A Measurement Test Set for ALMA Band 9 Amplifiers

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Outline

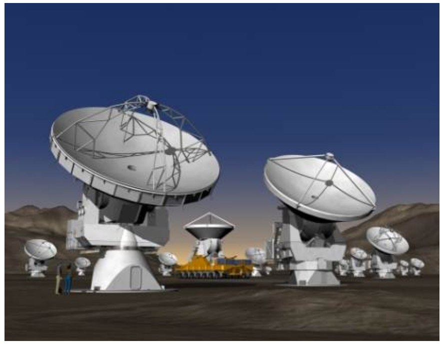
- Introduction
- System description
- Noise measurements
- Calibrations

- Lessons learned after many measurements
  - Problems related to the cold attenuator
  - Problems with the impedance presented at the input of the amplifier
  - Other problems

- Results

Introduction

- ALMA: 66 antennas
  - Main: 50 12-m antennas
  - Compact Array (ACA):12 7-m + 4 12-m antennas
  - 4 Bands to be fully completed in the first phase



- Yebes is producing ALMA IF LNAs
  - Band 7 (IRAM+ACA):
    - 2 amplifiers 4-8 GHz per pol.: > 200 + 64 units
    - Production transferred to industry
  - Band 9 (SRON+ACA):
    - 1 amplifier 4-12 GHz per pol.: > 100 + 32 units
    - More complex design, production in house

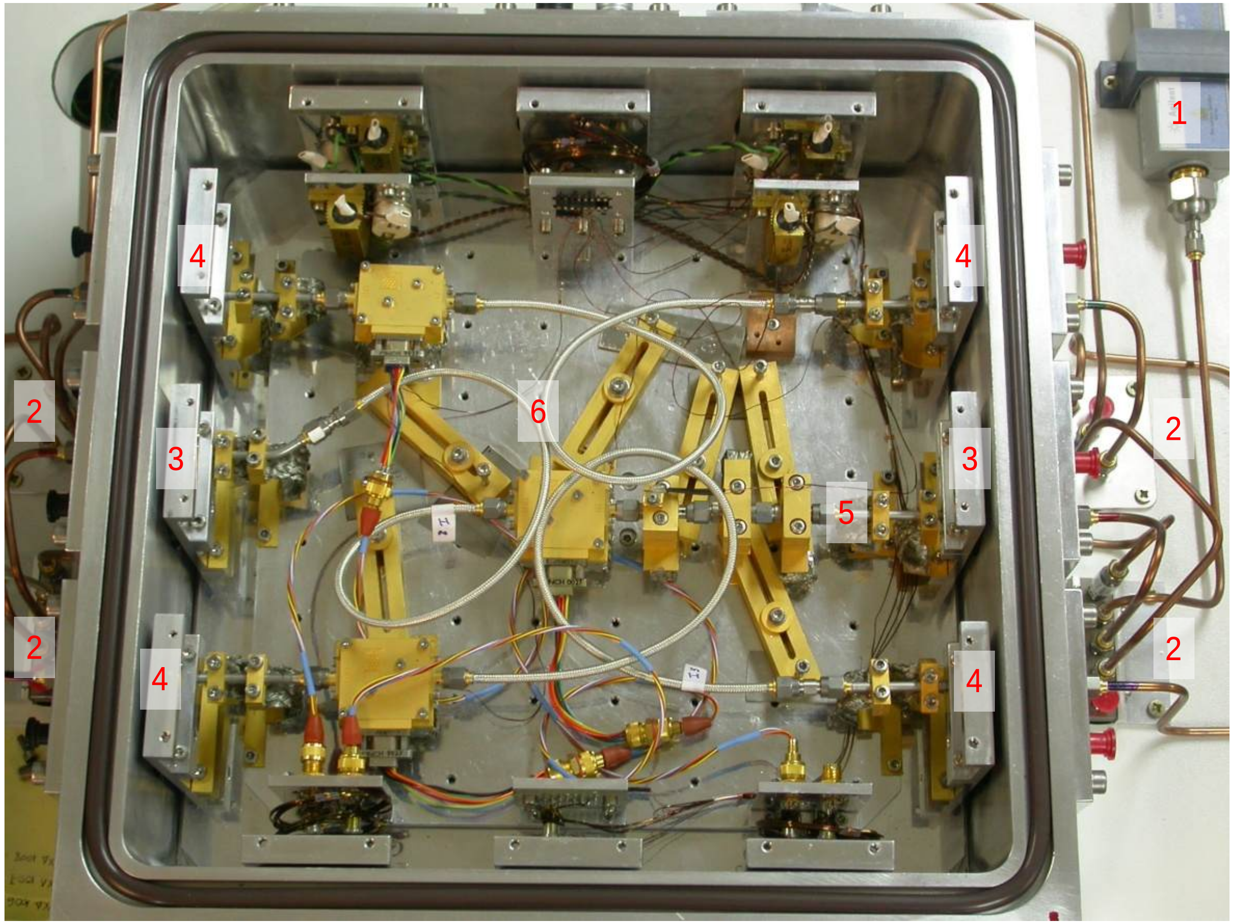
- A more capable, automated and dedicated system was needed

System description: general view

Conceived to perform systematic measurements of noise and S parameters of 4-12 GHz amplifiers at 13 K. Other setups exist for less frequent measurements.

1. Multiport laboratory dewar, NRAO style
2. VNA Agilent E8364B with time domain extension
3. NFM Agilent N8975A
4. Feedback power supplies
5. Programmable precision power supplies (for HEMT diagnosis)
6. CTI 1020 refrigerator
7. Computer to Automate test procedures using our own software
8. Cryogenic thermometer Lakeshore 218

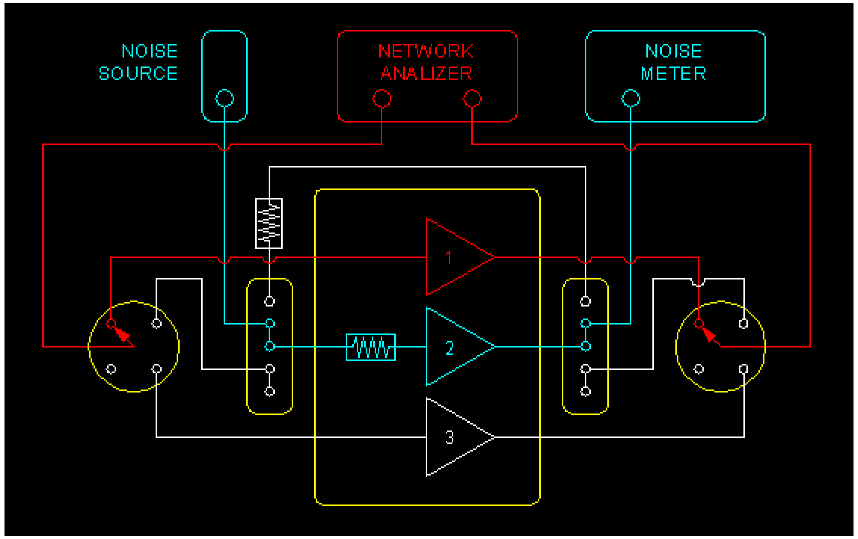
System description: dewar inside

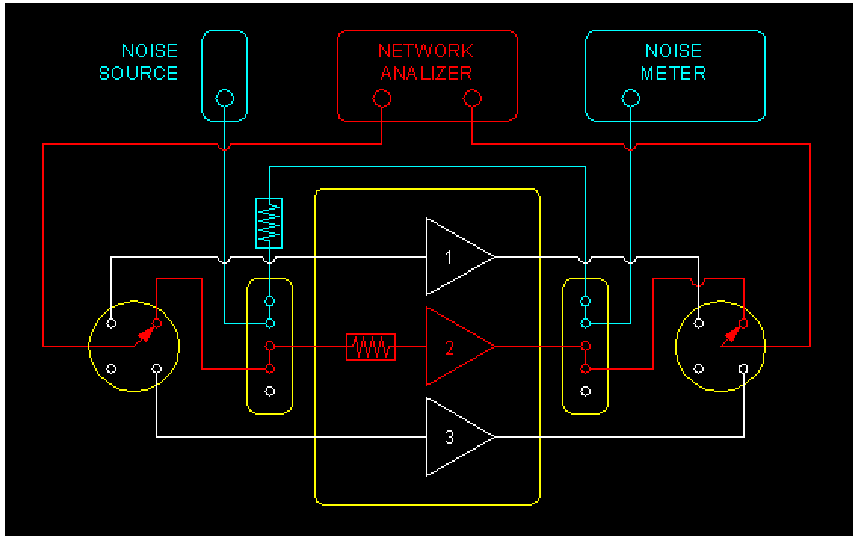


Capable of measuring three amplifiers simultaneously, one of them in noise and S parameters. Noise measurements follow the cold attenuator method.

1. Noise source
2. Multiport coaxial switches Agilent N1812UL and 87104B
3. Noise / S par. line with cold attenuator
4. Direct lines
5. Stainless steel cables with K connectors
6. Semi-flexible cables with expanded TEFLON dielectric

System description: Measurement configurations





- Integrated coaxial switches, computer controlled, make possible multiple measurements during the same cool down.
- No need to mate and de-mate any connectors, not even to calibrate.
  - One DUT can be measured in noise.
  - Any of three DUTs can be measured in S parameters switching the appropriate relays and calibrations.
    - The possibility to know simultaneously the cold S parameters and noise of a DUT is very useful to choose the best bias to fulfill the specifications and frequently avoids and additional cool down.
  - The same noise source, with or without an external attenuator is used to calibrate the system and to measure the DUT.

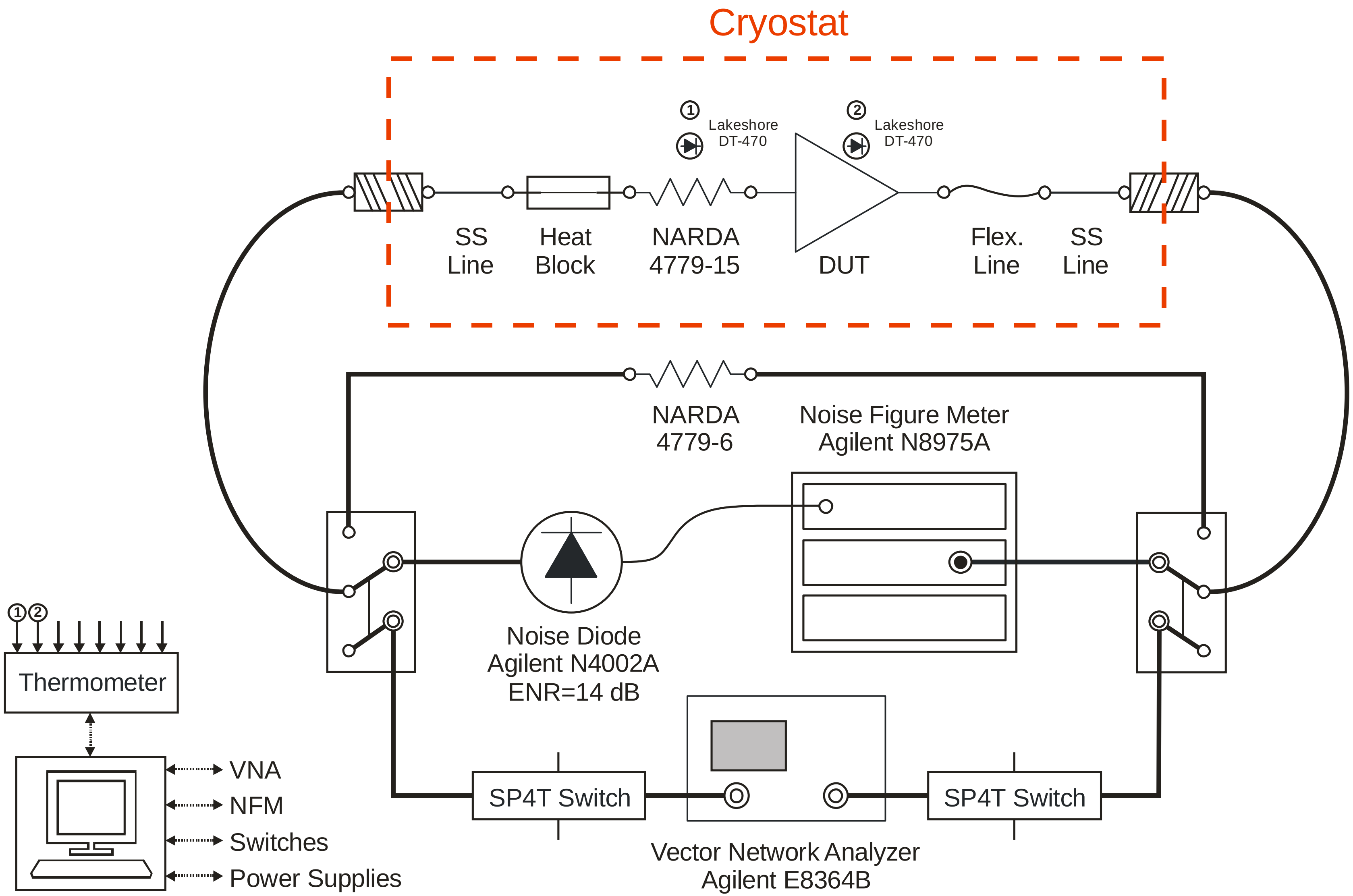
System description: Some notes about cabling

- Cables from DUT port to input/output
  - Semi-flexible cables Suhner Sucoform-141-LL allow insertion of calibration module.
  - Expanded TEFLON dielectric
    - Low loss
    - Almost null dielectric expansion, very high phase stability with temperature
  - Cable at the **output** of the amplifier for **noise** measurements (connected directly to the attenuator)
  - Cable at the **input** of the amplifier in “direct lines” to improve more critical output return loss measurements
- Transitions $T_{amb} \rightarrow T_{cryo}$
  - Stainless Steel cables Microcoax UT-141-B-SS with low thermal conductivity and losses constant with temperature
  - Standard TEFLON dielectric (not found better alternative; ideas?)

Noise measurements: The cold attenuator method

- Cryogenic temperature methods:
  - Hot/cold loads
  - Diode noise sources
  - Variable temperature cryogenic load
  - Diode noise source and cold attenuator
- Cold Attenuator Method:
  - Advantages:
    - Reduces the error caused by transitions
    - Minimizes sensitivity to changes in reflection of noise source
    - Allows fast sweep measurements in automatic systems
    - Takes advantage of features of existent Noise Figure Meters
  - Disadvantages:
    - Needs careful calibration of noise source, lines, attenuator
    - Relies on accurate temperature measurement of attenuator

Noise measurements: Noise set up schematic



System calibration: Noise measurements

- Noise and Gain are calculated from power measurements using frequency dependant values of T_{hot} and T_{cold}
- Needed: T_{hot} and T_{cold} (ref. plane → amplifier input)
- T_{hot} : calculated from ENR of noise source and total loss (available) of the path (cables, switches, hermetic transitions, SS cables, heat-block, attenuator…)
- T_{cold} : calculated from external temperature and loss and temperature of components inside the cryostat
  - Effect of temperature gradient in SS lines taken into account. Not negligible!!!
  - Cold Att=15 dB, $T_{physical}$~15 K
  - T_{cold} value is needed with very good accuracy (T_{cold}~22 K)

System calibration: Noise measurements

- A good value for the losses is fundamental
  - S parameters measured with VNA for single components; then “assembled” with CAD software
  - Main source of error: change in loss of VNA cables

    → minimize movement from cal. to meas.
- Loss of components inside the cryostat is assumed constant
  - Good approximation for attenuator and SS lines
  - Not as good for “good conductor” components (connectors, heat block)
  - In general acceptable in this frequency range, but worse at higher frequency
- Automatic calculation of T_{hot} and T_{cold}:
  - Tables of ENR and losses stored in files
  - Physical temperatures read automatically

System calibration: Noise accuracy

Gross error budget in Cryogenic Measurements [1]

(f=8 GHz, T_N=4 K, G=30 dB)

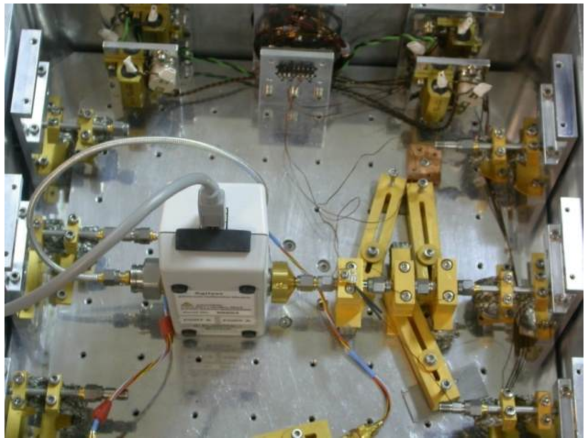
SOURCE OF ERROR	CONTRIBUTION
Calibration of noise source	0.75 K
Calibration of cold attenuator	0.58 K
Calibration of temperature sensor [2]	0.96 K
All other	0.44 K
TOTAL (RSS) [2]	**±1.42 K**

[1] Repeatibility is typically ± 0.2 K – Refer to talk by J. D. Gallego *"Estimation of Uncertainty in Noise Measurements Using Monte Carlo Analysis: A Practical View "*

[2] System 1020_3 has a temperature sensor calibrated with ±0.01 K. Assuming the same error in the attenuator temperature, we will have a total error of ±**1.05 K**.

System calibration: S parameters

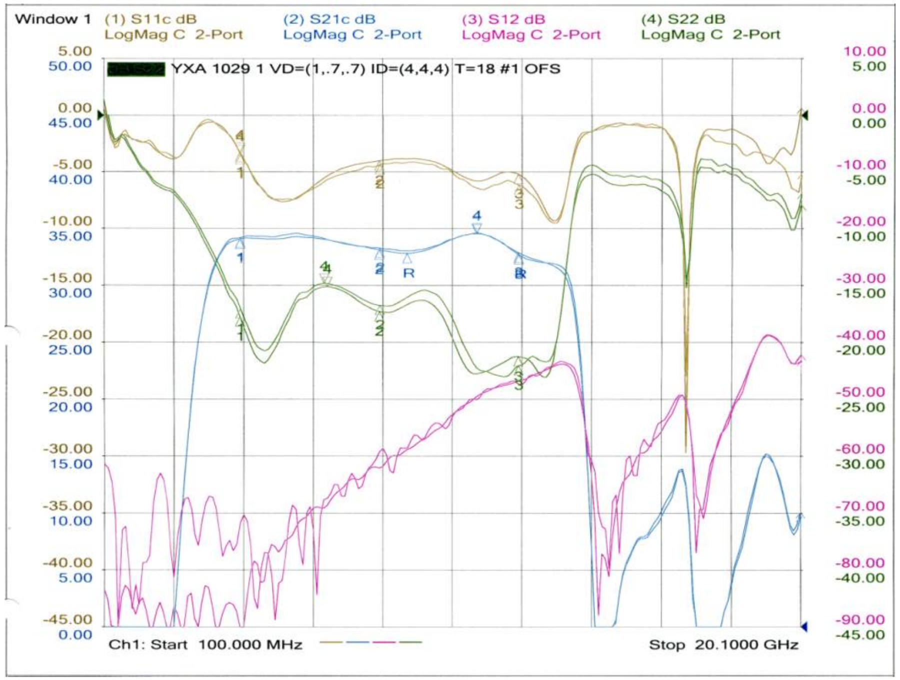
- Performed SOLT calibration (thru as unknown) with Electronic Calibration Module Agilent N-4693-60001 in the DUT ports at room temperature.
  - This module allows an easy (and therefore more frequent) calibration inside the dewar
- Assumed no variation of losses with temperature in stainless steel lines inside the dewar
- Applied a measured correction for variation of losses with temperature in flexible cable at the DUT input
- Applied a time domain gate to exclude the phase variations outside the DUT when cooling that distort the reflection measurements



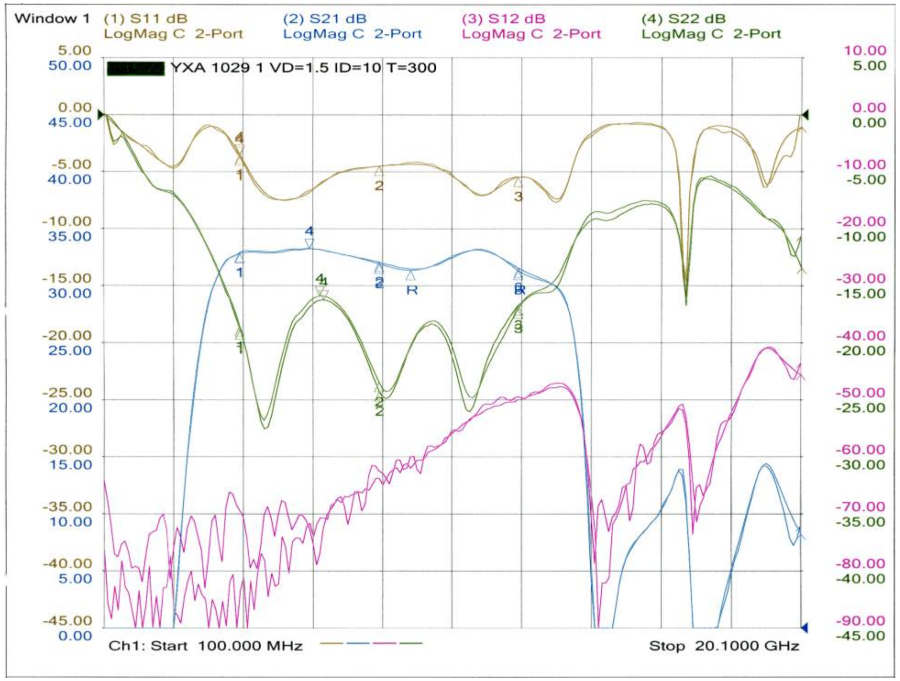
System calibration:
S parameters

Even S11 is measured with remarkable precision through the attenuator!

Comparison of **cryo** S parameters measured in a **“direct line” vs the “noise line”** (in which noise and reflection can be measured simultaneously)

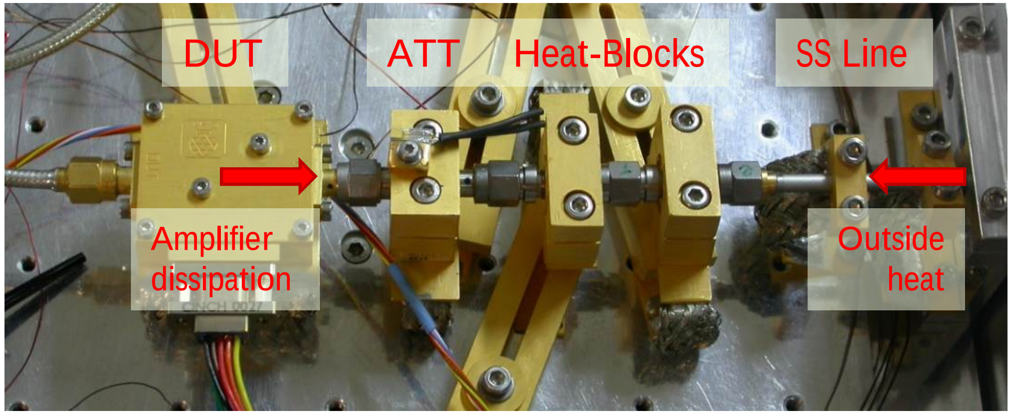


Comparison of **ambient** S parameters measured **outside the dewar vs the “noise line”** (in which noise and reflection can be measured simultaneously)



Problems related to the cold attenuator

- It is difficult to accurately measure the real temperature of the resistive element in the attenuator.
- An error in the cold attenuator physical temperature translates directly to a similar error in the DUT noise temperature.
- The temperature measured in the outside chassis of the attenuator may differ from the inside temperature mainly due to:
    1. Deficient heat transfer to the interior through the attenuator structure
    2. Heat transmission from the outside through the inner coaxial conductor
    3. Heat transmission from the DUT through the inner coaxial conductor



Problems related to the cold attenuator: Deficient heat transfer to the inside

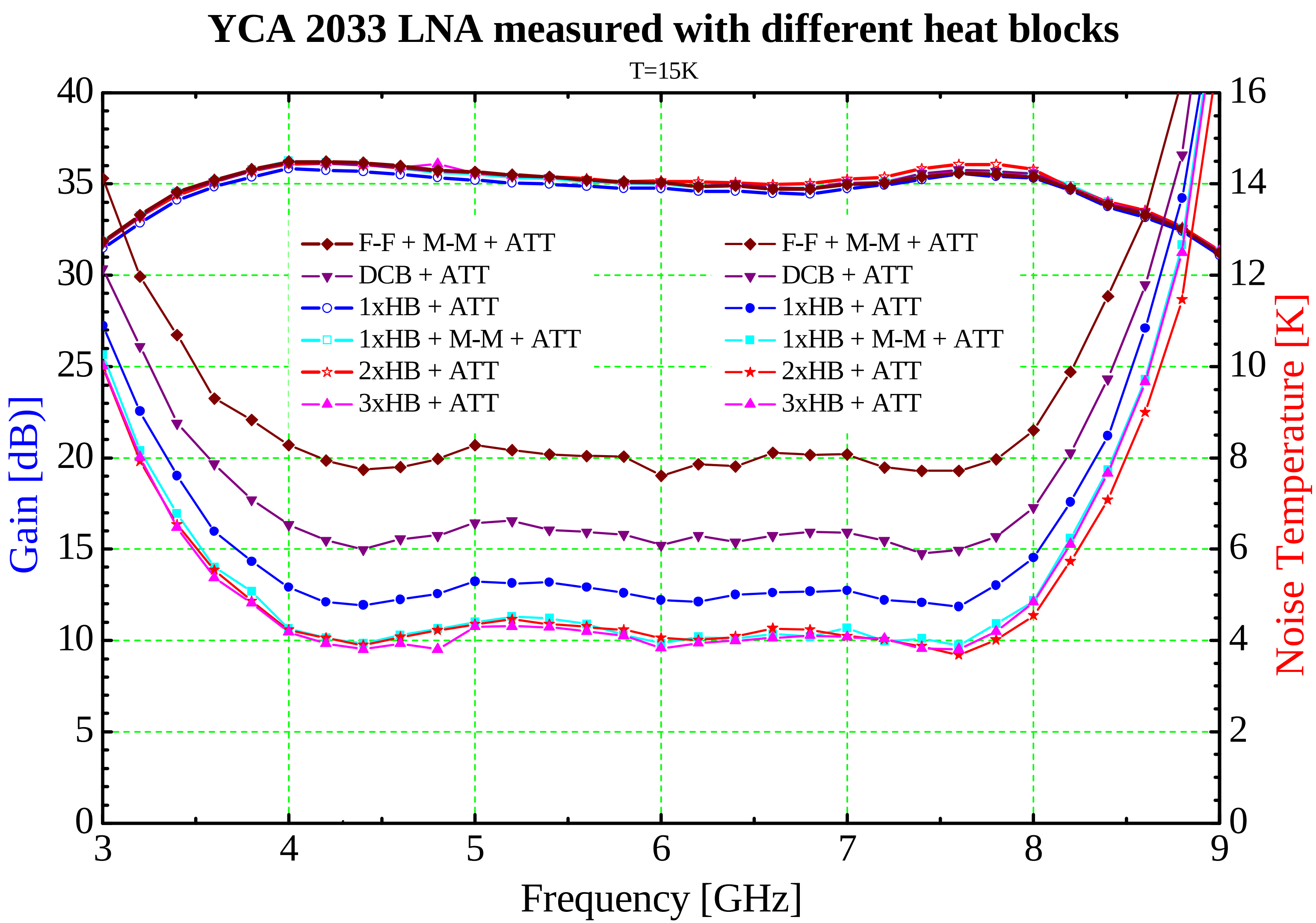
- The attenuator is cooled down by means of a copper structure pressed around its body and anchored to the cold plate.
- The temperature sensor is positioned in the upper half of the copper structure, which is in contact with the lower half only by two steel screws. We believe that the temperature measured is exactly the temperature of the body, and assuming that no heat is coming through the connector, it will be the inside temperature.
- We have noted after several hundreds cooling cycles an increase in the noise temperature of a reference DUT (~0.5 K in 5 K).
  - This difference disappeared using a NEW attenuator.
    - We have already changed 2 times the attenuators of our system in 3 years.
  - It is possible that the thermal contact of the ceramic plate of the attenuator with the pin and body deteriorates due to fatigue induced by thermal stress.

Problems related to the cold attenuator: Heat transfer through the inner coaxial conductor

- Heat coming from the outside is blocked in this system by what we call a heat-block: a series of K female sparkplug launcher transitions interconnected by a glass bead (Wiltron K102F + Wiltron K100).
  - The contact between the glass bead pin and the launcher makes a very weak thermal interface

- We determined that 2 heat-blocks in series were sufficient to isolate thermally the inner conductor.
- We also compared this configuration with others: male-male and female-female transitions, and DC-blocks

Problems related to the cold attenuator: Heat transfer through the inner coaxial conductor



Problems related to the cold attenuator: Heat transfer through the inner coaxial conductor

- Heat coming from the amplifier was not a major concern, as its temperature is similar to the attenuator. Measuring so many amplifiers let us notice some odd results and we performed some tests changing the temperature of a reference amplifier.
  - The contribution of the true noise temperature variation of the DUT due to a physical temperature change is significantly smaller than differences measured.
  - Heat is very efficiently transferred from the DUT to the attenuator.
  - A small change in the DUT temperature due to a higher bias or a worse thermal contact with the cold plate (keeping the attenuator temperature stable) produces noticeable effects in the noise temperature.
  - In the range of 4-5 K of noise temperature, a change of 1 K in the temperature difference between DUT and attenuator produces 0.25 to 0.3 K change in the DUT noise temperature.

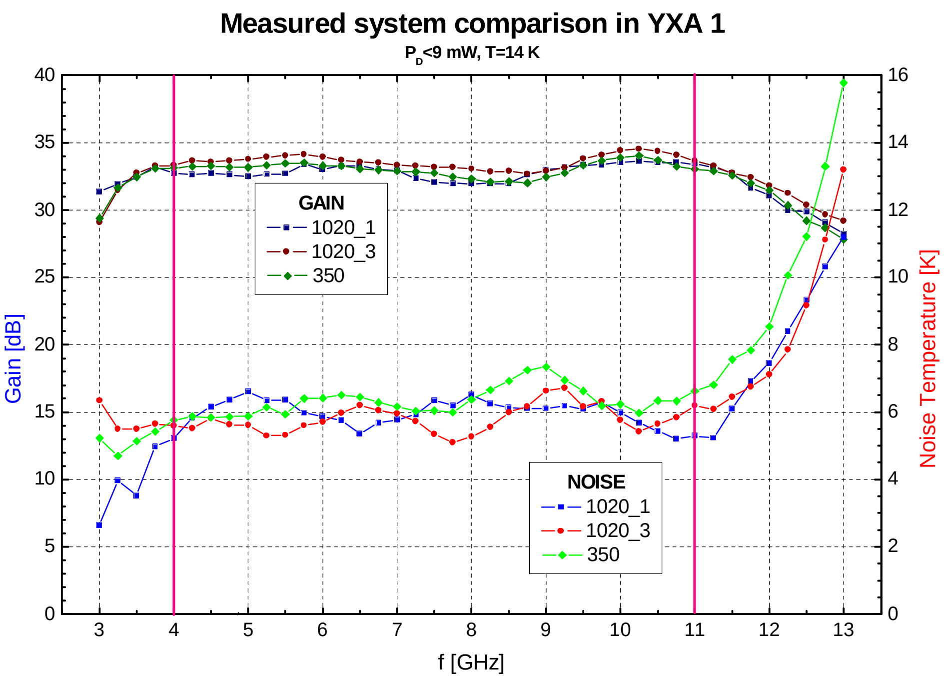
Our “hot amplifier” empirical formula

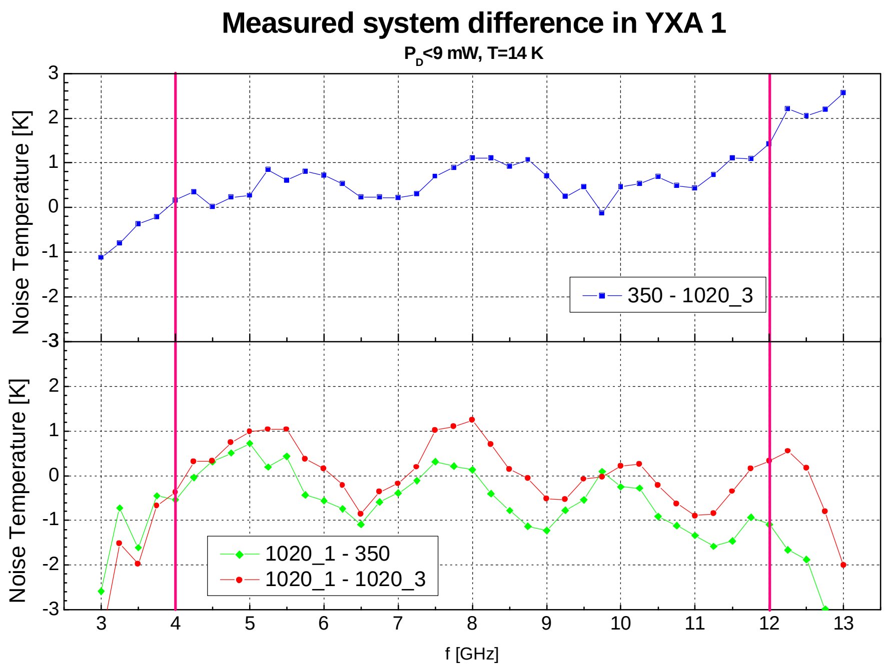
$$TN_{DUT2} - TN_{DUT1} \approx \left[\left(T_{att1} - T_{DUT1}\right) - \left(T_{att2} - T_{DUT2}\right)\right] \cdot 0.3$$

where 1 and 2 refer to two different measurement events

Problems related to the system input impedance

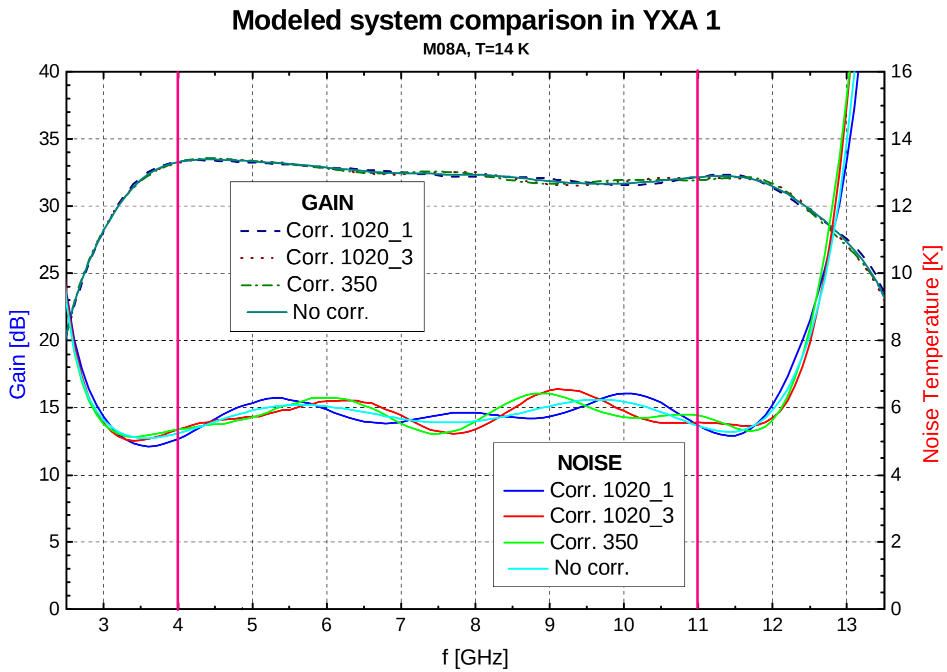
- The impedance presented at the input of the amplifier (mostly by the attenuator) has significant impact in the noise results
- We compare the measurements of an amplifier in three different systems:
  - There are systematic errors between them that could be traced down to differences in components, connectors and cables seen by the amplifier input.
    - Systems 1020_3 and 350 use the same attenuator model!

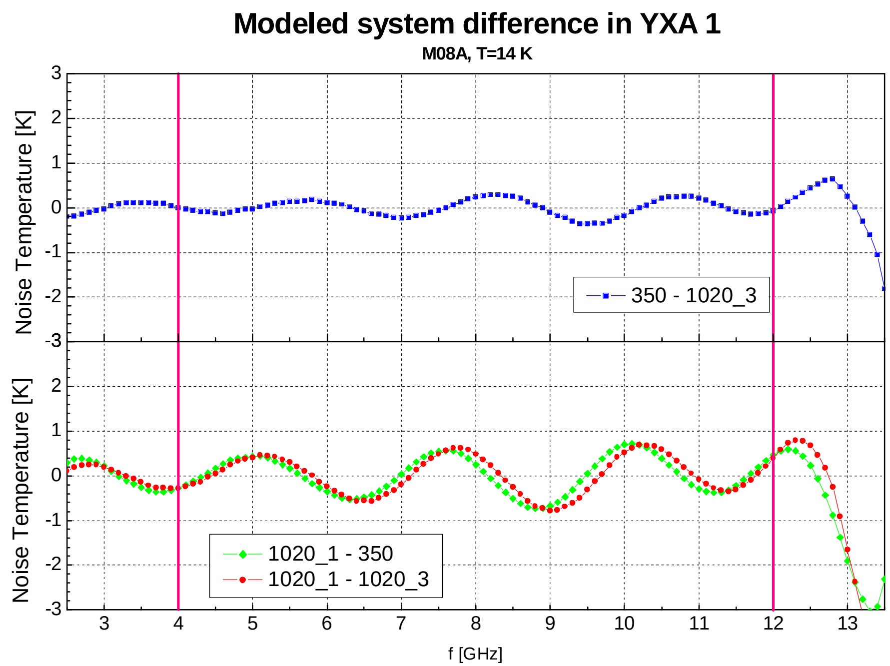




Problems related to the system input impedance

- The impedance presented by the system at the input of the amplifier should be taken into account in case an accurate correction of the amplifier response is needed.
- It is important to consider carefully the return loss when selecting an attenuator
- An LNA model including test-system component measurements is able to predict much better the results of the measurements

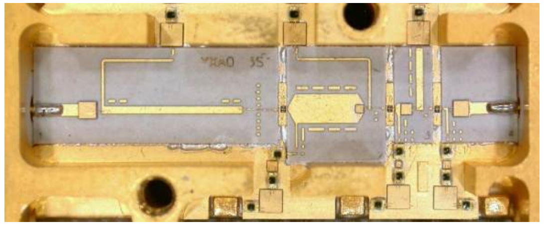




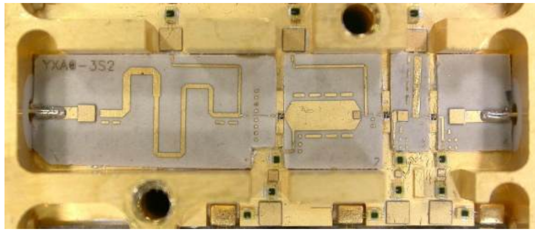
Problems related to the system input impedance

- The ripple in the response is clearly related with the length of the line were the noise standing wave is formed
- We repeated the tests of the three systems with another amplifier with a longer line at the input

YXA 1

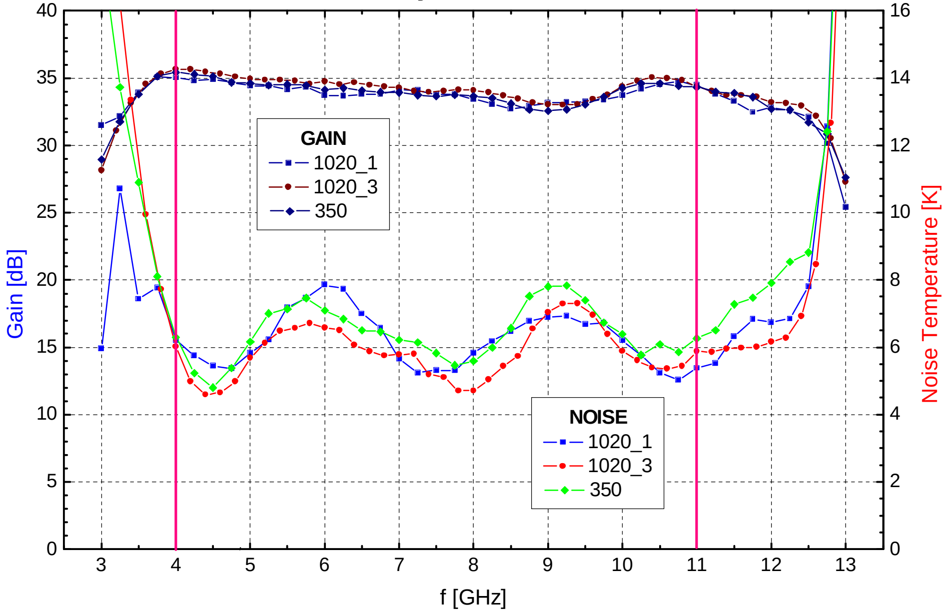


YXA 2



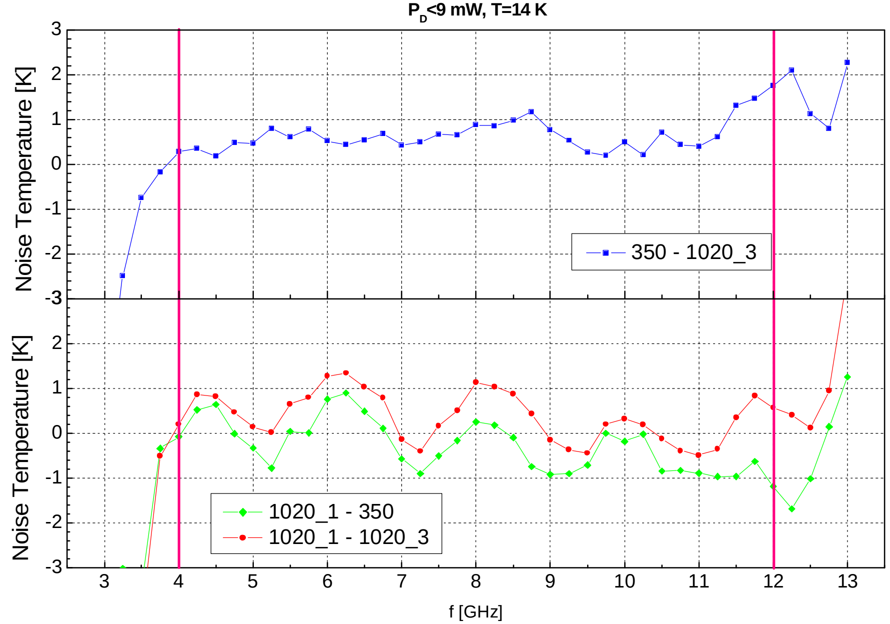
Measured system comparison in YXA 2

P_D<9 mW, T=14 K



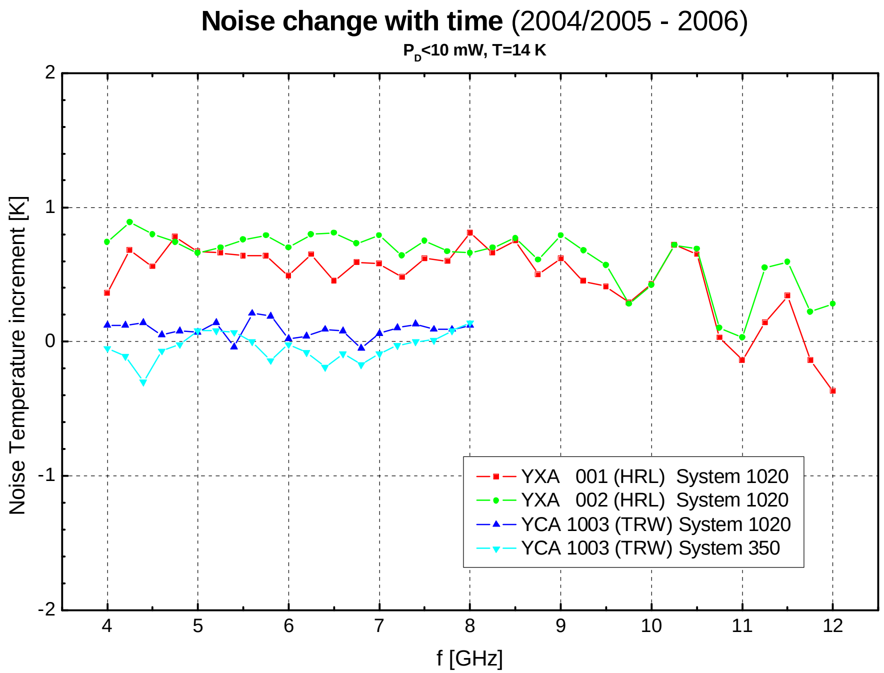
Measured system difference in YXA 2

P_D<9 mW, T=14 K



Some other problems

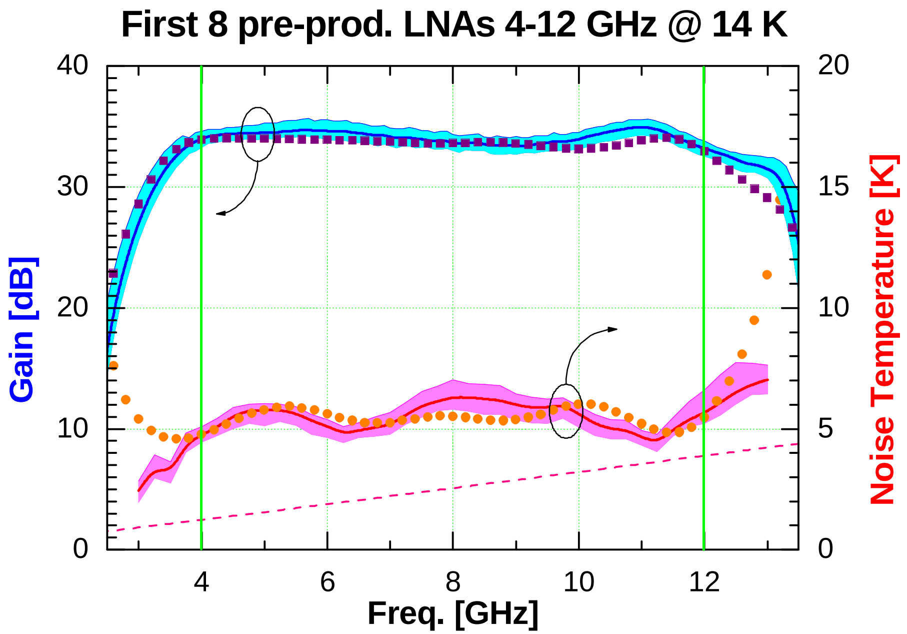
- Transistor aging:
  - Some transistors may experience an increase in noise temperature after many cool downs and/or a long period of time
  - Not to be mixed up with attenuator aging!
    - Test in different systems
    - Test with different amplifiers

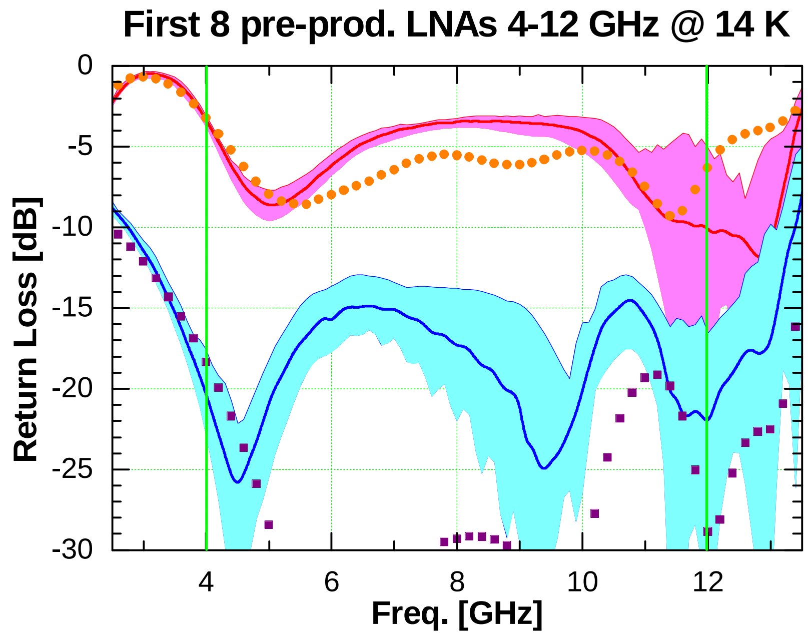


- Broken cables:
  - Despite using all flexible heat-sinks, after several tens cool-downs, cables to the hermetic transition tend to break always at the same point, in the solder joint to the connector.
    - Probably related to fatigue of the joint due to the different axial contraction of the outer conductor and the connector
  - Obvious impact in reflection that translates into a little degradation in noise

Finally, some sample results

- 18 delivered pre-production LNAs
- 66 production LNAs delivered up to date
- Excellent behavior of the test system, many man-hours saved
  - Tuning needed in most units to meet the specs (extra cool-downs)
  - Variability of HRL transistors forced some rework in the design
  - Very good repeatability within a similar transistor lot (despite tuning and bias opt.)

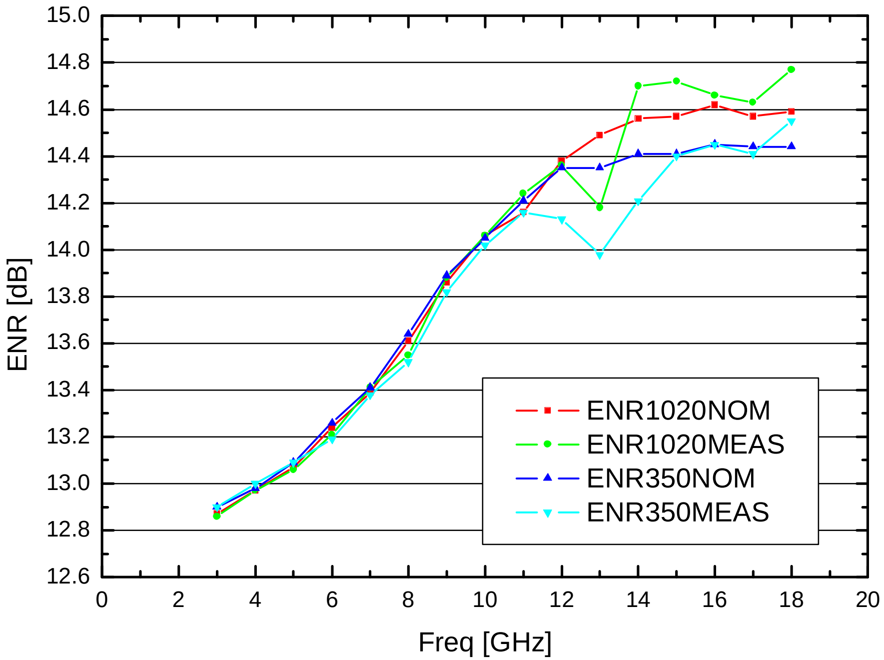


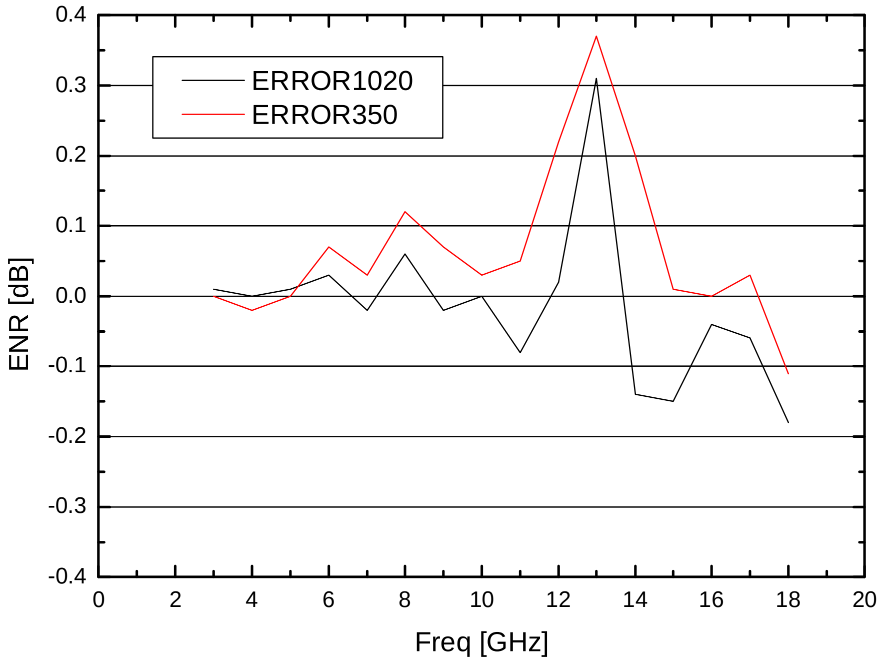


Conclusions

- New measurement system designed and built specifically to enable fast, accurate and repeatable testing of ALMA 4-12 GHz LNAs
  - 3 simultaneous measurement lines
  - Coaxial switches speed up measurements and improve repeatability
  - Possibility to measure noise (by the cold attenuator method) and S parameters of a DUT in the same cool-down with surprising accuracy, very convenient for bias optimization
- More than 85 identical amplifiers measured up to date, many lessons learned
  - Errors in noise temperature due to wrong cold attenuator temperature:
    - Control attenuator aging, prevent an insufficient thermal isolation through the inner conductor using a good heat-block, ensure a good and repetitive cooling of the DUT and monitor its temperature…
  - Errors in noise temperature due to poor impedance presented by the measurement system to the amplifier:
    - Choose good attenuator, measure it carefully and include its effect in simulations

Errors in noise sources





Error in 1020_3 system noise source (used as reference for these measurements)