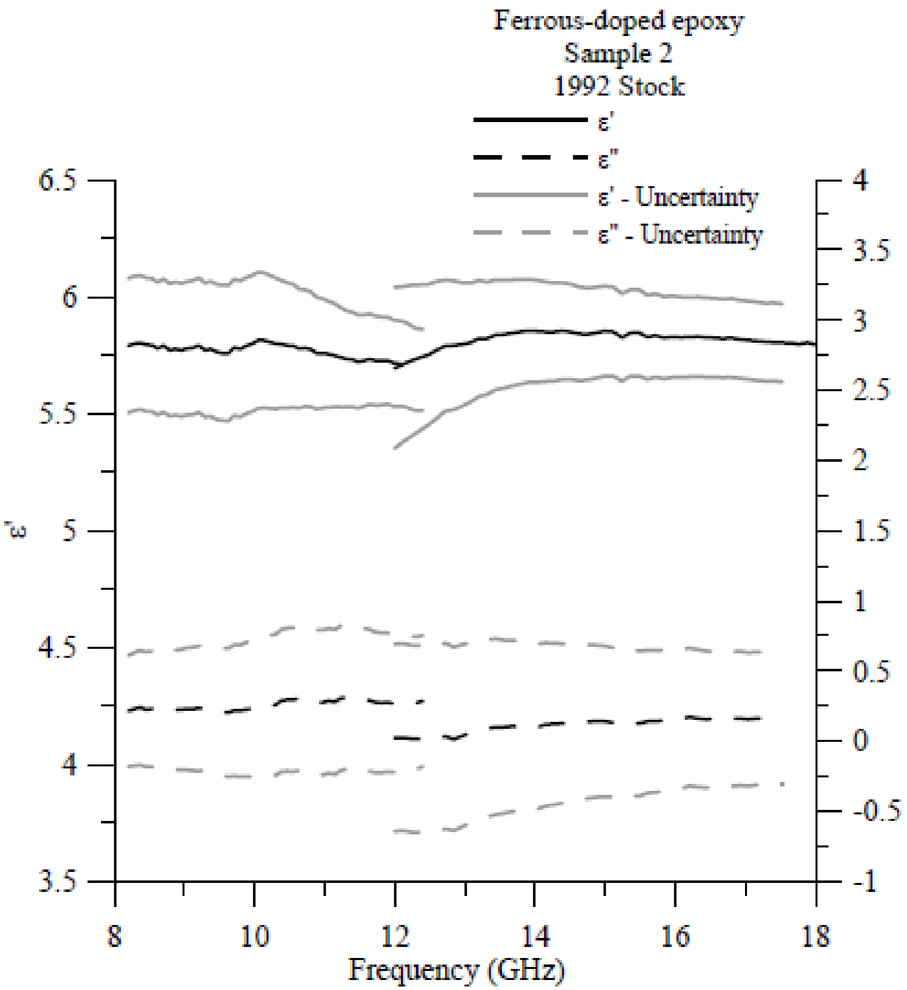
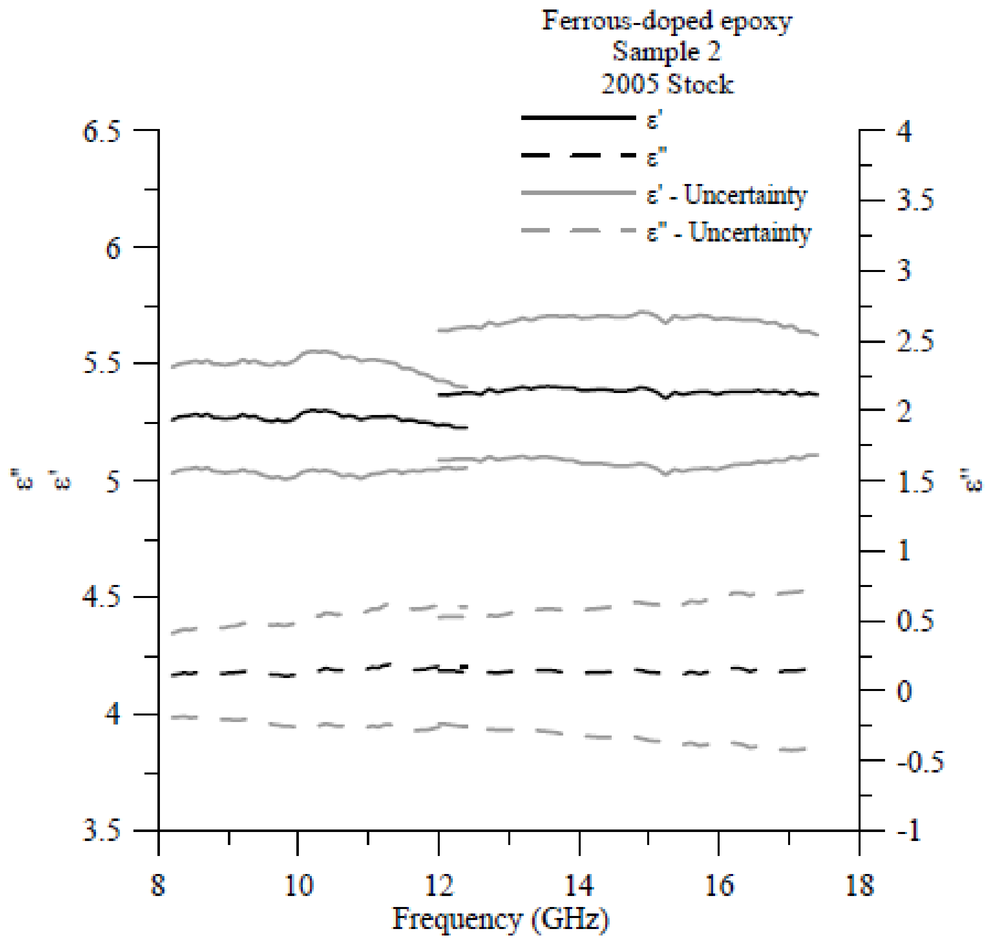
Target Absorber Measurements

- In waveguide
  - Measuring permeability and permittivity for frequencies beyond those provided by mfr.
  - Discovered batch-to-batch variation in one sample set
  - Plans to measure castable material
- Free space
  - Measurement technique verified
  - Several samples obtained for testing

Permittivity Measurements (showing batch-to-batch variation)





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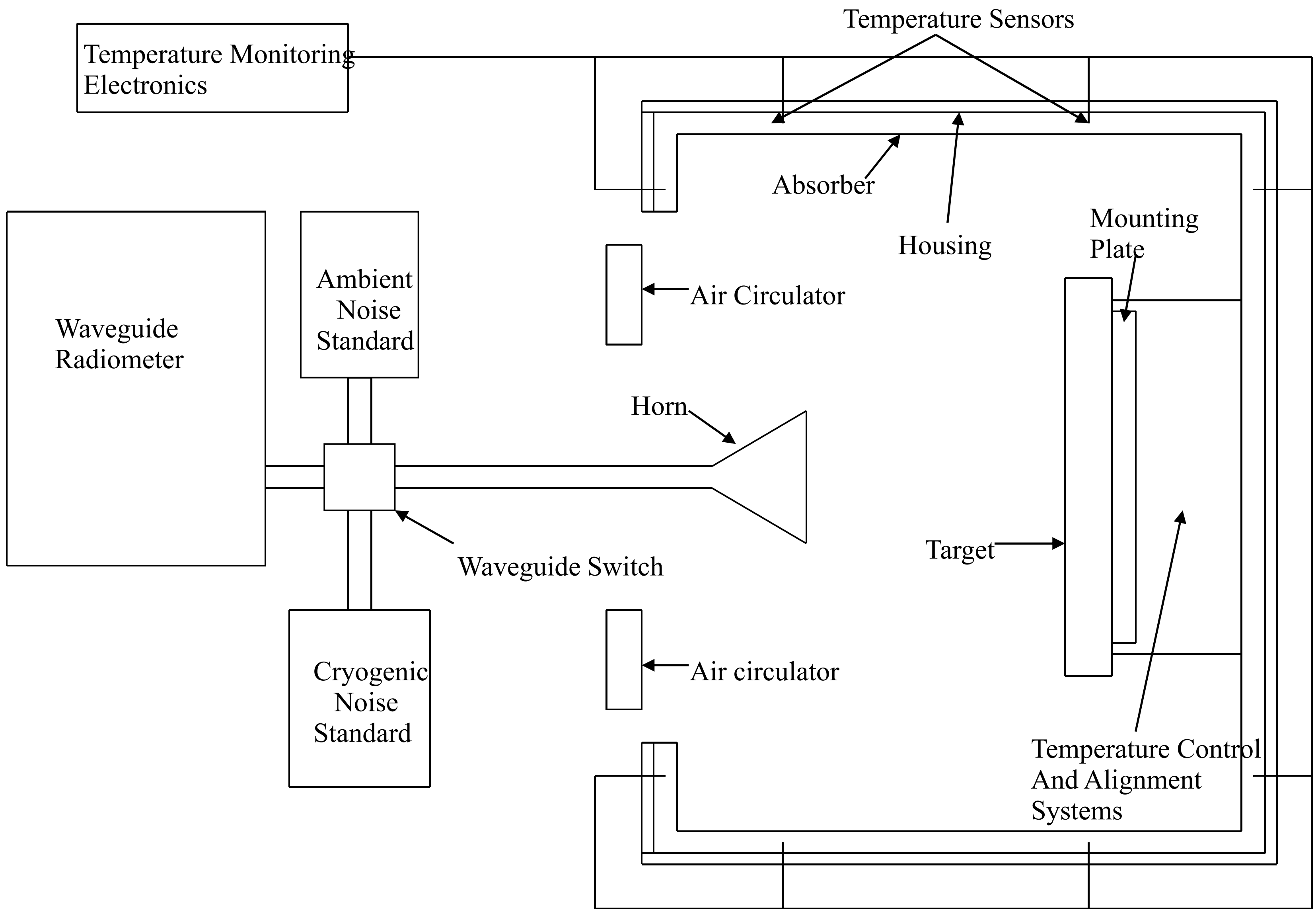
Additional Capabilities

- Complex permeability and permittivity of many materials (in waveguide)
  - Solids (e.g., moist soil)
  - Liquids (e.g., salt water)
  - Gasses (e.g., greenhouse gases)
- Noise diode and cold-FET internal cal source characterization (T; stability)
- Detector nonlinearity
- Antenna characterization (pattern, gain, near-to-far-field pattern transformation)

Summary

- The need for a national (i.e., SI-based) T_B standard is being recognized and accepted in the remote-sensing community
- Substantial progress made at NIST on various “foundational” aspects of a T_B standard
- Propose a combined standard radiometer+target
  - Potential reduction in uncertainty
  - Provides a means for checking and transfer
- Initial development would be 18-26.5 GHz band; extend up to 65 GHz
- Working on special test chamber…

Next: Special test chamber



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Summary

- Development of a microwave brightness temperature standard is non-trivial
- NIST has multiple capabilities to support pre- and post-launch cal/val efforts
- Other support tests and collaborations are available in the interim
- Your input and suggestions are welcomed
  - “The better you understand the parts of the system, the easier it is to analyze (or re-analyze) the system transfer function” –D. Kunkee