Characterization of FhG-IAF low-noise mHEMTs at cryogenic temperatures: DC, S-parameters and noise

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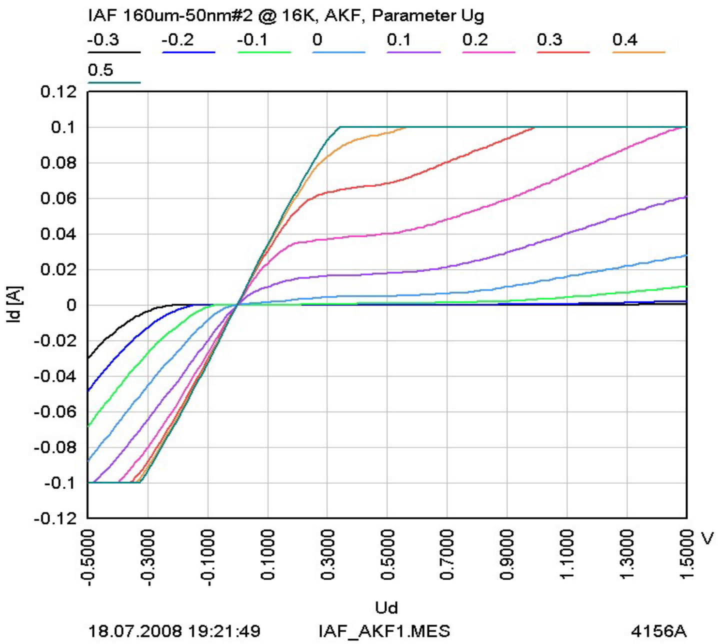
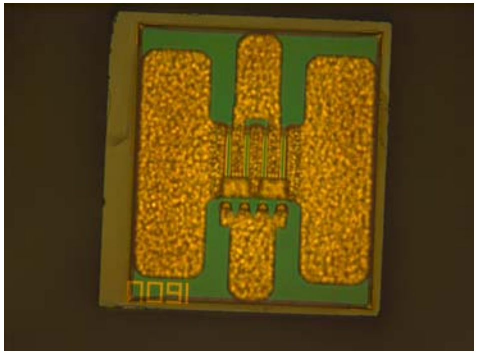
Preliminaries

- EU RadioNet-FP7 projects **Amstar+** and **Apricot** will investigate performance of low-noise HEMT devices from several sources for application in cryogenically cooled LNAs for radio astronomy, aim is to demonstrate at least performance of current state-of-the-art InP based HEMTs (reference: JPL/TRW, Cryo3 „golden“ wafer)
- MPIfR is participating in both projects, this presentation will report on work that already started for Amstar+ (partners: FhG-IAF - MPIfR – IRAM - CAY)
- Goal of Amstar+ is the demonstration of a prototype pixel for a cryogenic heterodyne multibeam receiver at W-band : based on MMICs, full WG-bandwidth, 2 polarizations, design must be suitable for arraying to a larger camera possibly for the IRAM 30m
- Design of cryogenic LNAs first of all needs a reliable model of the active HEMT device at cryogenic temperatures under different bias conditions to be used in a standard circuit design suite
- For IAFs 50 and 100nm gate length mHEMT devices that are subject of this presentation a foundry-model characterizing the HEMT under different bias conditions at temperatures around ambient is existing
- Here we‘re describing the cryogenic measurements that are needed to extend this model down to cryogenic temperatures, the IAF mHEMT process and modeling of the devices will be described in detail in the presentation by M. Seelmann-Eggebert later in this workshop

Results from cooperation IAF / IRAM / MPIfR before start of FP7:

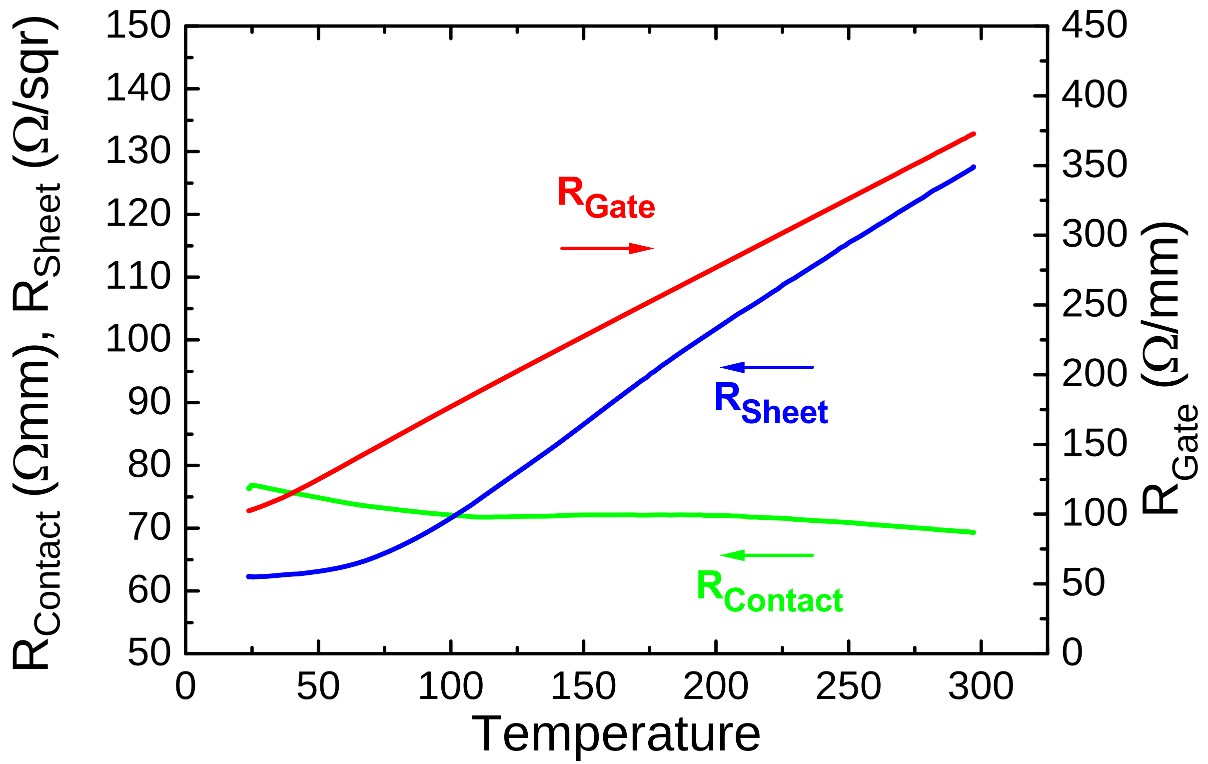
- Low frequency LNAs only, designs up to 25GHz maximum
- DC IVs of 100nm gatelength devices tend to show instabilities (kinks, hysteresis) at cryogenic temperatures
- We did not see this problem for 50nm devices so far, problem will be investigated further
- LNAs redesigned for 50nm process are currently processed



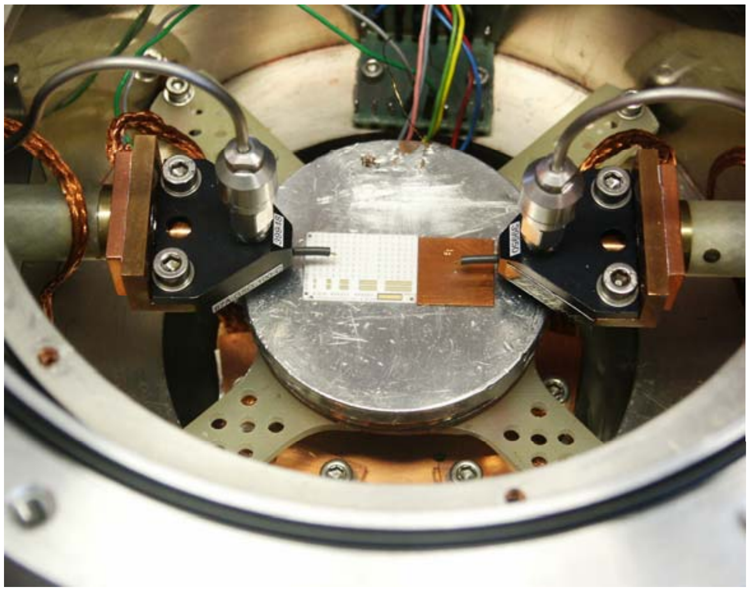


Id vs Ud at 16K for IAF 50nm device: well-behaved, stable DC–IVs at cryogenic temperatures

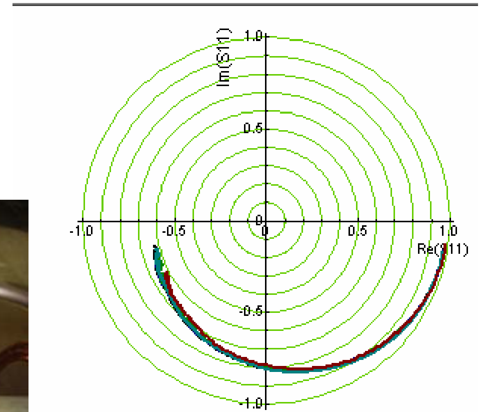
- **Measure variation of access resistances of device down to cryogenic temperatures**

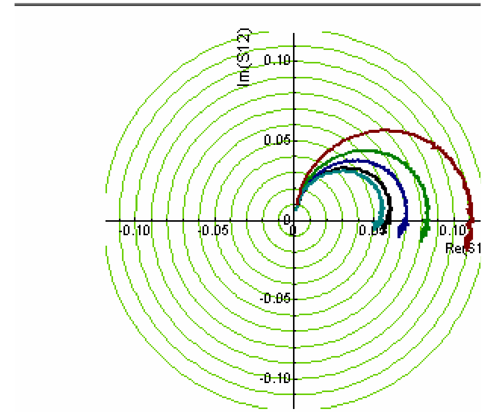


Cryogenic S-parameters up to 50GHz

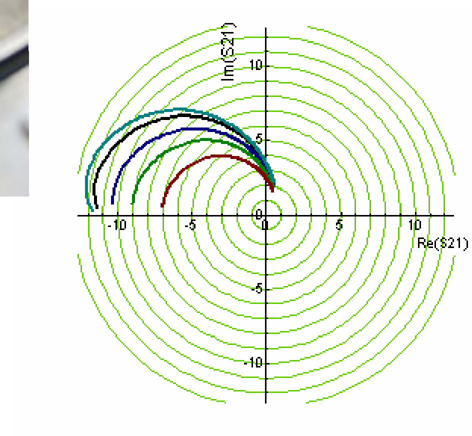


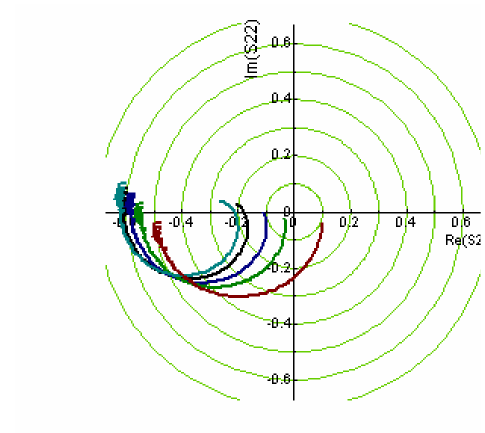
15K plate of MPIfR cryogenic
S-Parameter Prober station





Cryogenic S-Parameters 1-50GHz
for 50nm IAF device at U_d=1 [V],
I_d = 100/150/225/300 [mA/mm]





Noise characterization : Why F50 ?

Several variants possible for measurement of NT at cryogenic temperatures

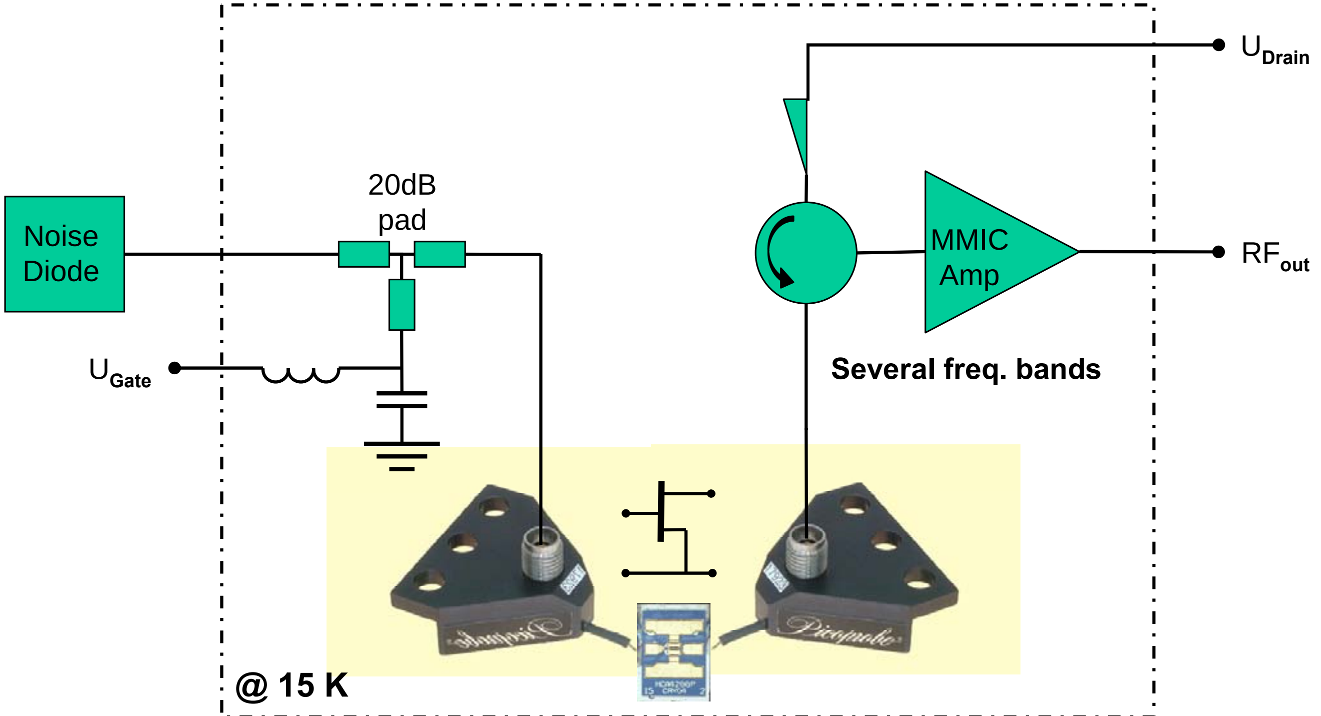
1. Standard method determines NT parabola from NT-measurements at different source impedances
   - Direct measurement of T_{min} possible
   - Needs automated tuners (mechanical or electronic) and for calibration permanent VNA control of impedances at cryogenic temperature
   - Since (standard) tuners have to be at ambient temperature the important length of (coaxial) cable necessary for the transition from ambient to cryogenic temperatures adds uncertainties especially at higher frequencies

2. F50 method (proposed by Dambrine, Cappy et.al in 1993) measures NT versus frequency in a 50 Ω System
   - Only measurements at a single, rather well controllable impedance level necessary

   - Original F50 exploits circuit properties of standard extrinsic FET model to directly measure R_n and $|Y_{opt}|$ from linear dependency of NF_{50} versus ω^2, additional assumption on correlation coefficient (i.e. Pospieszalski model) then give complete set of noise parameters

   - IAF model uses least squares to fit the channel temperature T_c to measured NF_{50} data, the other access resistances are at physical temperature of device

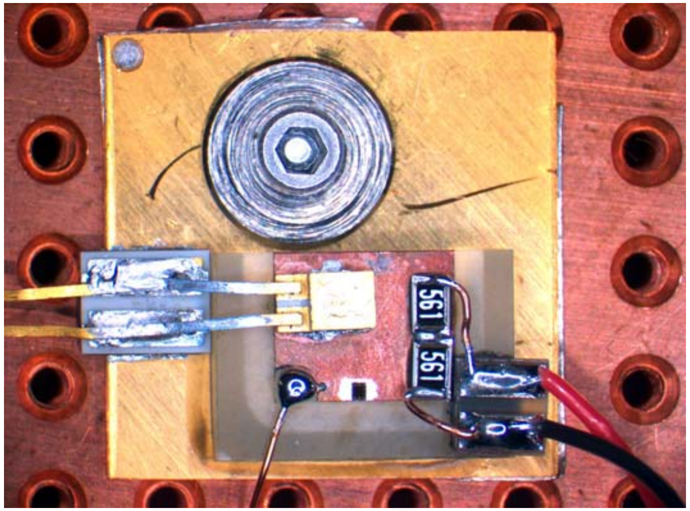
A possible cryogenic F50 setup



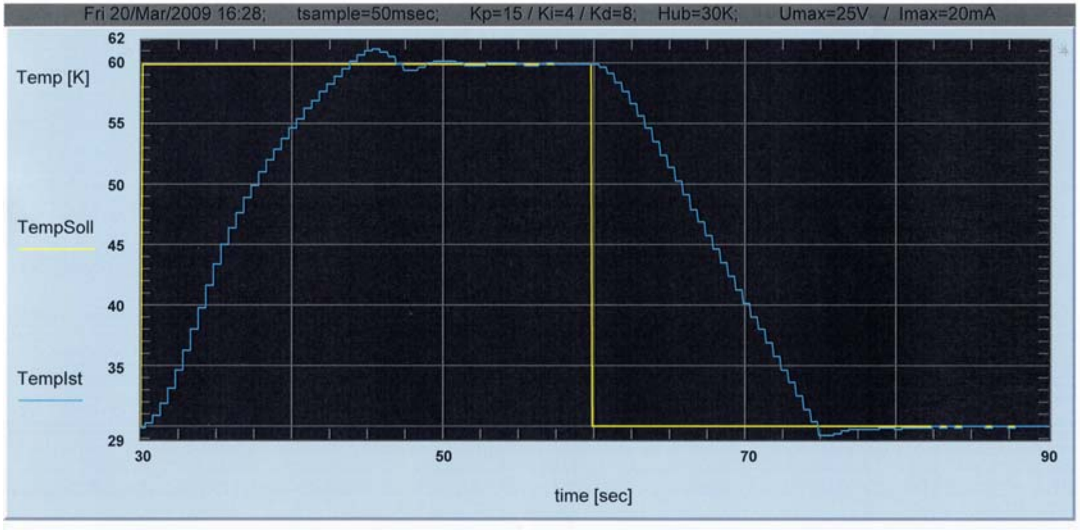
- Uses cold-attenuator method for good match and adequate source temperatures
- Still needs additional VNA to calibrate source temperature at probe tip reference plane, calibration prone to errors due to different media (coaxial/coplanar) and assumptions for temperature distribution on input line to cold pad

Internal CAL load for F50

Solution of calibration problem at 15K using a well matched internal heated load @ known absolute temperature:



Test load

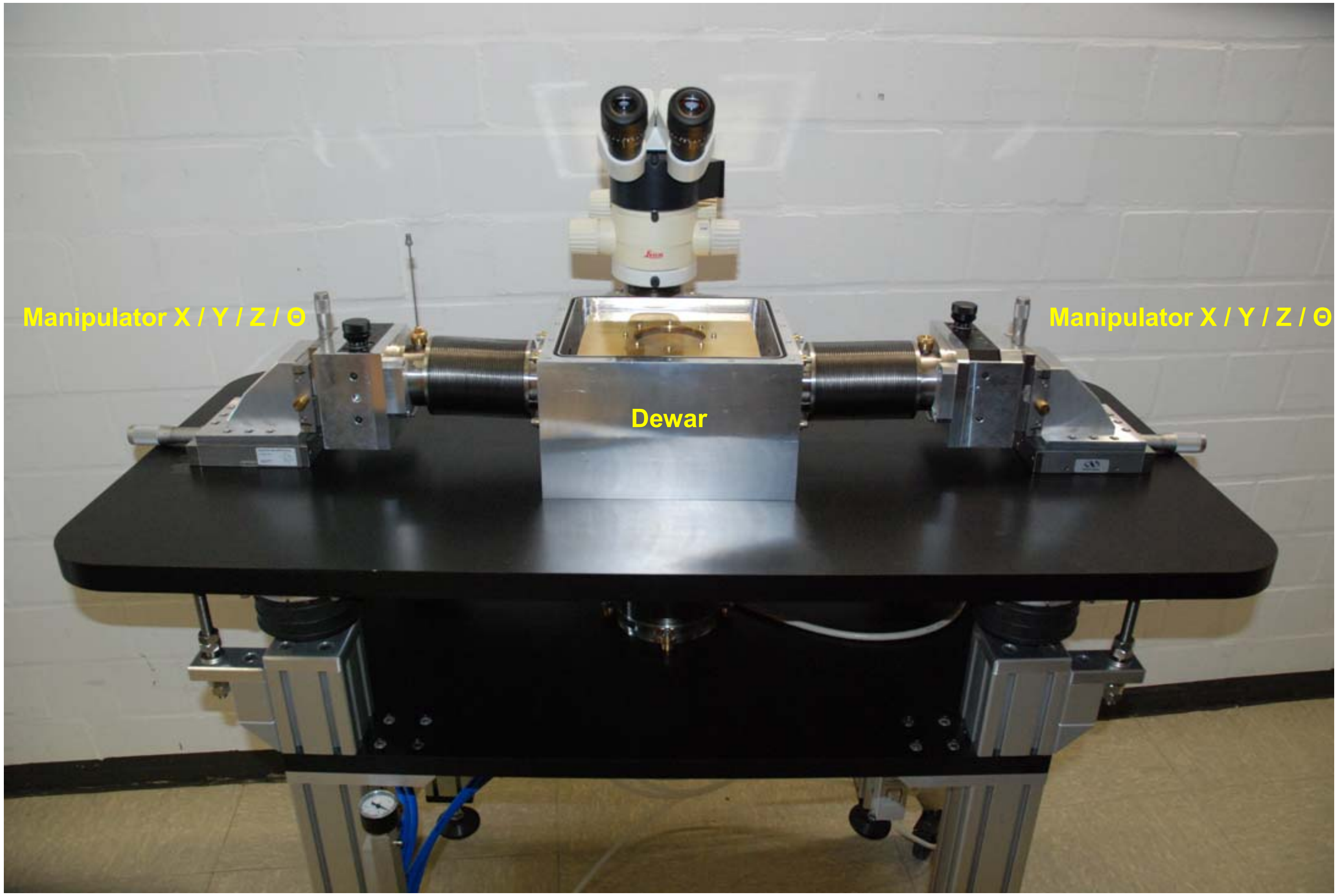


Profile of 30K temperature step

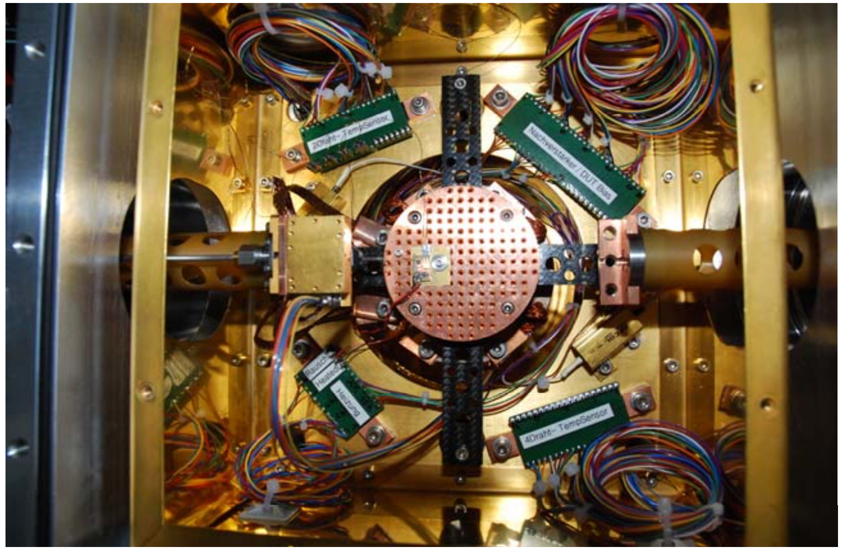
Heated load must have short time constant to minimize errors from NFA gain drifts :

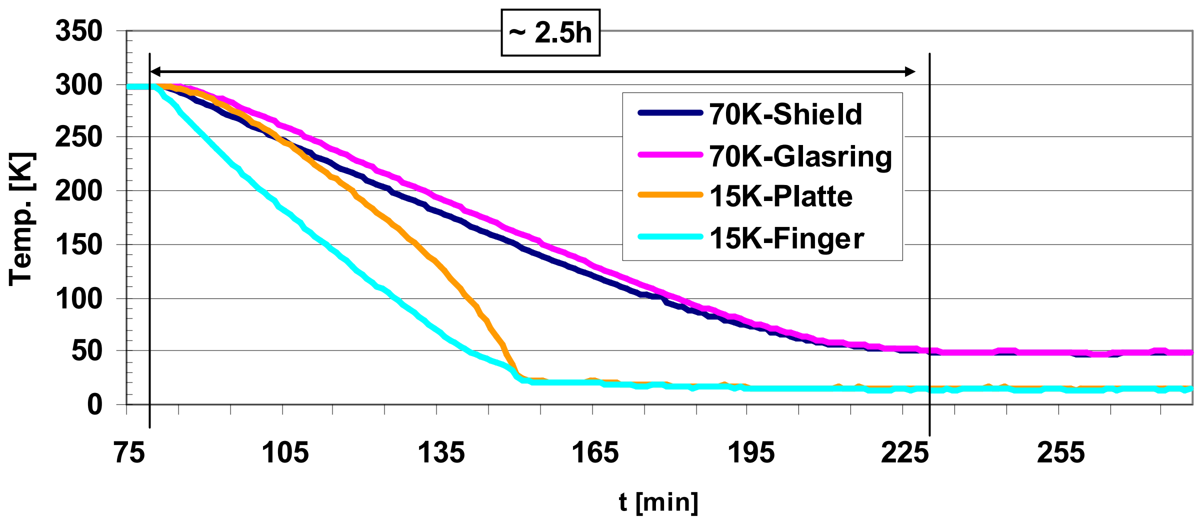
- low thermal mass of heated parts
- + software PID for heater control gives ~ 15sec for this test load

New MPIfR F50-Prober



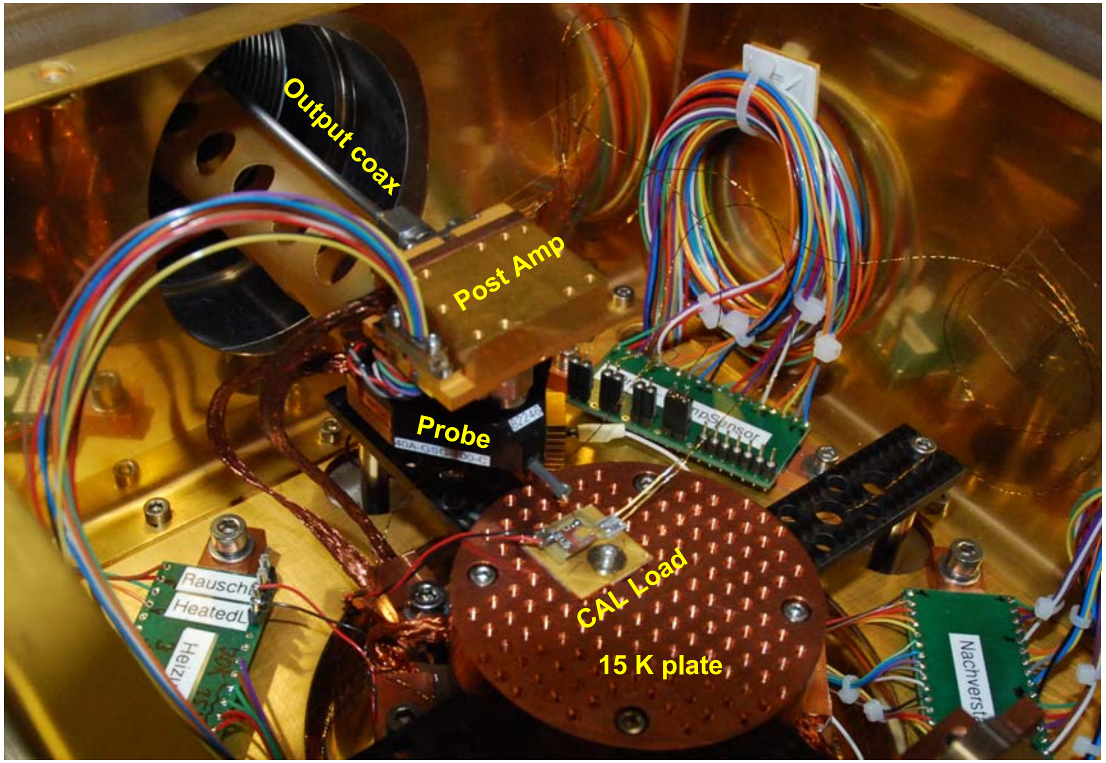
New F50-Prober : 70K shield and 15K plate





Cooldown
(standard CTI 350 refrigerator)

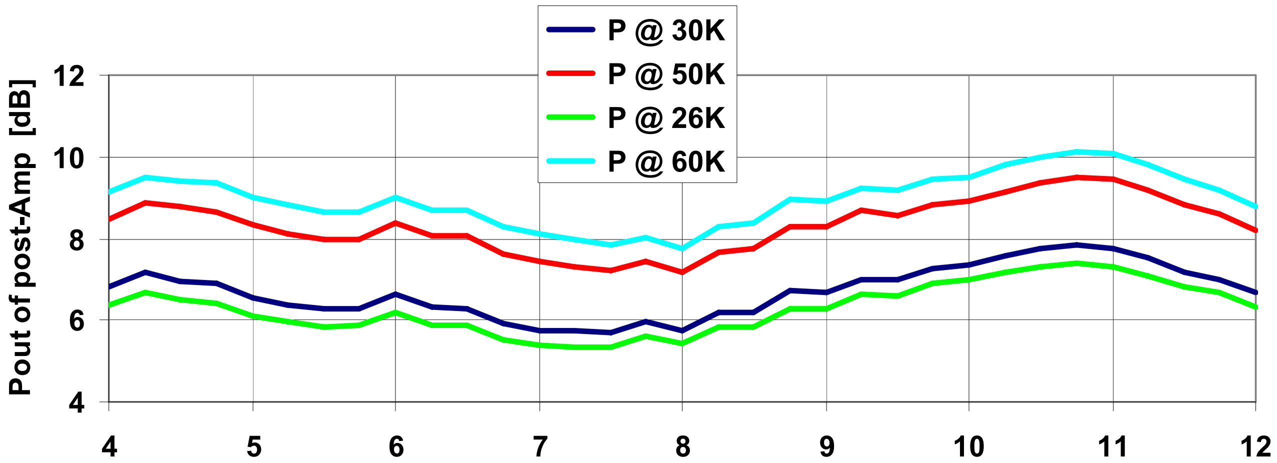
New F50-Prober : Close-up of output probe arm



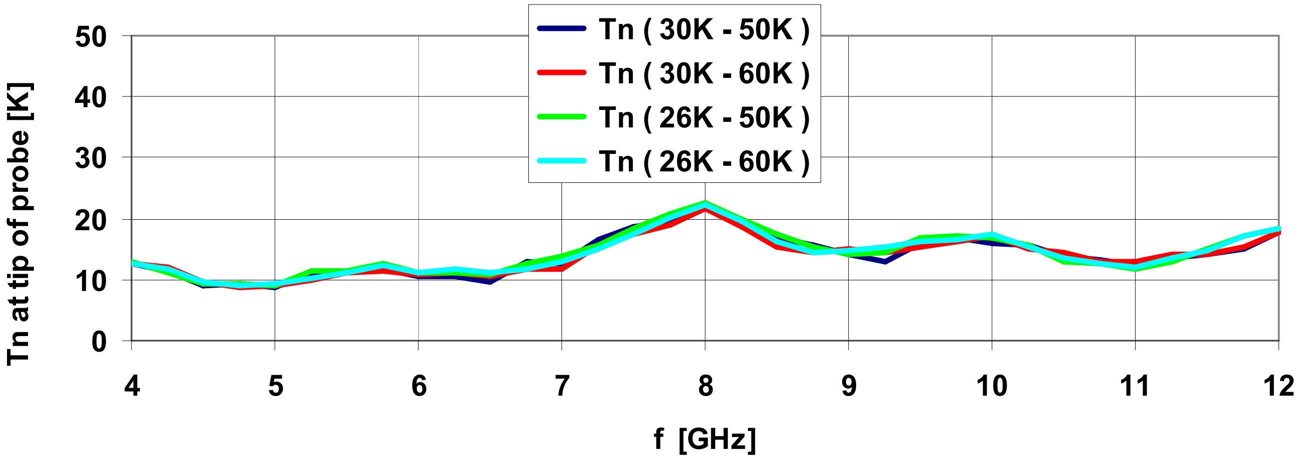
Cryogenic post–amp module for this test :

- WBA13 4-12GHz MMIC LNA from Caltech / NGST (Cryo-11 run, larger noise)
- includes drain bias-tee and 90° coax to MS transition
- single ended input matching designed for power match (IRL ~ -15dB)
- further bands could also use balanced designs to achieve necessary matching

New F50-Prober - First Tests : post-Amp Calibration



Output power of cryogenic post amplifier for different temperatures of internal heated load



Calculated noise temperature at the probe-tip including bias tee for diffferent temperature pairs :

No systematic effects with temperature

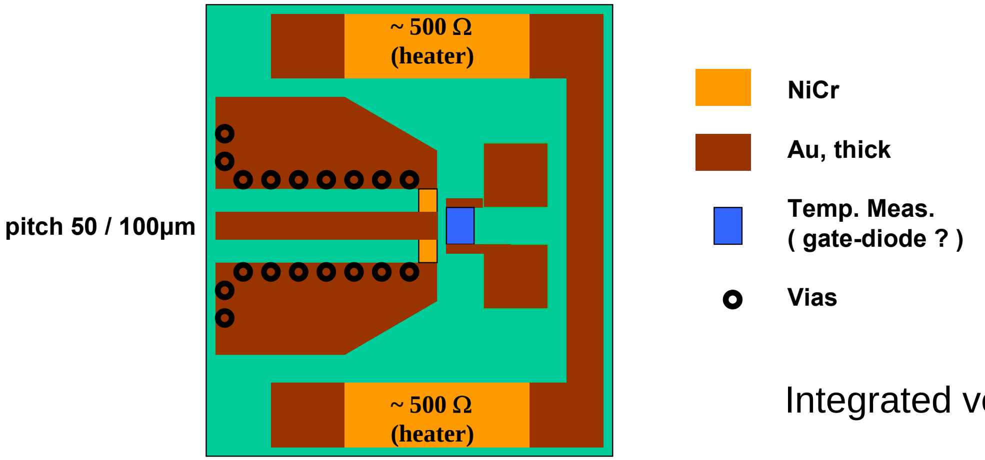
Further plans for cryogenic NT measurements 1

1. Production of absolute temperature calibration standards on wafer is underway, will give faster time constant due to lower thermal mass as compared to hybrid approach used so far

2. Test of two ideas for electronically switched sources that are inherently fast but need to be calibrated repeatedly against absolute temperature standard :

   - Commercial avalanche noise diodes in chip-form + cold attenuator (operability at cryogenic temperatures ?)

   - Gate-diode or HEMT at switched bias + cold attenuator as noise source: would give on wafer electronically switchable noise source @ 15K using IAF process

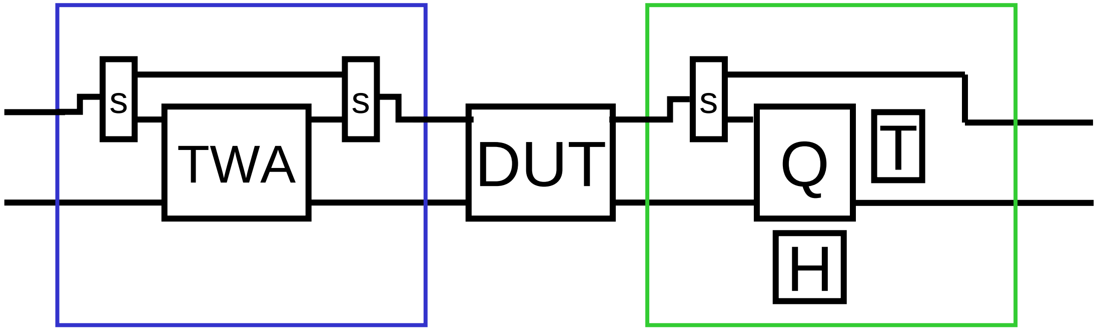


Integrated version of coplanar heated load

Further plans for cryogenic NT measurements 2

Potential of using IAFs 50nm MMIC process for NT probing setup :

- Fully integrated input and output probe units at cryogenic temperature
- Measure S-parameters in same setup with internal switches
- This allows full S- and noise parameter characterization of the units and at same time avoids problems of external tuners @ 300K



Output Probe Unit

- broadband low-noise TWA
- FET SPDT switches
- temp. sensor

Input Probe Unit

- use diode + TL for impedance variation
- FET SPDT switches
- heater for absolute temp. calibration
- temp. sensor

Conclusions

- FhG-IAF mHEMTs with 50 and 100nm gate length were characterized at cryogenic temperatures measuring DC-IVs, DC access resistances and S-parameters to 50GHz in order to extend the IAF foundry model down to cryogenic temperatures
- Our F50 probing system was described and first tests to validate it's calibration scheme using heated calibration loads on the 15K plate were shown
- Plans to extend the capabilities of the cryogenic noise probing setup were presented