Extraction of Reflectivity from Microwave Blackbody Target with Free-Space Measurements

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Outline

- Motivation
- Theoretical background
- Measurement setup
- Results
- Discussion and Conclusion

Motivation

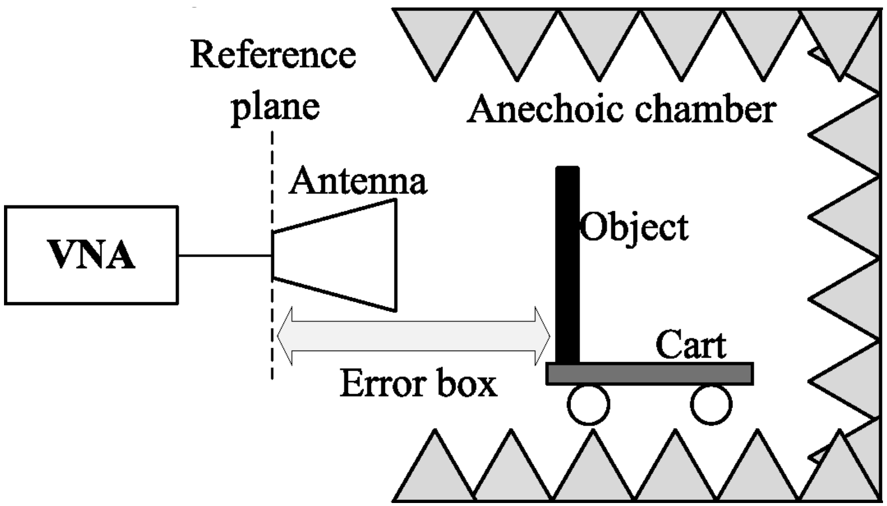
- Microwave imagers and sounders often use blackbody targets as T_B reference
- Climate change studies rely on the (absolute) accuracy of the T_B reference
- Reflectivity links to emissivity that quantifies how close the target is to an ideal blackbody.
- Calibrated (SI-traceable) T_B standards under development at NIST

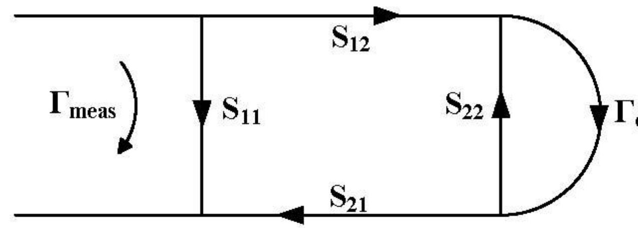
The Non-Ideal Target Problem*

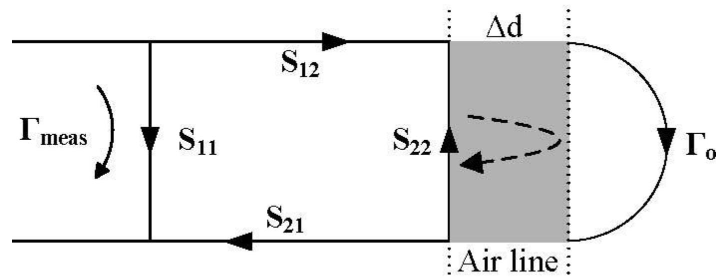
- Calibration targets close to the sensing antenna:
  - linear radiometers need ≥ two standards for calibration.
  - satellites: cold sky, if possible (far-field)
  - otherwise: hot & cold targets (near-field)
  - Scene is always far-field
- Near-field targets introduce two general types of error in a total-power radiometer:
  - Antenna+target affects antenna pattern, directivity (ignore)
  - $\Delta\Gamma$ at antenna output due to non-ideal target (this work):
    - Difference in M (mismatch factor) for target, scene
    - Difference in system F and G_{av} " " "
- $u_{tot}^{(0)} \approx 0.1 - 5.2\,K$ for actual cal. targets measured

*"Errors Resulting From the Reflectivity of Calibration Targets" J. Randa, D.K. Walker, A.E. Cox, and R.L. Billinger, IEEE Trans. Geosci. Remote Sens., vol. 43, no. 1, pp. 50 - 58, (2005).

Theoretical Background I







$$\Gamma_{meas} = S_{11} + \frac{S_{12}S_{21}\Gamma_o}{1 - S_{22}\Gamma_o}$$

$$\Gamma_{meas} = e_1 + \frac{e_2\Gamma_o}{1 - e_3\Gamma_o}$$

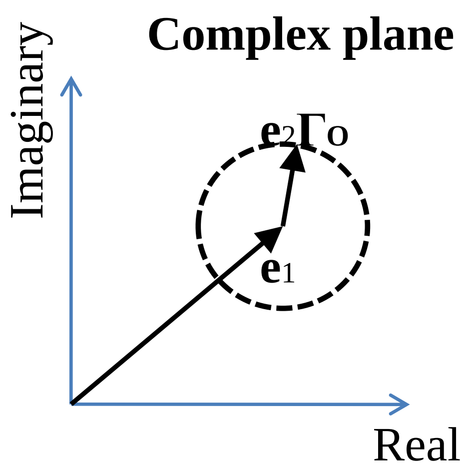
Goal: solving error terms e_1, e_2, and e_3.

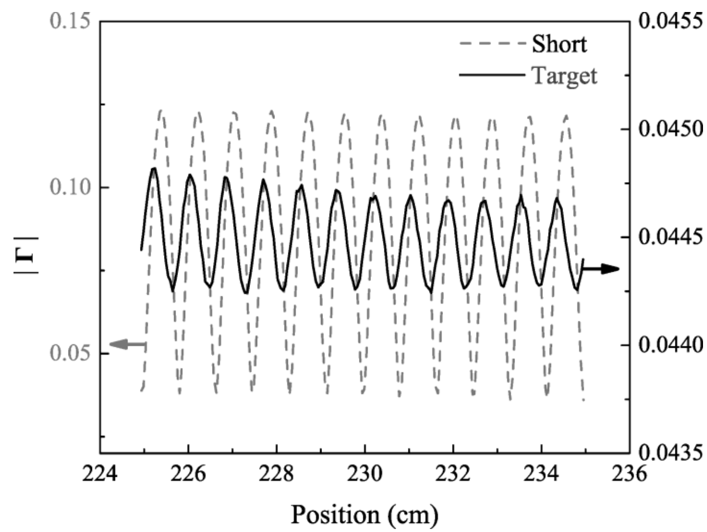
$$\Gamma_o = \frac{\Gamma_{meas} - e_1}{e_2 + e_3(\Gamma_{meas} - e_1)}$$

Theoretical Background II

- Measure empty chamber, offset short (a flat metal plate), and target in far-field
- In addition, a loss factor γ is included to account for the change of the radiation that intercepts the target.

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & -\exp\left(-2\gamma\Delta d^{(0)}\right) & \left(\Gamma_{\text{meas}}^{\text{chamber}} - \Gamma_{\text{meas}}^{\text{offset}(0)}\right)\exp\left(-2\gamma\Delta d^{(0)}\right) \\ \vdots & \vdots & \vdots \\ 0 & -\exp\left(-2\gamma\Delta d^{(n)}\right) & \left(\Gamma_{\text{meas}}^{\text{chamber}} - \Gamma_{\text{meas}}^{\text{offset}(n)}\right)\exp\left(-2\gamma\Delta d^{(n)}\right) \end{bmatrix} \cdot \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \Gamma_{\text{meas}}^{\text{chamber}} \\ \Gamma_{\text{meas}}^{\text{offset}(0)} - \Gamma_{\text{meas}}^{\text{chamber}} \\ \vdots \\ \Gamma_{\text{meas}}^{\text{offset}(n)} - \Gamma_{\text{meas}}^{\text{chamber}} \end{bmatrix}$$





Theoretical Background III

- Uncertainty analysis

$$u_{|\Gamma_o|} = \sqrt{\sum_{m,n=1}^{8} \frac{\partial |\mathbf{\Gamma}_o|}{\partial x_m} \frac{\partial |\mathbf{\Gamma}_o|}{\partial x_n} \rho_{mn} u_{x_m} u_{x_n}}$$

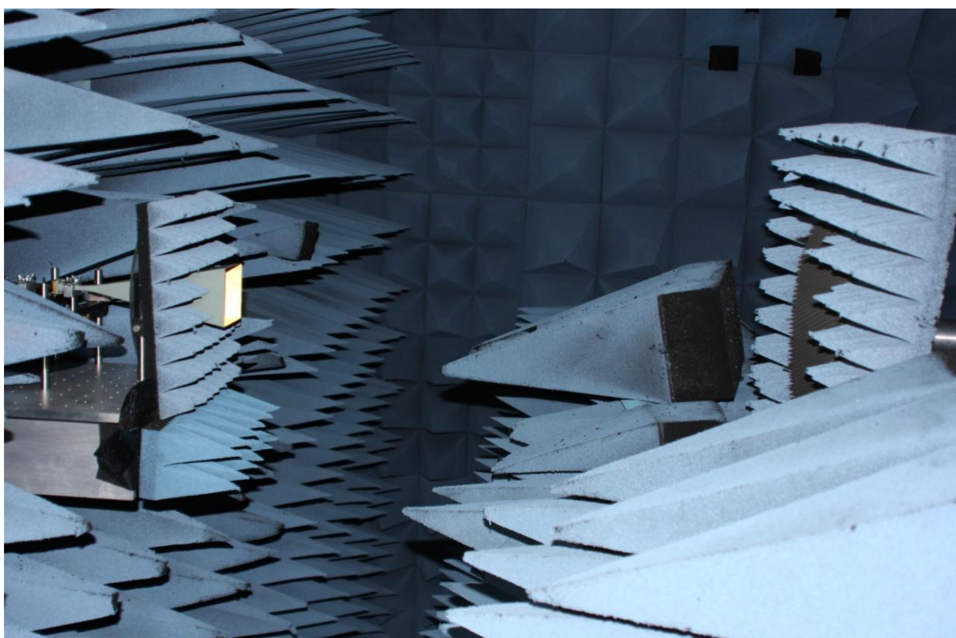
$x_{m,n}$ = Real or Imginary of e_1, e_2, e_3, or $\mathbf{\Gamma}_{meas}$, ρ is the correlation factor.

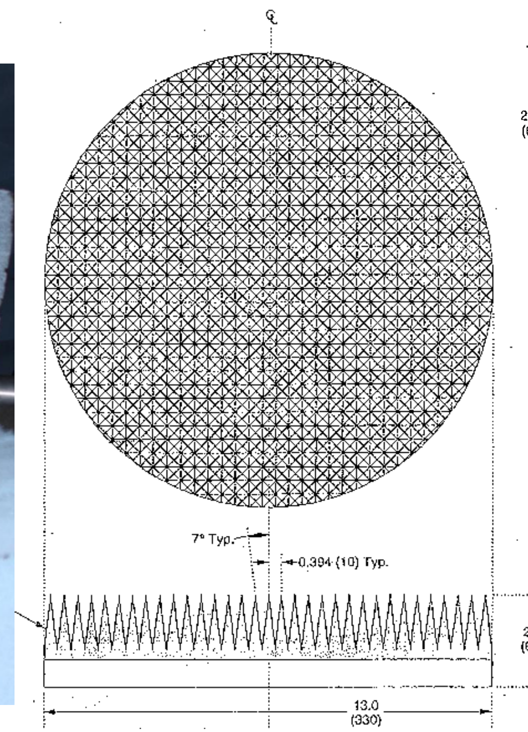
Error Terms and Measured Reflection at 18 GHz

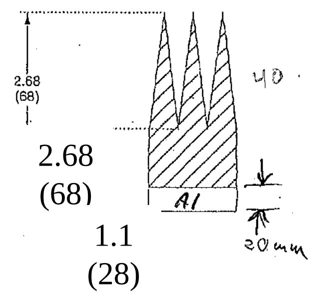
	$\mathbf{e}_1$	$\mathbf{e}_2$	$\mathbf{e}_3$ [a]	$\mathbf{\Gamma}_{meas}$
Value	$0.0420 - j0.0153$	$-0.0167 + j0.0674$	$0.0014 - j0.0235$	$0.0418 - j0.0150$ [b]
Type-A uncertainty	$1.4 \cdot 10^{-4} + j1.4 \cdot 10^{-4}$	$1.5 \cdot 10^{-4} + j2.7 \cdot 10^{-4}$	$0.0020 + j0.0019$	0 [c]
Type-B uncertainty	$0.0001 + j0.0001$	$0.0001 + j0.0001$	$0.0001 + j0.0001$	$0.0001 + j0.0001$

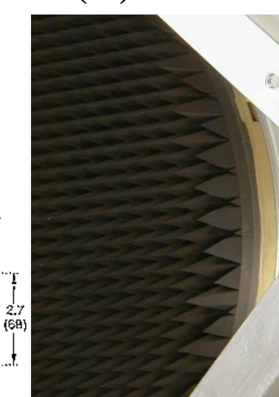
Measurement Setup

- NIST anechoic chamber (usable 400 MHz – 40 GHz)
- *K*-band pyramidal horn and conical horn
- Rexolite (x-linked polystyrene) verification sample
- 13-inch target from GSFC (P. Racette)



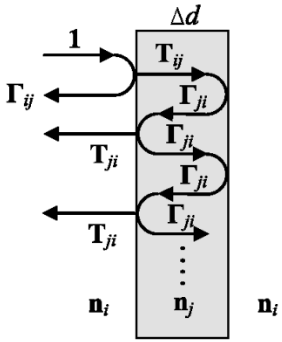






Calibration verification

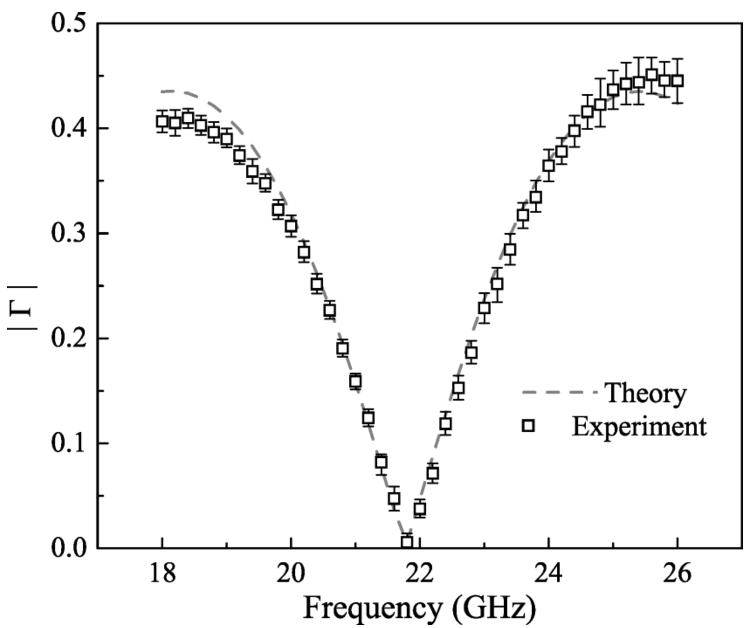
- Cross-linked polystyrene (Rexolite) slab

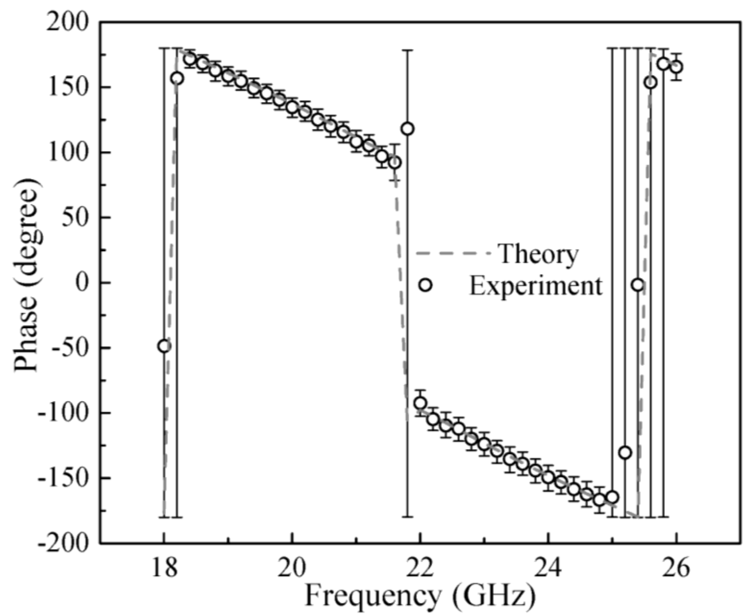


$$\begin{aligned}\Gamma_{total} &= \Gamma_{ij} + \mathbf{T}_{ij}\Gamma_{ji}\mathbf{T}_{ji}\exp\left(-\gamma\cdot 2\Delta d\right) \\ &\quad + \mathbf{T}_{ij}\Gamma_{ji}^{3}\mathbf{T}_{ji}\exp\left(-\gamma\cdot 4\Delta d\right) + \cdots \\ &= \Gamma_{ij} + \frac{\mathbf{T}_{ij}\Gamma_{ji}\mathbf{T}_{ji}\exp\left(-\gamma\cdot 2\Delta d\right)}{1-\Gamma_{ji}^{2}\exp\left(-\gamma\cdot 2\Delta d\right)},\end{aligned}$$

$$\Gamma_{ij} = \frac{n_i - n_j}{n_i + n_j}$$

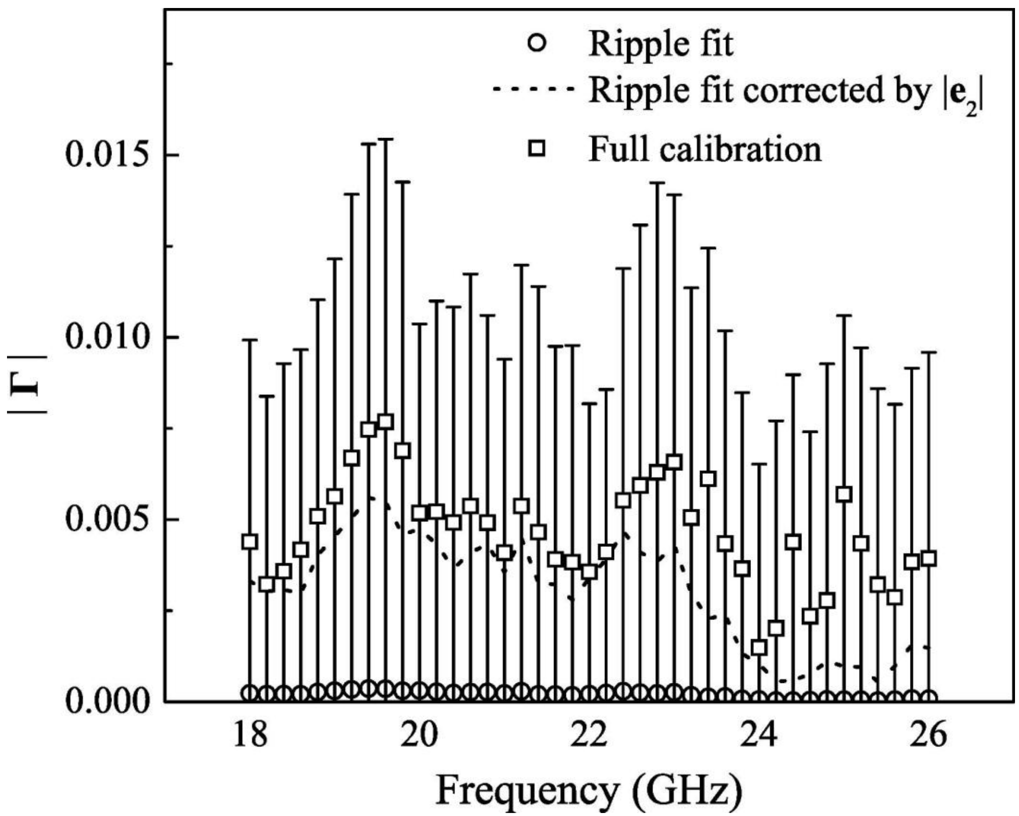
$$\mathbf{T}_{ij} = \frac{2n_i}{n_i + n_j}.$$





Target Results I

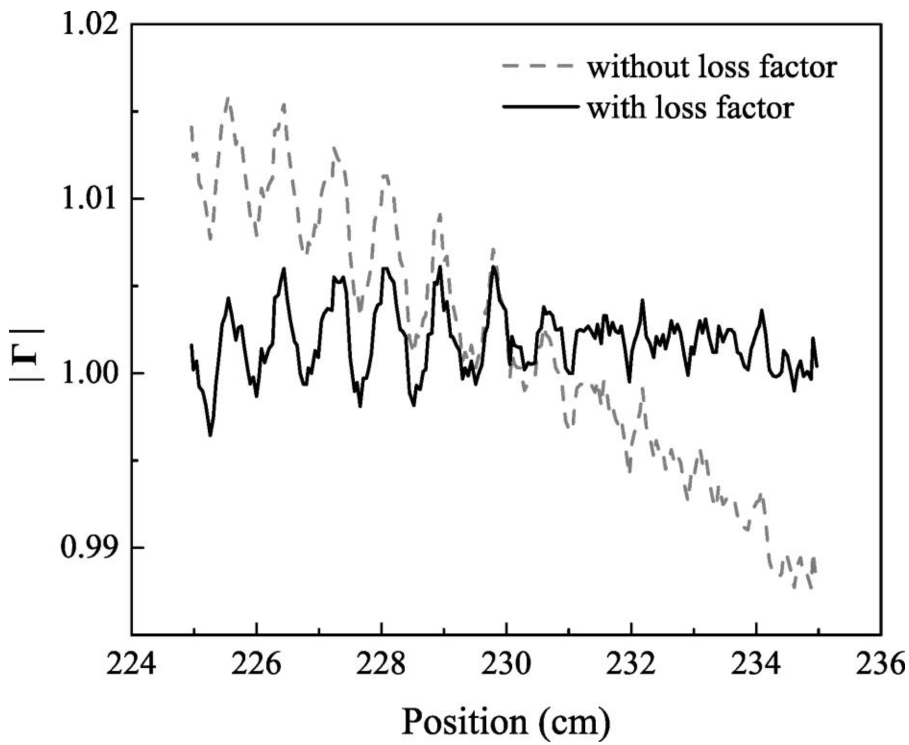
- Ripple method approximation: $|\mathbf{e}_2\boldsymbol{\Gamma}_o| = (|\boldsymbol{\Gamma}_{meas}|_{max} - |\boldsymbol{\Gamma}_{meas}|_{min})/2$,
- $\mathbf{e}_2$ disguises the true value of $\boldsymbol{\Gamma}_o$.



Results II

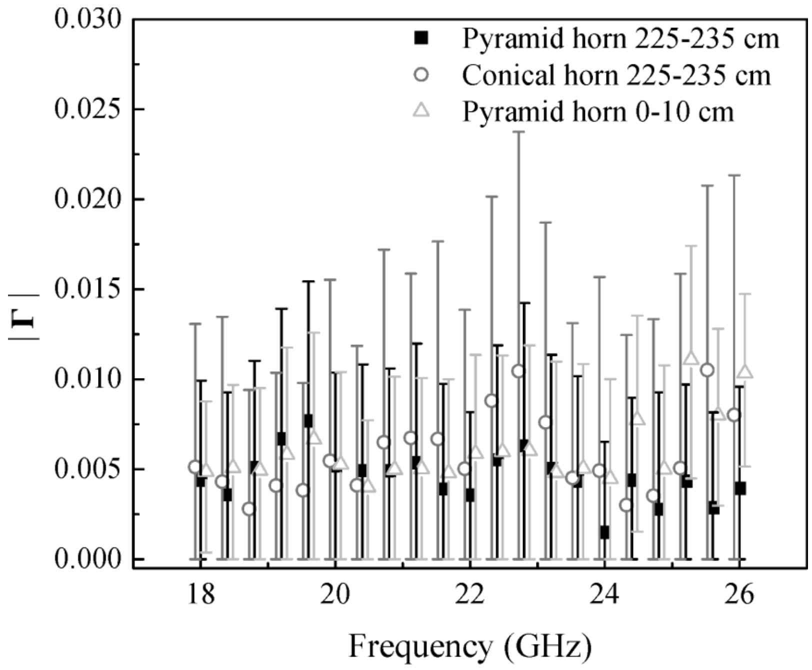
- The loss factor is important to correct the reduced intercept ratio of the radiation pattern as the object moves along the longitudinal direction.

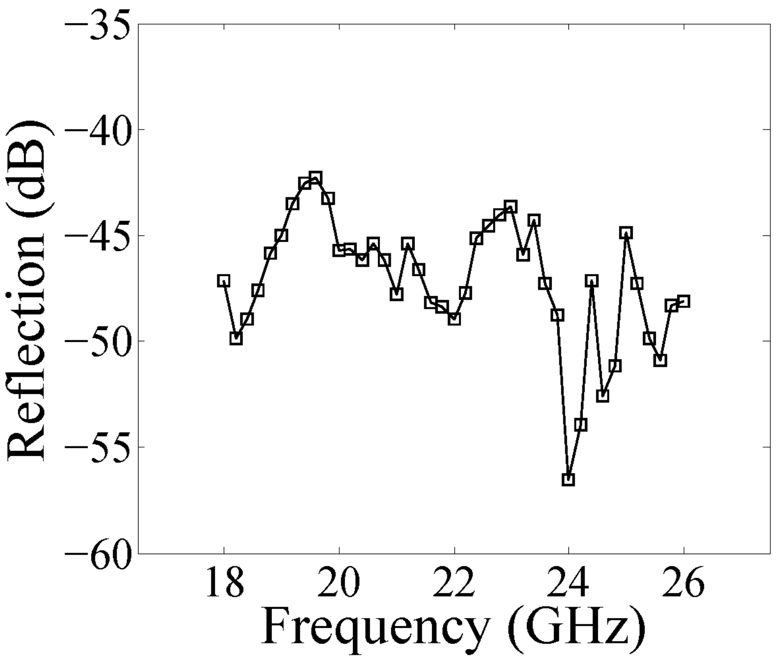
Corrected reflection magnitude of the metal plate



Results III

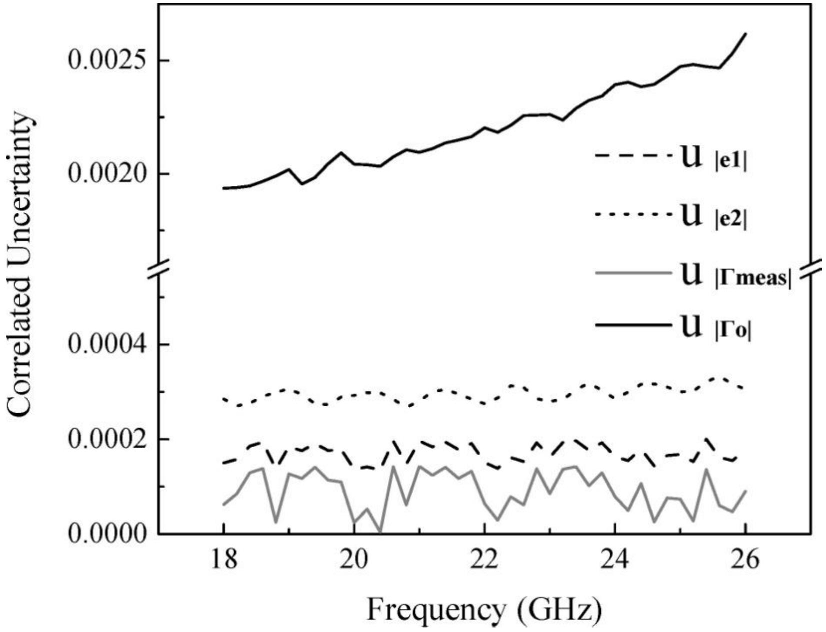
- Reflectivity lower than 40 dB in K-band (18-26 GHz), inline with the specification of the target.
- Negligible difference between hot and ambient conditions.
- Validated by different hardware and measurement conditions

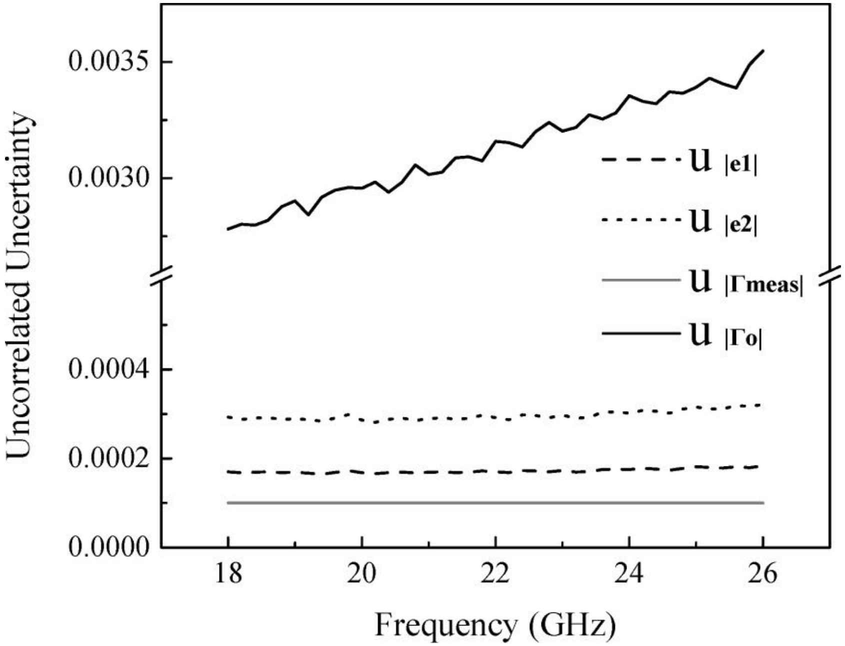




Results IV

- Uncorrelated uncertainty is higher than correlated uncertainty.
- The uncertainty contributed from Γ_{meas} dominates due to large derivative factor $\partial|\Gamma_o|/\partial\Gamma_{meas}$.





Discussion

- Conservative uncertainty estimate due to limited knowledge of VNA measurements on such low-reflectivity components.
- Environment drift somewhat degrades the repeatability.
- Mechanical alignment is crucial.
- De-embedding method extendable to other frequency bands.

Conclusion

- A free-space calibration technique is established to characterize blackbody targets.
- Simple target ripple method is not accurate.
- The loss factor accounting for the radiation pattern variation is critical to accuracy.
- Calibration verified by various methods.
- The target under investigation shows close-to-perfect blackbody properties in this f range.
- T-GRSS publication out soon.