Modeling of the Coolable 2-14 GHz Eleven feed for future radio telescopes for SKA & VLBI 2010

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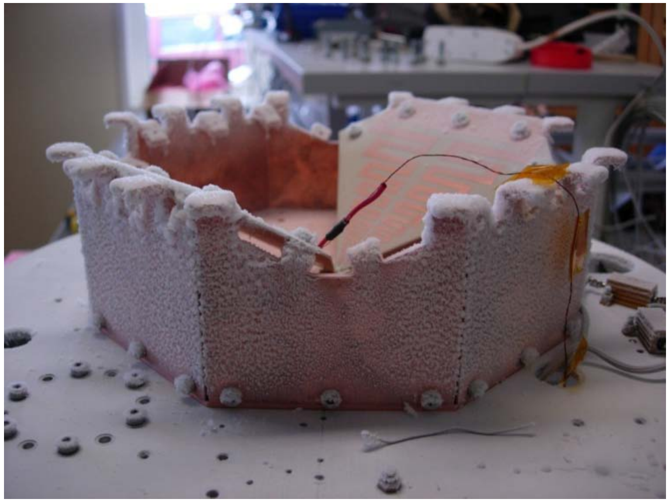


Eleven feed after survival test to 14 K = -259˚C

Future Radio astronomical receivers

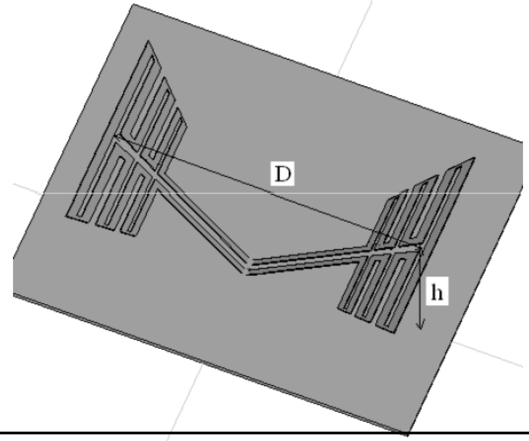
Main requirements

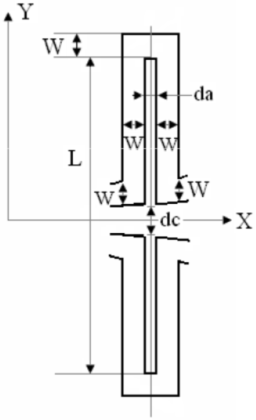
- Demand for broader bandwidth from projects like Geo-VLBI 2010 and Square Kilometer Array (SKA)
- Low noise, (cooled front-end)
- Constant illumination over the band
- Constant phase centre

Eleven feed - electrical design and performance

Six parameters are optimized:

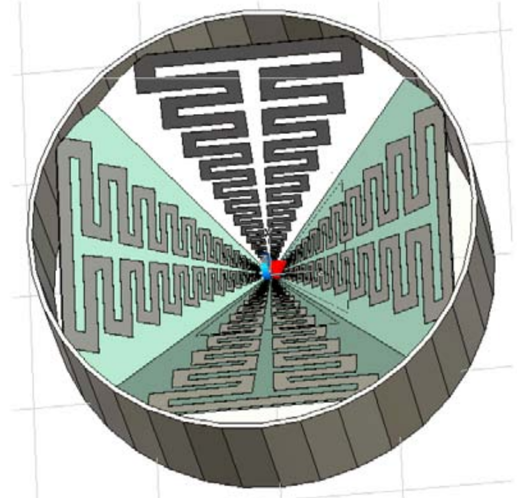
- scaling factor **k,** and the 5 dimensions in drawing**.**
- 14 dipoles needed to cover 2-12GHz
- port impedance 200 Ω





Feed parameters over 2-12GHz

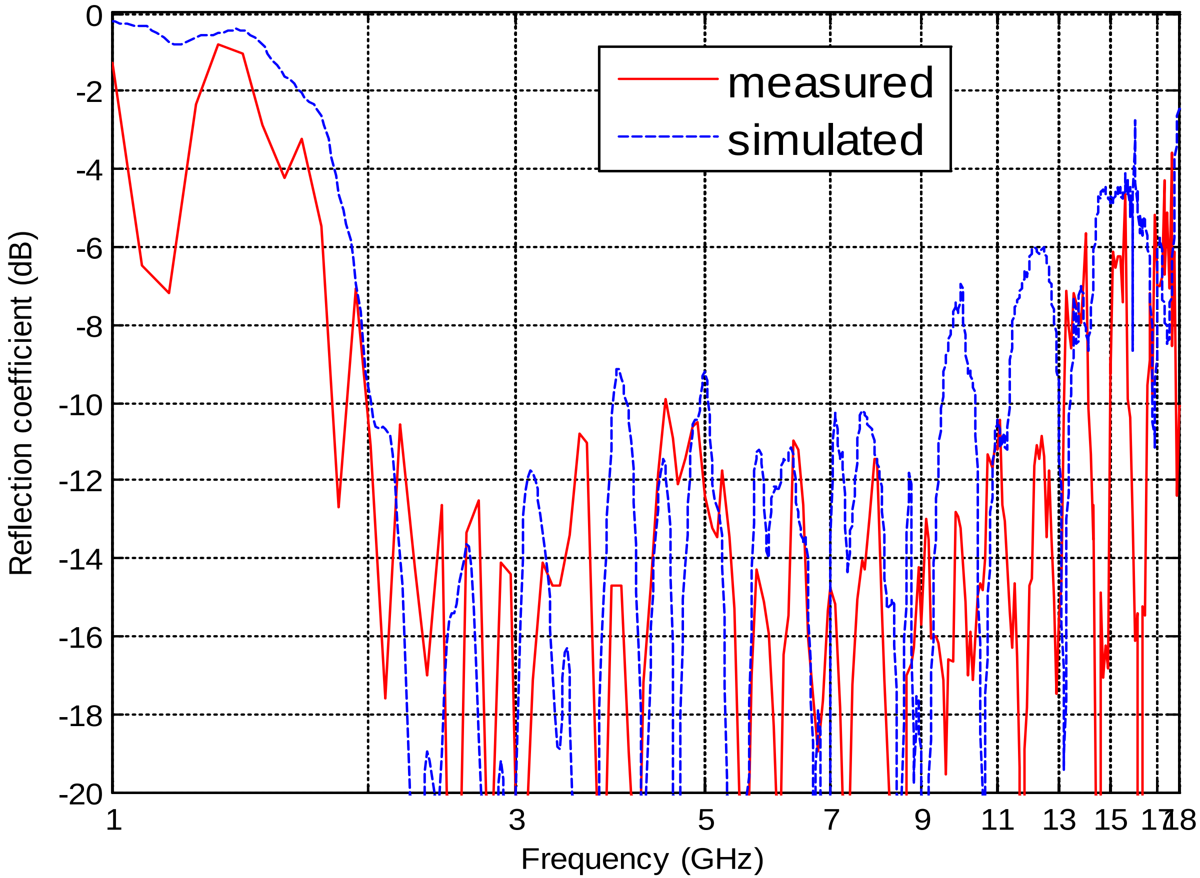
- Reflection coefficient below -10 dB
- Directivity is about 11 dBi
- The radiation pattern is constant with low cross polarization level
- Aperture efficiency of 2x55 deg paraboloid is better than – 3 dB



Simulations and Measurements at Chalmers

of input reflection coefficient

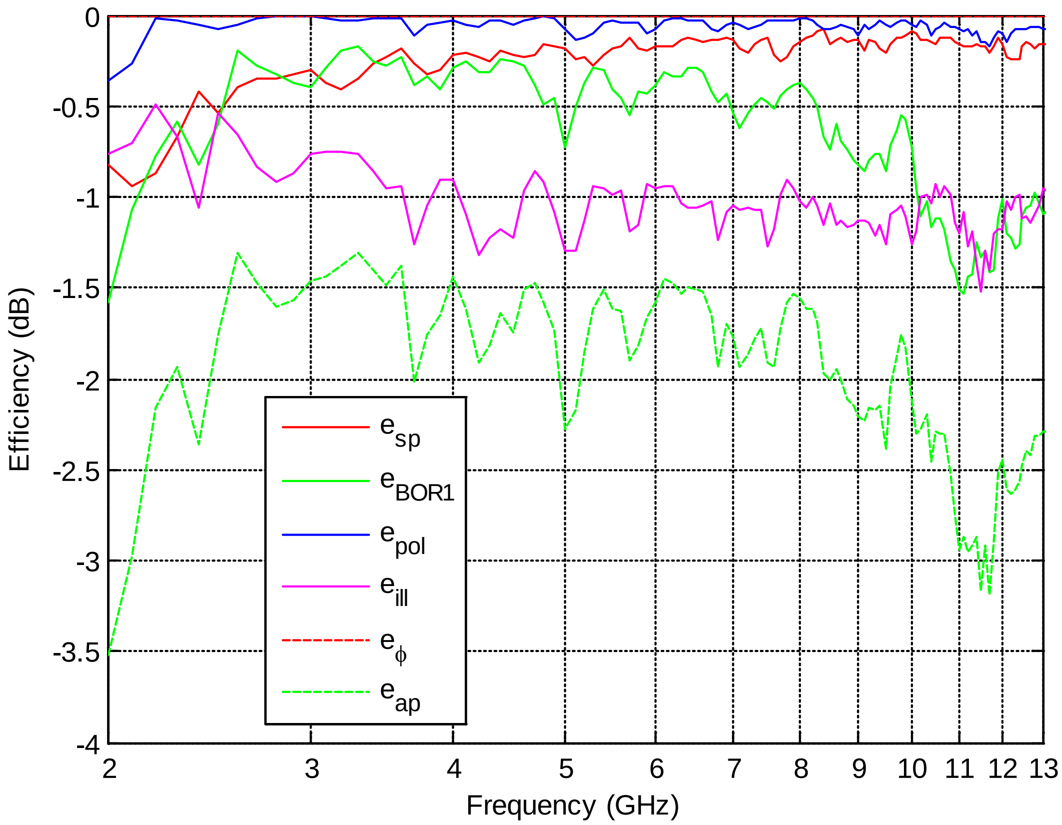
(power dividers and cables were calibrated away)



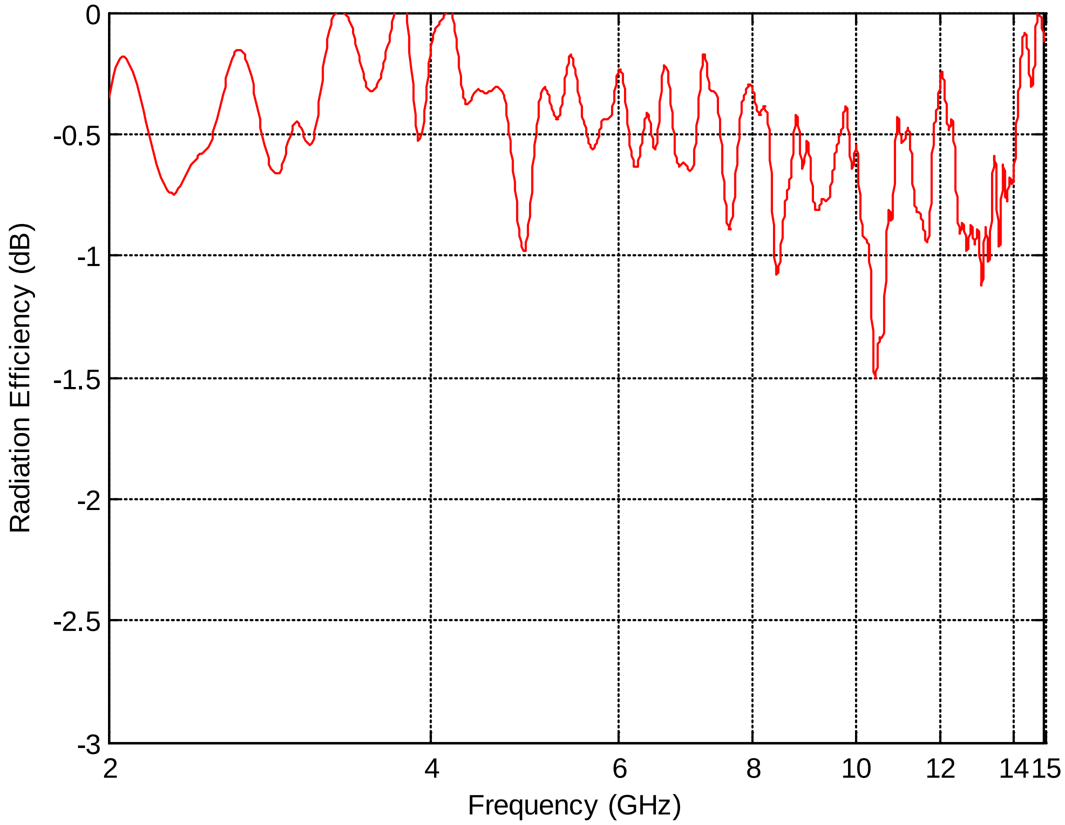
Sub-efficiencies from measured radiation patterns at TUD

Looks good, except for BOR1 efficiency below 2.5 GHz and above 9 GHz.

BOR1 efficiency is power lost in sidelobes due to higher order ϕ variations.



Radiation Efficiency



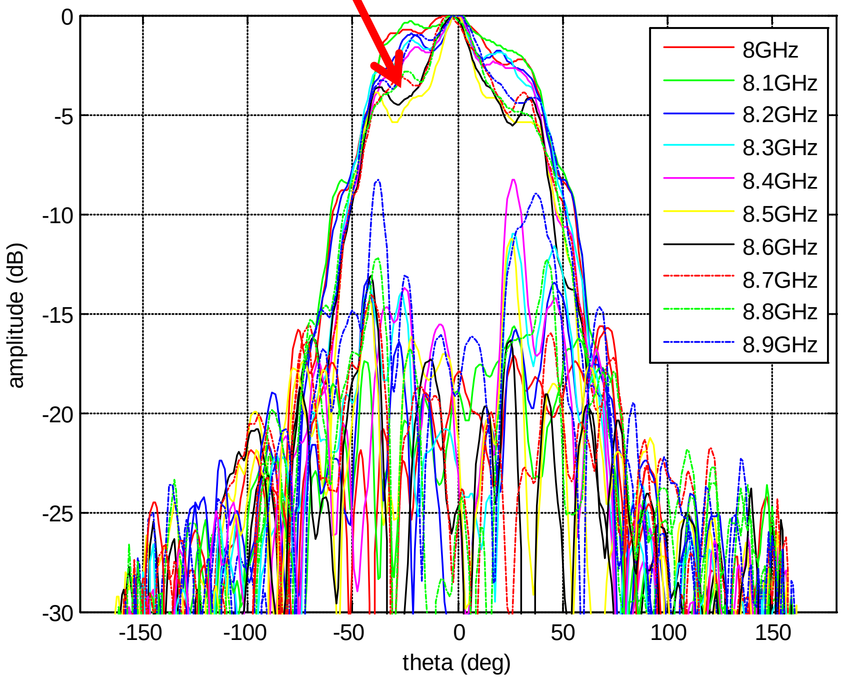
Obtained from gain and radiation patterns measured at TUD.

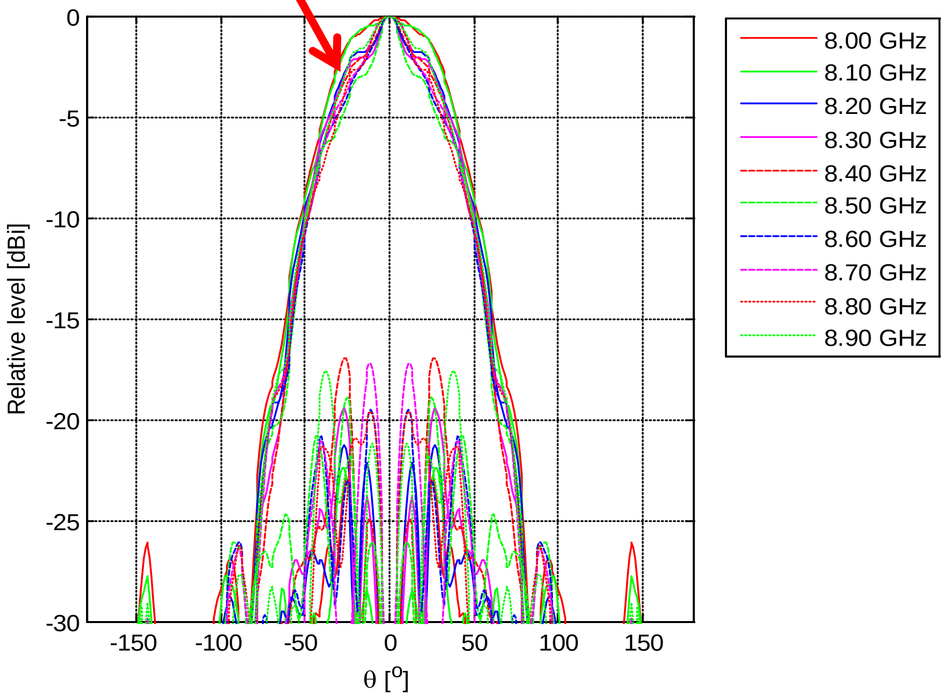
Not very accurate due to the multiple reflections in the feeding network, specially for high frequencies.

It looks as if losses in feed itself are better than 0.5 dB.

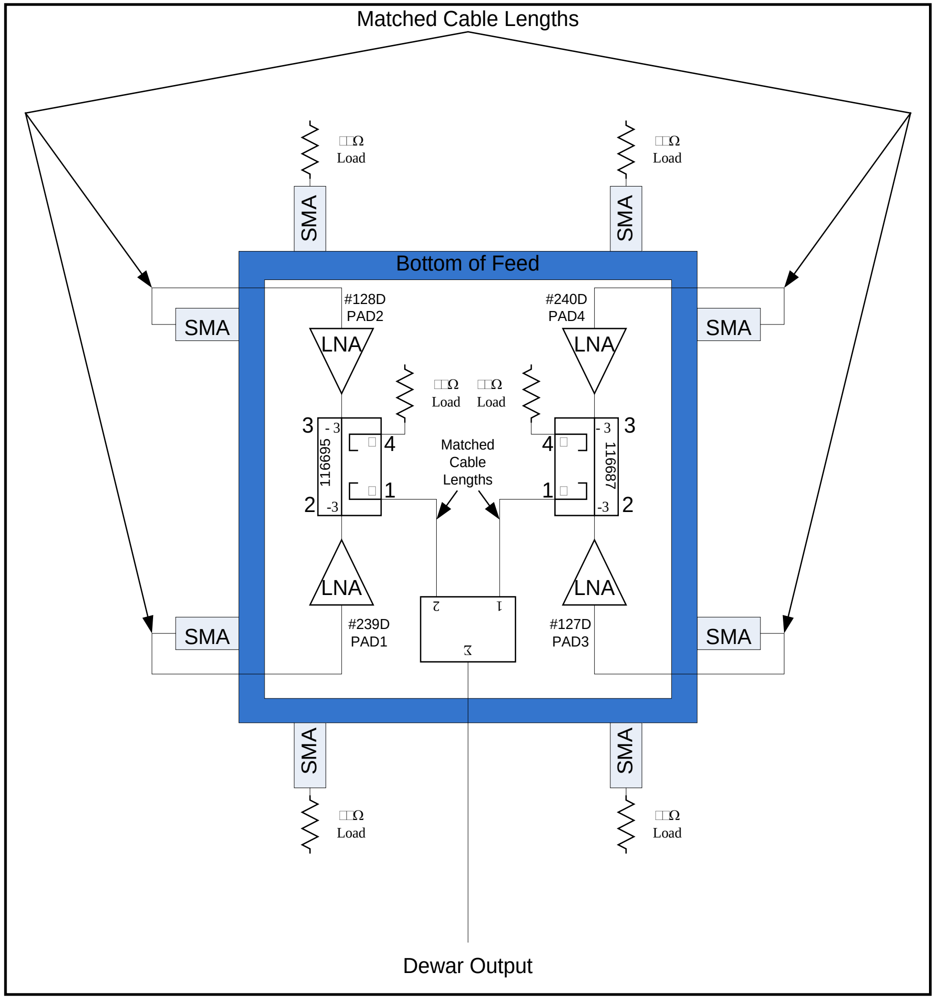
Co- and crosspolar patterns in 45 deg plane

total and with removed higher order ϕ variations

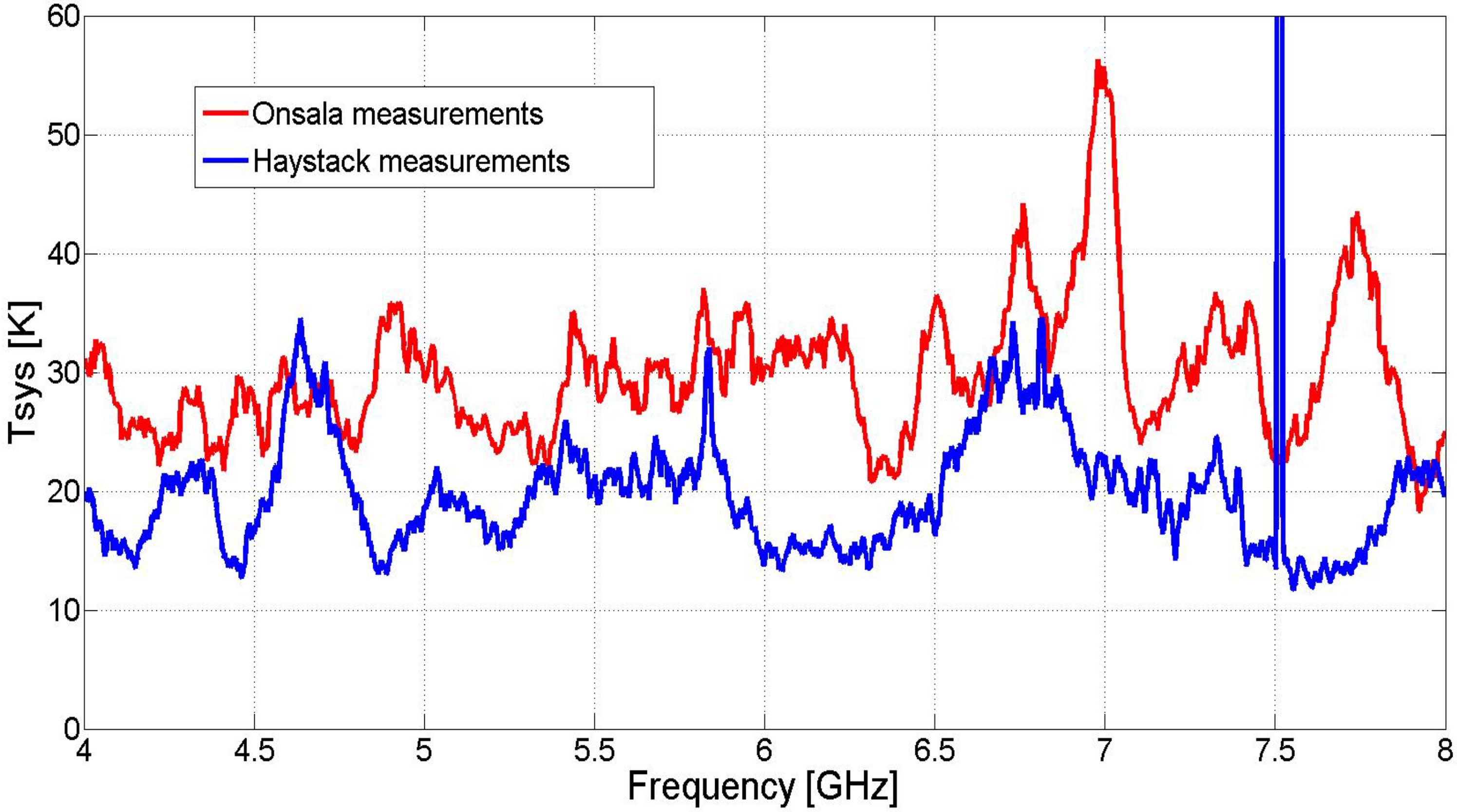




Noise Temperature Measurements



Measured System Noise Temperature



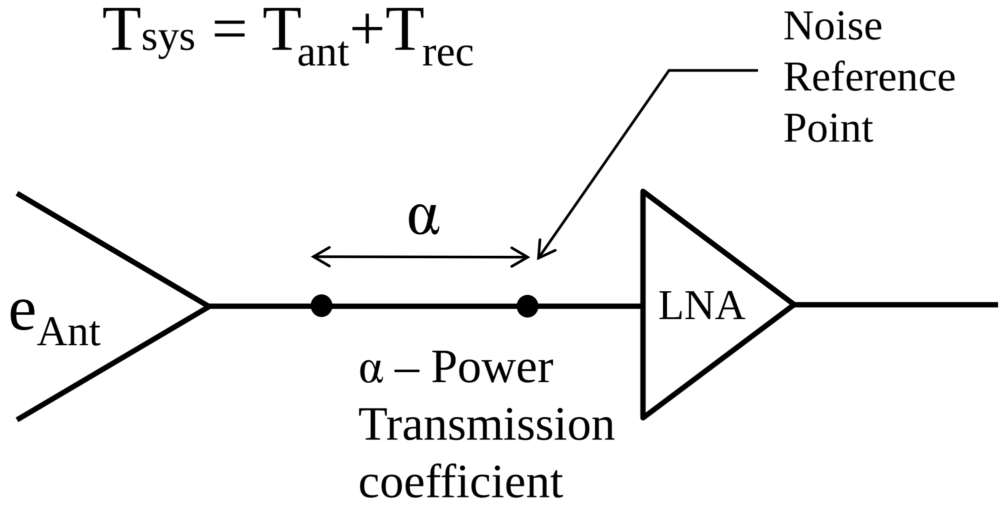
Average Tsys of Onsala: 29K (4-8GHz), Haystack: 17 K (2-10 GHz)

Standard System Noise Model

$$T_{sys} = T_{ant} + T_{rec}$$

$$T_{ant} = T_{bg} e_{Ant} + T_{amb}(1 - e_{ohmic})$$

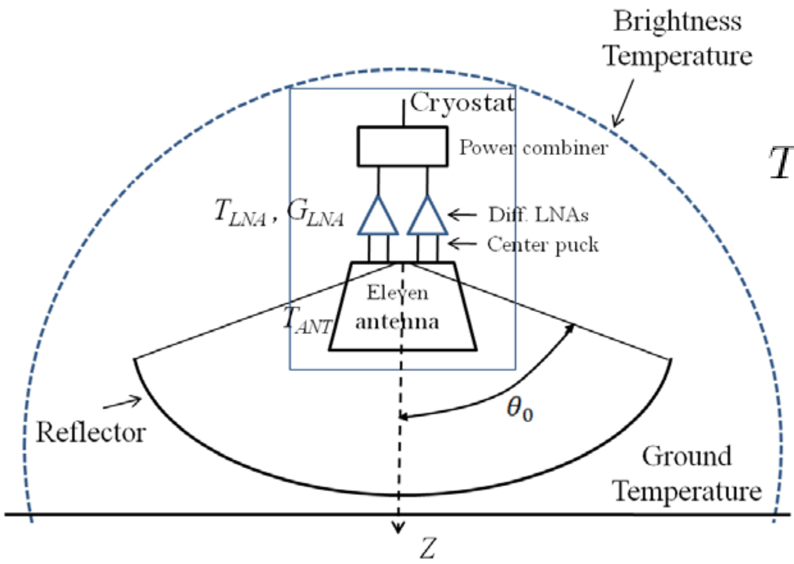
$$e_{Ant} = e_{ap} e_{pol} e_{rad}$$



$$T_{rec} = (1-\alpha)T_{amb} + T_{LNA} \qquad (1 \geq \alpha > 0)$$

Kildal P., Foundations of Antennas, 2009
Woestenburg B., SKA Memo 98 2008

Brightness Temperature



$$T_b(f) = T_{b0}(f)\, e^{-\tau_\nu(s_0)} + \int_0^s k_a(f,s)\, T(s)\, e^{-\tau_\nu(s)} ds$$

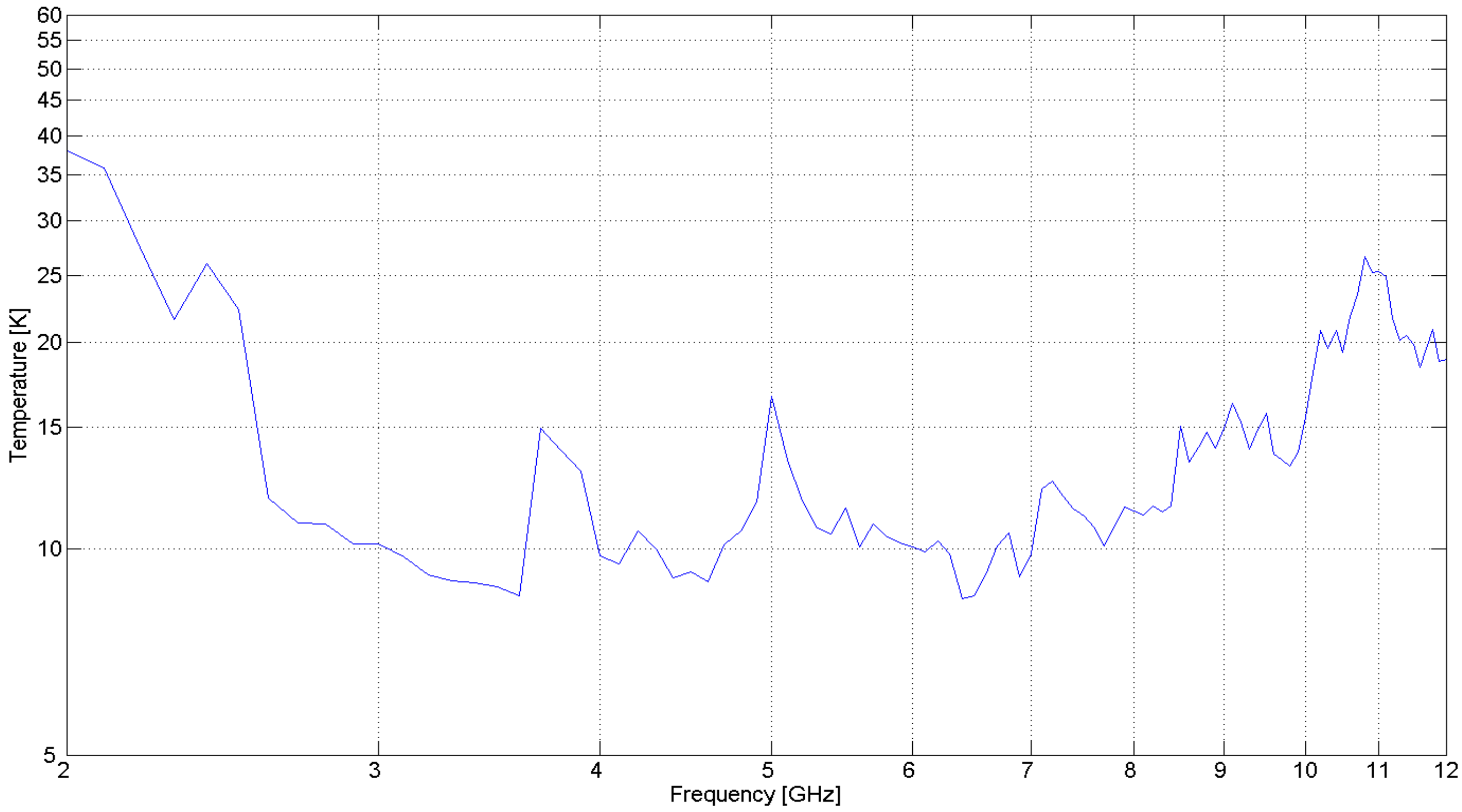
$$\tau_\nu(\theta) = \int_0^\infty \frac{k_a(f,s)}{\sqrt{1 - [\sin\theta/(1+s/R)]^2}} ds$$

$$T_a = \frac{\iint\limits_{4\pi} T_{bg}(\alpha(\theta,\varphi)) \left[|G_{\mathrm{co}}(\theta_f)|^2 + |G_{\mathrm{xp}}(\theta_f)|^2 \right] \sin\theta d\theta\, d\varphi}{\iint\limits_{4\pi} \left[|G_{\mathrm{co}}(\theta_f)|^2 + |G_{\mathrm{xp}}(\theta_f)|^2 \right] \sin\theta d\theta\, d\varphi}$$

1

Medellin G. C., SKA Memo 95

Predicted Brightness Temperature



LNA Noise Model

$$T_{LNA} = T_{min} + 4\mathrm{N}T_o \frac{|\Gamma_{in} - \Gamma_{opt}|^2}{(1-|\Gamma_{in}|^2)(1-|\Gamma_{opt}|^2)}$$

Assuming a common system impedance:

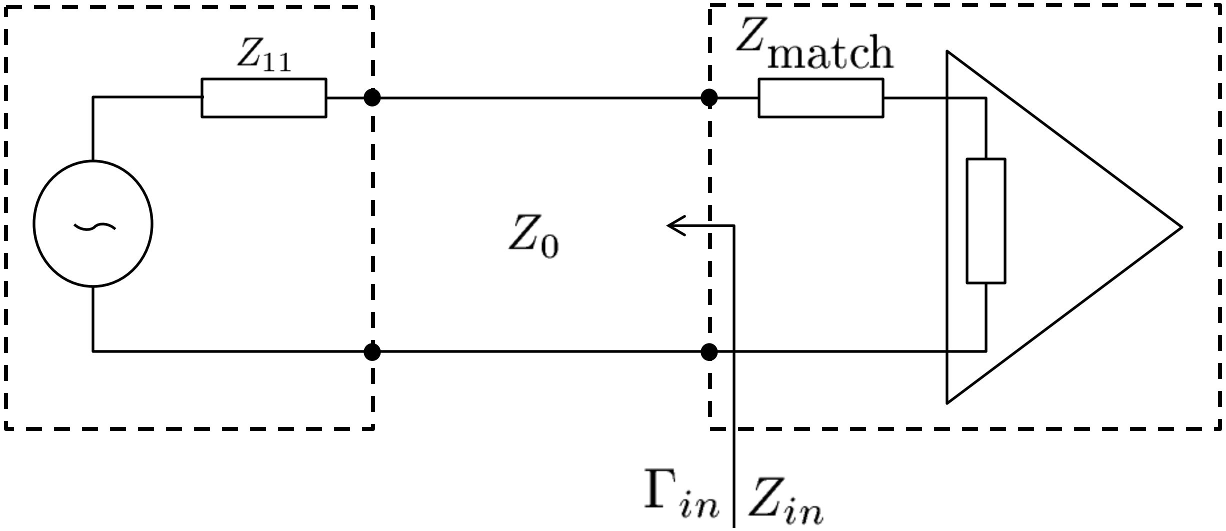
$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad \Gamma_{opt} = \frac{Z_{opt} - Z_0}{Z_{opt} + Z_0}$$

Gives the form:

$$T_{LNA} = T_{min} + \mathrm{N}T_o \frac{|Z_{in} - Z_{opt}|^2}{R_{in} R_{opt}}$$

Hilbrand H., Russer P. H., IEEE Transactions 1976
Rothe H., Dahlke W., Proceedings of the IRE 1956

LNA Noise Model

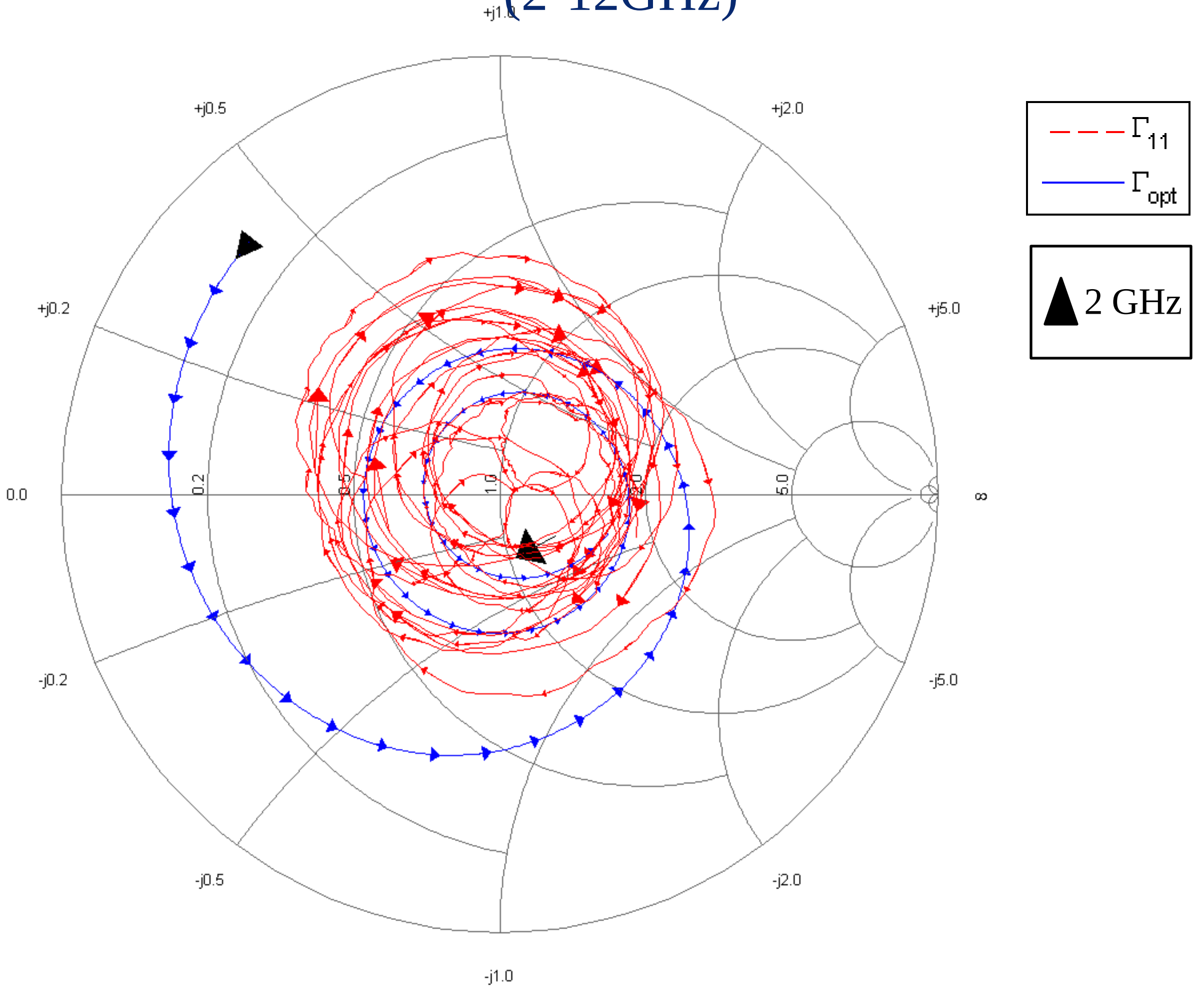


$$T_{LNA} = T_{min} + \mathrm{N}T_o \frac{|Z_{in} - Z_{opt}|^2}{R_{in} R_{opt}}$$

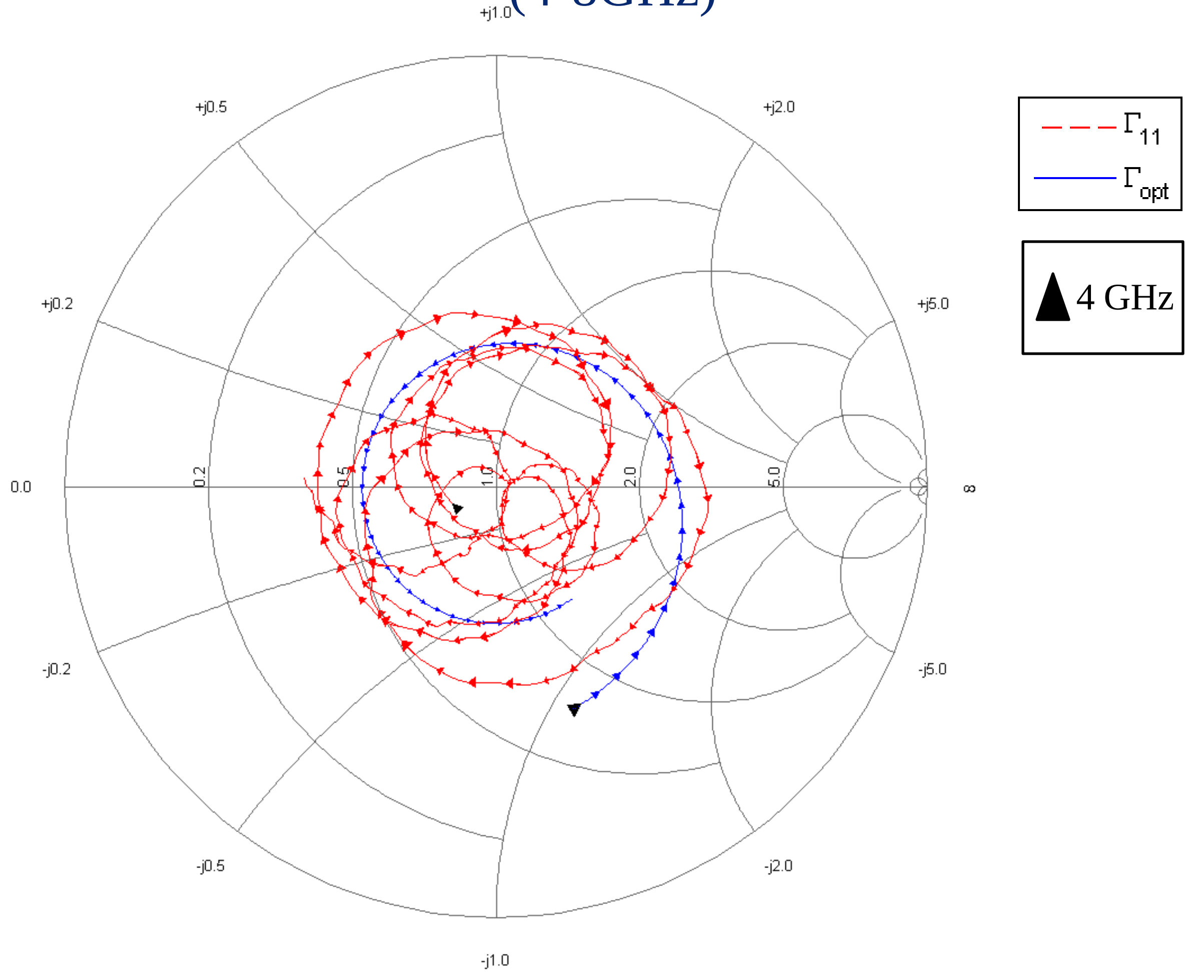
$$Z_{\text{match}} = Z_{optLNA} - Z_{in} \text{ (ideal)}$$

$$Z_{\text{match}} = Z_{optLNA} - Z_0 \text{ (system)}$$

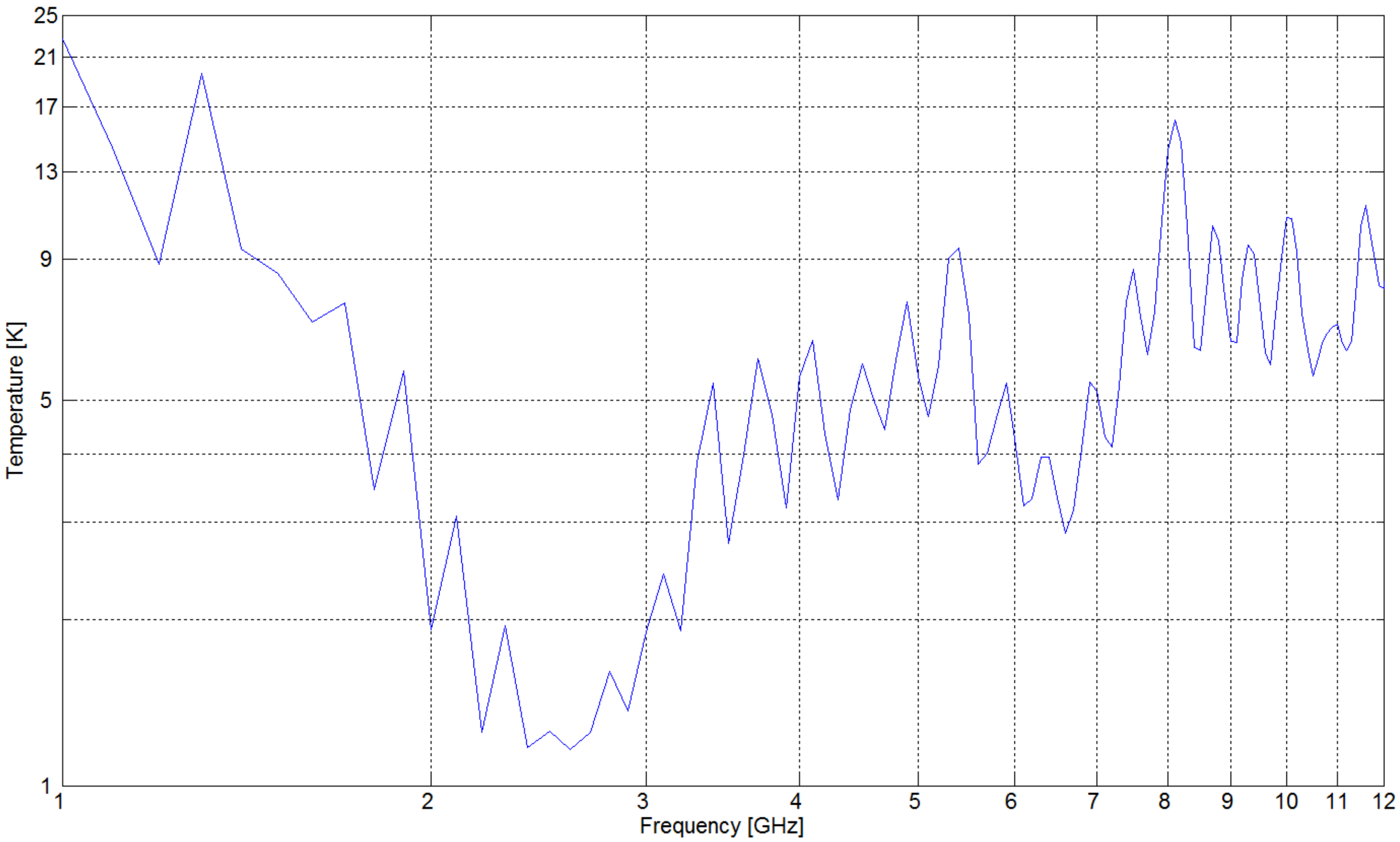
Γ_{opt} and Γ_{11} Comparisons (2-12GHz)



Γ_{opt} and Γ_{11} Comparisons (4-8GHz)

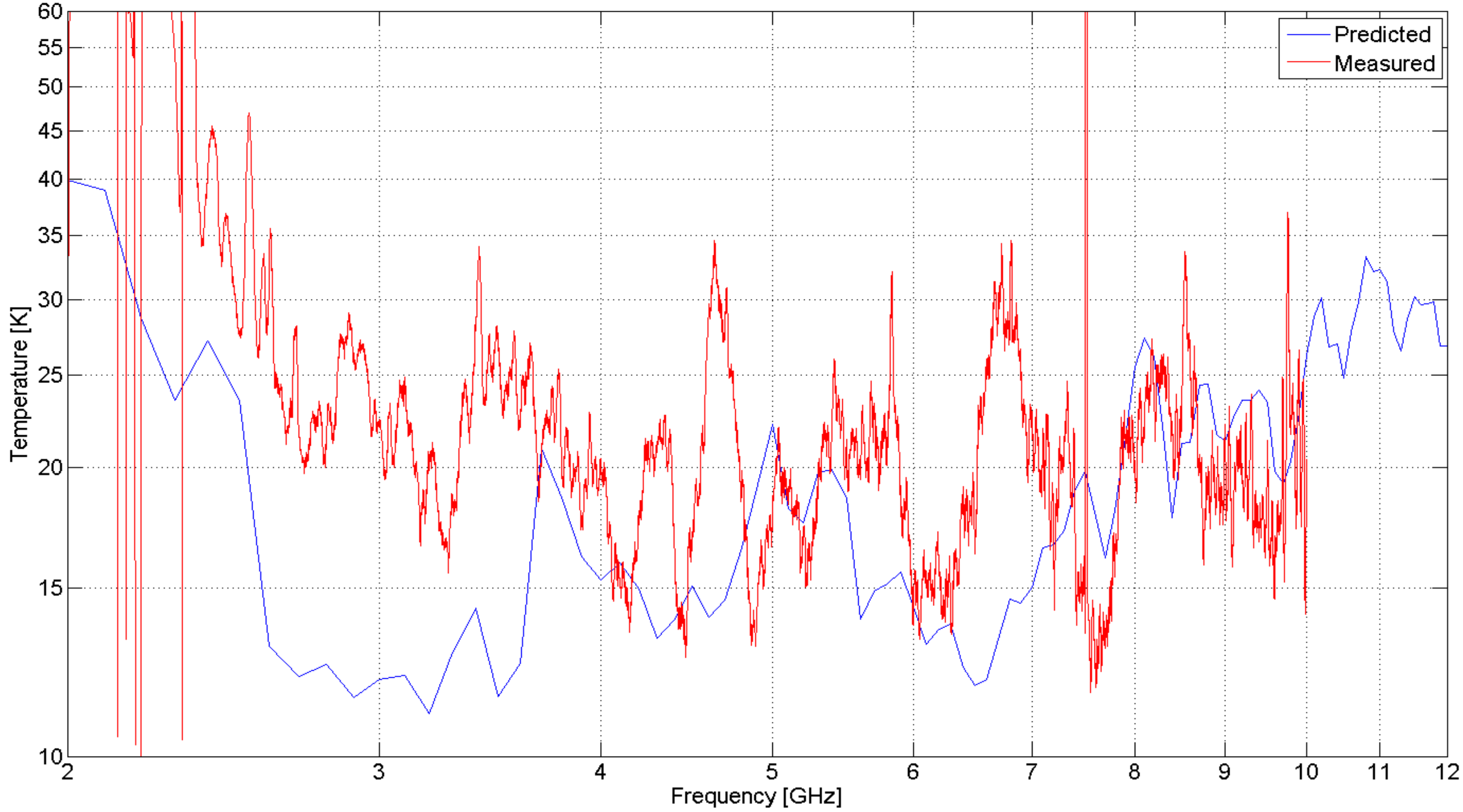


Modeled LNA Noise Temperature, (with missmatch)

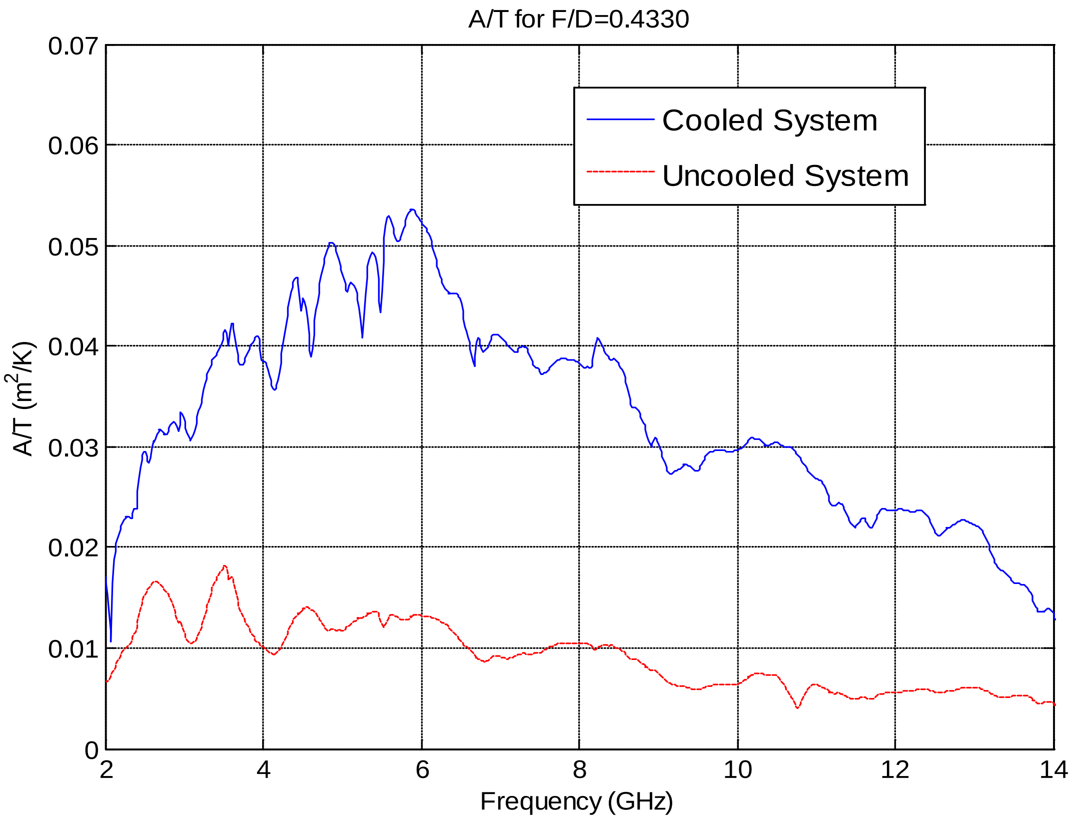


Measured vs. Simulated Results

(Haystack Observatory)



Predicted figure of merit A/T



A/T of the Eleven feed system

- For a reflector of 1 m^2 area with subtended half angle of 60^o, i.e. F/D = 0.433.
- Cooled system is with Caltech cryogenic LNA and cryostat is at 30 K.
- The uncooled system is with Chalmers room temperature LNA at room temperature.

Conclusions

- The cooled Eleven feed, with LNA, provides measured Tsys of 13-30 K with Caltech LNAs, a bit higher than predicted.
- Could be improved by better impedance matching, although not critical.
- A Better loss estimate is need for a more realistic model.
- Cooling, of such systems, is considered critical.

References and Acknowledgments

Acknowledgments

- Work done in collaboration with the MIT Haystack Radio Observatory and Onsala Radio Observatory.
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- References
- Definition of Array Receiver Gain and Noise Temperature, Bert Woestenburg, SKA Memo 98.
- Antenna Noise Temperature Calculation, German Cortes Medellin, SKA Memo 95
- Foundations of Antennas, Per-Simon Kildal.