Cryogenic integration of the 2-14 GHz Eleven Feed in a wideband receiver for VLBI2010

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Outline

- The Eleven Feed Project
- Electrical design
- Mechanical and cryogenical design
- Room temperature measurement results
- Cryogenic performance
- Noise model, expected performance and measurements
- Future development

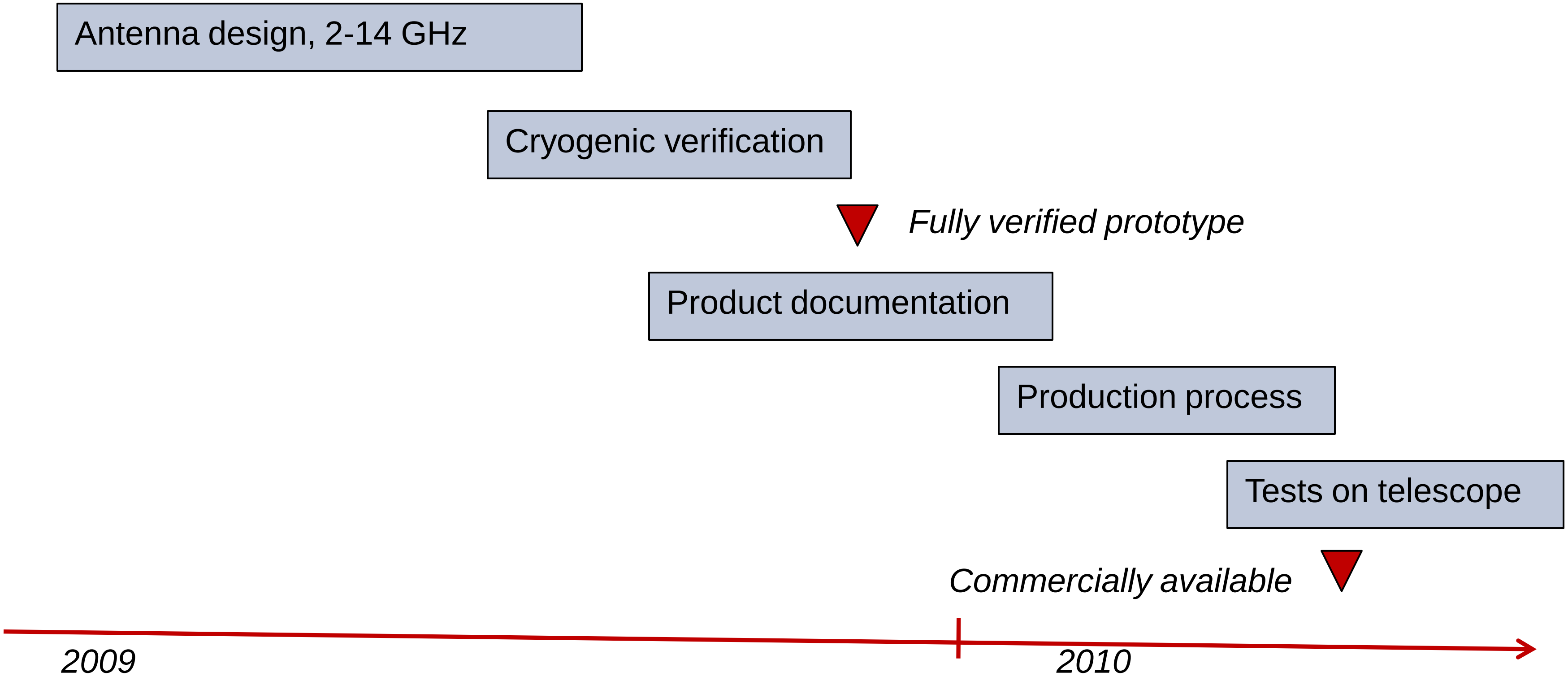
Organization of the project

- **Prof Kildal's antenna group, Chalmers:**
  - electrical design of the feed (Per-Simon Kildal, Jian Yang)
  - characterization measurements (Jian Yang)
  - descrambling board (Mojtaba Zamani, Master student)
  - packaging (Ashraf Uz Zaman)
  - twin lead line and wide band baluun (Yogesh Karandikar, Ahmed Hussain)
- **Onsala Space Observatory (OSO), Chalmers:**
  - Project leadership (Miroslav Pantaleev)
  - mechanical design (Leif Helldner), fabrication of mechanical components (workshop at OSO), cryogenics (Christer Hermansson, Per Björklund, Miroslav Pantaleev, Leif Helldner).
- **Department of Microelectronics and Nanoscience (MC2), Chalmers:**
  - design and fabrication of uncooled LNA (Niklas Wadefalk)
- **Hartebeesthoek Radio Astronomy Observatory (HartRAO), South Africa:**
  - PhD student (Benjamin Klein) working on the Feed system design

Partners

- **California Institute of Technology (Caltech):**
  - Sander Weinreb –integration of cryogenic LNA in one feed prototype
- **Haystack radio telescope, MIT:**
  - Christopher Beaudoin, Arthur Niell - VLBI 2010 with Eleven Feed and Lindgren feed on two telescopes in US

Eleven Antenn – Development Roadmap



- This was shown on the VLBI2010 workshop at Wettzell in 2009, and so far we follow the plan.

Eleven Antenn – Production so far

- Feed #1 - ordered by Norwegian Mapping Authority “Statkart”
- Feed #2 – ordered by “Vertex Antennentechnik GmbH”
- Feed #3 – Cryogenic tests at OSO
- Feed #4 – Spare
- Feed #5 – ordered by Haystack Observatory

Electrical design

Design goal:

- Minimize the reflection coefficient at the input port of the petals
- Retain the good radiation performance, between 2 and 14 GHz
- By avoiding a strong reflection at the input port of the feed, the system noise temperature will be reduced

Special computation approach for log-periodic geometries :

- New Method: Scaled S-parameters if the log-periodic array is infinite, we have the frequency scaling on s-parameters
- Analyzed only two opposing dipole petals with both excited with the same amplitude and phase and chose the allowed dimensions within the ranges that give the best radiation field functions
- Ignoring mutual coupling between far separated elements.
- Result: reflection coefficient below –9.4 dB over 2–14 GHz when referred to an input balanced port impedance of 200 Ω

Electrical design - optimization

Six parameters are optimized:

– scaling factor **k,**

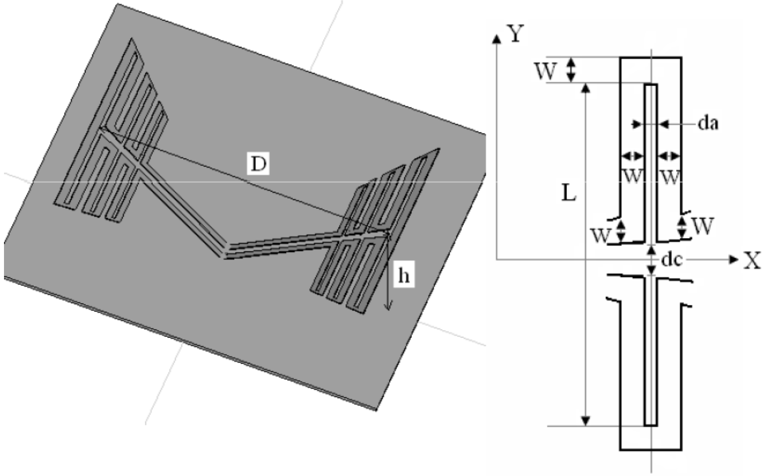
– dipole length **L,**

– arm width **w,**

– arm spacing **da,**

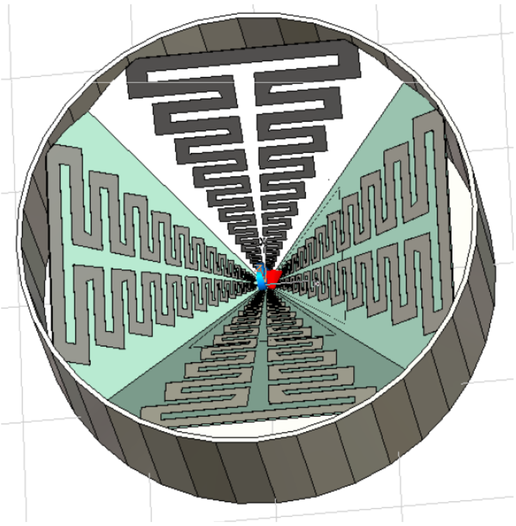
– transmission line gap **dc,**

– height above ground plane **h.**

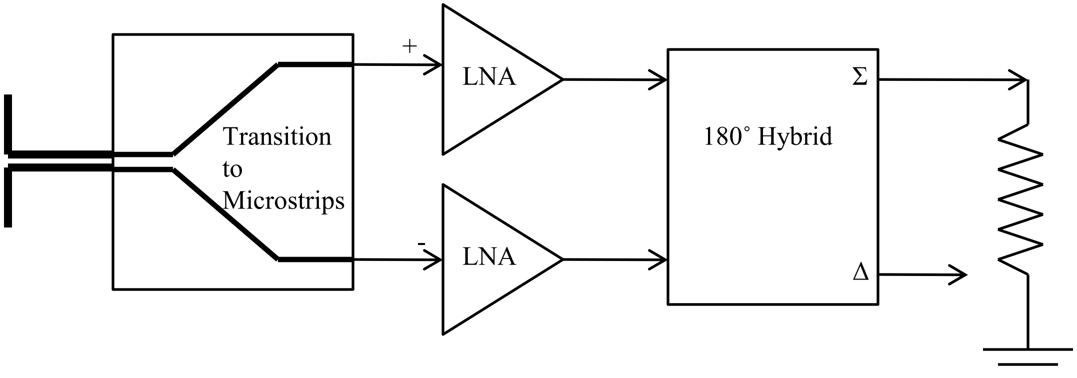


Result of optimization:

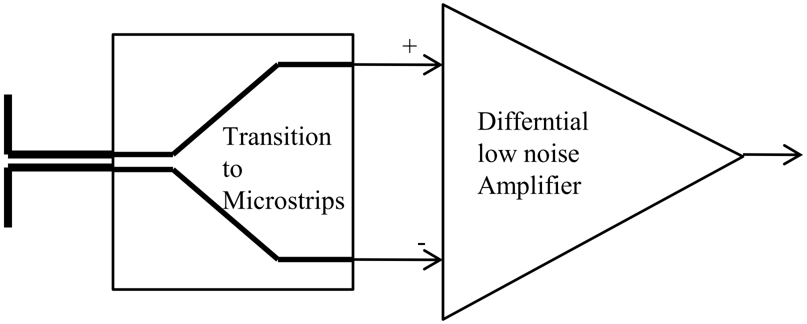
- 14 pairs of folded dipoles with scaling factor 1.24
- Reflection coefficient below –9.4 dB over 2–14 GHz
- Port impedance of 200 Ω



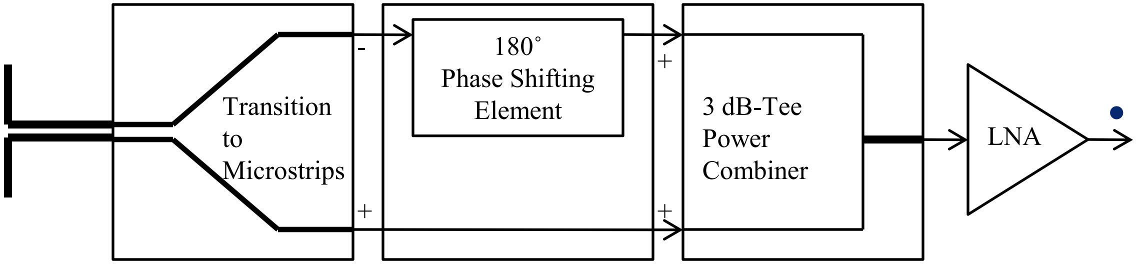
Descrambling and LNA-Integration Alternatives



- Two 50Ω LNAs and one 180˚ hybrid per petal.
- Outputs from the hybrids are connected to power combiner to get one polarization



- Active balun, i.e. one differential LNA per petal.
- Outputs from LNA are connected to power combiner to get one polarization



- Passive balun realized as 180˚ phase shifter on one line

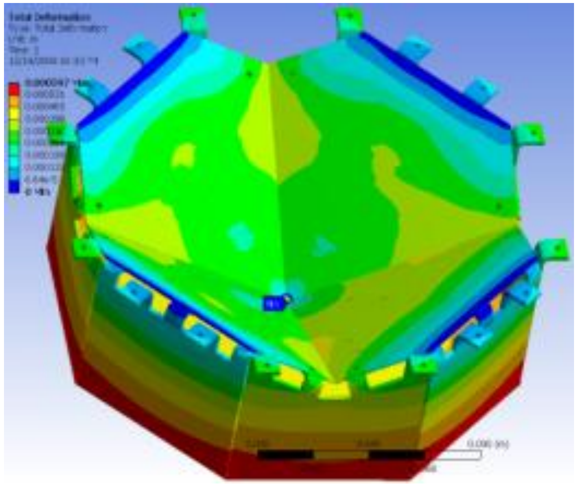
Cryogenic design

Considerations

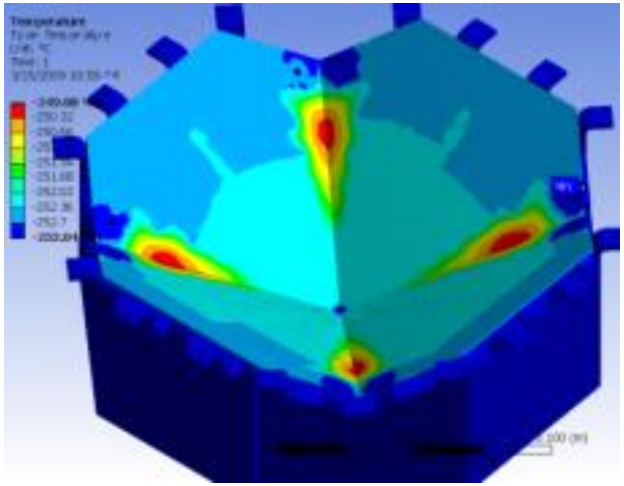
-Microwave substrate with well matched thermal expansion coefficient of copper and dielectric

-Varying thickness under dipoles at higher frequencies

-Each petal is mechanically attached to the 20K stage cooled at the centre and at 5 points at the top

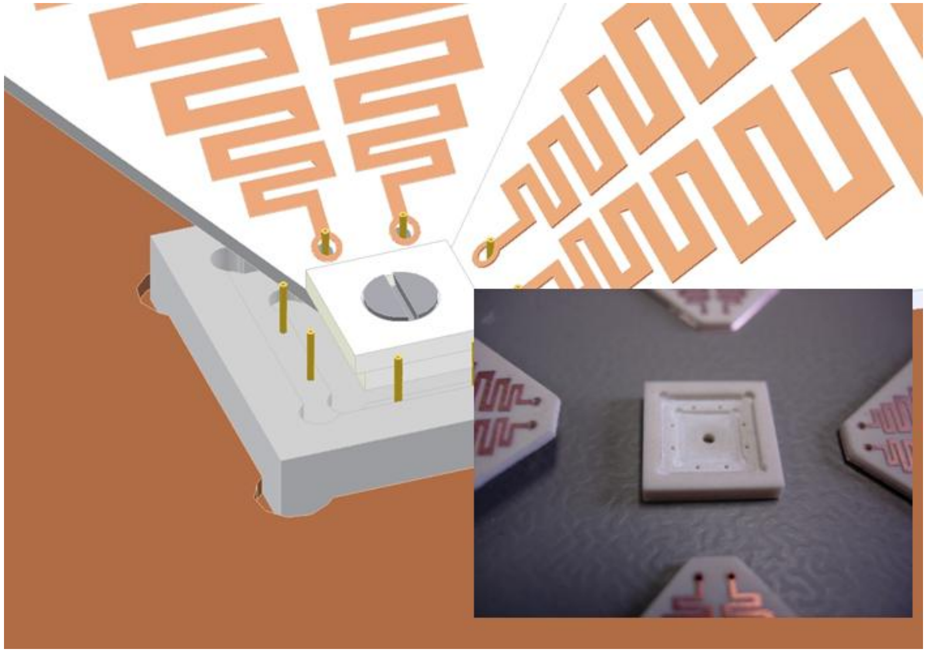


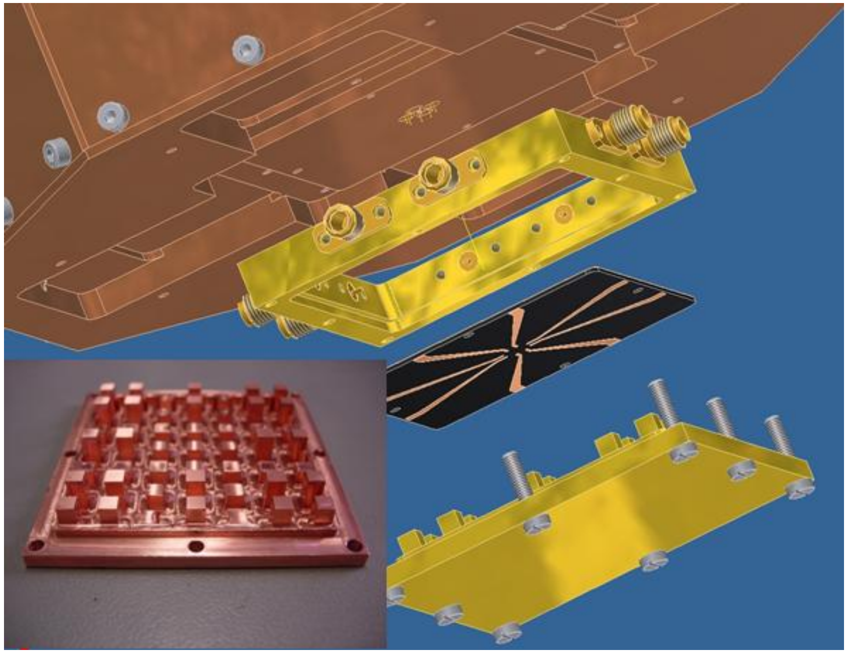
Simulated geometrical deformations of the Eleven feed when it is at the cryogenic temperature of 20 K.



Steady state analysis of the thermal distribution along the feed with head load of 20W/m2. The temperature difference between cold blue parts (-253°C) and hot red spots (-249 °C) is about 4K.

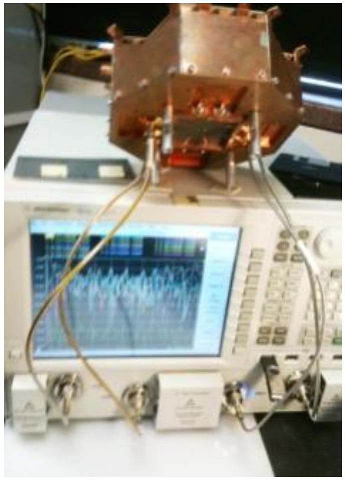
Mechanical design

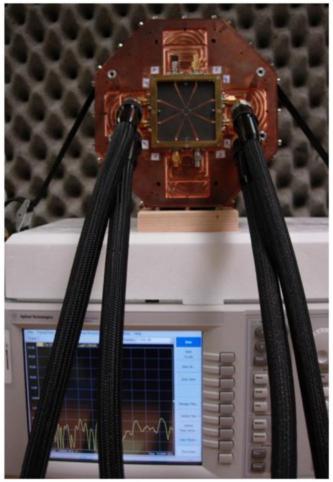


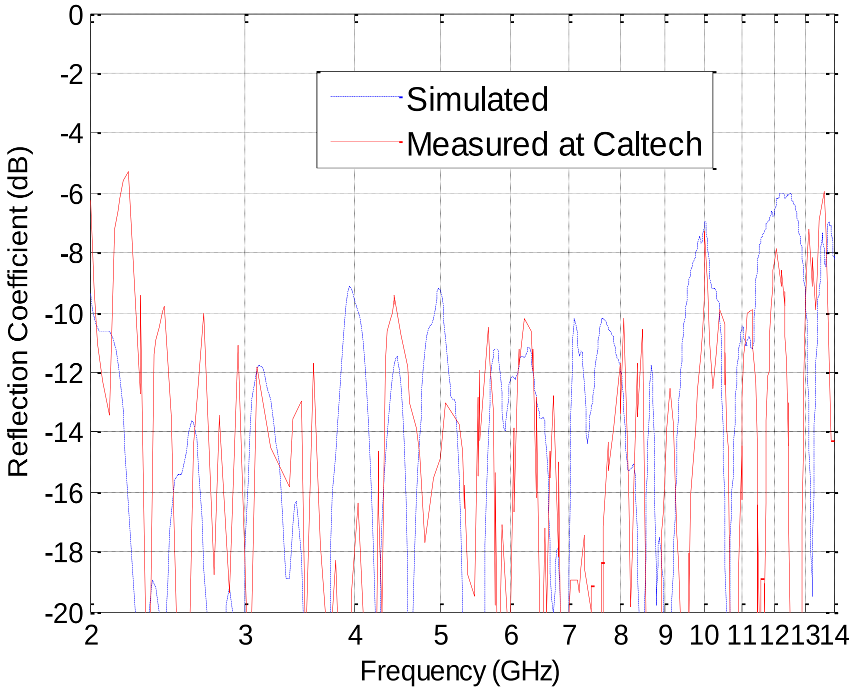


Mechanical parts:
-Four Eleven Feed petals
-Center puck
-Center plate
-8 petal support
-8 port assembly

Room temperature performance



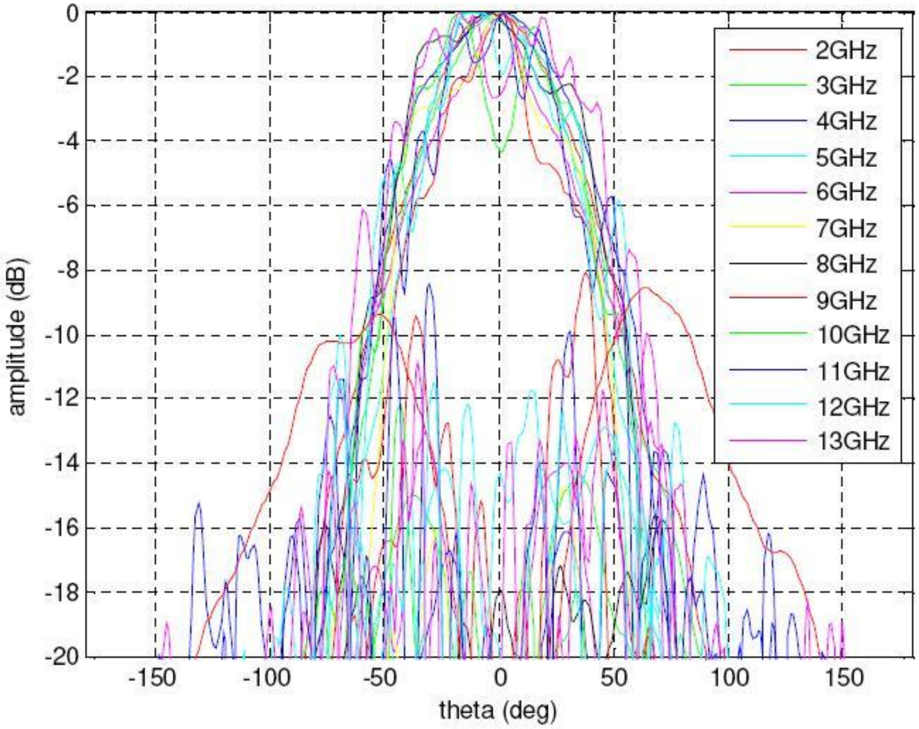


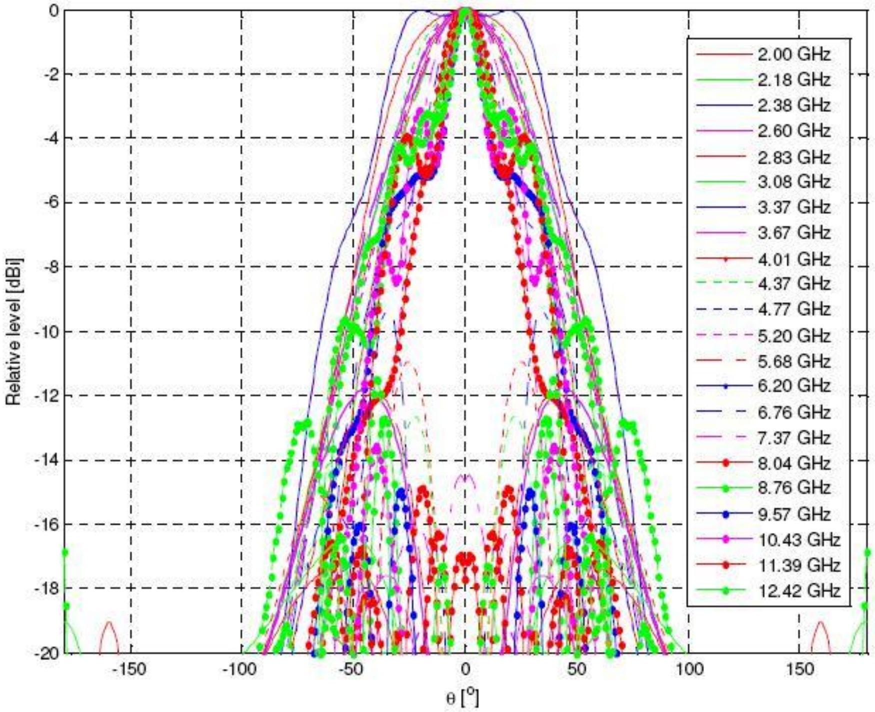


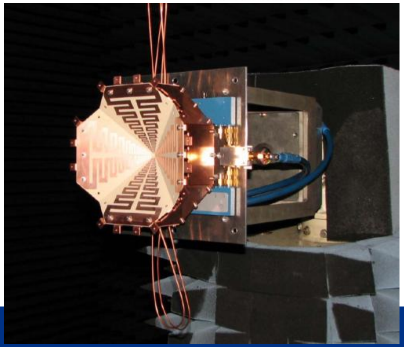
S11 measurement

- 4-port Vector Network Analyzer
- Two Feeds were measured at different laboratories: Chalmers and Caltech
- Measurement results are very close and agree very well with the simulations

Measured radiation patterns at Technical University of Denmark

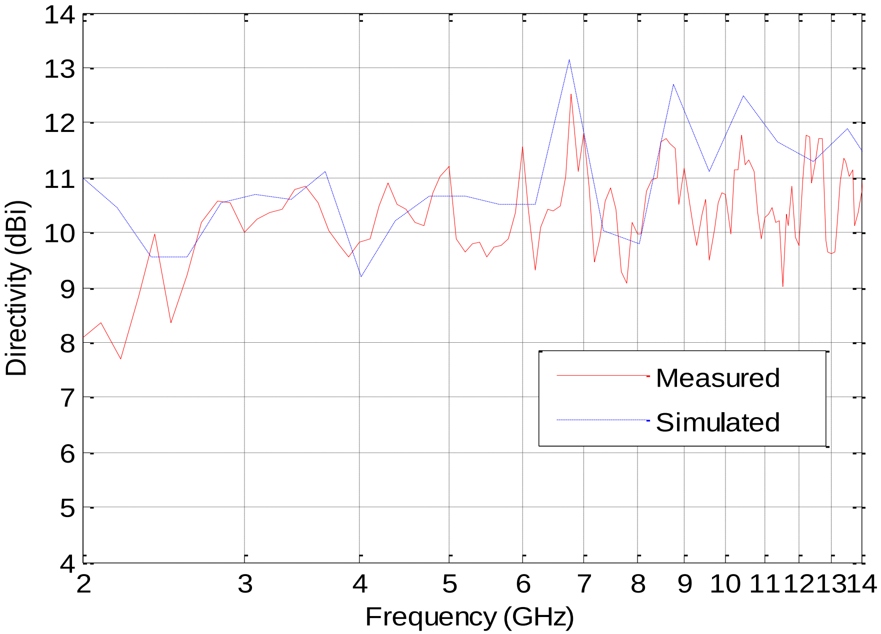


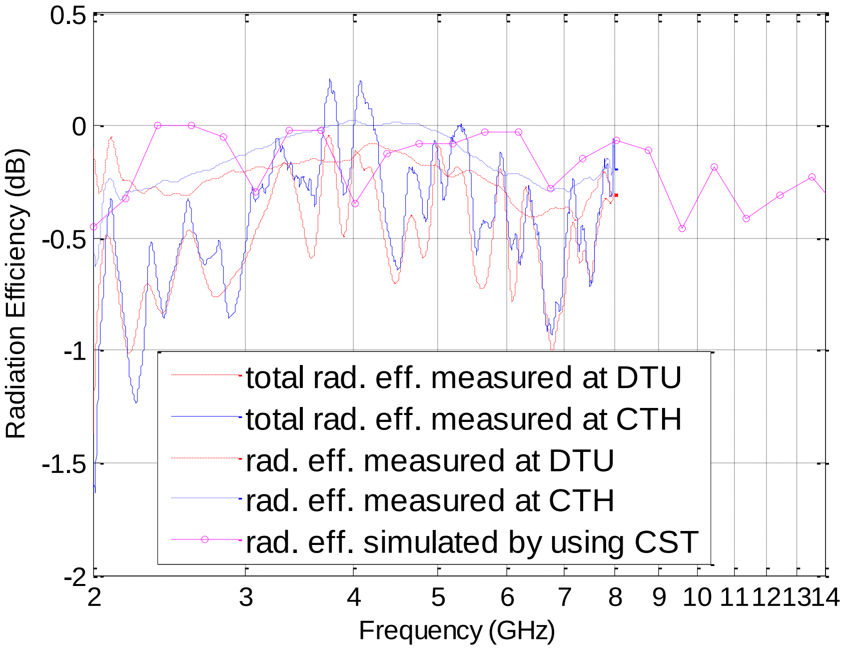




- φ : 0-360° with step 1°
- θ : 0-180° with step 1°
- Frequency: 2–15 GHz with step 0.1 GHz.
- Spherical near field measurement

Directivity and radiation efficiency





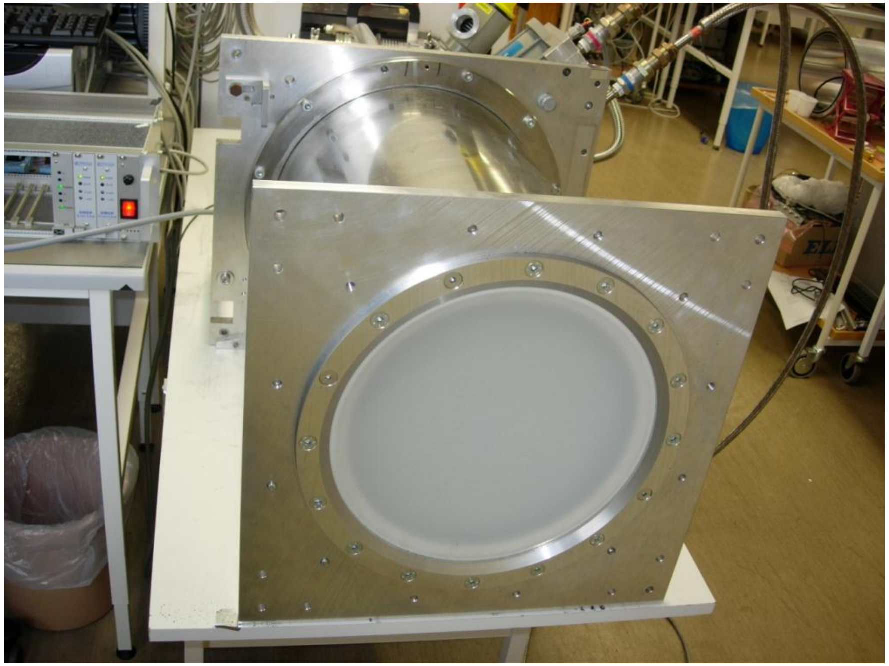
Summary on Radiation performance

- The reflection coefficient is below –10 dB for 2–13 GHz.
- The radiation pattern is constant with low cross polarization level for 2–13 GHz.
- Directivity is about 11 dBi for 2–15 GHz .
- Aperture efficiency is better than –3 dB for 2–13 GHz.

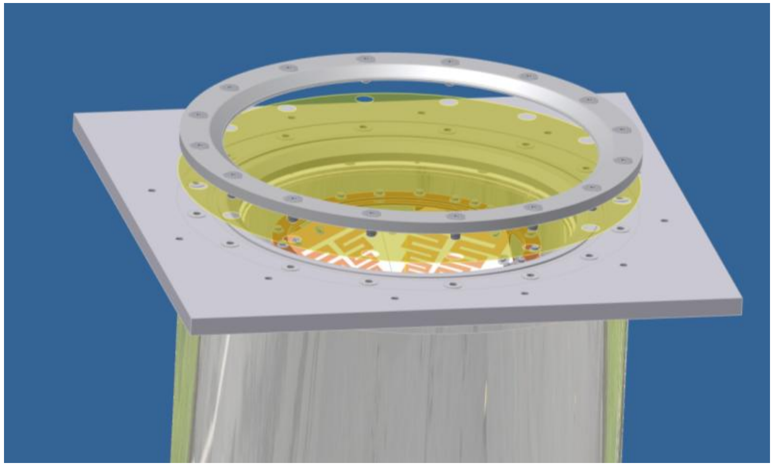
Cryogenic tests

- Test the mechanical stiffness of the feed and possibility to cool it to about 20K
- Perform S-parameter measurements to study possible degradation of the performance due to mechanical deformations
- Perform Measurements to get an idea about the expected system noise temperature

Cryostat design

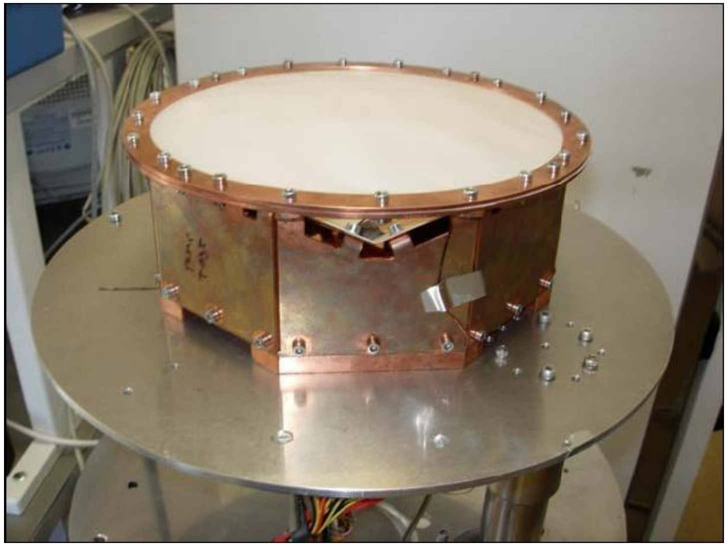


- Vacuum window 0.35mm thick Mylar
- Deflection of about 25mm
- The Feed must be moved down to allow space for the deflection

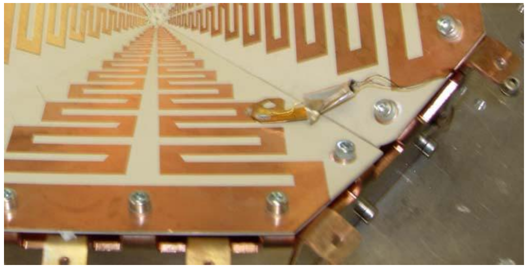


Cooling the Eleven feed to 20K

The 70K shield has infrared window of one layer Teflon

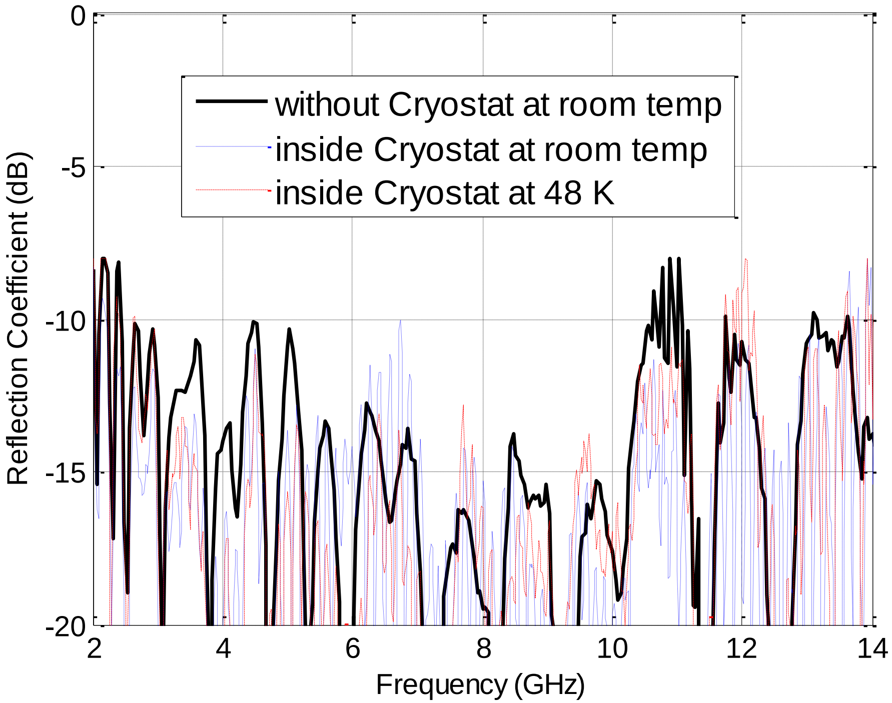


The infrared filter in front of the Feed has only two layers of Teflon separated by wedding veil. ***The temperature on the surface of the petal was 53K.***



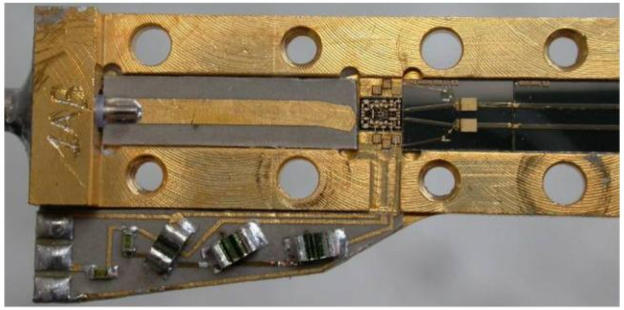
The temperature on the Feed surface is measured with temperature sensor Lakeshore DT-470 mounted on thin copper support soldered at the edge of the third dipole.

Cryogenic S-parameters measurements

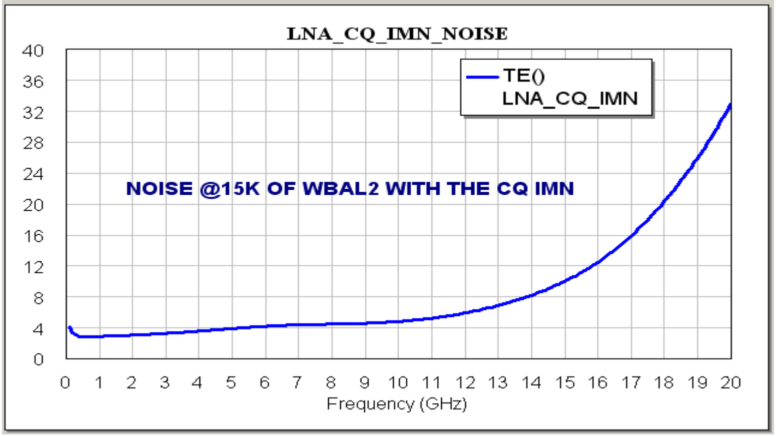


- S11 does not change when feed is cooled to cryogenic temperature.
- The small variations can be explained with the temperature dependent permittivity.
- Feeding network was connected outside cryostat
- Study of the effects of the cryostat walls at radiation pattern done at Haystack: (poster)

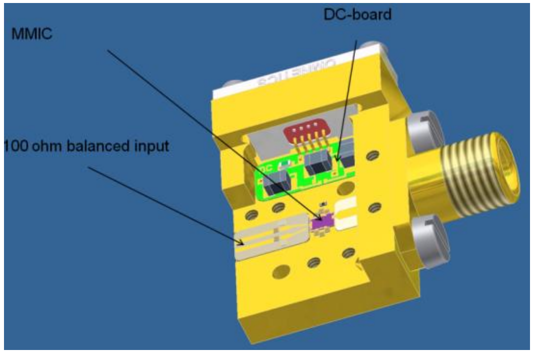
Active balun and single ended LNA - alternatives



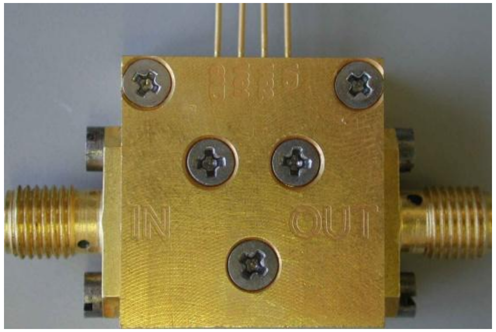
The active cryogenic balun developed at Caltech mounted in module.

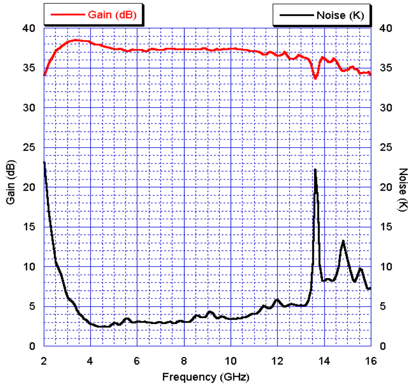


Active balun, developed at Chalmers University

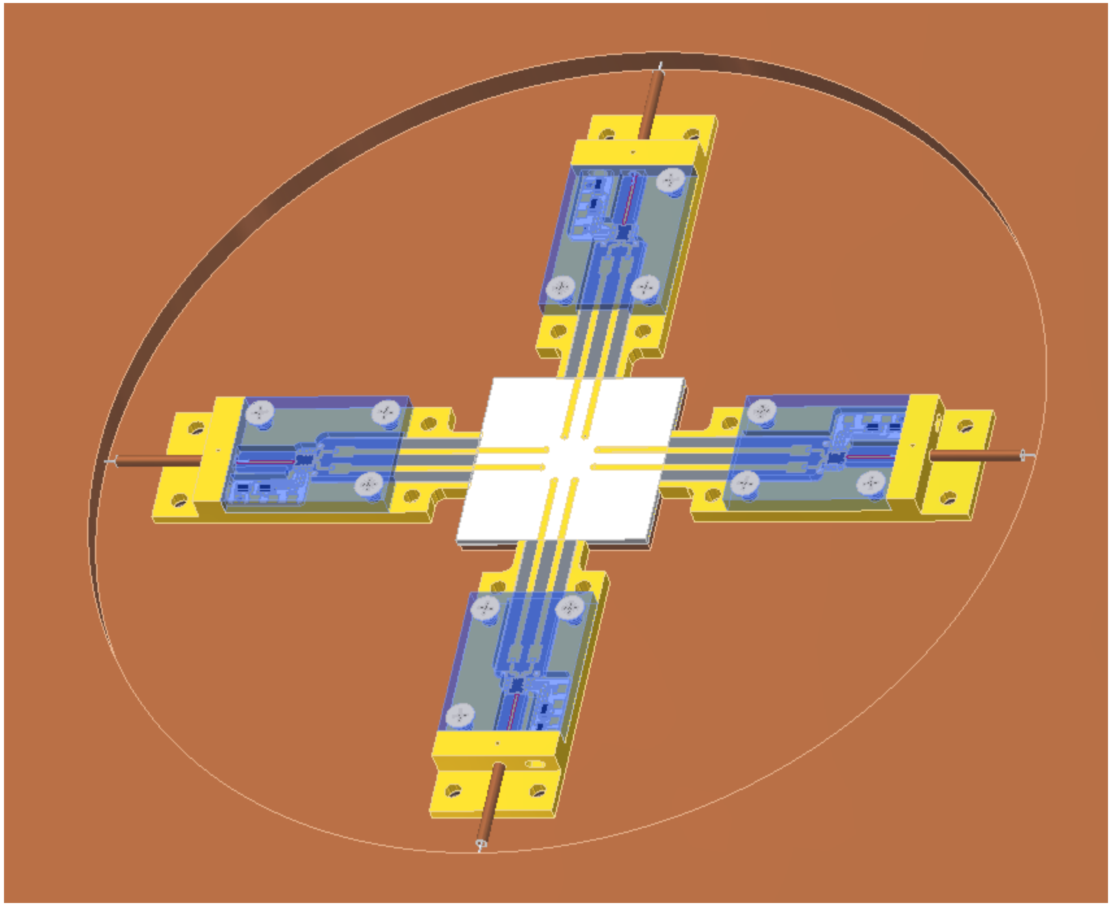


- 50 Ω cryogenic LNA developed at Caltech and its noise and gain



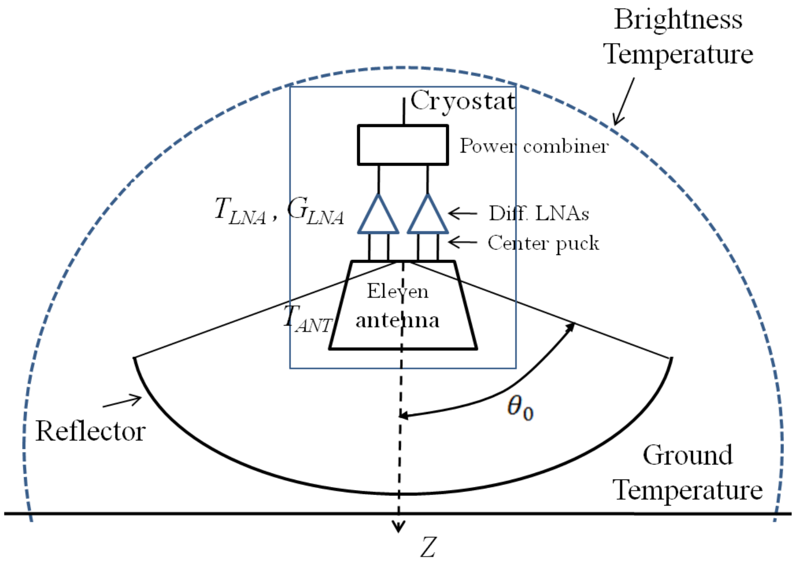


Integration with active balun



- Four active cryogenic balun from Caltech mounted on the back side of the ground plane
- Two power combiners to get two polarizations out from the cryostat
- Expected delivery of LNAs: early April 2010

System Noise Temperature Model



- Losses in the Vacuum window and IR filter are small and are neglected.
- Gain of the LNA is about 30dB and losses in cables and noise in the following components can also be neglected

- Overall system noise temperature T_{SYS} can be approximated by:

$$T_{SYS} = T_{ANT} + T_{LNA} + L_{PC}\frac{T_{PC}}{G_{LNA}} \approx T_{ANT} + T_{LNA}$$

- The antenna noise temperature T_{ANT}, which includes the effect of the mismatch between the feed and LNA, can be expressed as

$$T_{ANT} = \left[T_a e_{rad} + (1-e_{rad})T_{PhFeed}\right]e_{mismatch}$$

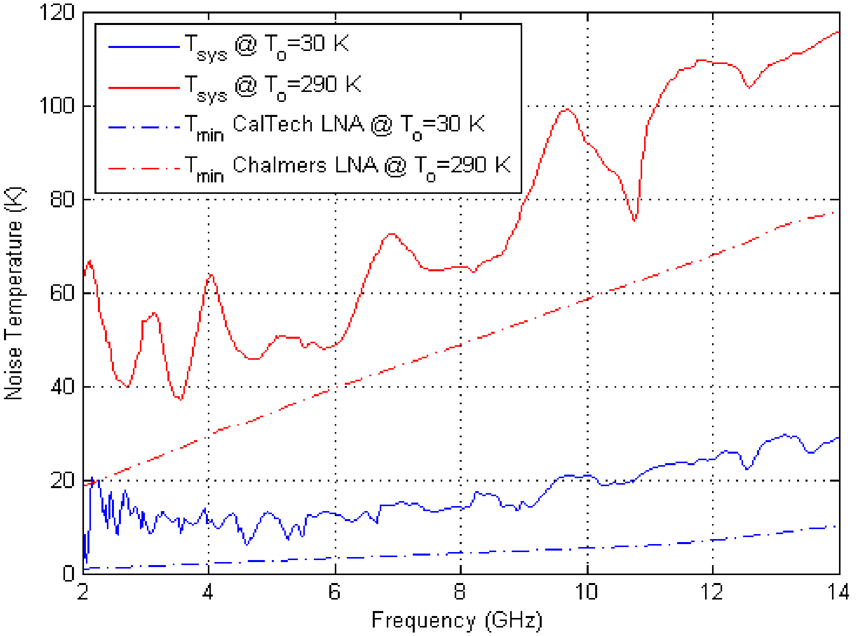
- the mismatch factor between the feed and the LNA which can be expressed as

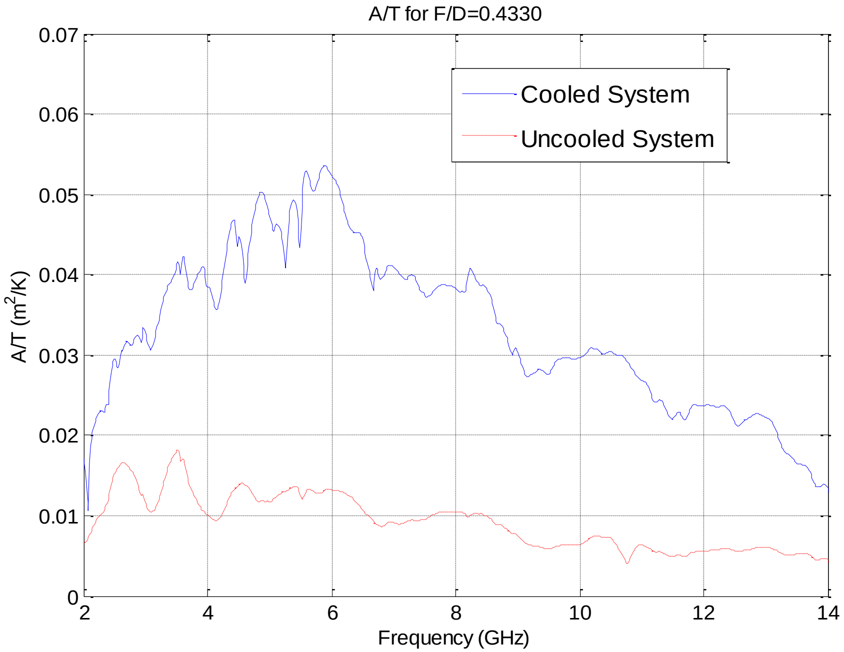
$$e_{mismatch} = 1 - \left|\frac{Z_{Eleven} - Z_{LNA}}{Z_{Eleven} + Z_{LNA}}\right|^2$$

- A/T is calculated as:

$$A/T_{m2} = \frac{e_{ap}e_{rad}e_{mismatch}\cdot 1m^2}{T_{SYS}}$$

Predicted figure of merit A/T





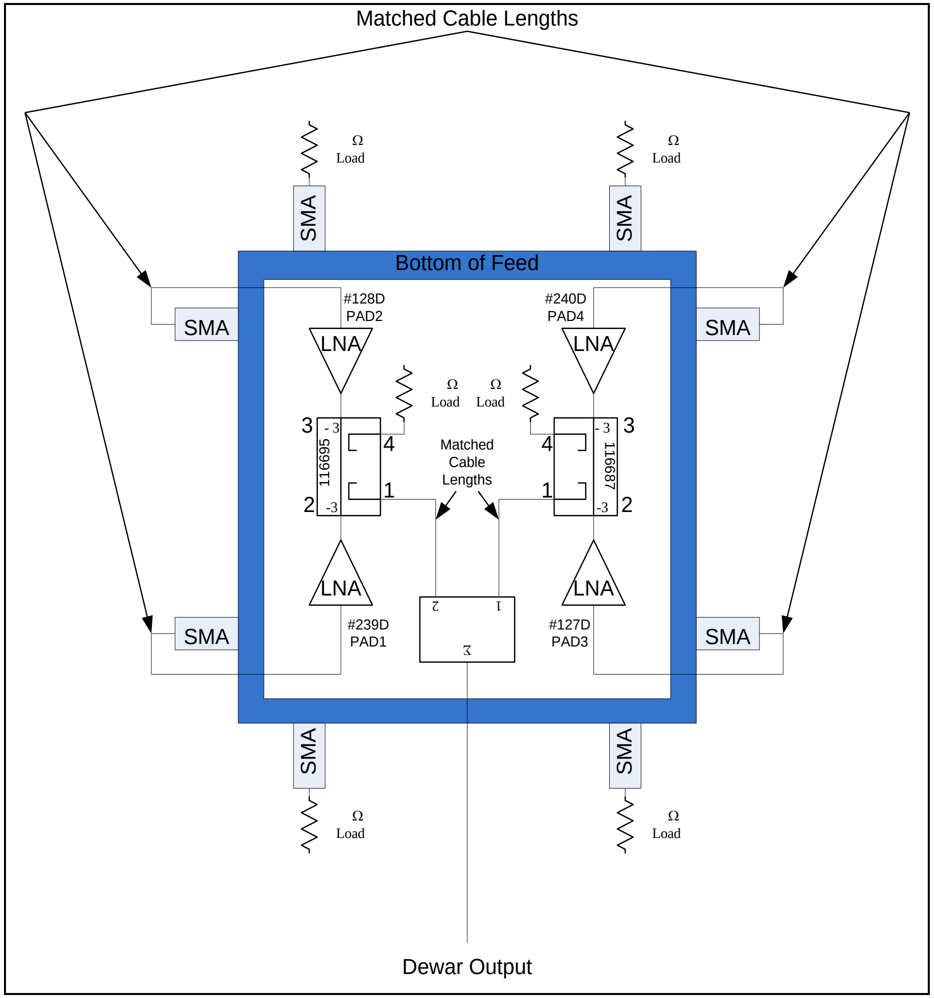
Simulated fundamental noise temperatures

- T_{LNA_min} of Caltech cryogenic LNA and Chalmers room temperature LNA,
- Estimated system noise temperatures for the cooled Eleven feed system with cryogenic Caltech LNAs
- Room temperature Eleven feed system with room temperature Chalmers LNAs.

A/T of the Eleven feed system

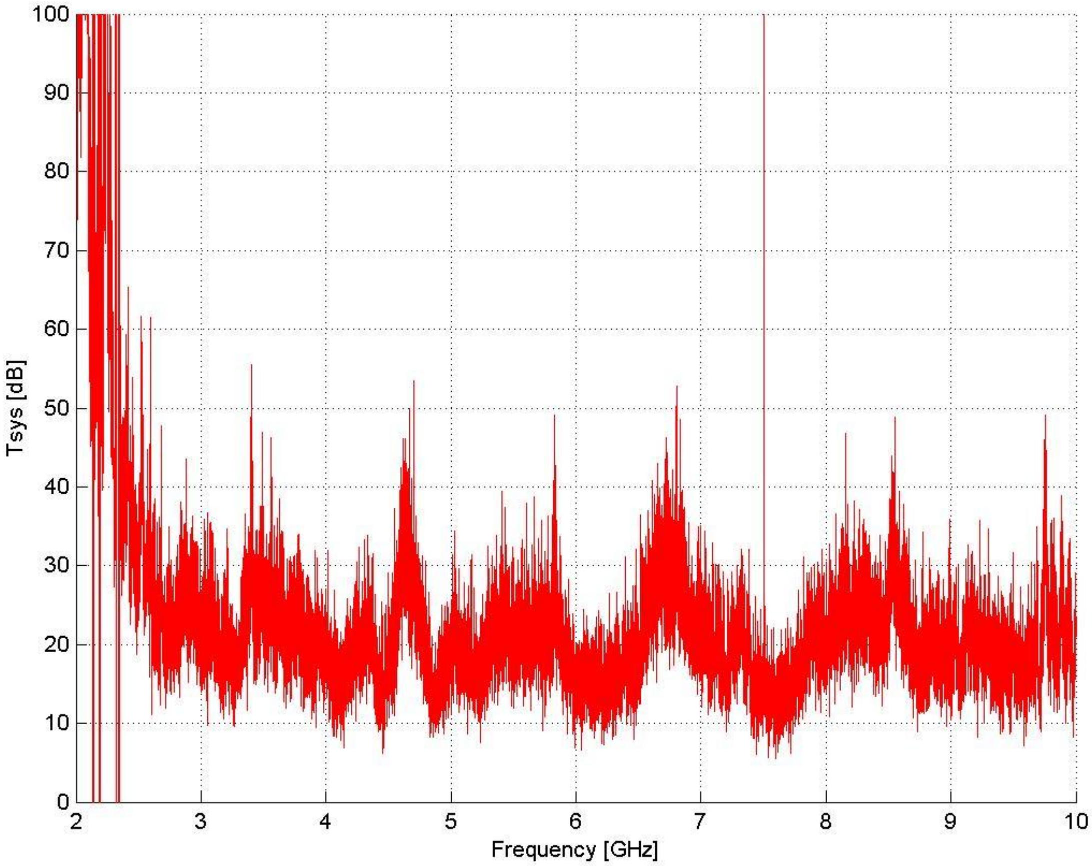
- for a reflector of 1 m^2 area with subtended half angle of 60^o, i.e. F/D = 0.433.
- Cooled system is with Caltech cryogenic LNA and cryostat is at 30 K.
- The uncooled system is with Chalmers room temperature LNA at room temperature.

Eleven feed noise measurements at Haystack



Courtesy of:
Christopher Beaudoin,
Haystack Observatory, MIT

System noise measured at Haystack



Average Tsys of 17K over 2–10 GHz band

Future work

- Integration of cryogenic differential LNA
- System noise tests
- Collaboration with MEL at Chalmers on GaAs MMICs
- Design study for installation of the feed on the Onsala 20m antenna during 2010
- Tests with broad band room temperature LNAs at one of the Onsala 2.5m antennas
- HTSC superconductors for the feeding network and the discrambler board