SI-Traceable Microwave T_B Standards Development at NIST

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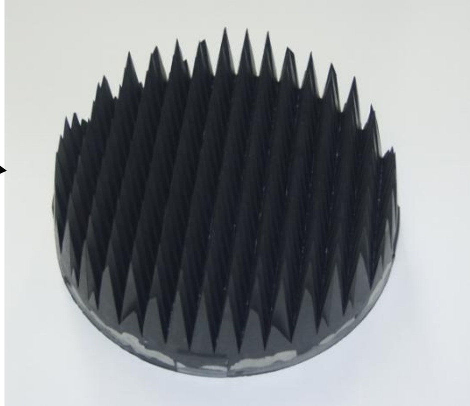
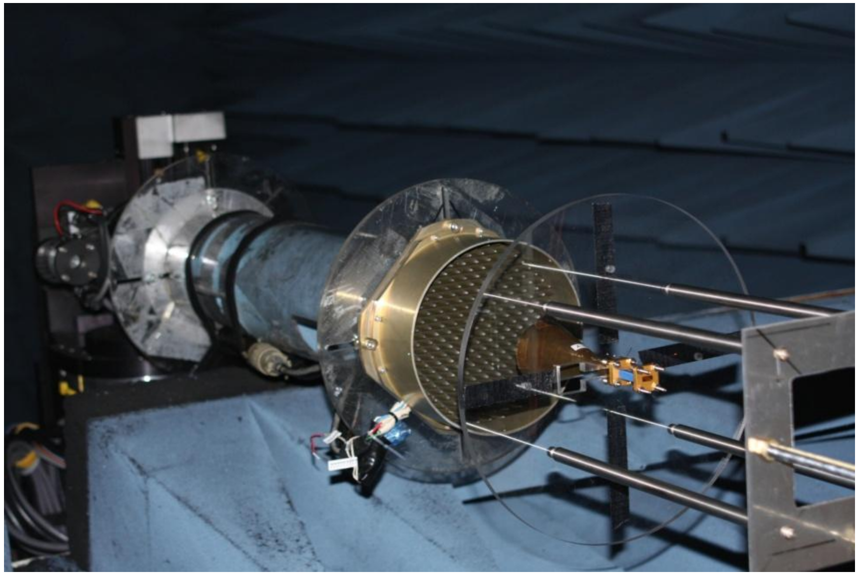
SI-based µW Measurements

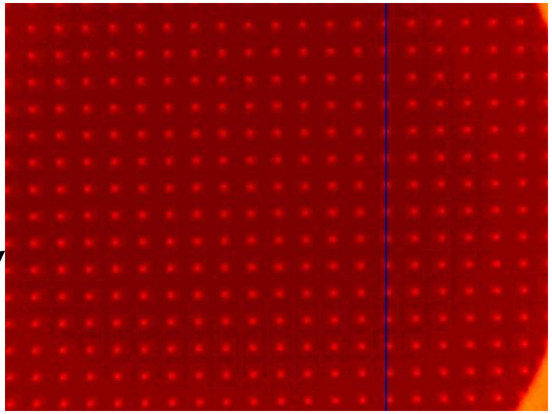
- Most radiometers use a two-point calibration (observe hot and cold black-body target) to determine the antenna temp.



- *SI-traceable radiance standards needed*
- NIST is developing such standards, including *identifying and quantifying error sources* (uncertainty statements)

NASA BB target undergoing testing in NIST anechoic chamber





IR thermal imaging to evaluate T nonuniformity

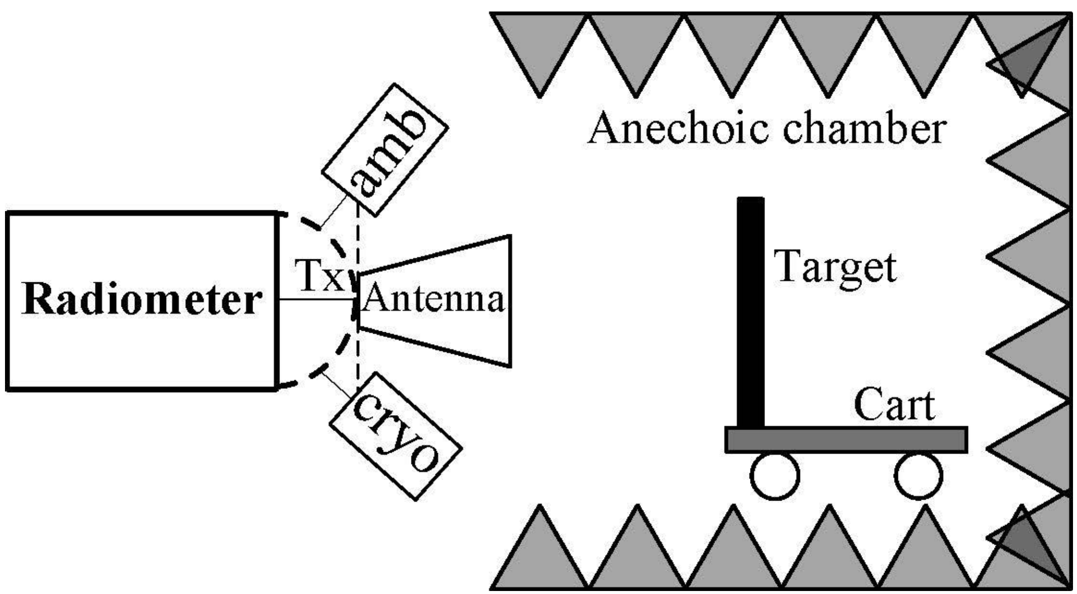
Microwave T_B standard

- Either one or both (statistically combined):
  - Standard Radiometer
    - Free space radiometric measurements
    - Identifying and quantifying error sources
  - Standard Target
    - Target characterization: T_B , Γ, ε
    - Materials measurements
- More to SI traceability than this, but a T_B standard is fundamental
- Std. radiometer realized (TGRS pub. soon)
- Std. target—significant progress made
  - Absorber measurements: ε, μ
  - Target modeling: CU CET FDTD model

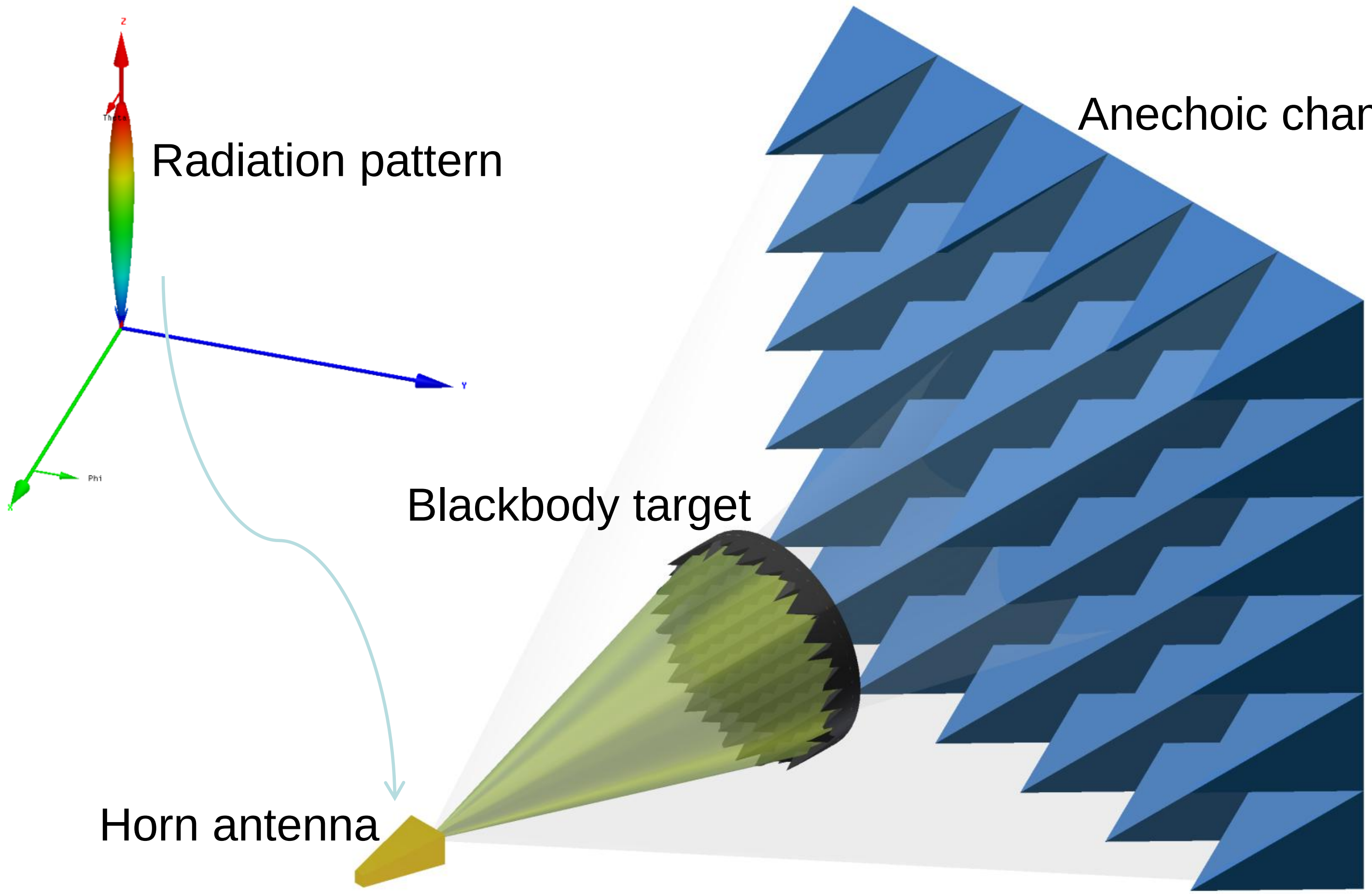
Microwave Remote Sensing Radiometric Measurements

$$T_x = \alpha\left(\frac{\int_{\text{target}} T_{tg}(\theta,\varphi)\,F_n(\theta,\varphi)\,d\Omega}{\int_{4\pi} F_n(\theta,\varphi)\,d\Omega} + \frac{\int_{\text{other}} T_{bg}(\theta,\varphi)\,F_n(\theta,\varphi)\,d\Omega}{\int_{4\pi} F_n(\theta,\varphi)\,d\Omega}\right) + (1-\alpha)\,T_{ant}$$

$F_n(\theta,\varphi)$: normalized radiation intensity
T_{tg} and T_{bg}: brightness temperature of target and background
α: antenna radiation efficiency

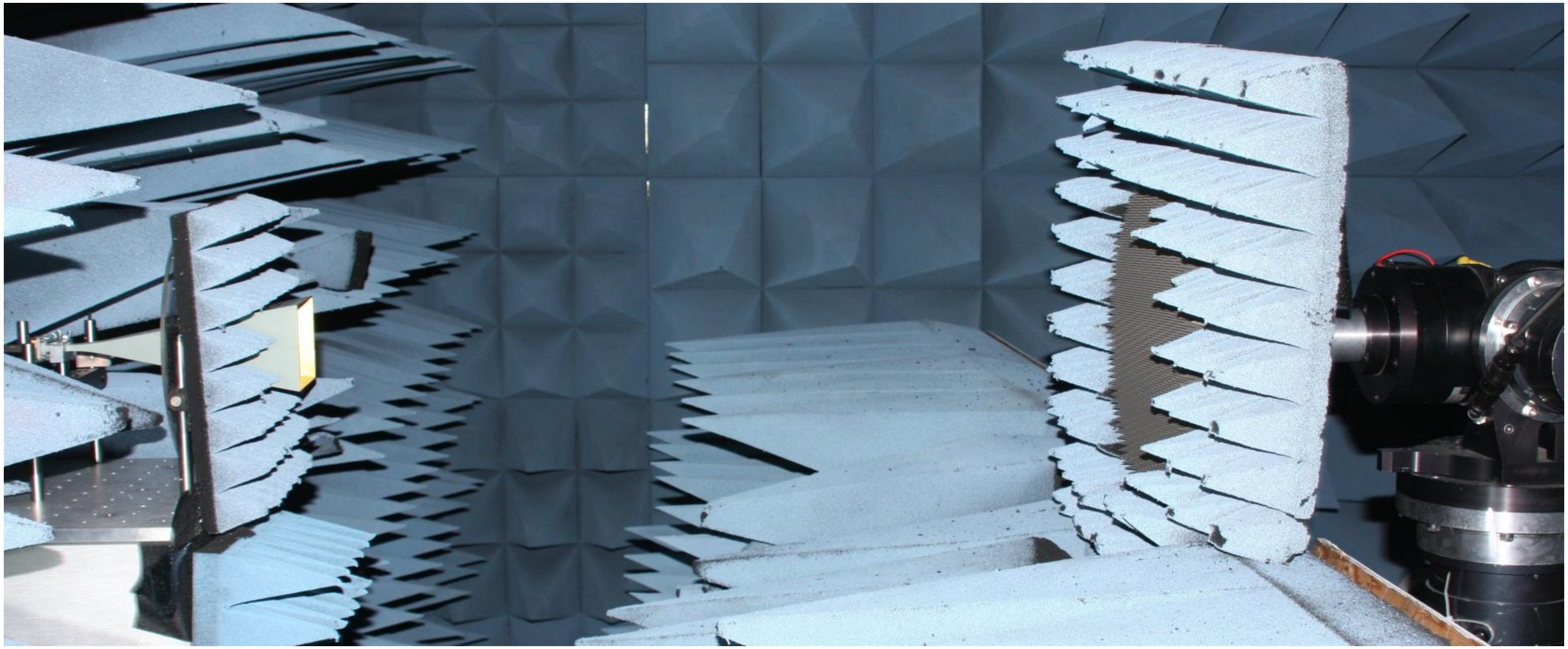


Antenna Spillover $\rightarrow \eta_{IE}$



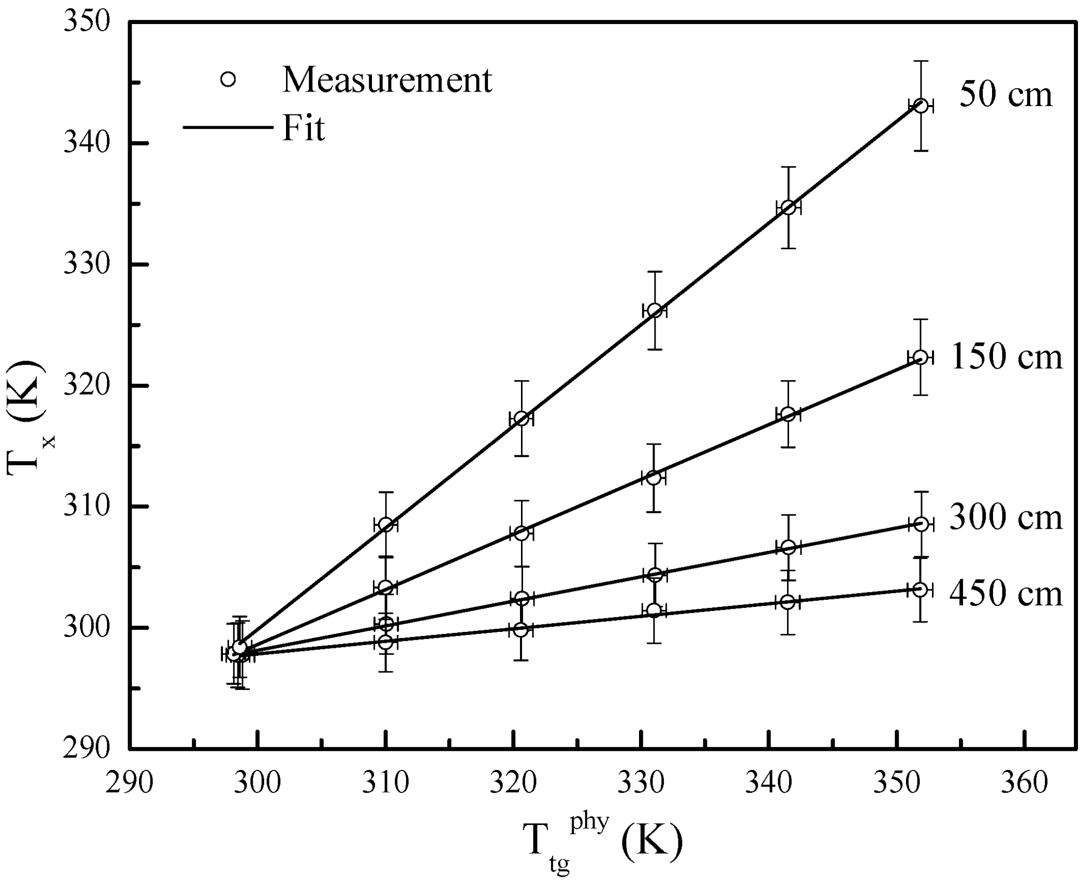
Illumination efficiency: $$\eta_{\mathrm{IE}} = \frac{\int_{\mathrm{target}} \mathrm{F_n}(\theta,\varphi)\, d\Omega}{\int_{4\pi} \mathrm{F_n}(\theta,\varphi)\, d\Omega}$$

Measurement Setup



- Experiments carried out in an anechoic chamber 5mX5mX8m
- 33 cm diameter pyramidal-array target with substrate heater
- WR-42 standard-gain (pyramidal horn) antenna connected to NIST radiometer with primary noise standards as references

Chi-square Minimization



- Six temperature settings at ~10 K apart.

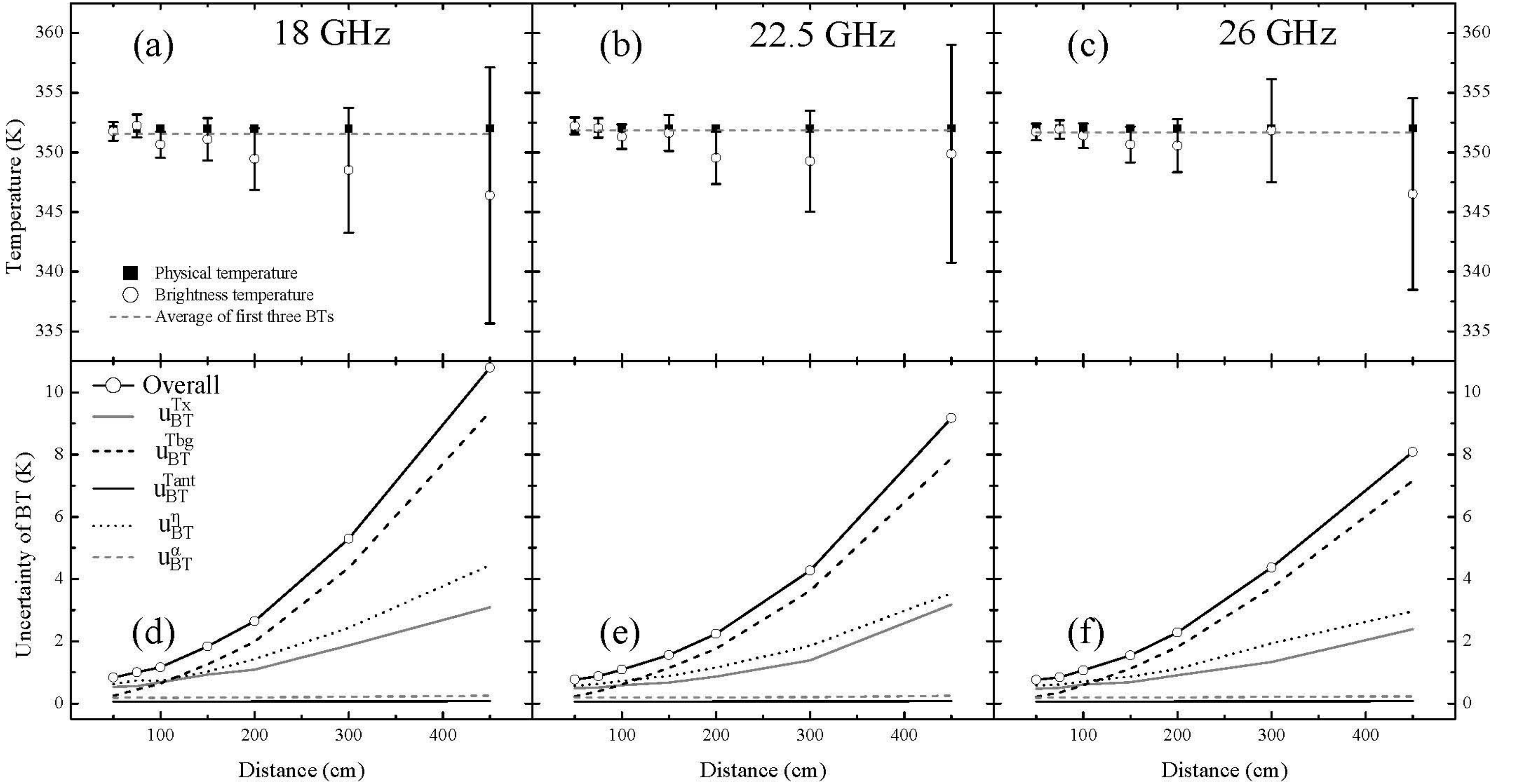
$$T_x = a \cdot T_{tg}^{phy} + b$$

$$\chi^2 = \sum_{i=1}^{6} \frac{\left(T_{x\_i} - a \cdot T_{tg\_i}^{phy} - b\right)^2}{u_{T_{x\_i}}^2 + a^2 \cdot u_{T_{tg\_i}^{phy}}^2}$$

$$u_b^2 = 2 \cdot \Delta\chi^2 \cdot \left(\mathbf{H}^{-1}\right)_{22}$$

Brightness Temperature

$$\bar{T}_{tg} = \frac{1}{\alpha\eta_{IE}} T_x - \frac{1-\eta_{IE}}{\eta_{IE}} T_{bg}^{phy} - \frac{1-\alpha}{\alpha\eta_{IE}} T_{ant}$$



Conclusion

- Radiometric T_B standard based on η_{IE} extraction method eliminates complex ant. characterization
  - IGARSS 2012 Poster: “AN INVESTIGATION OF ANTENNA CHARACTERIZATION TECHNIQUES IN MICROWAVE REMOTE SENSING CALIBRATION”
- Report *effective* T_B ($\bar{T}_{tg}$) vs. T_{tg}^{phy} (i.e., *transfer function*) for a given antenna+target arrangement
- Conservative estimate of T_B measurement uncertainty ~1 K (~ 0.3%), with a minimum of 0.7 K
  - Present NIST coverage: 1 to 65 GHz
- NIST standard radiometer meets the accuracy requirement of some climate variables…

Measurement Accuracy

- Ultimate goal is to reach the accuracy requirement for climate change study.

	NIST radiometer	Troposphere	Stratosphere	Precipitation	Water vapor	Sea surface temp
Accuracy	≈ 1 K	0.5 K	1 K	1 K	1.25 K	0.03 K

Quoted from “Stability and accuracy requirements for satellite remote sensing instrumentation for global climate monitoring,” ISPRS 2004.

Conclusion

- Uncertainty dominated by T_x and η_{IE} for close distance (< 1 m), whereas the U in T_{bg} dominates at longer range
  - need to control/know T_{bg} well if η_{IE} “small”
- Target convection and conduction effects
  - PE foam cover improves T uniformity and *stability*
  - Thermal-Vac (TV) chamber useful

- η_{IE} method in space-borne inst. calibration
  - η_{IE} and *a* determined pre-launch
  - *b* (intercept term) can be determined on-orbit
- If $\overline{T}_{tg} = T_{tg}^{phy}$, why calibrate? Useful check; near-field effects
  - Determine target ε (or Γ), antenna α separately
- Antenna pattern still important, but independent issue

Microwave Challenges

- T_B standards/metrology
- Accurate antenna pattern metrology
  - Main-beam efficiency, side lobe char., edge-of-scan biases
  - New NIST robotic spherical-scanning range: 40-500 GHz coverage
- Antenna emissivity characterization (near SI traceability!)
  - Test coupons, duplicates can be extremely useful (SSMI/S example)
- RFI analysis: assessment and mitigation
- Receiver nonlinearity
- Radiometer Calibration
  - Consistent pre-launch testing cross-instrument/platform
  - Consistent uncertainty analyses
  - NIST-NASA GSFC MOU signed Jan. 2010: calibration issues incl. NS
    - Radiometer stability metrics: specification and verification
    - EDA: Modeling, simulation, calibration with multiple references
- Pre-launch vs. on-orbit calibration methods: End-to-end calibration *on orbit* presently not verifiable by pre-launch testing
- Transparency and documentation essential!