Development and Characterization of Microwave Calibration Targets

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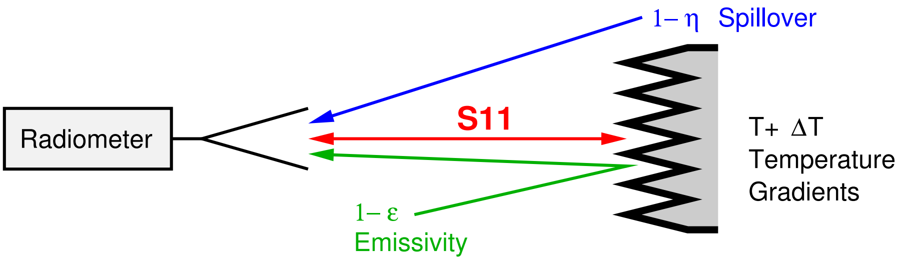
Topics

- Critical aspects of calibration targets
- Absorbing Materials
- Calibration target characterization
- Targets developed in collaboration with TK: CHL, ALMA, Sentinel-3, LMCL
- New developments at IAP

Requirements for Microwave Calibration Targets



- Low temperature gradients ΔT
- High coupling efficiency $\eta \geq 99.99\%$
- High emissivity $\epsilon \geq 99.99\%$
- Low coherent return loss S11 $\ll$-40dB

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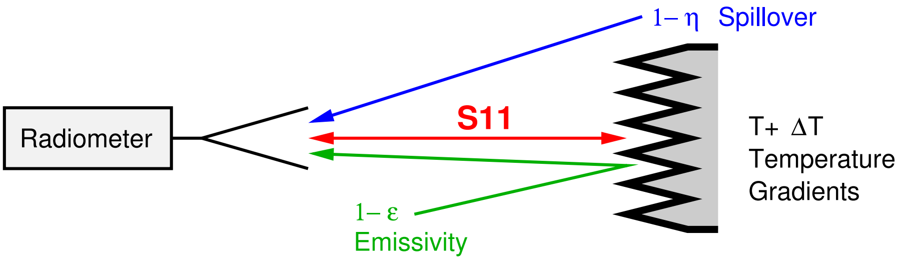
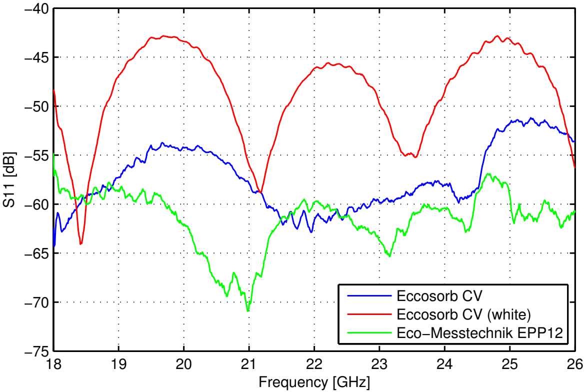


- Low temperature gradients ΔT
- High coupling efficiency $\eta \geq 99.99\%$
- High emissivity $\epsilon \geq 99.99\%$
- Low coherent return loss S11 ≤ -60dB

Pyramidal or convoluted polyurethane foam absorber

- e.g. Eccosorb CV (Emerson&Cuming) or EPP (Eco-Messtechnik)
- Relatively low S11 (but degraded if painted)

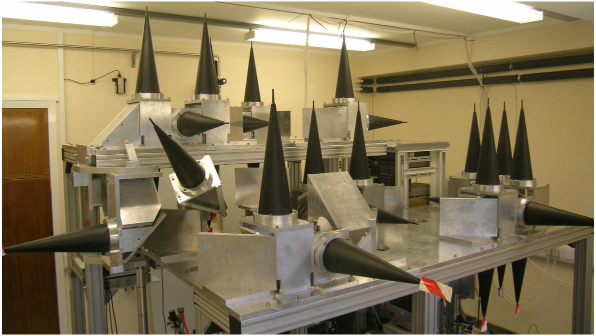


- Low thermal conductivity ⇒ Risk of significant temperature gradients!

Absorbing Materials

Polypropylene with carbon loading (TK)

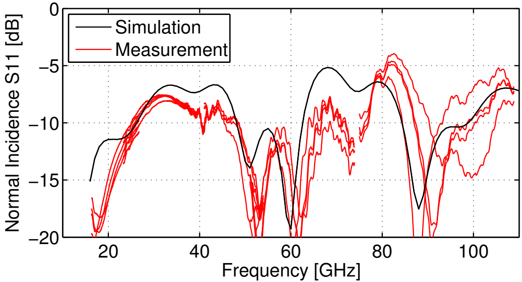
- TK-RAM (pyramidal surface) or "Hiper" Cones
- Still only moderate thermal performance

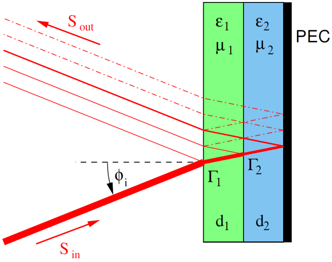


Conical beam dumps in the 94GHz pulsed ESR spectrometer "HIPER"
(Rev. Sci. Instr. 80, 103102, 2009)

Magnetically loaded Epoxy or Silicone (Eccosorb CR110, CR114 ...)

- Very lossy ⇒ thin absorber layer on a metal backing reduces ΔT
- Bad matching to free space ⇒ requires multiple reflections
- Tuned multilayer of different absorber grades can improve the matching in selected frequency bands.





Measured and predicted normal incidence S11 of a tri-layer optimized for Metop-SG frequencies 20, 30, 50–57 and 89GHz

Window Materials and LN2

Low density and low loss foams to isolate targets

- Plastazote LD15 closed cell PE foam seems to be best
- Styrofoam quality is variable
- Emerson&Cuming PE foam Eccostock PP2 is worse

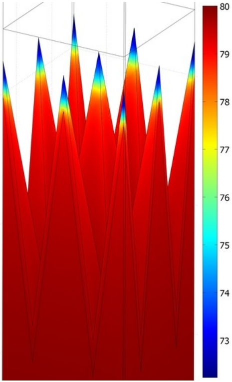
"Stabilization of the Brightness Temperature of a Calibration Warm Load for Spaceborne Microwave Radiometers," De Amici et al., IEEE TGRS vol. 45, no. 7, 2007.

LN2 Cold Loads

- Primary reference point for many instruments, but how accurate is T?
- Refractive index $n = 1.2 \implies R_\perp = \left(\frac{n-1}{n+1}\right)^2 = -21\ dB$
- Warm bias of at least 1.8K just from LN2 reflections
- Significant standing waves, phase drifts while LN2 evaporates
  Solution: do not observe at normal incidence!

Temperature Gradients

- Microwave absorbers have relatively low thermal conductivity $\Rightarrow$ temperature gradients, depending on thermal environment.
- Pyramidal targets are more affected than other designs.
- Examples of a heated target for ALMA with gradients up to 5K:



Thermal simulation

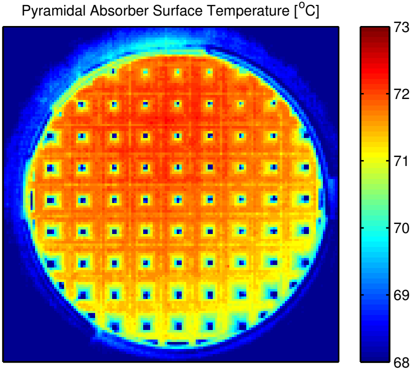
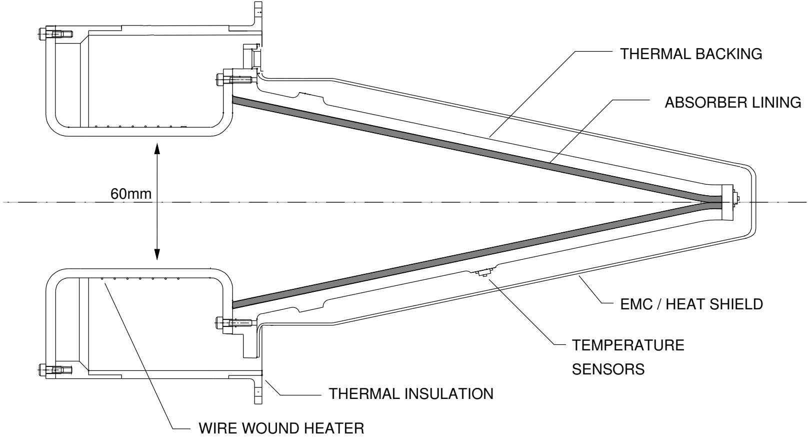


Image with thermal IR camera

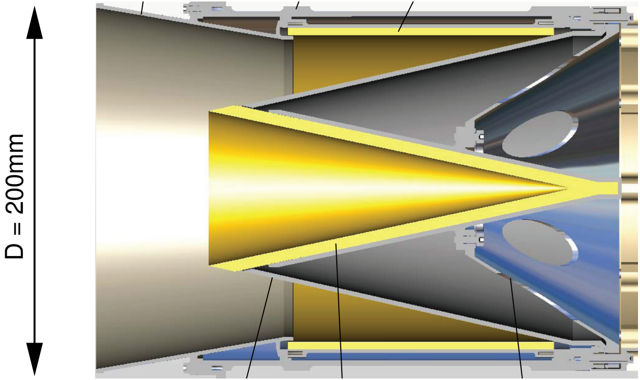
Conical Hot Load (CHL)

- Initially developed for ESA submm-wave limb sounder >300GHz
- Successfully flown on various air- and balloon-borne instruments
- Lower temperature gradients and S11 than pyramidal targets



Conical Hot and Ambient Targets for ALMA

- Frequency bands between 30-950 GHz
- Tuned multilayer absorber in a folded cone geometry



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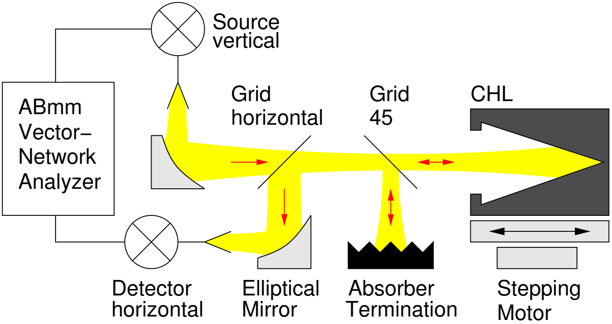
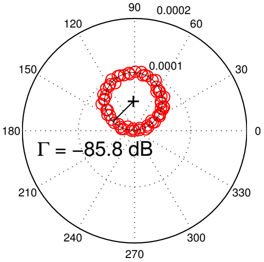
S11 Test Setup

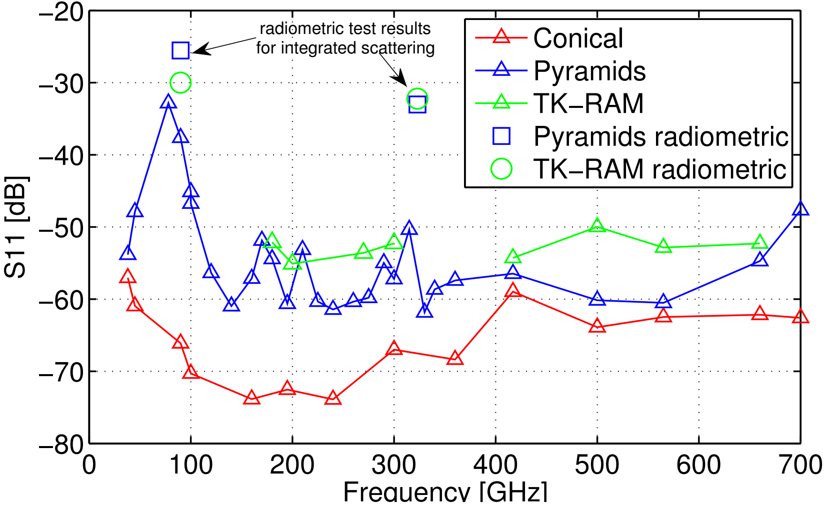
- S11 measurement with VNA
- Directional coupler up to 100 GHz, quasi-optics above.
- Test object measured at different distances *d* to calibrate directivity of the test setup ⇒ phase changes, fit of a circle to the complex data





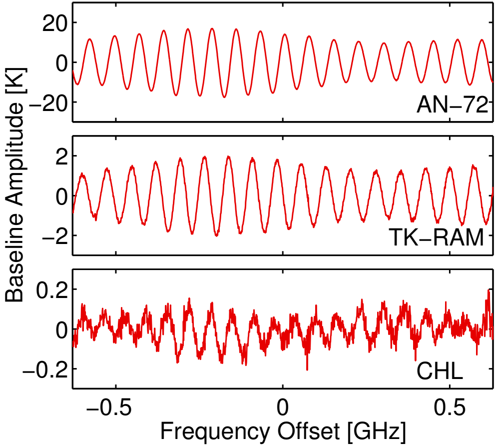
S11 Test Results for Conical and Pyramidal Targets

- S11 backscatter measurements for different targets



Standing Wave Baseline Ripple

- Spectroscopic baseline of different ambient temperature targets observed with a cryogenic 300 GHz receiver (MIRA, KIT).



- Flat foam absorber:
  S11 = -25dB
  $\Delta T_B \approx 20K$
- Pyramidal plastic absorber:
  S11 = -50dB
  $\Delta T_B \approx 2K$
- Conical Target:
  S11 = -65dB
  $\Delta T_B \approx 0.2K$

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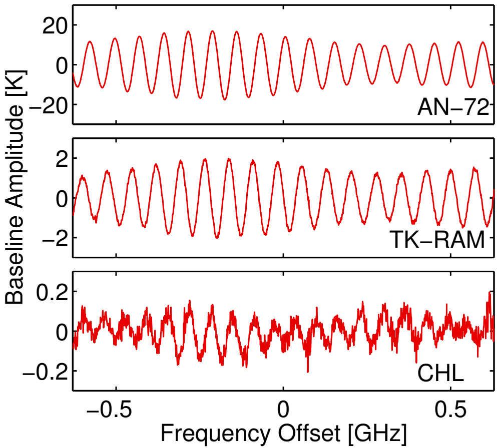

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- **Low S11 is most crucial for spectroscopic observations!**

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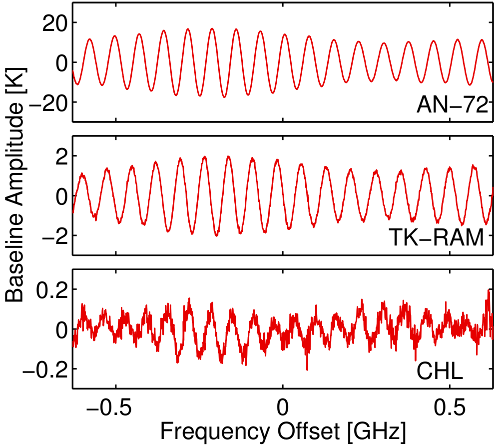

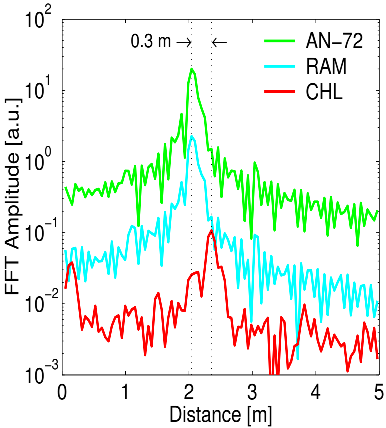

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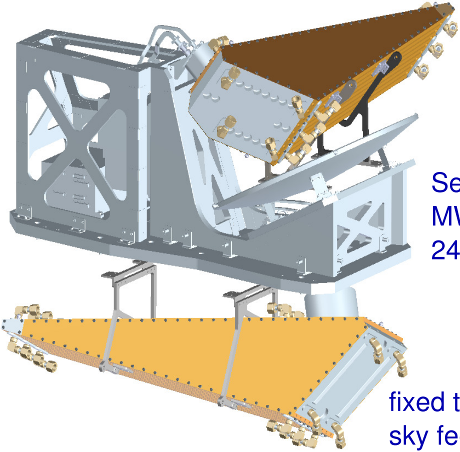
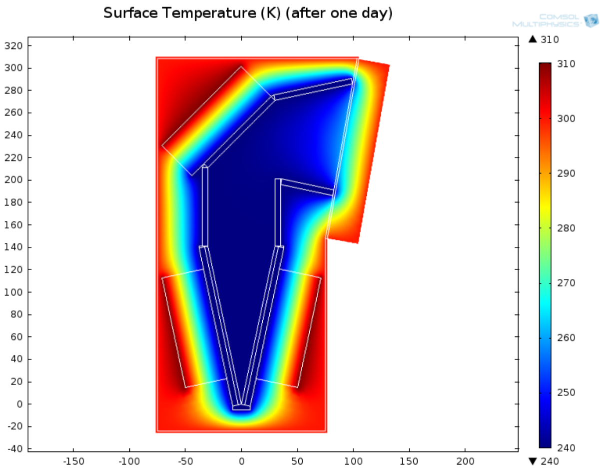
Ground Calibration Targets for SENTINEL-3 MWR

- Fixed and variable cryogenic target for 24 and 36 GHz
- Wedged blackbody for single TM polarization
- Temperature stabilized shaped reflector minimizes IR loading



Wedged -30°C Target for GROMOS-C

- Peltier coolers, Aerogel isolation, normal pressure
- New Eccosorb MMI absorber for MM-waves (1mm thick)



COMSOL Multiphysis FEM Simultion: **Temperature**

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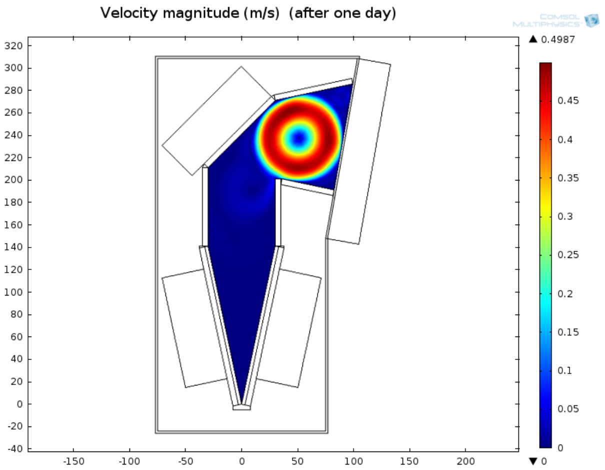

COMSOL Multiphysis
FEM Simultion:
Convective Air Flow

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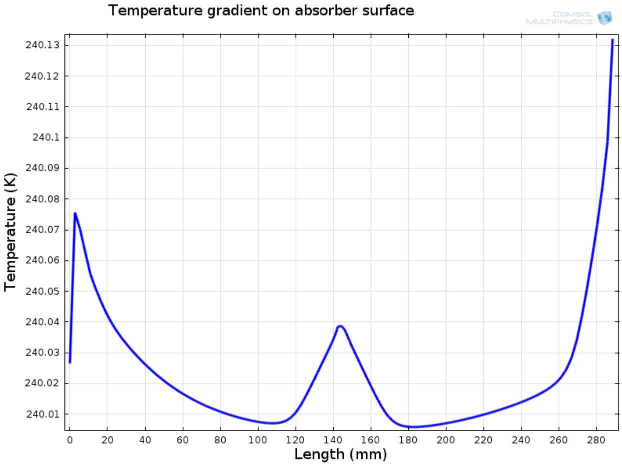

COMSOL Multiphysis
FEM Simultion:
ΔT <0.1K

S. Fernandez

Conclusions

- Calibration targets are crucial for accurate microwave radiometry.
- Temperature gradients are a common source for calibration errors (e.g. SSMI calibration anomalies).
- Low S11 is a key requirement for spectroscopic observations.
- Conical and wedged targets have better RF and thermal performance than standard pyramidal targets.
- Performance can be optimized with multilayer absorber designs. This requires detailed knowledge of the absorber's dielectric and magnetic material parameters.

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  European Space Agency
  Peter de Maagt
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  Target manufacture
- **ABSL Enersys, UK**
  Thermometry and thermal design