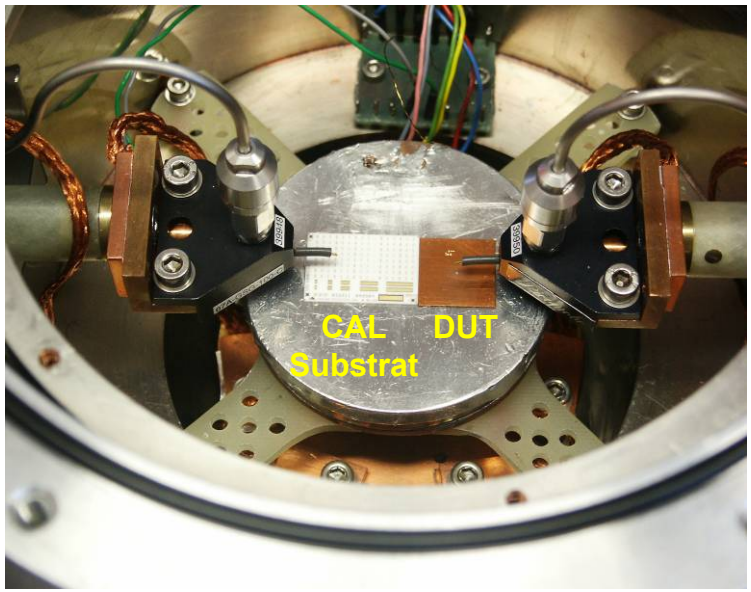
Cryogenic Characterization of mHEMTs at MPIfR Bonn

F. Schäfer, S. Lenz, S. Tuerk, W. Meiers;
D. Bruch, M. Seelmann-Eggebert, B. Aja (IAF)

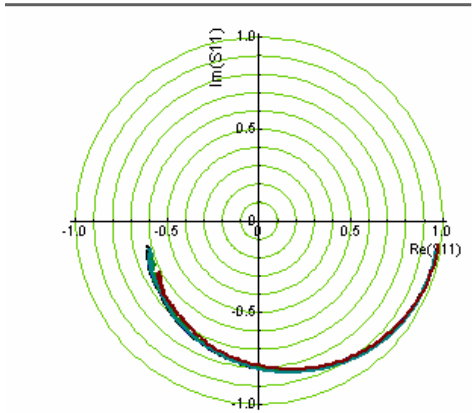
Introduction

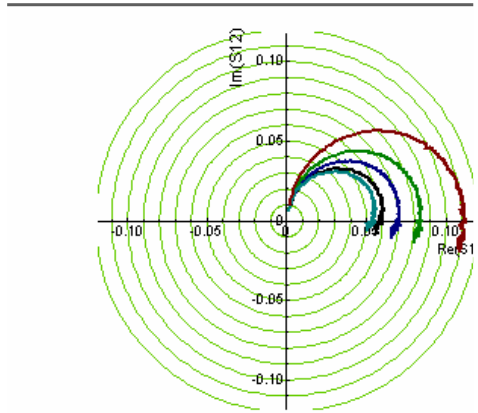
- Motivation : Designs of cooled LNAs for radioastronomy needs a HEMT transistor model at cryogenic temperatures
- Technical Basis : Expertise in work at low-temperatures from the construction of cryogenic frontends for low-noise receivers for radioastronomy
- A prober station for the measurement of cryogenic S-parameters up to 50GHz has been available at MPIfR since beginning of the 90's
- This has particularly enabled our participation in the **C**ryogenic **H**EMT **O**ptimization **P**rogram (**CHOP**) initiated by NASA/JPL
- This talk will give an overview of the facilities available and under development

Prober 1: Measurement of cryogenic S-parameters to 50GHz

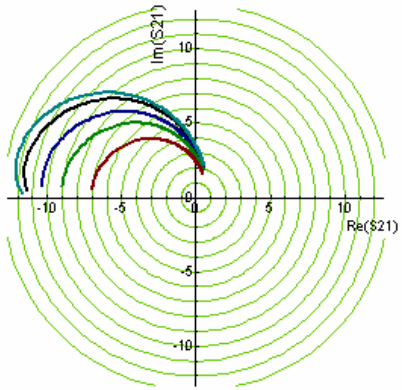


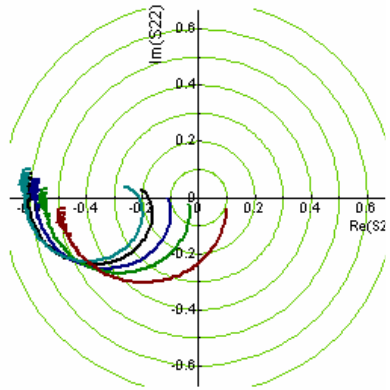
15K plate of current cryogenic probe station





S-Parameter 1-50GHz bei 15K
für 50nm IAF mHEMT bei U_d=1 [V],
Id = 100/150/225/300 [mA/mm]



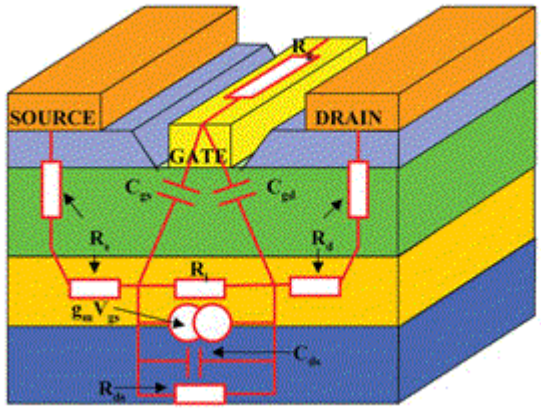


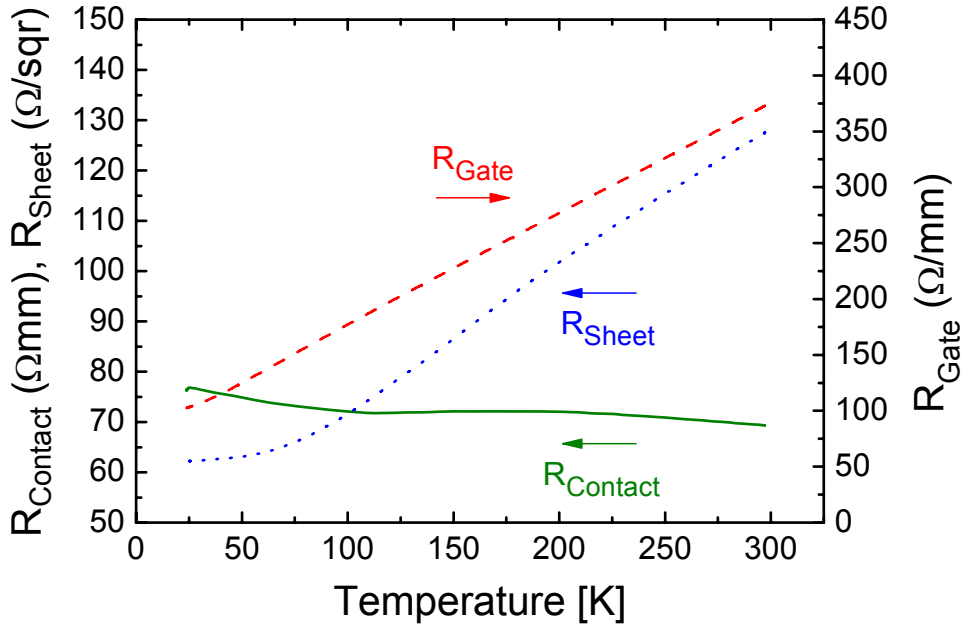
MAX-PLANCK-GESELLSCHAFT

Fraunhofer IAF

Max-Planck-Institut für Radioastronomie

Prober 2: Measurement of cryogenic DC parameters

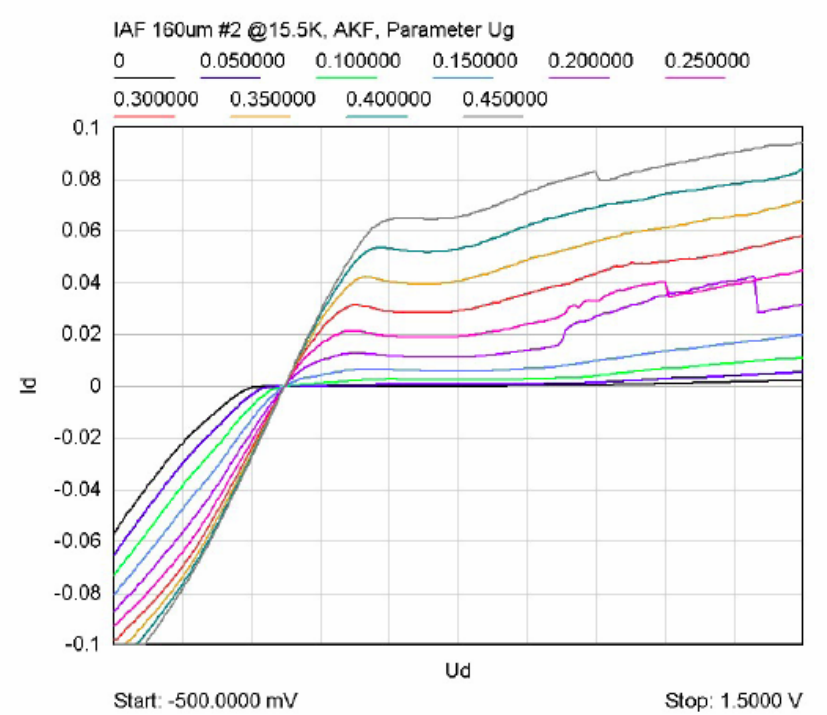




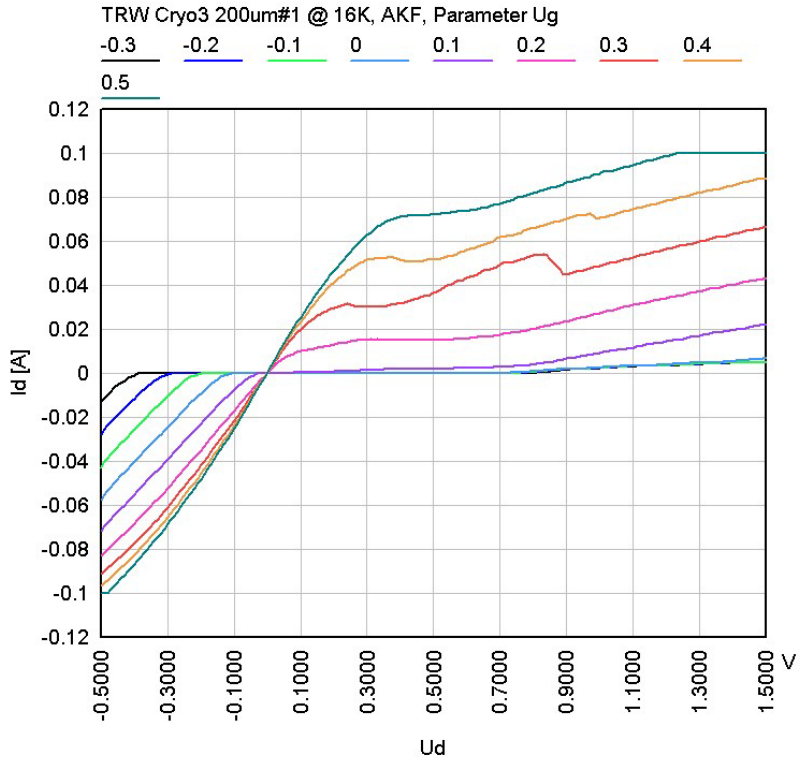
T_A = 300 K → 15 K

- **Sheet resistance R_{sheet} ↓ (- 55 %)**
- **Contact resistance R_c ↑ (+ 10 %)**
- **Gate line resistance R_g ↓ (- 66 %)**
- **Output conductance g_{DS}, transconductance g_M ↑ (+ 20 %)**
- **Capacities C_{gs},C_{gd},C_{ds} ↑ (+ 8 %)**
- **T_{CE} → ? (Assumption: no dependence on T_A)**

Prober 3: Anomalies at cryogenic temperature



IAF 100nm device



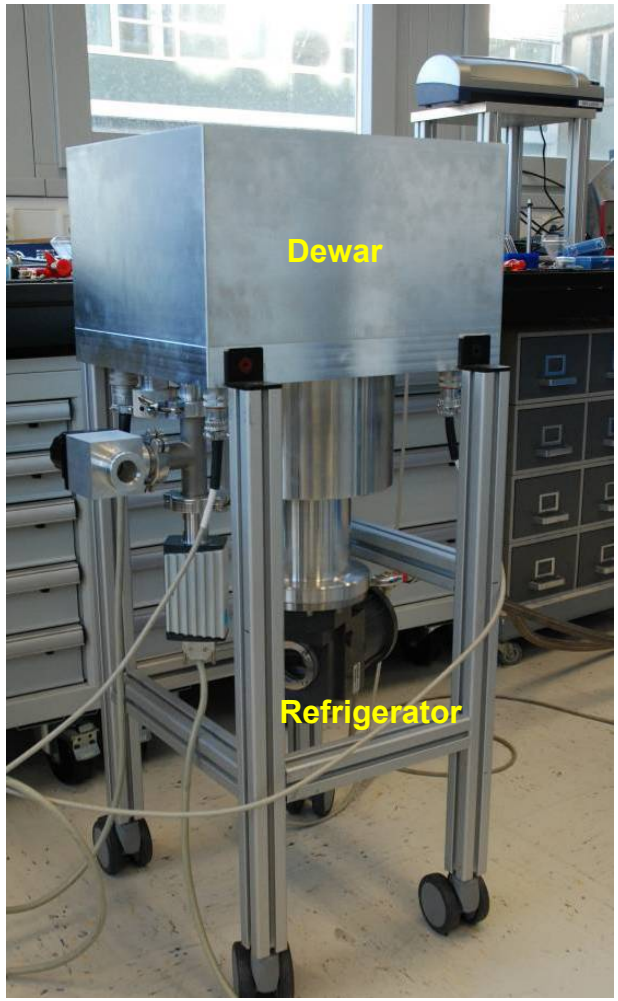
NGST Cryo3 device

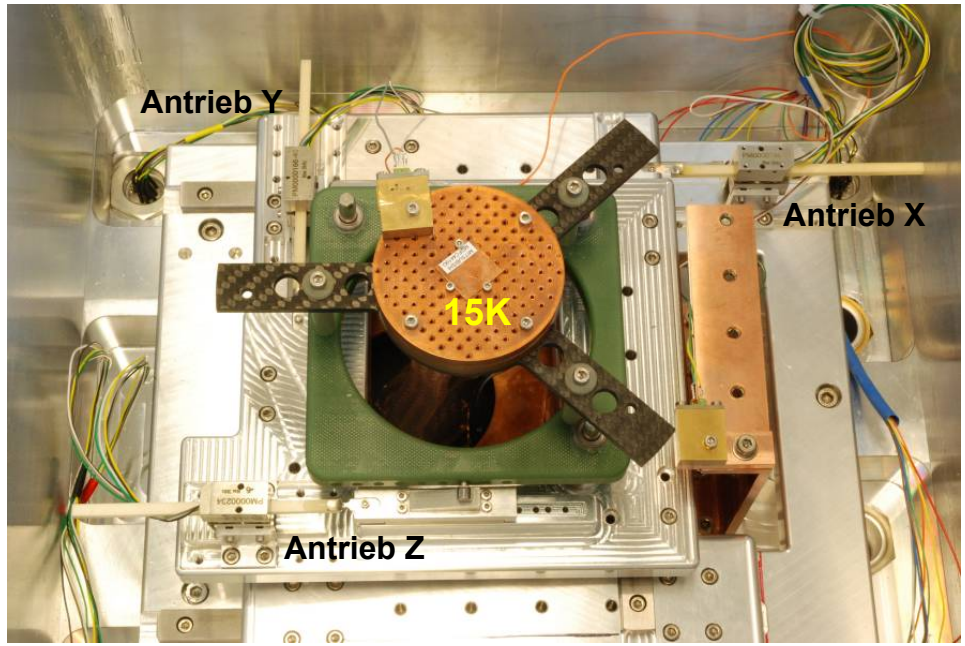
MAX-PLANCK-GESELLSCHAFT

Fraunhofer IAF

Max-Planck-Institut für Radioastronomie

Prober 4: Extension for 100GHz and Wafermapping

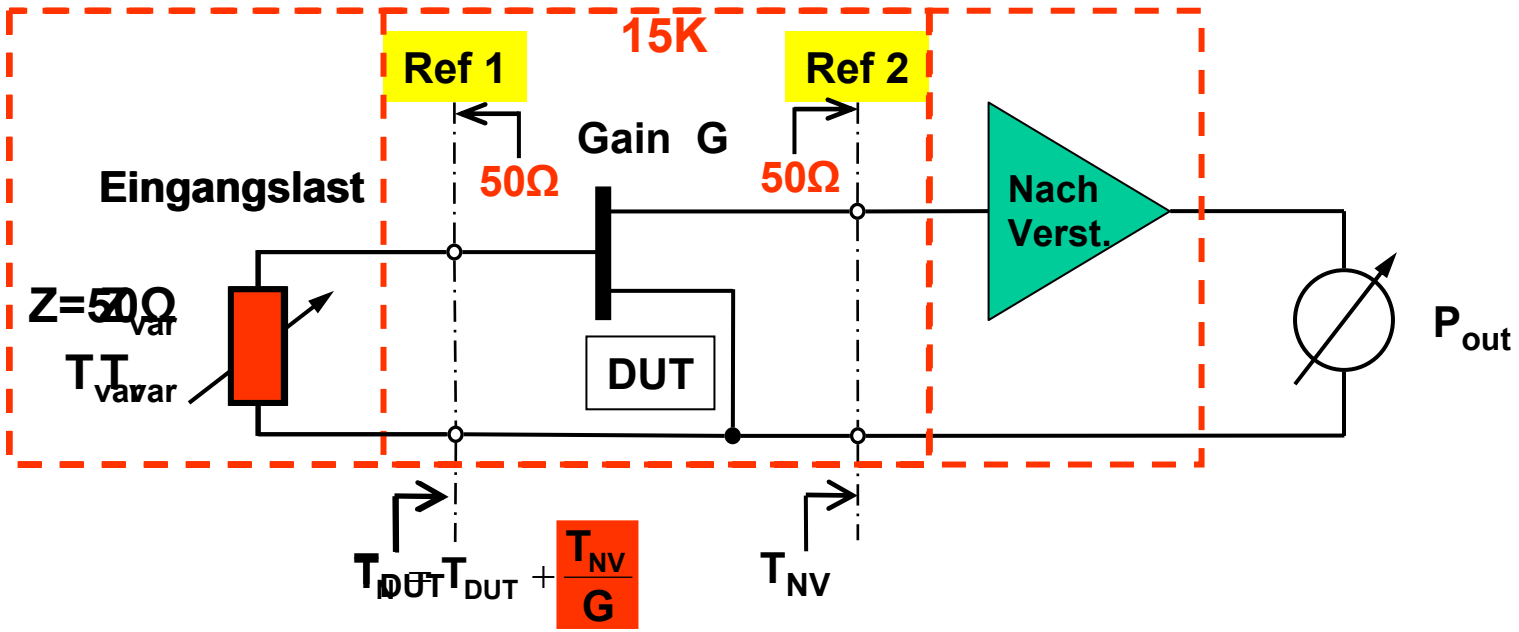




Prototype Cryostat of 100GHz Waferprober:

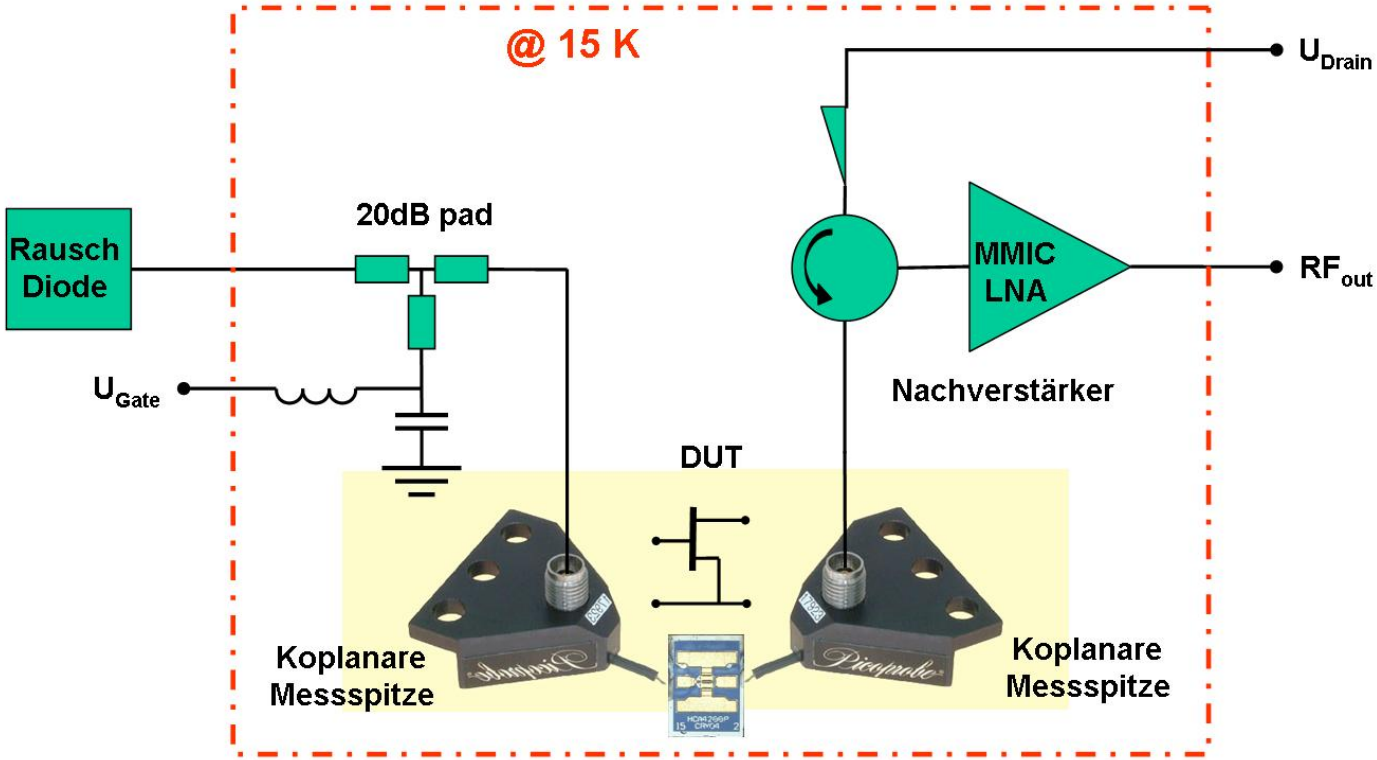
- 3 axis movement of 15K Probeplate (2“)
- Piezo linear motors inside the dewar

Basics of noise measurements for single transistors



- **Standard Method with Tuner (Z=var)**
- **Strong constraints due to Cryo – DUT**
- **Practibcable Method: F50 - but needs additional assumptions (Z=50Ω)**
- **Our F50 Variant**
  - **Input load / cooled pad at 15K**
  - **Post Amplifier at 15K**
- **Future : SPRP system – needs no additional assumptions**

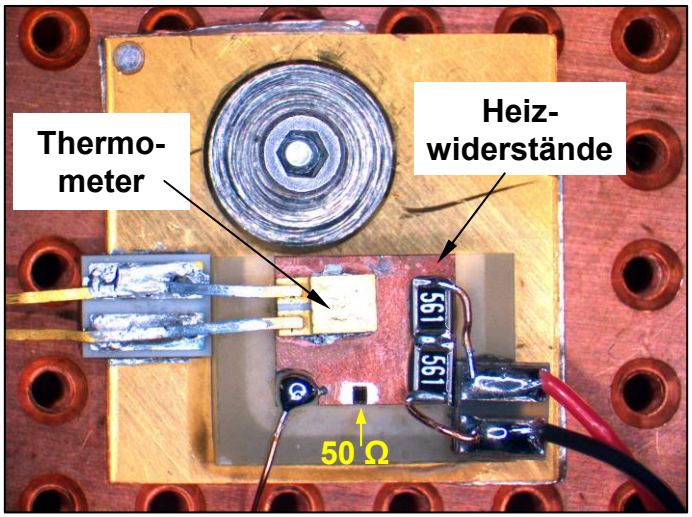
Cryogenic F50 Measurement Setup



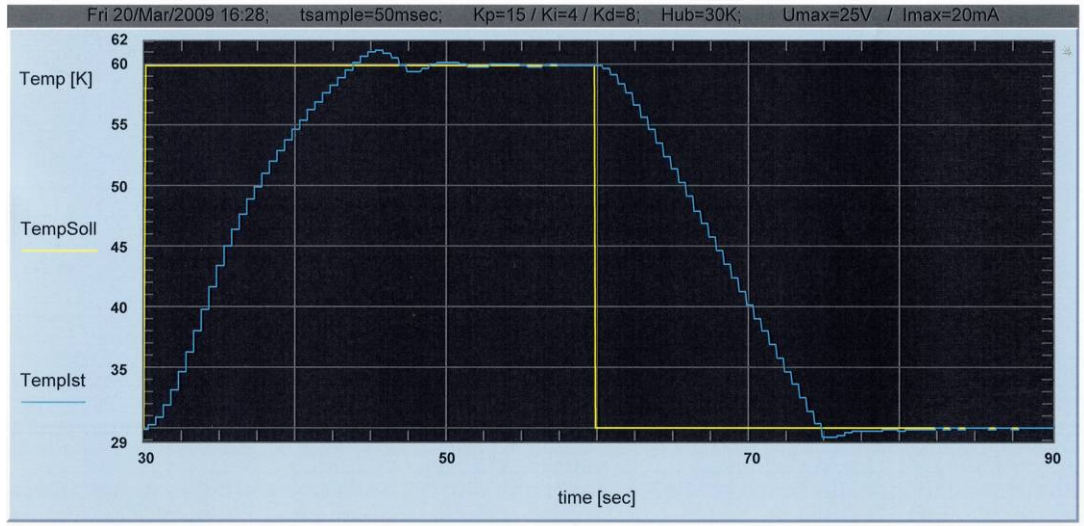
- Cooled attenuator : Input match, source temperatures
- Cooled post amplifier: Small contribution of post amplifier to total noise
- Requirement: Calibration plane of Measurement ≡ Coplanar probetips (DUT)

Internal calibration load for Cryo-F50

- Cryogenic setup: Measurement of input line losses using a VNA is impractical !
  - coplanar 15K / coaxial 300K
  - Calibration plane is at 15K
- Solution: heatable internal calibration load at 15K > absolute standard of noise temperature
- Short thermal time constant needed to cope with drifts
  - Small thermal mass
  - Software PID controller: ♦~15sec

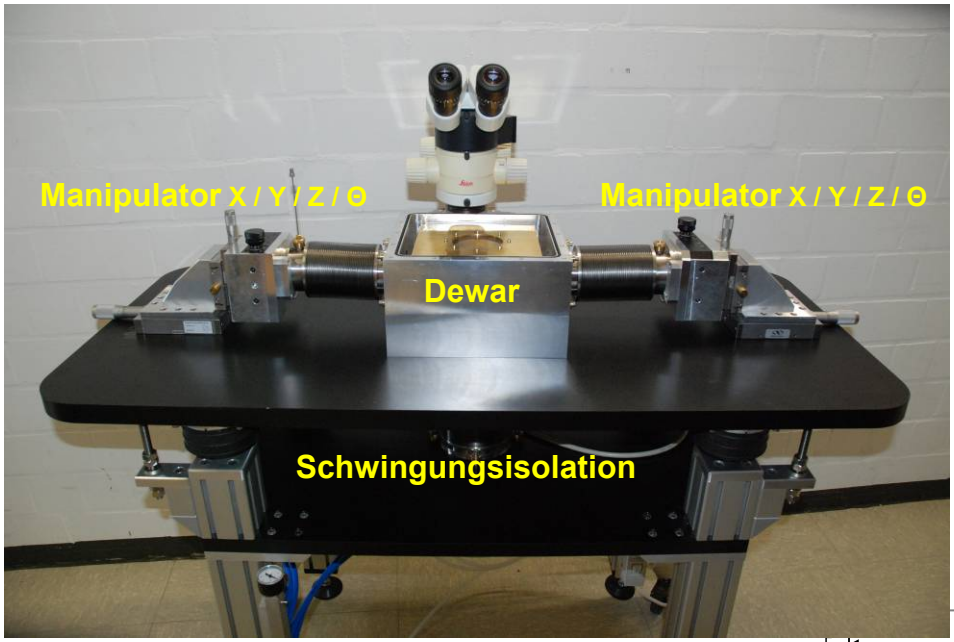


Heatable Load

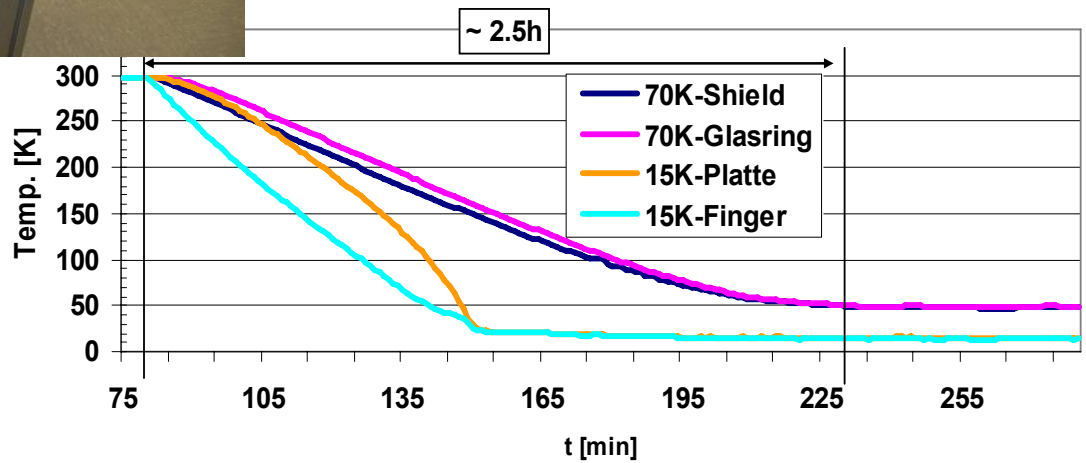


Profile of 30K temperature step

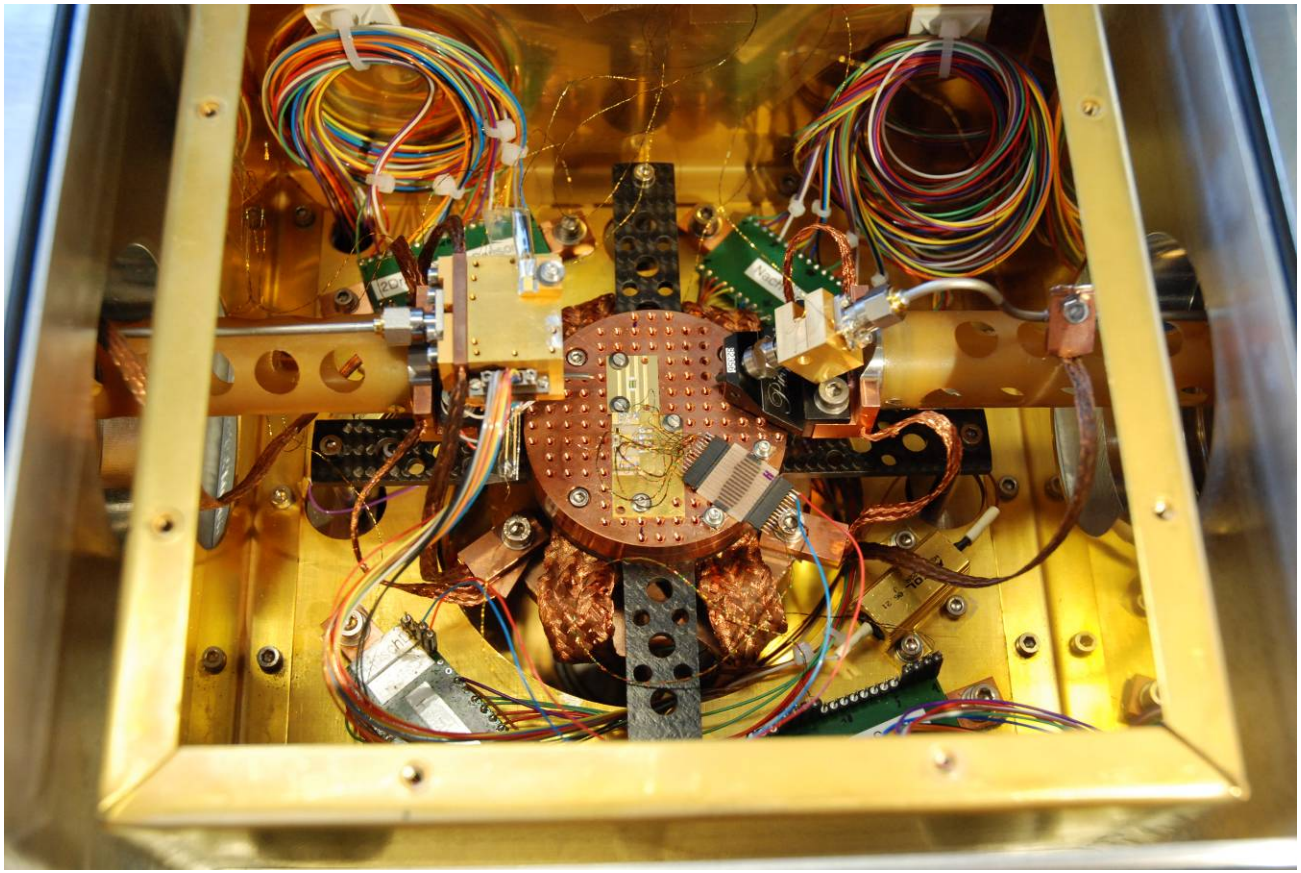
Current MPIfR F50-Prober



Cooling cycle
(Standard CTI 350 refrigerator)



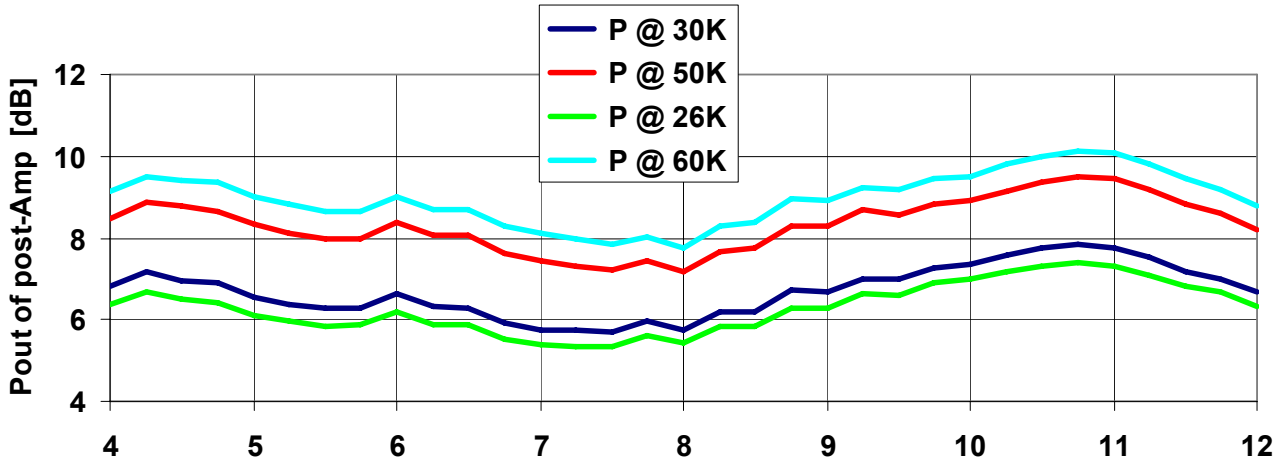
F50-Prober : Internal view



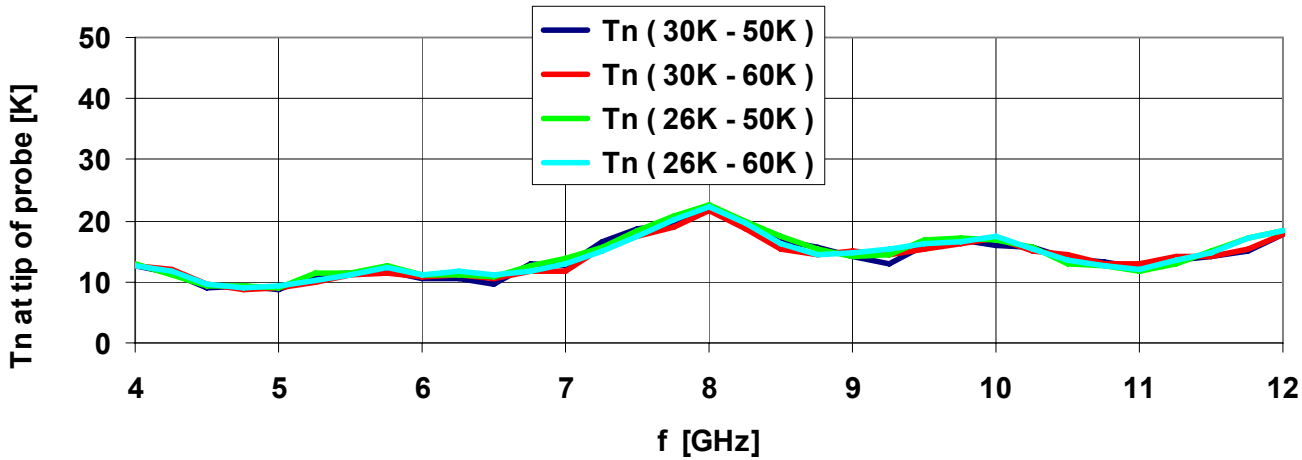
Post amplifier module for this test

- 4-12GHz MMIC LNA Typ WBA 13 from CHOP with integ. drain bias-tee
- 20dB pad integ. with gate bias-tee
- Good Input match (IRL ~ -15dB)
- Other frequency bands will be added

F50-Prober : Test of post Amp calibration with internal load



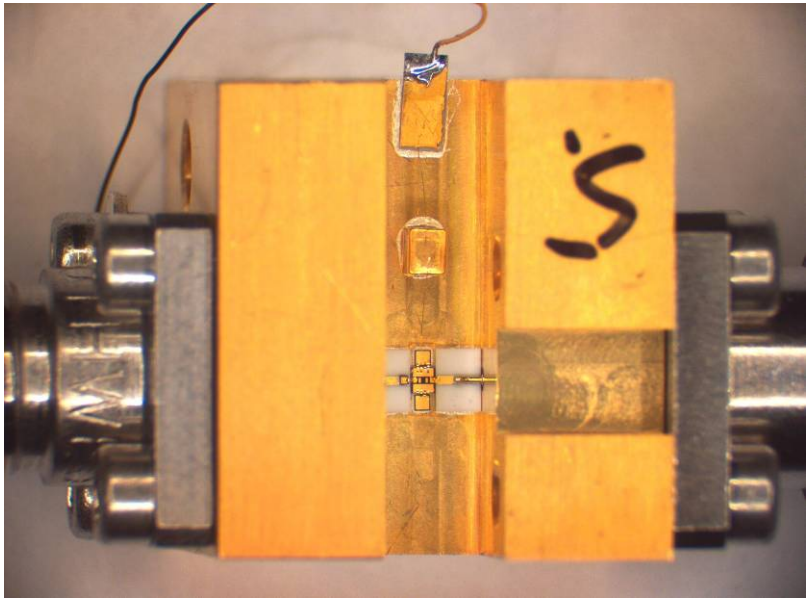
Output power of cryogenic post amplifier for different temperatures of internal heated load



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

No systematic effects with temperature

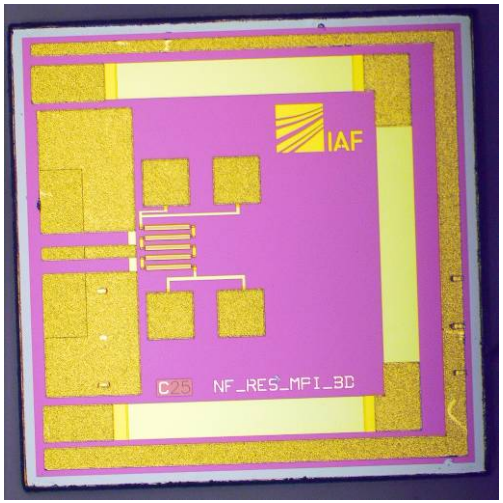
F50-Prober : 20dB pad with gate bias-tee

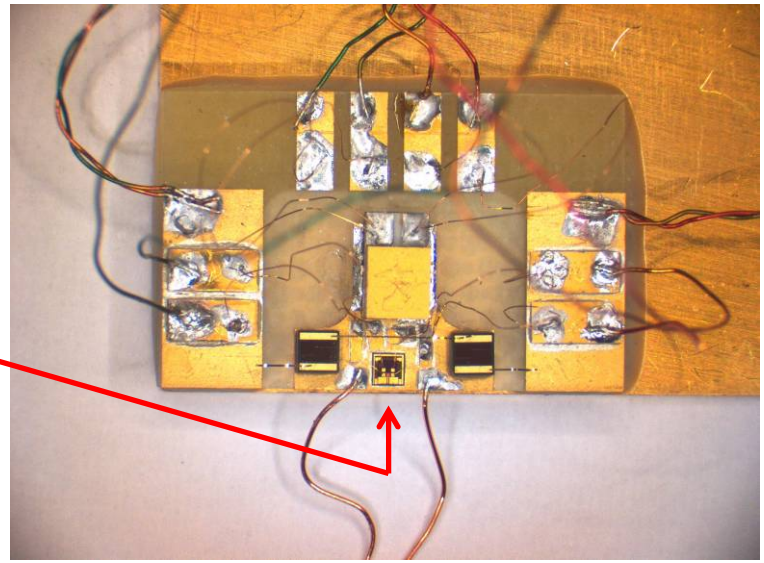


Further developments for F50 Prober

- Integrated version of heated, coplanar calibration load :
  - Faster thermal time constant
  - Can be placed On-wafer
- Test of electronically (τ~1msec) switched noise sources at 15K :
  - Avalanche Diode + cooled pad
  - mHEMT with switched bias + cooled pad

Chip





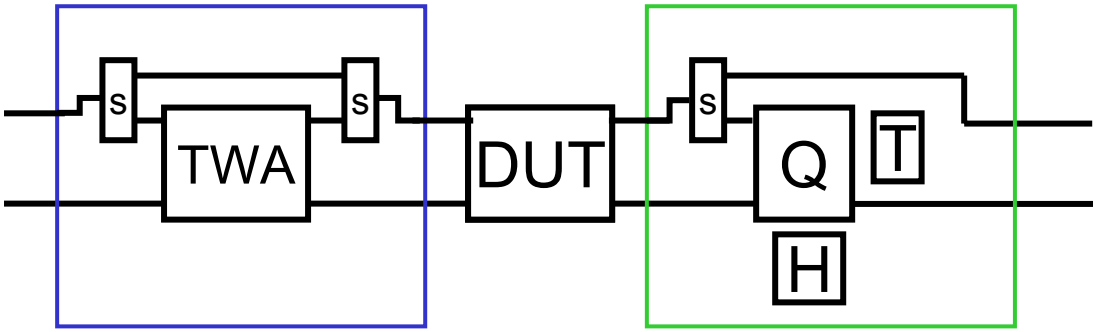
Test jig

Integrated version of heated, coplanar calibration load

Removing contraints of F50 in cryogenic NP measurements

Potential of using IAFs 50nm MMIC process for noise parameter measurements :

- 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

IAF MMICs for radioastronomical receivers 1

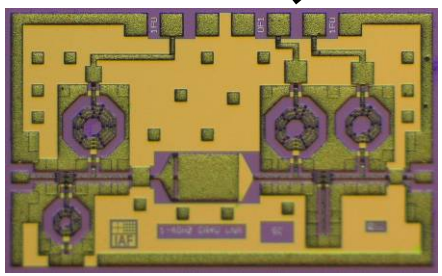
1-4GHz MMIC LNA @ 15K

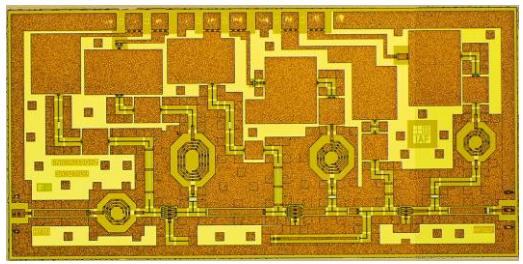
Cooperation IAF / MPIfR / IRAM Grenoble

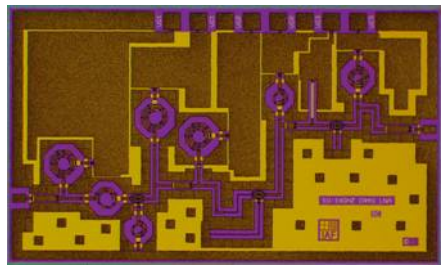
- Goal: Cryo-testing of existing 100nm mHEMT Technologie IAF M39
- Result : Need better understanding of device
- Specifications :

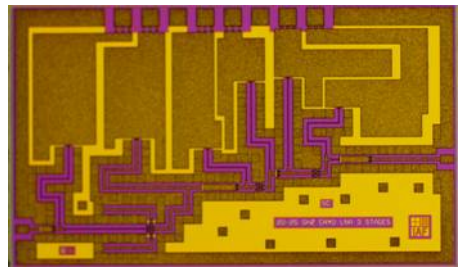
Frequency [GHz]	Gain [dB]	S_{11}, S_{22} [dB]	T_N [°K] (*)	P_{DC} [mW]
1-4	>27	< -15, -10	T_N~1..2	<15
4-12	>27	< -15, -10	2<T_N<4	<15
10-18	>30	< -15, -10	5<T_N<9	<15
20-25	>30	< -15, -10	10<T_N<12	<15

(*) Best effort, goal is InP performance







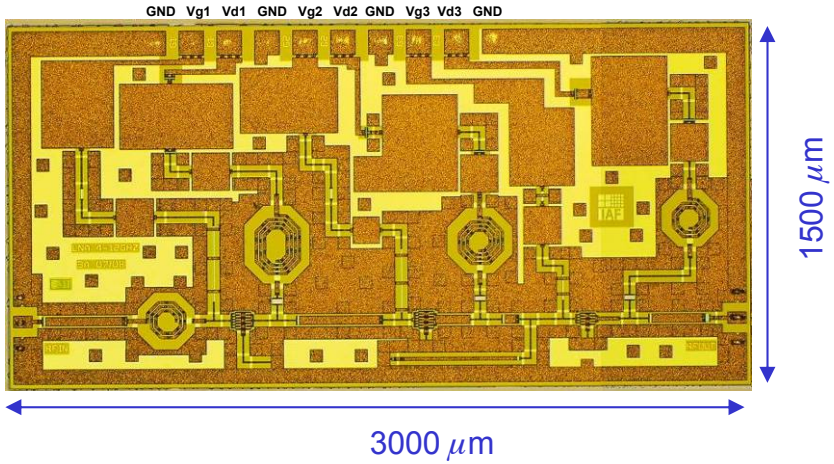


MAX-PLANCK-GESELLSCHAFT

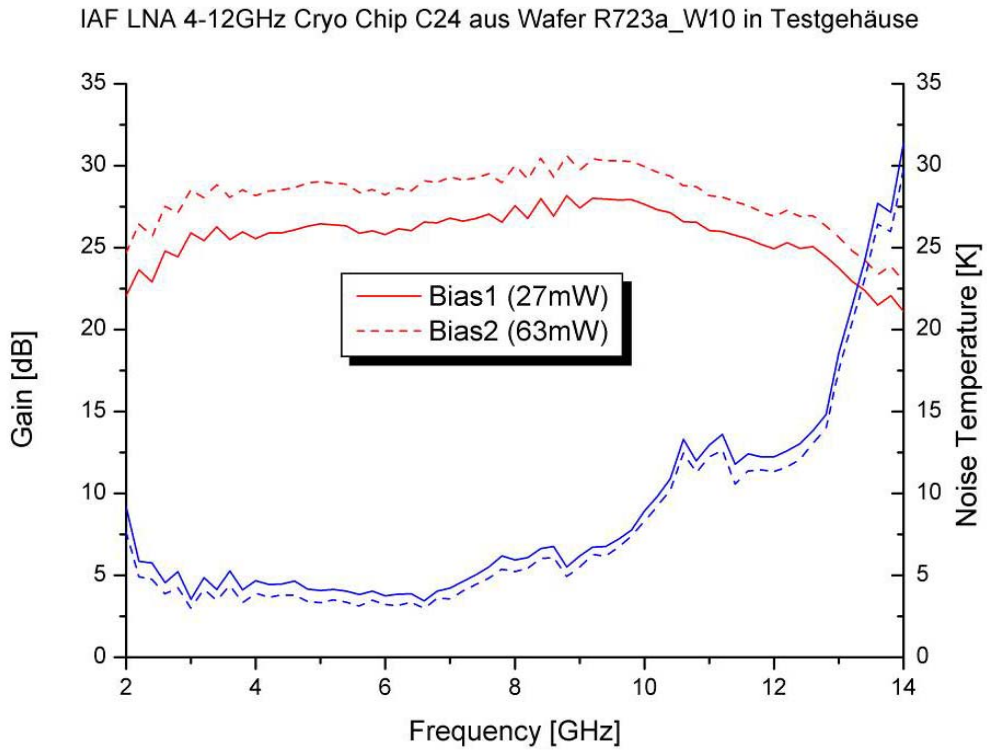
Fraunhofer IAF

Max-Planck-Institut für Radioastronomie

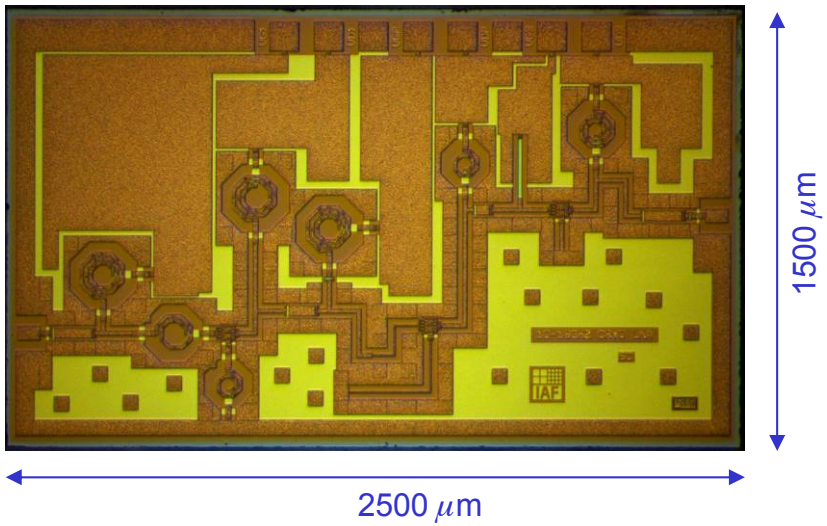
IAF MMICs for radioastronomical receivers 2

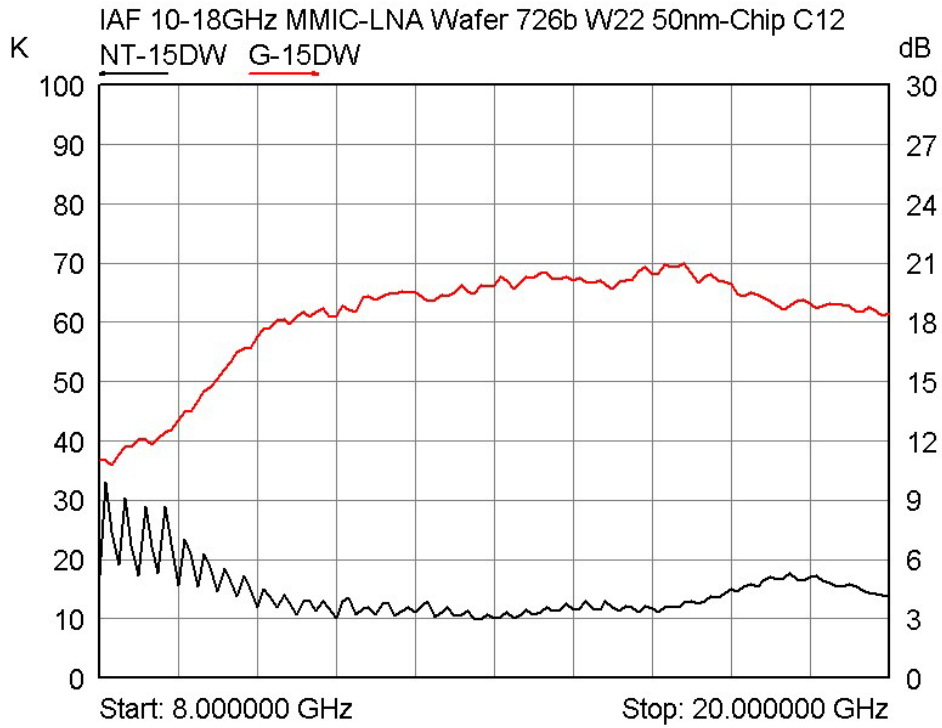


4-12 LNA performance @ 15 K
wide band design, 3 stages,
for 3 < f < 9 GHz
- Gain ~28 dB
- Noise Temp. ~ 5 K



IAF MMICs for radioastronomical receivers 3





10-18 LNA performance @ 15 K

- 3 stages,
- slighty low on gain

Outlook

- Cryogenic testing of W-band LNAs using IAFs standard 100/50nm process have just started
- The first dedicated cryo-run will probably happen end of this year
- Several partners from within the EC contribute funding to the project
- A project within the european FP7 is funded till end of 2011, another 3 years extension seems likely at the moment
- A research cooperation between IAF and MPIfR on cryogenic mHEMTs has sucessfully applied for considerable funding from the Fraunhofer/MPG joint research program
- This will allow for several dedicated cryogenic wafer runs for the optimization of the process