Fraunhofer IAF

The IAF mHEMT-Technology for low-noise mm-Wave and cryo-MMICs

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From Room-Temperature to Cryogenic Applications

- Status of the IAF-HEMT-Technology :
  - IAF well established as european source for MMICs
  - MMICs from 1 GHz to 500 GHz
  - State of the art RT noise figure

- Motivation:
  - Crosslink with radioastronomy
  - Increasing demand for Cryo-MMICs
  - Scientific Challenge

- Objective:
  - Cryo-Optimization of low noise HEMT-Technology

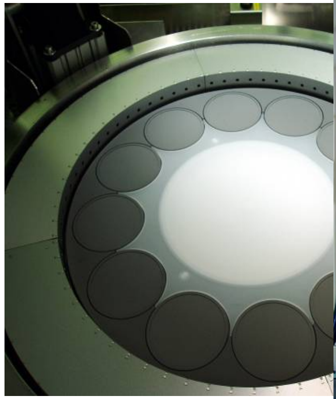
Outline

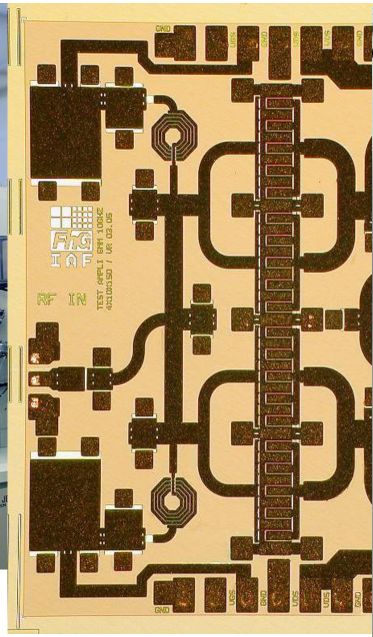
- IAF Facilities for High Frequency Electronics
- The IAF mHEMT Process
- MMICs for RT applications
- Process Monitoring
- Assessment of the potential for Cryo-MMICs
- Modelling
- Summary

IAF Expertise High-Frequency Electronics

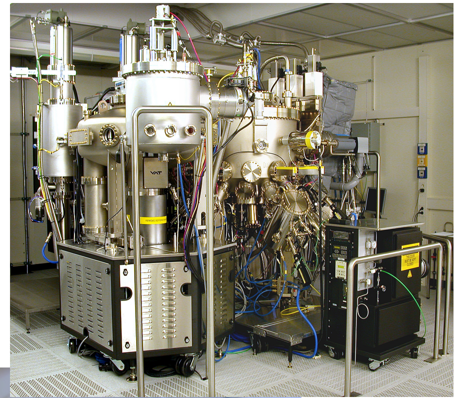
European Source for HF-devices, -circuits and -modules

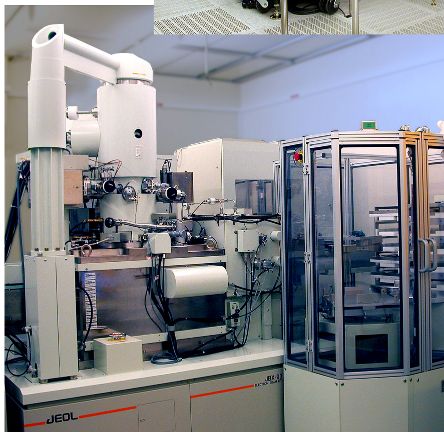
Material Epitaxy	Process Technology	Design MMICs	Measurement Reliability	Packaging Modules





Processing Equipment used for the IAF Technology





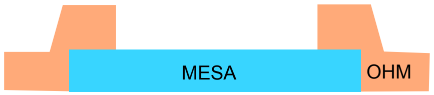
- **4 x 4" Wafer MBE "GEN 200"**
- **Jeol JBX 9300 Electron Beam Lithography**
- **Canon 5000+ wafer stepper**

Automatic Batch Tools for

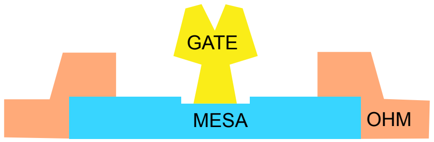
- **Wafer Coating and Developing**
- **Plasma Etching**
- **Plasma Deposition**
- **Thermal Annealing**
- **Metal Deposition (Sputtering, Evaporation, Galvanisation)**

IAF mHEMT-Technology: Processing

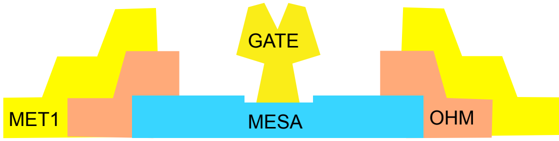
wet etched MESA



GeAu Ohmic contacts

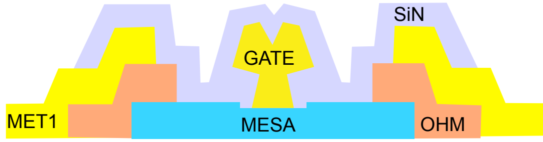


PtTiPtAu e-beam gate



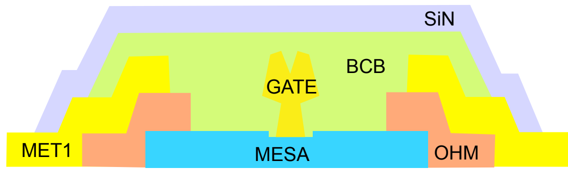
1. Metall

100 nm technology



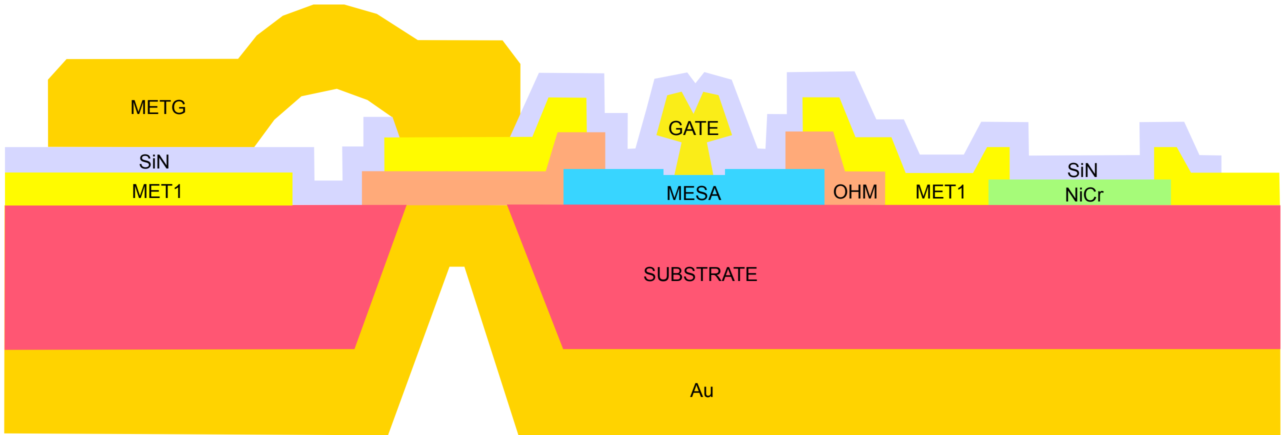
250 nm SiN passivation

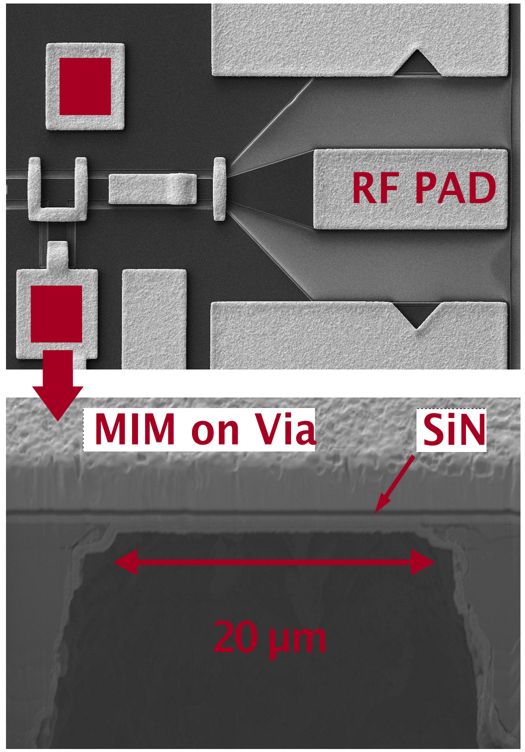
50/35 nm technology



250 nm SiN passivation on BCB

IAF mHEMT Technology für MMICs



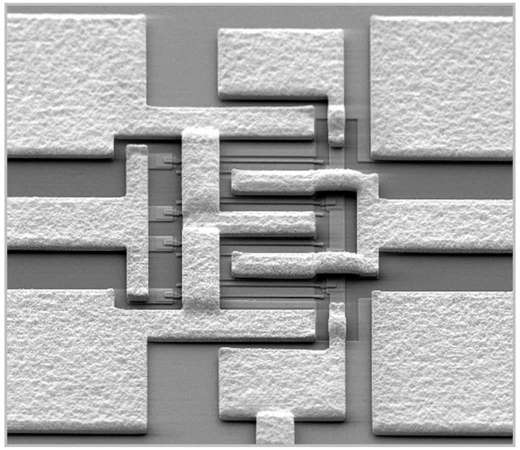


Characteristic features

- 2 Metallization layers
- 2.7 µm Au air bridges
- 225 pF/mm^2 MIM capacities
- 50 Ω/❹ NiCr resistors
- 250 nm CVD SiN passivation
- Back side process (thinning and via-holes)

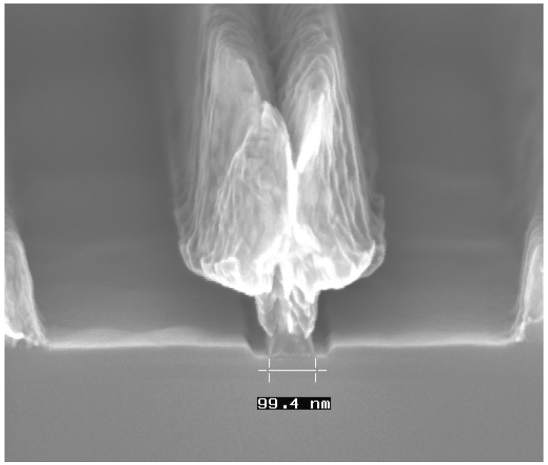
Transmission environment:
Grounded Coplanar

IAF mHEMT Processes

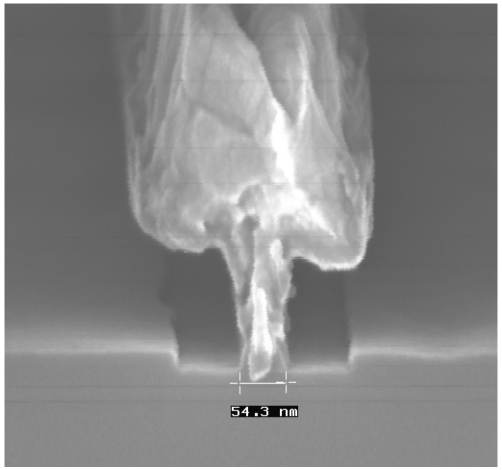


- mHEMT
  - **metamorphic High Electron Mobility Transistor**
- Comparison with InP-HEMTs :
  - **different substrates**
  - **identical active layer structure**

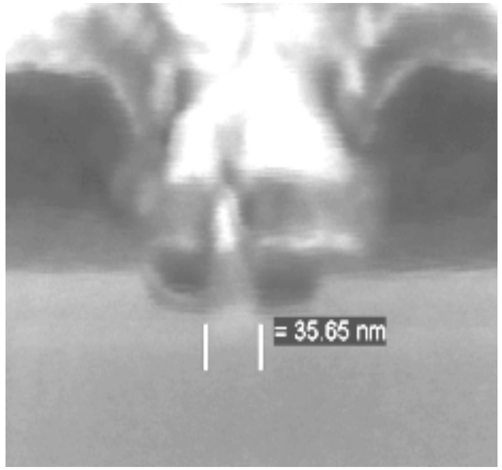
L_G = 100 nm
established



L_G = 50 nm
established

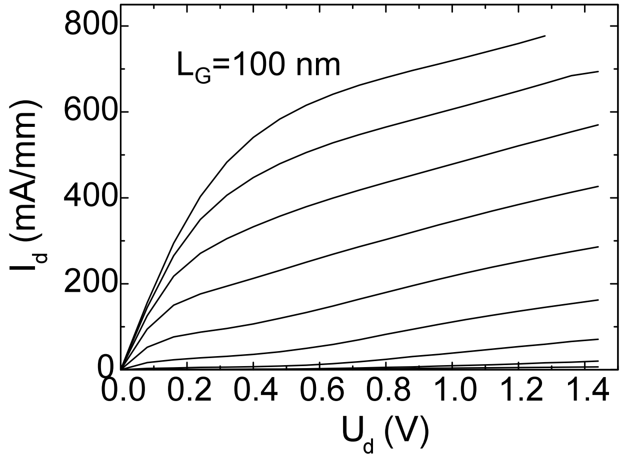


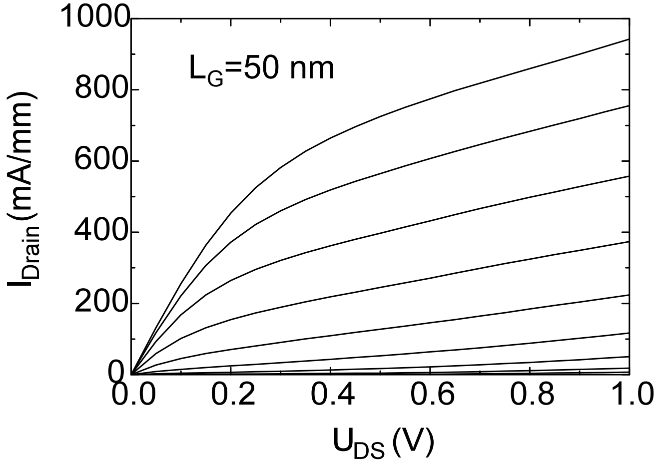
L_G = 35 nm
final test phase



IAF mHEMT Technologies: DC- und RF-Parameters

Characteristic Parameters for 35, 50 and 100 nm $In_xGa_{1-x}As$ mHEMTs





	35 nm	50 nm	100 nm
x (%)	80	80	65
R_C (Ωmm)	0.03	0.05	0.07
R_S (Ωmm)	0.10	0.15	0.23
R_g (Ω/mm)	250	250	400
$I_{D,max}$ (mA/mm)	1600	1200	900
V_{BD} (V)	2.0	2.5	4
$G_{m,max}$ (mS/mm)	2500	1800	1300
f_T (GHz)	550	380	220
f_{max} (GHz)	~900	~600	300

$$T_{min} = \sqrt{T_{amb} T_{CE}} \frac{f}{f_{max}}$$ für $f << f_{max}$

M.W. Pospieszalski, *IEEE Microwave Magazine*, vol. 6, no. 3, 62, 2005

RECEIVERS & ARRAY WORKSHOP 2010 19-20 September, 2010, MPIfR, BONN

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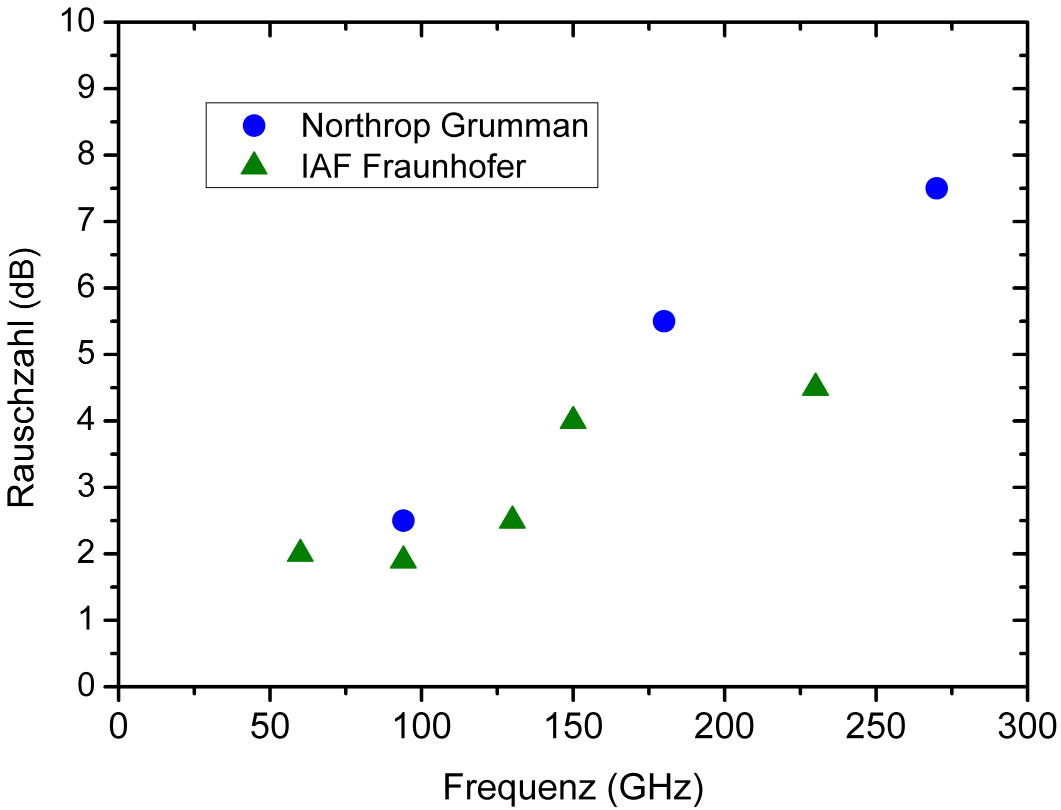
RT-Performance of the IAF-LNAs

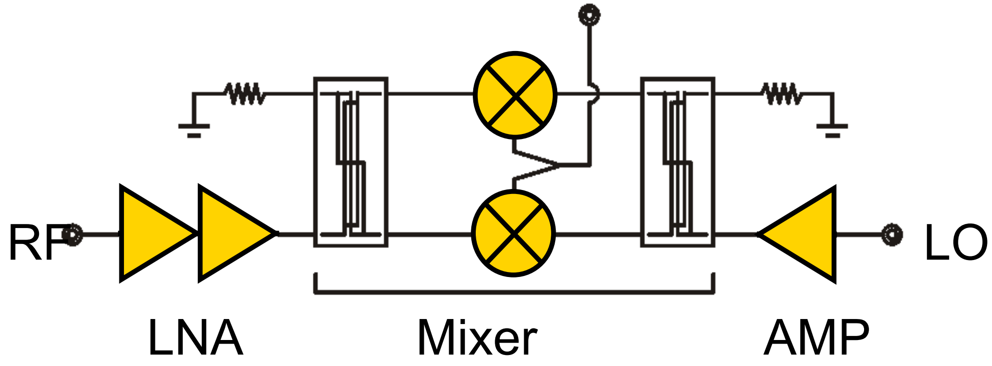
- Within Europe: leading position IAF
- Worldwide: neck-and-neck race with NGC



Data up to 2008

Multifunktional MW Circuits

W-Band Heterodyne Receiver MMIC



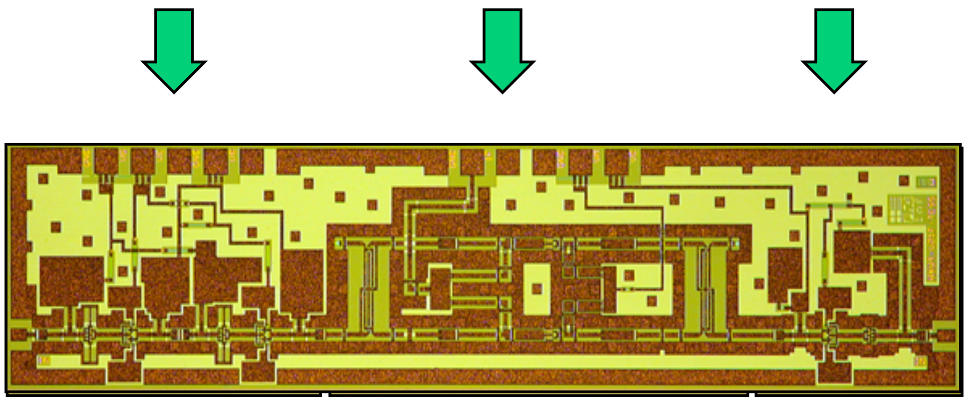
Building blocks :

two-stage low-noise amplifier

balanced resistive mixer
(2 Lange coupler)

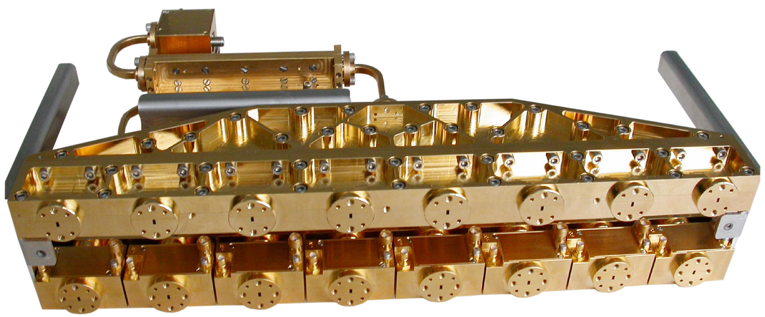
single-stage LO driver amplifier

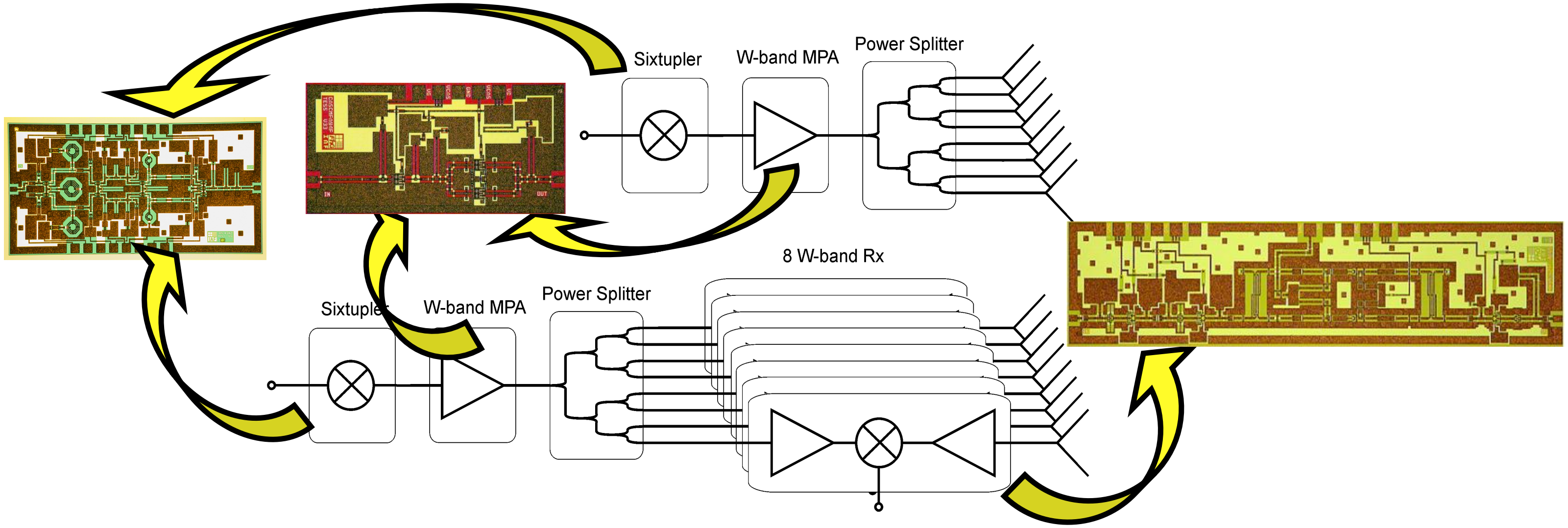
Chip Size: 1 x 4 mm^2



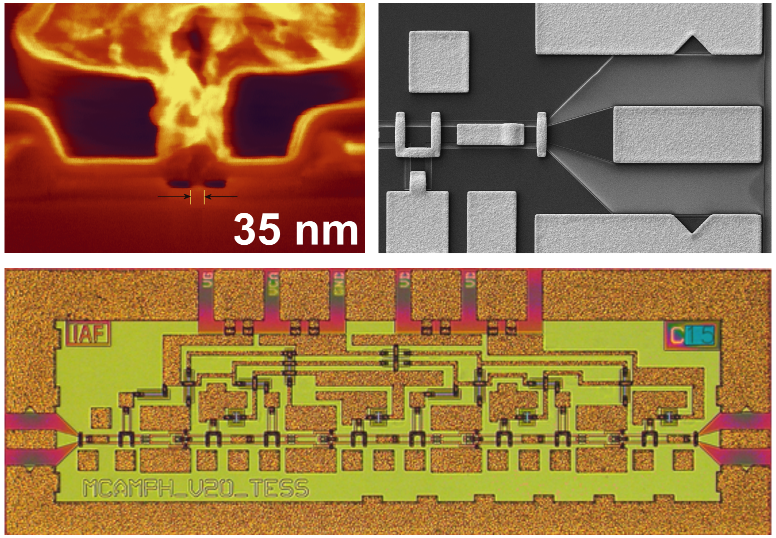
Module for Imaging Radar System at 94 GHz

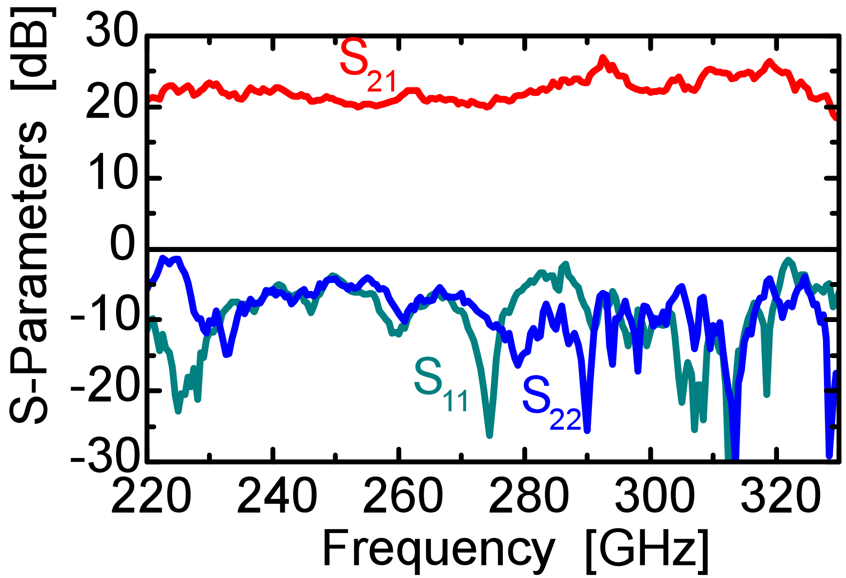
- 8-Channel-Radar for W-Band (75...110 GHz)
- Frontend MMIC built from IAF modules:
  - Frequency-Sixtupler: BW = 83...105 GHz
  - Driver Amplifier: P_{out} = 14 dBm
  - 1:8 Power Divider: A = 13 dB
  - Receiver: G_{conv} = 6 dB, NF = 4 dB





UWB Submillimeter-Wave Amplifier MMIC

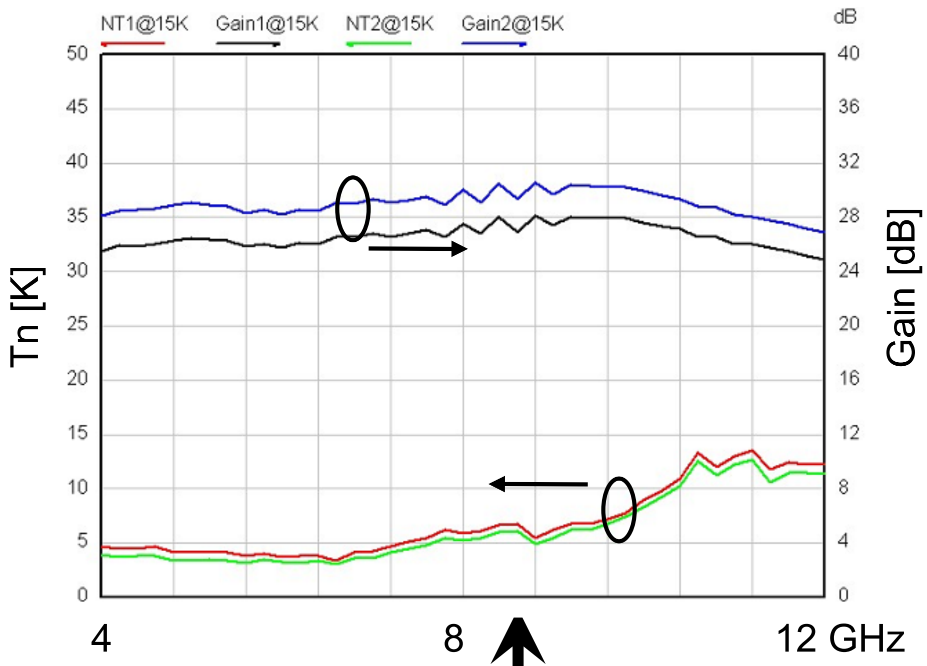




- 35 nm gate length mHEMT
- four-stage cascode LNA
- chip size 0.5 x 1.2 mm^2

- gain: > 20 dB @ 220…325 GHz
- noise figure: 6.9 dB (sim.)
- power consumption: 50 mW

IAF MMICs for Radioastronomic Receivers



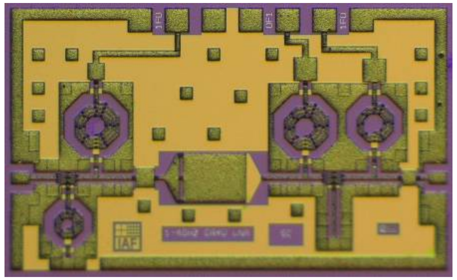
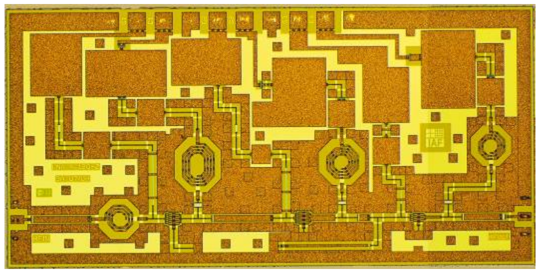
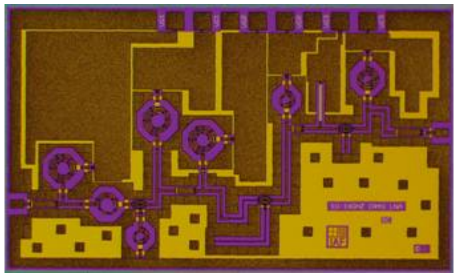
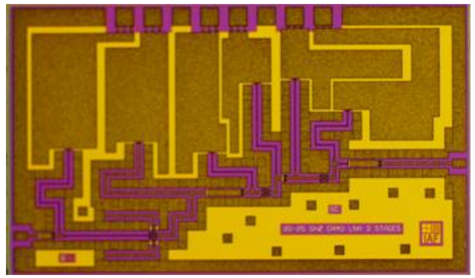
4 - 12 GHz MMIC LNA @ 15 K

First cooperation project IAF / MPIfR / IRAM
Goal: Cryo-Test of the existing 100 nm mHEMT Technology IAF M39

- **Result: More insight required**
- **Development of four IF amplifiers**

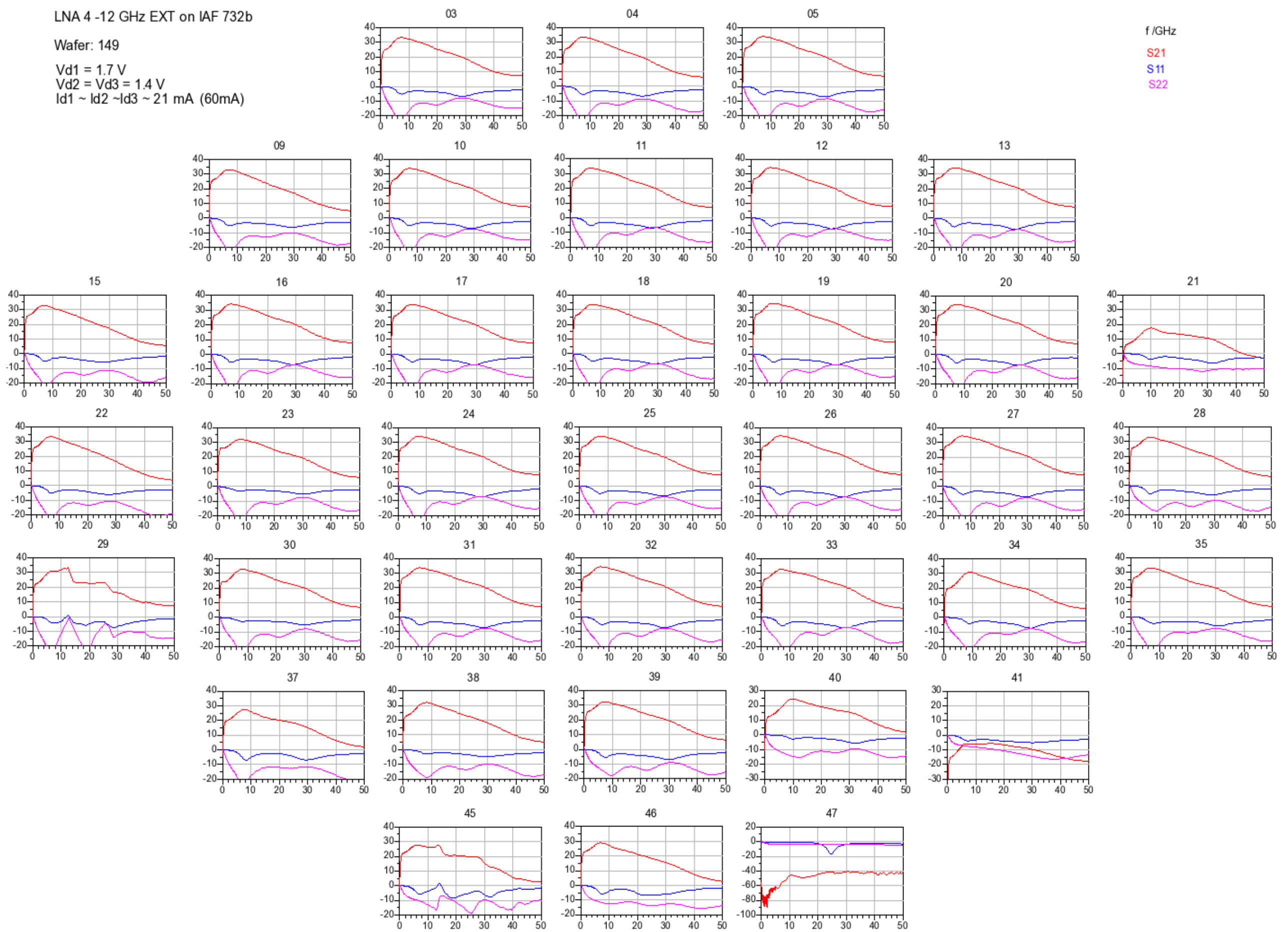
Frequenz [GHz]	Gain [dB]	S_{11}, S_{22} [dB]	T_N [°K] (*)	P_{DC} [mW]
1-4	>27	< -15, -10	T_N~1..2	<15
4-12	>27	< -15, -10	$2<T_N<4$	<15
10-18	>30	< -15, -10	$5<T_N<9$	<15
20-25	>30	< -15, -10	$10<T_N<12$	<15

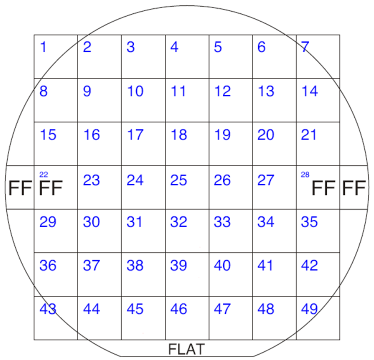
(*) Best effort, goal is InP performance

Mappings R732b W149

- LNA 4-12 GHz EXT





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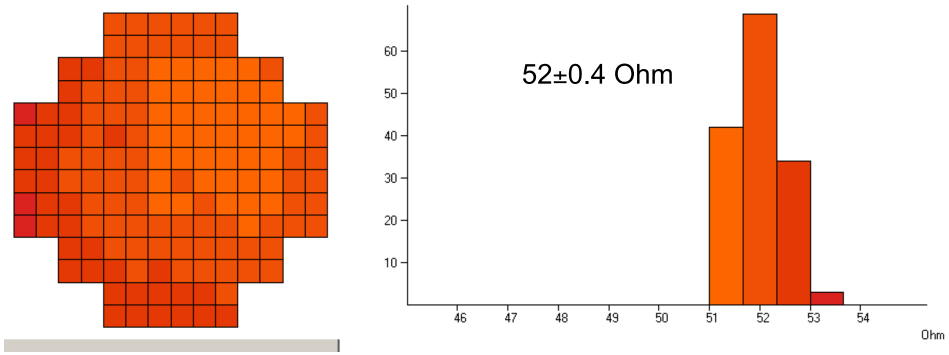
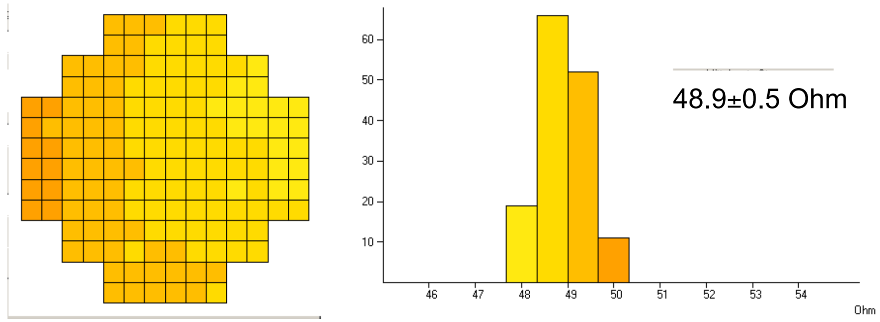
R729 NiCr Sheet

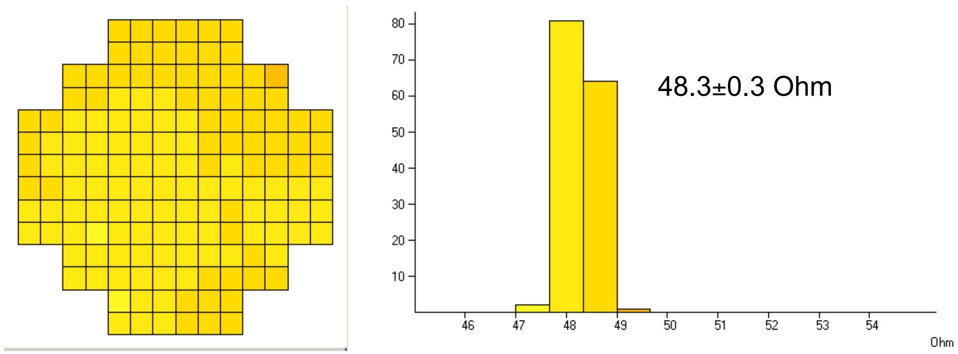
W87



W55



W88



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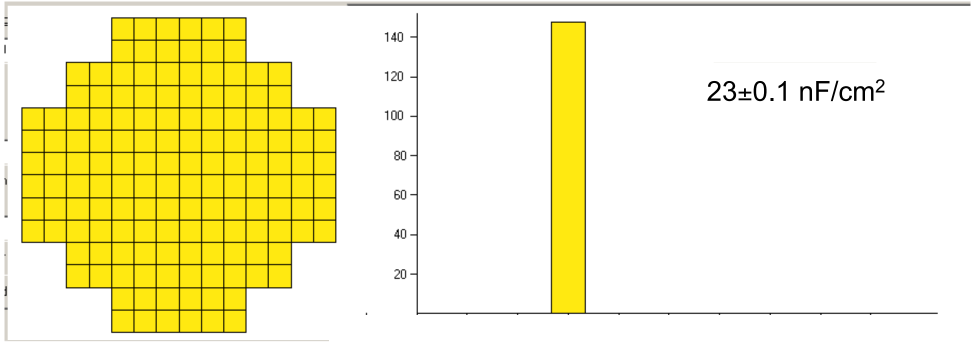
R729 MIM Capacities

W87



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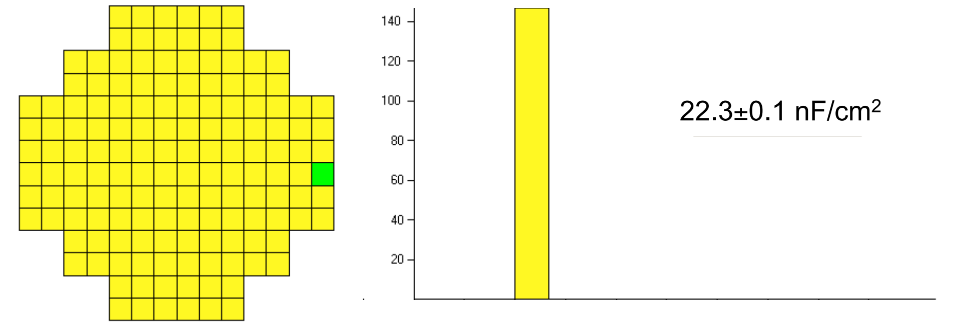

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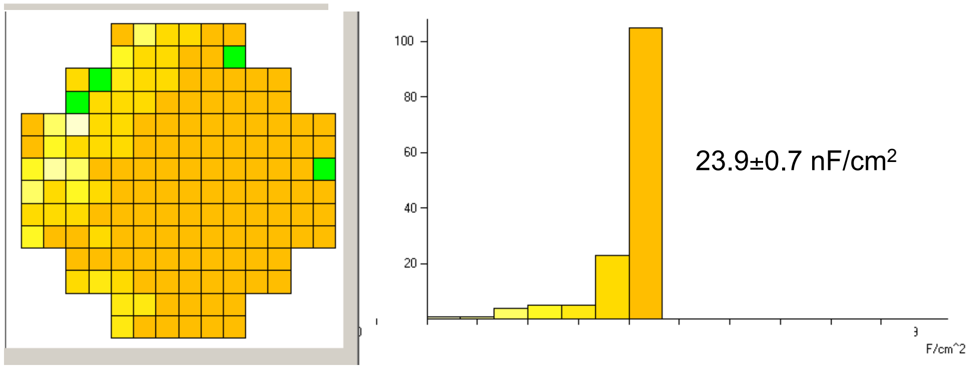
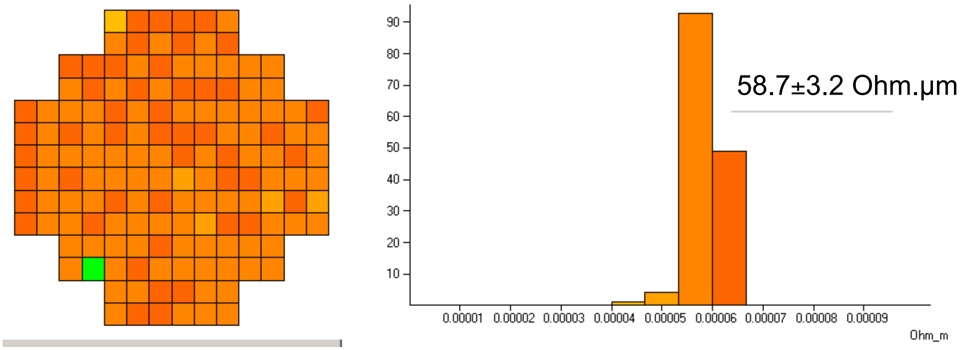


R729 Contact Resistance

W87



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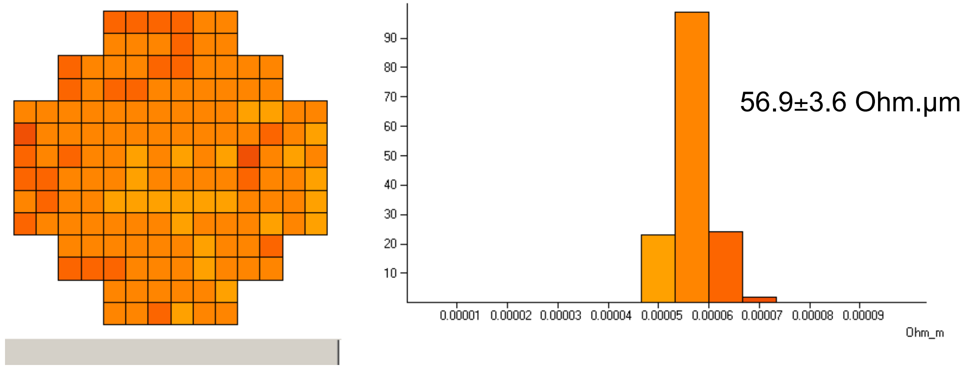

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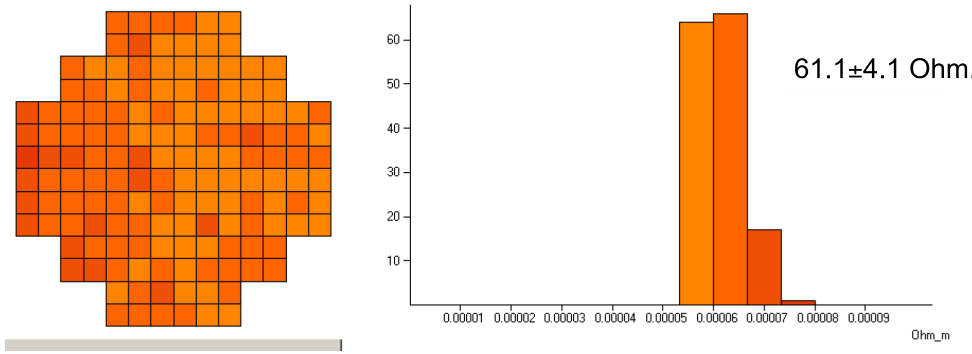
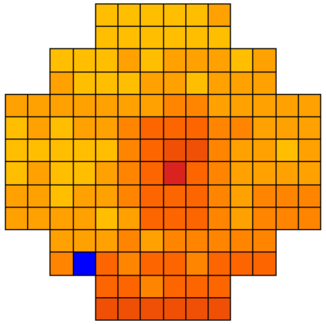
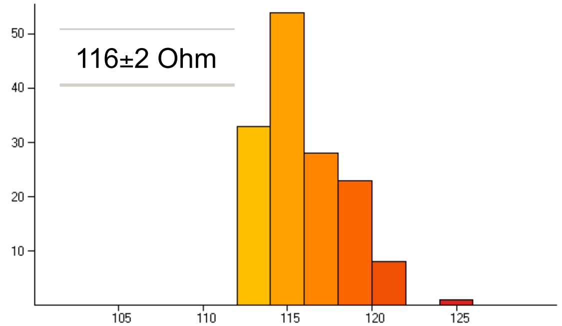


R729 Sheet Resistance

W87





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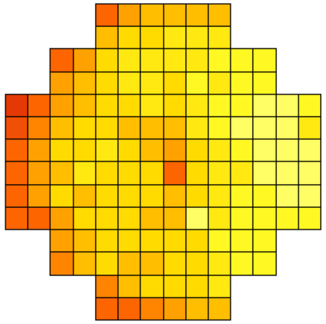

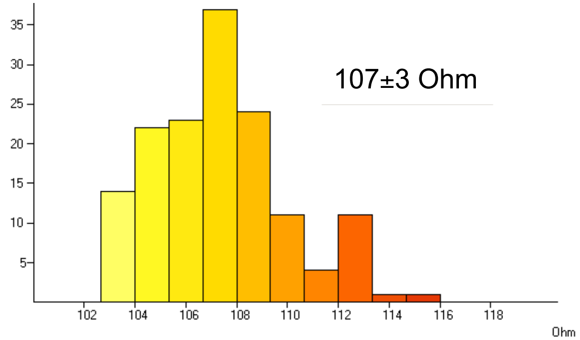

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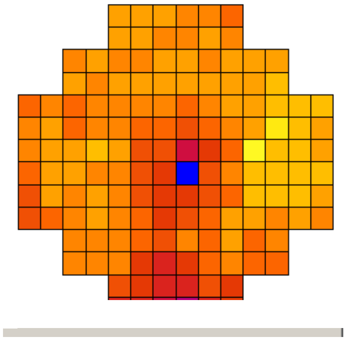

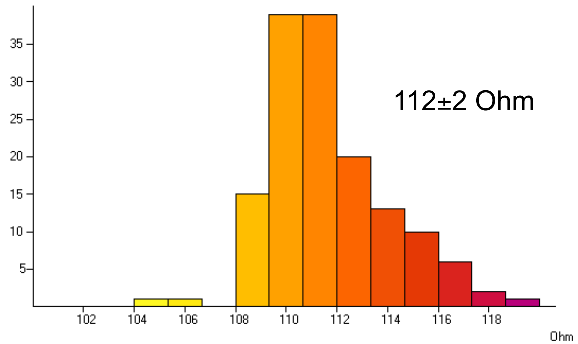

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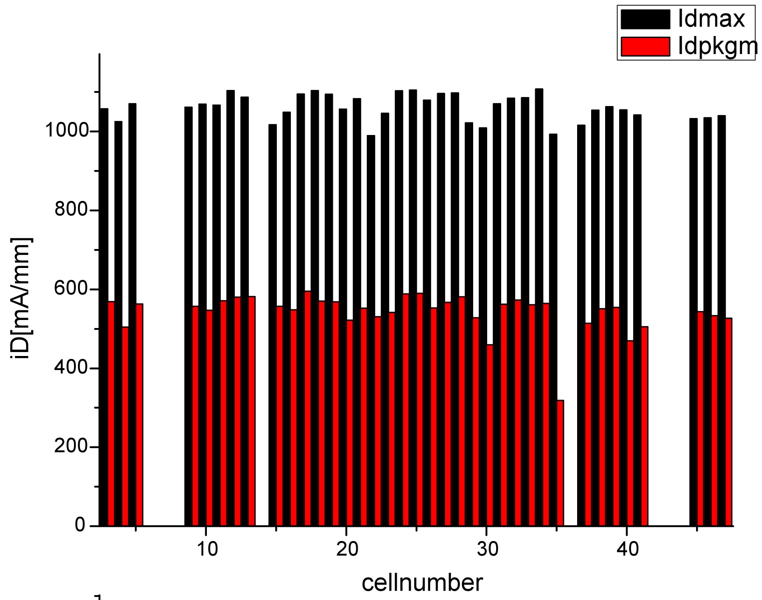
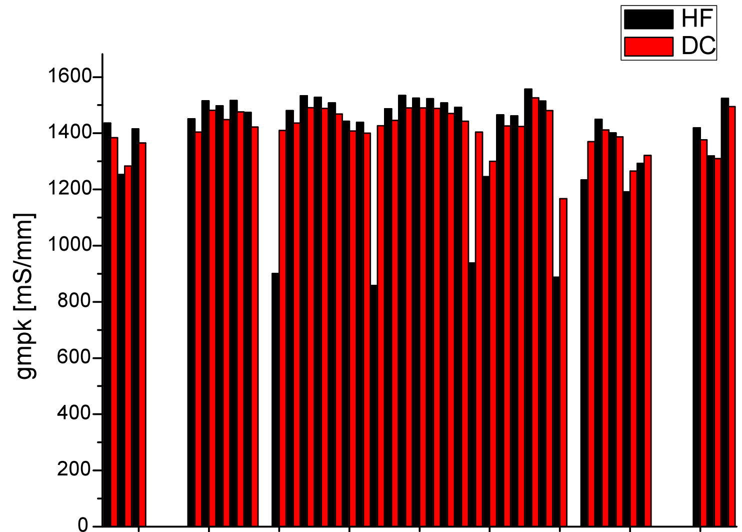
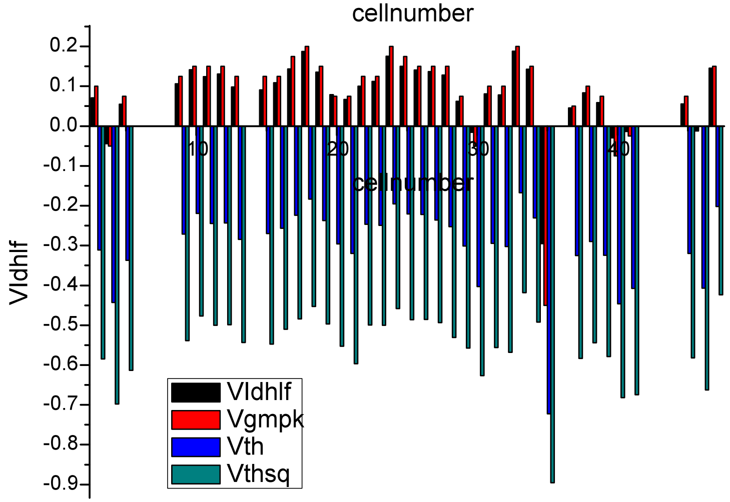
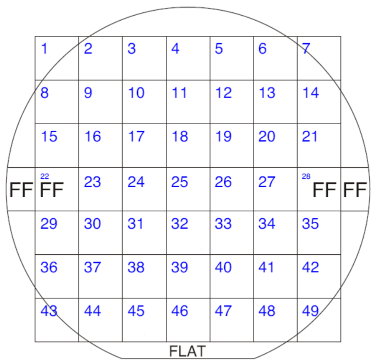
PCM Transistor Mapping DC

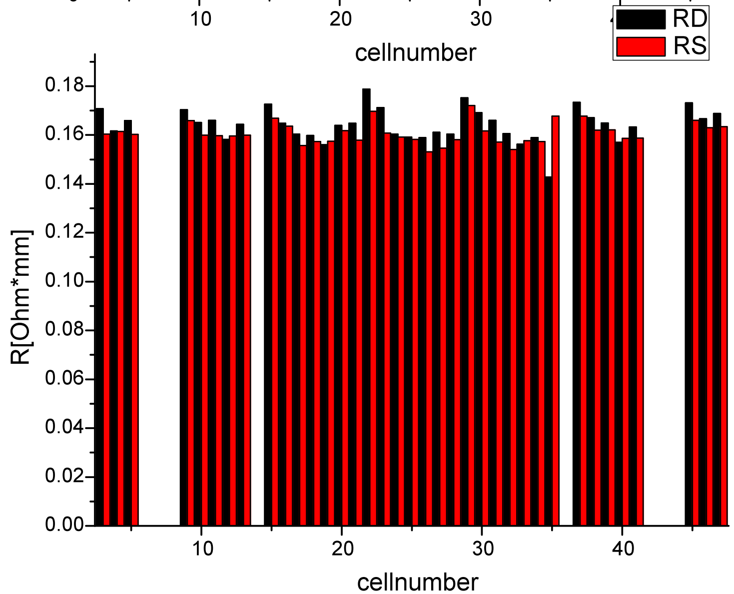




R729a
(AL090721)
M39
LG=100 nm
F2x30 Wafer 55







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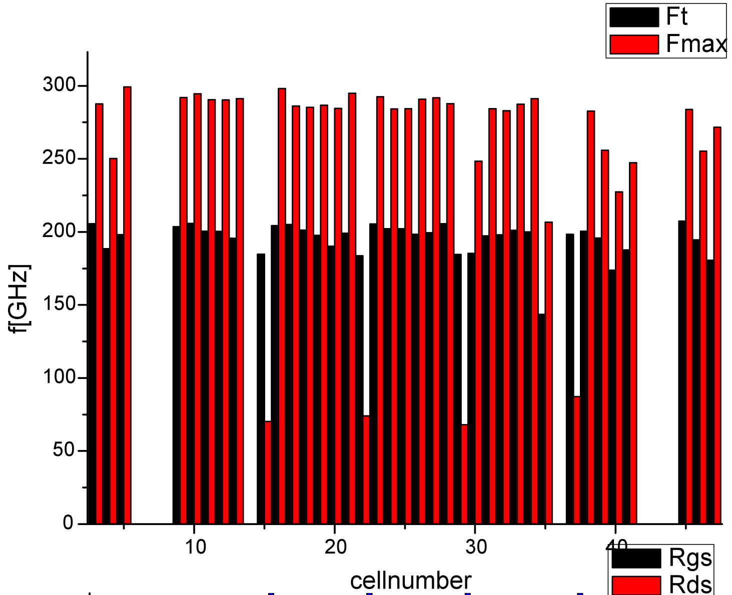
PCM Transistor Mapping HF



R729a
(AL090721)
M39
LG=100 nm
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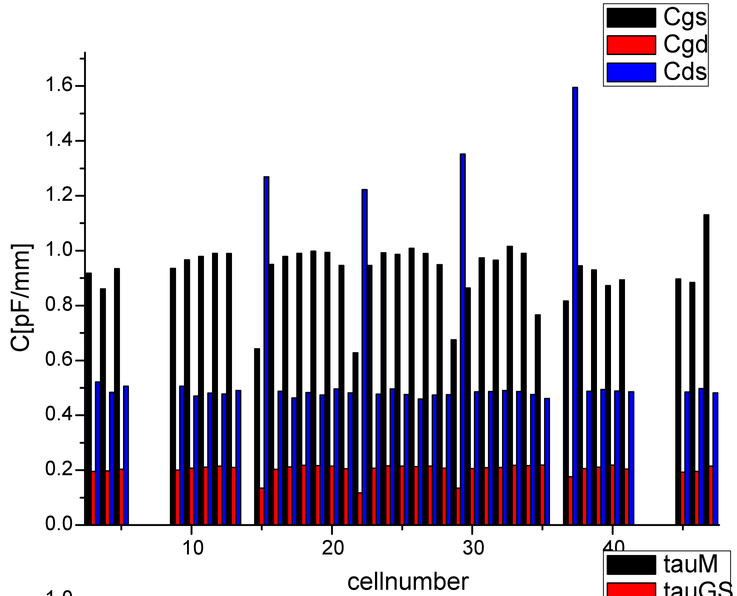

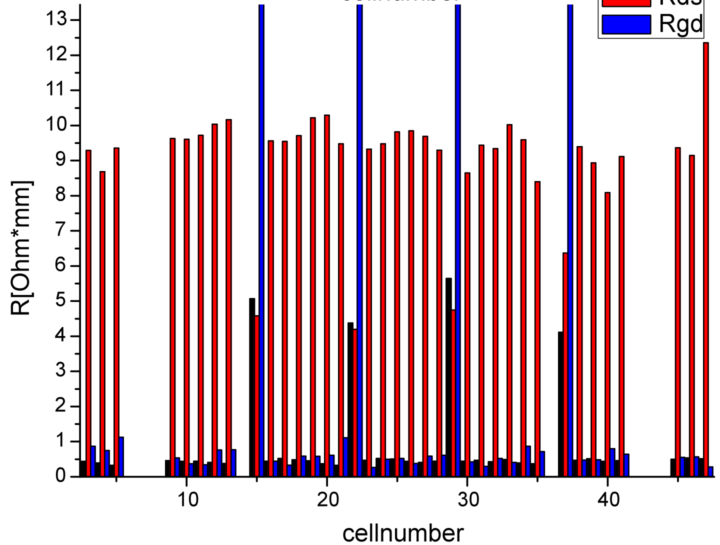

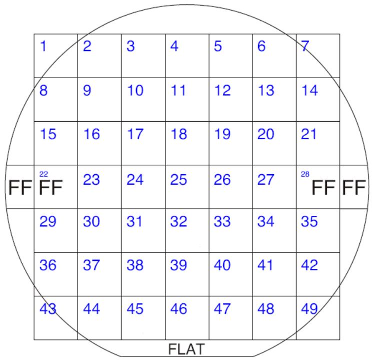

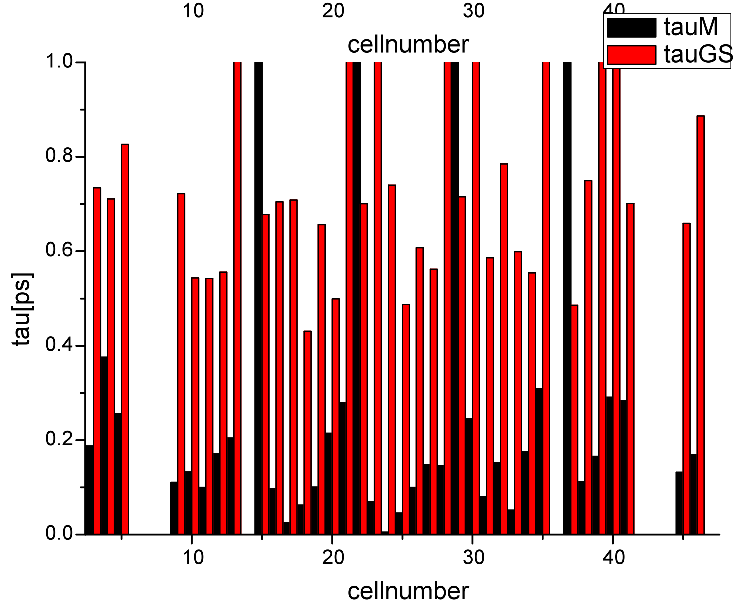

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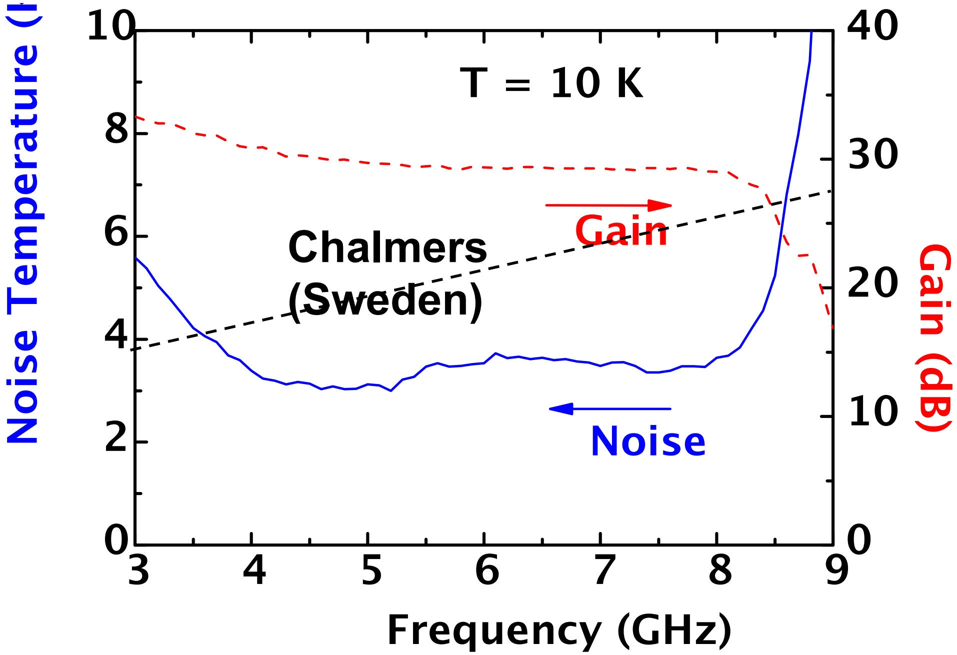
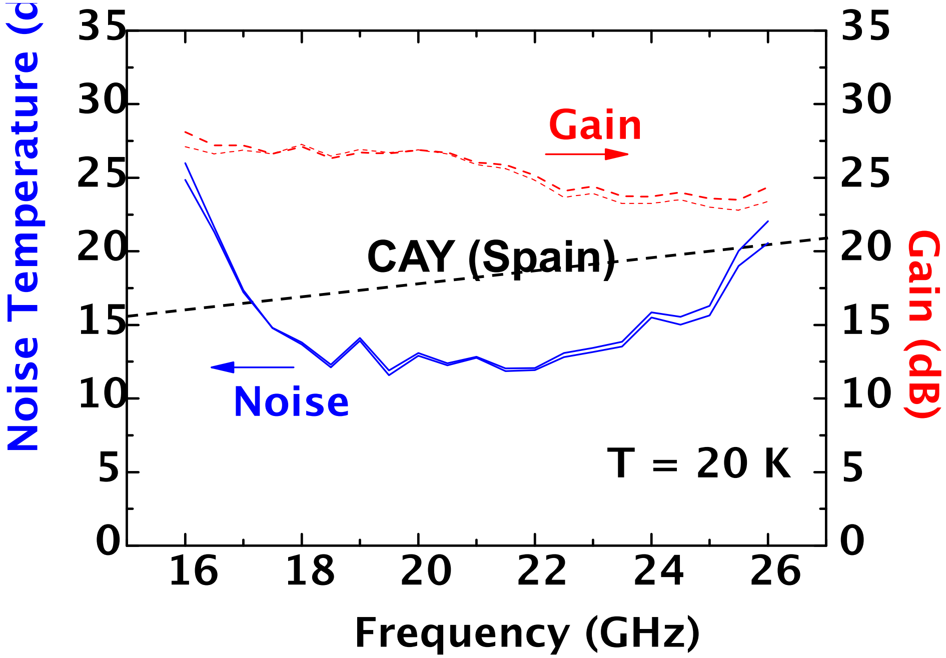
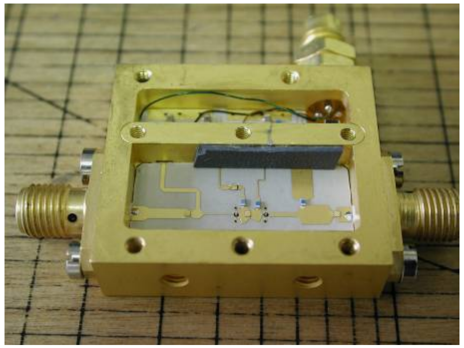
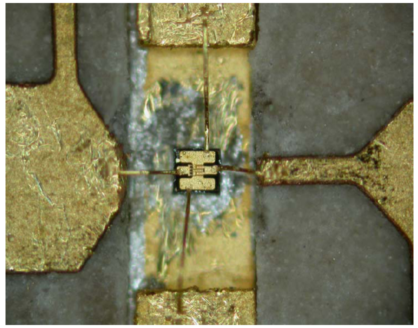
Performance of IAF mHEMTs at Cryogenic Temperatures



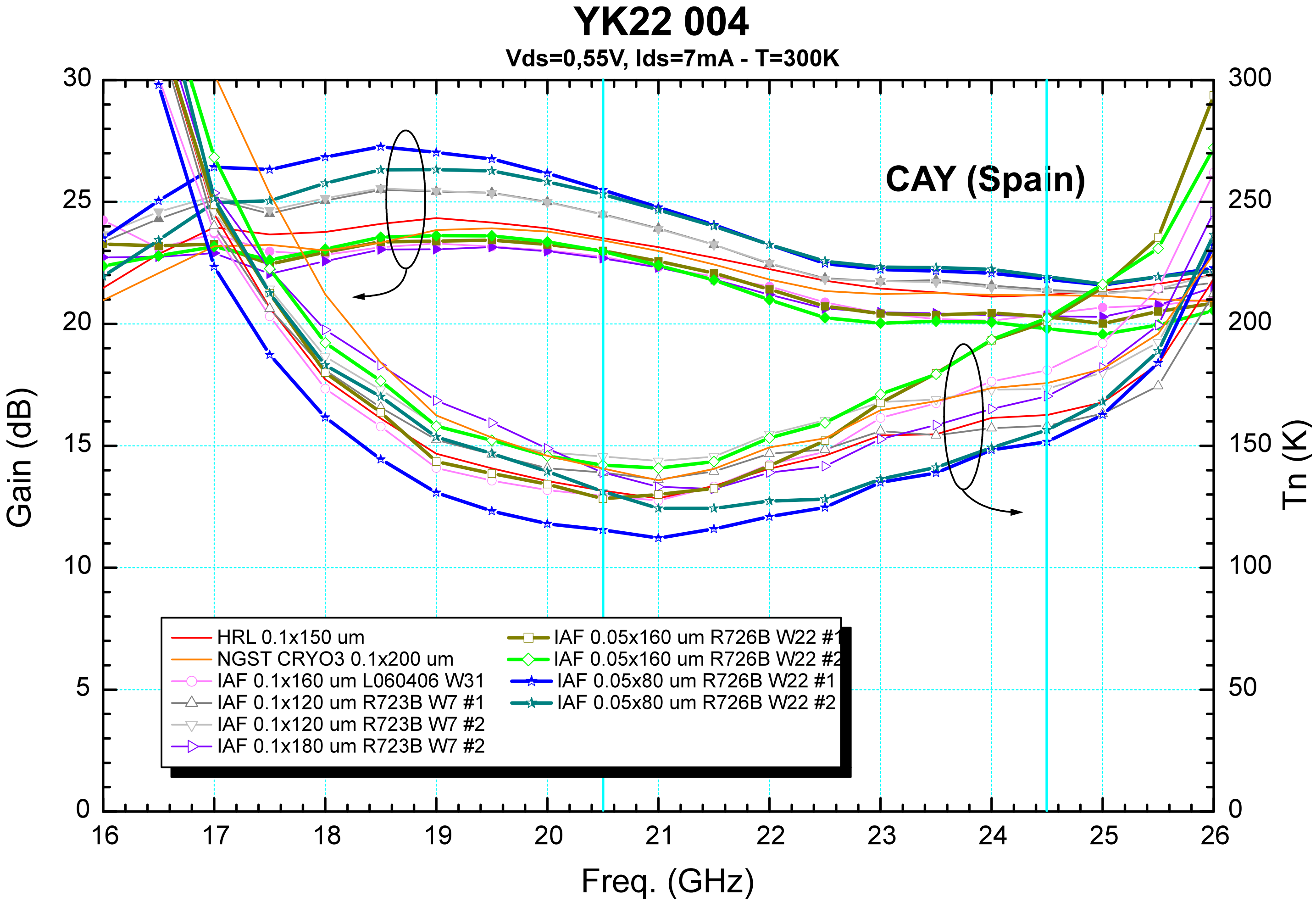


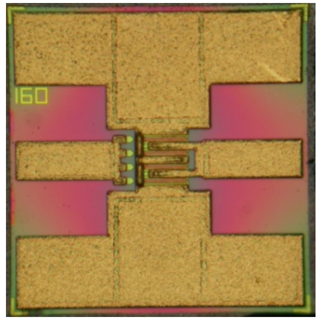


- Test in hybrid amplifiers
- Comparable with best InP-based HEMT performance (T_N [K] ~ f [GHz] / 2)



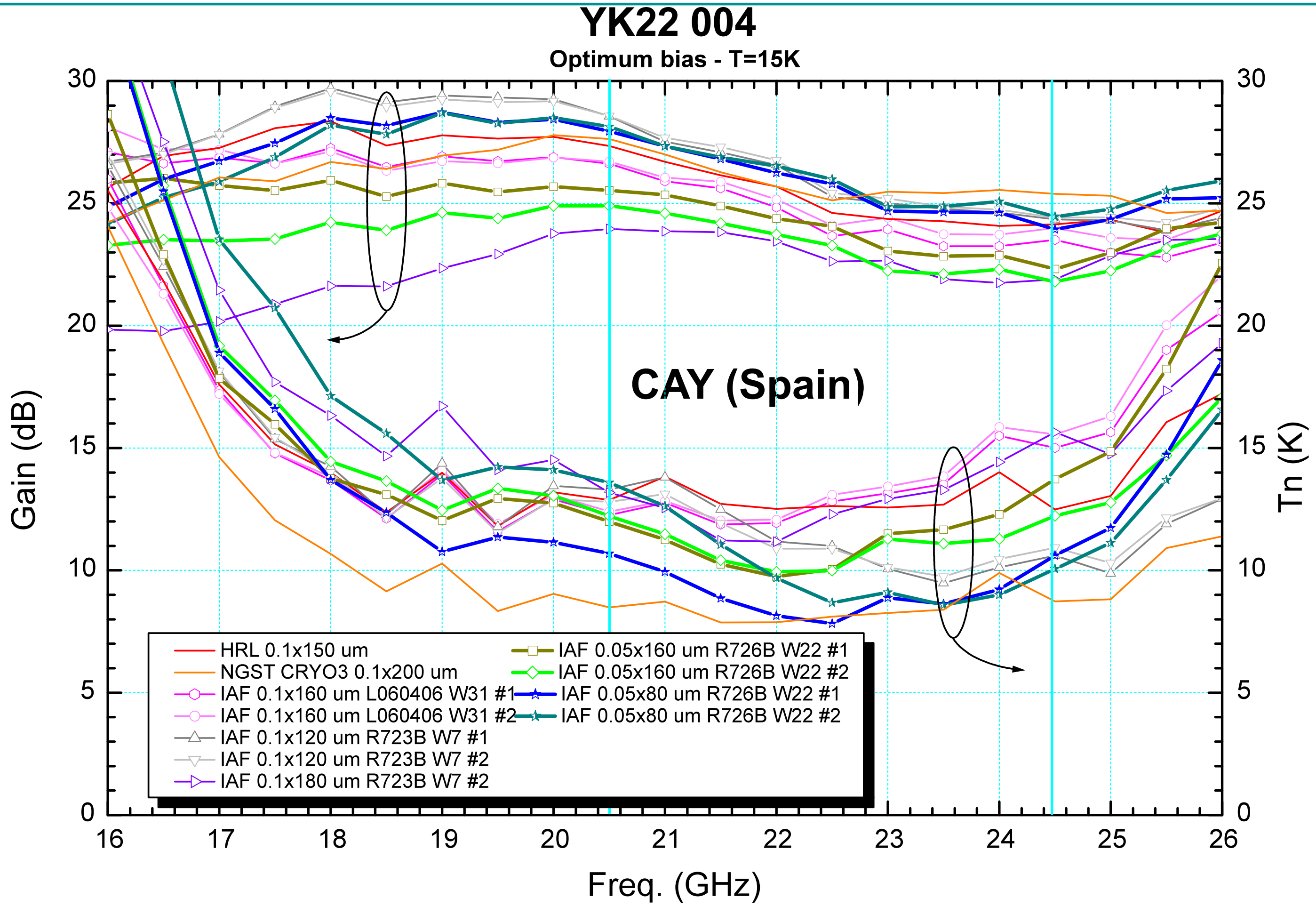
Performance of IAF mHEMTs at Room Temperature

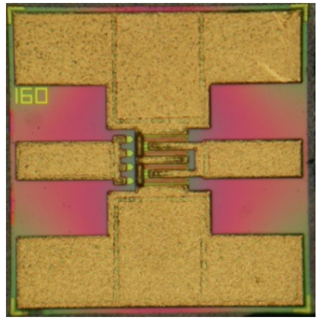




- Test in hybrid amplifiers at room temperature
- Better than best InP-based HEMT performance

Performance of IAF mHEMTs at Cryogenic Temperatures



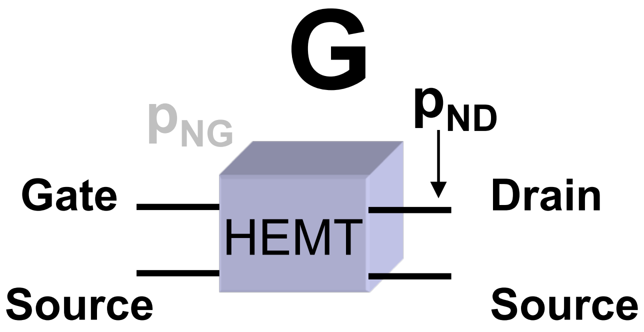


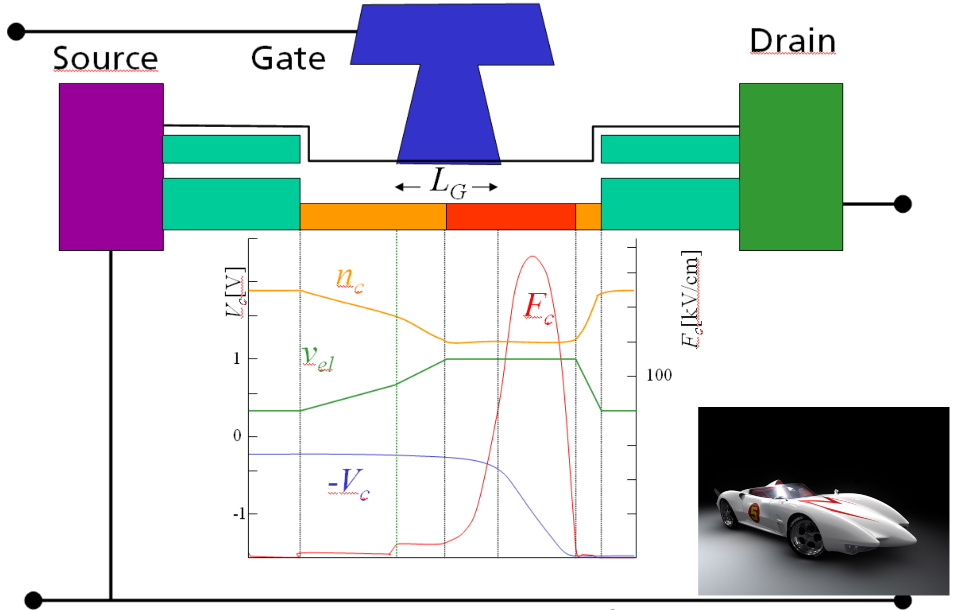
- Test in hybrid amplifiers at T = 15 K
- Equivalent to best InP-based HEMT performance (Cryo3)

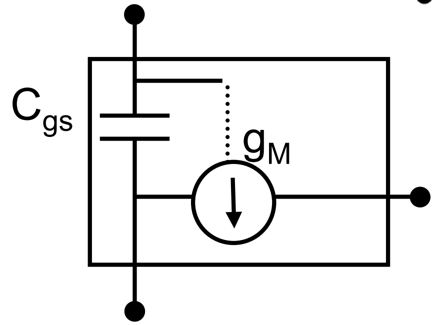
Technology Assessment for Cryo-Applications

- cryo-performance of Transistors:
  mHEMT (GaAs) and pHEMT-Transistors (InP) comparable !!!!
- Passive elements:
  Cryo-behavior is under investigation
  Cryo-compatibility?
  Grounded Coplanar vs Microstrip?
- MMICs
  First cryo-MMICs designed, fabricated and tested

Low Noise Properties of the HEMT

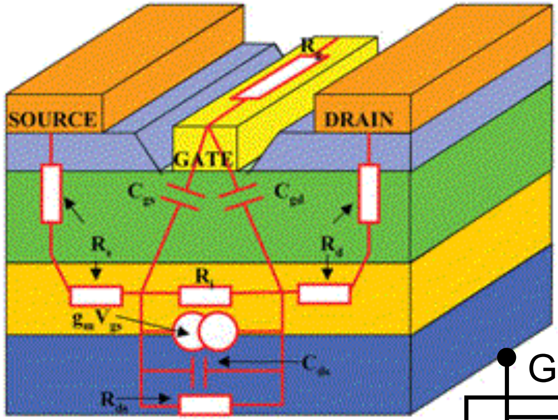






- **High electron velocity**
  - **⇒ high gain**
- **INPUT: Capacitive coupling of signal**
  - **⇒ resistive noise contribution is low**
- **OUTPUT: Hot electrons in the high-field zone between gate and drain**
  - **⇒ little effect on signal due to high gain and low conductance**

Small Signal Model Topology



Parasitics:

$L_g, L_d, L_s, R_g \sim$ WF/nF

$R_d, R_s \sim 1/(\text{nF WF})$

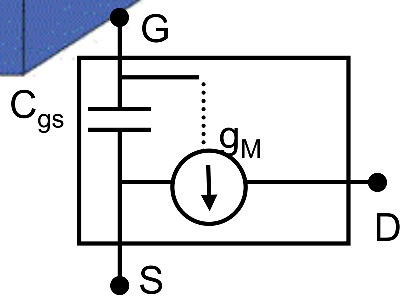
$C_{pgs}, C_{pgd}, C_{pds} \sim$ nF+const

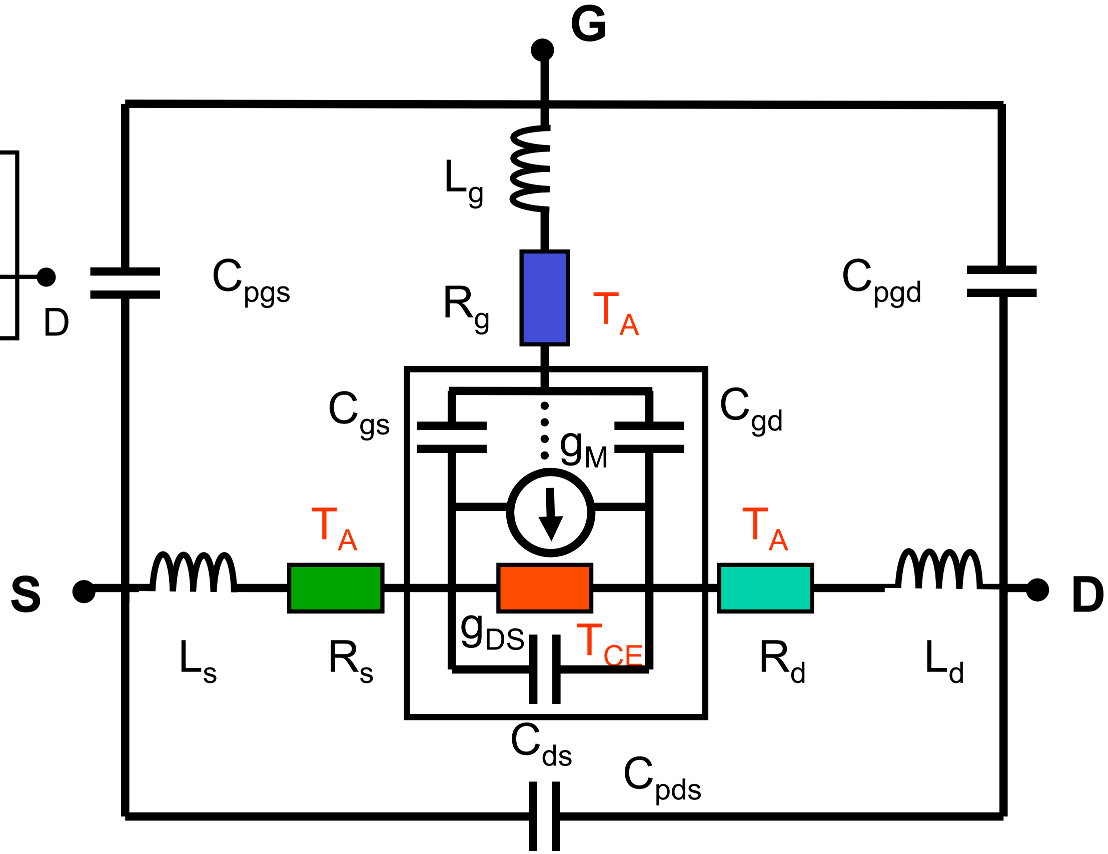
Noise:

4 resistive elements

Input: $R_g[T_A], R_s [T_A]$

Output: $g_{DS} [T_{CE}], R_d [T_A]$





Intrinsics (bias dependent)

$C_{gs}, C_{gd}, C_{ds} \sim 1/(\text{nF WF})$

g_{DS}, $g_M \sim 1/(\text{nF WF})$,

T_{CE} indep. of geometry

- Taylor expansion in i_D, V_{DS}
- Quadratic terms

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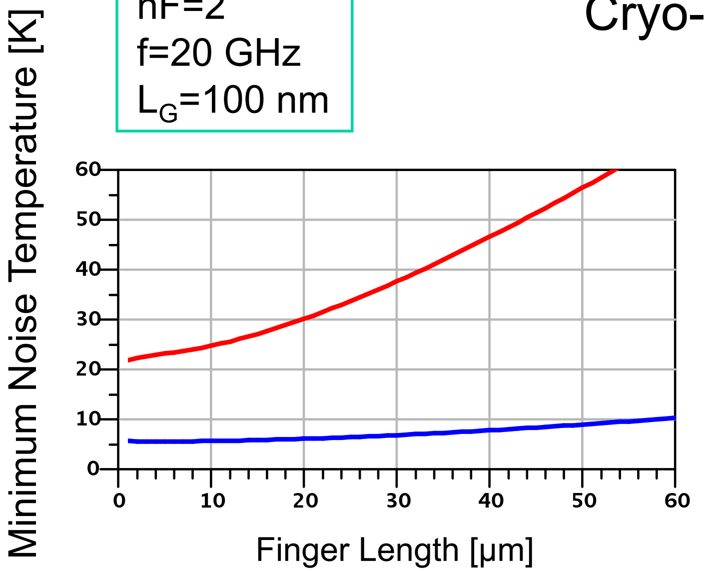
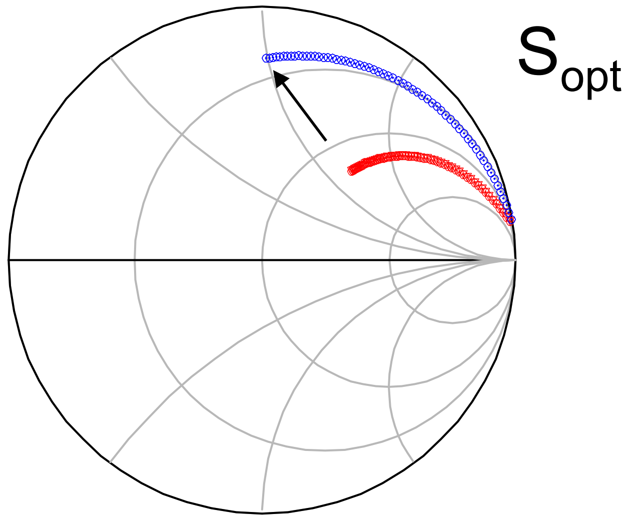
Noise Parameters vs. Finger Length

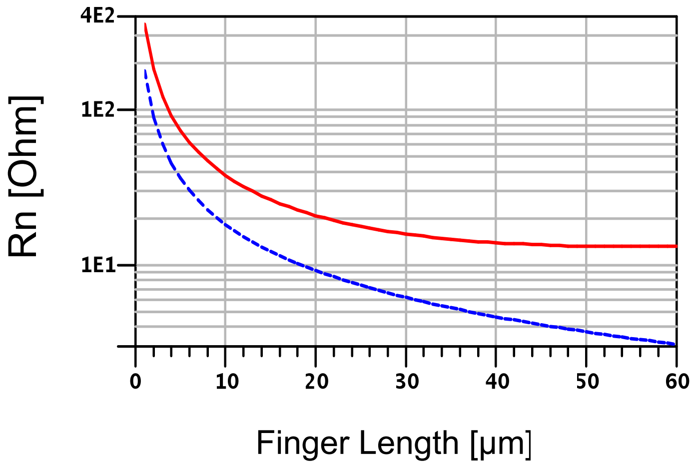
nF=2
f=20 GHz
L_G=100 nm

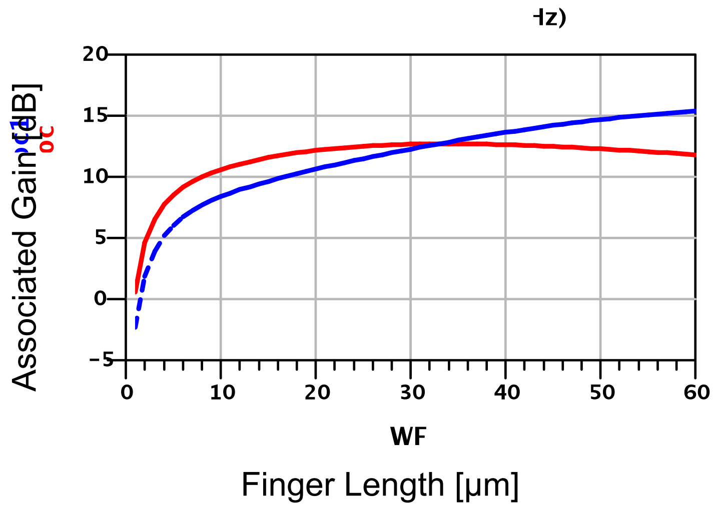
Cryo-LNA design with RT-Model???





T=300 K
T=16 K





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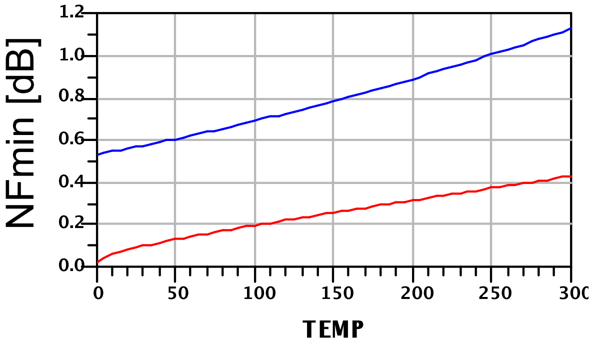
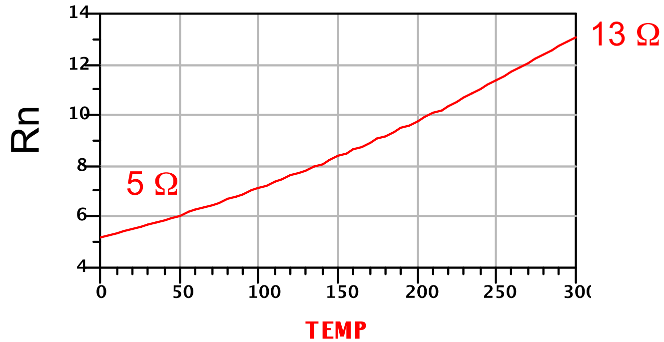
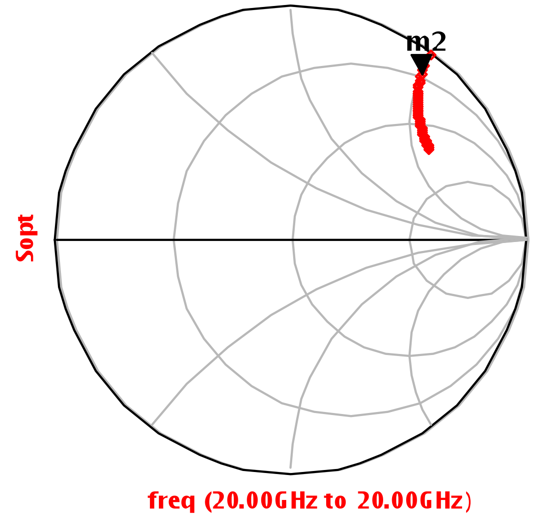
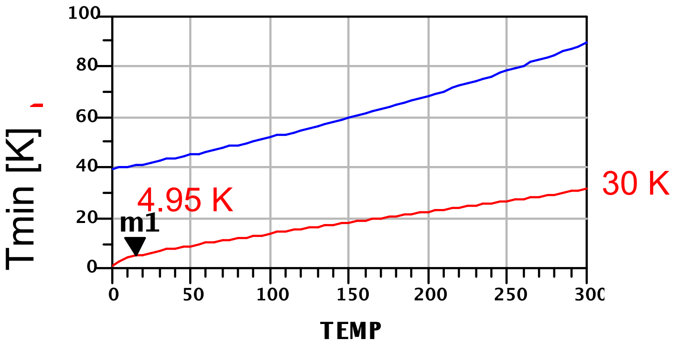
Model: Noise Performance vs. Temperature

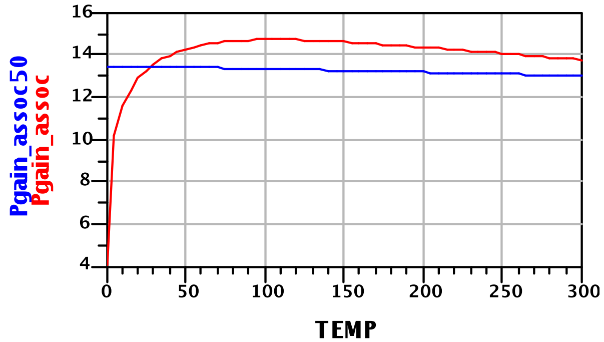
F2x40: LG=50 nm; id=150 mA/mm;Vd=1 V; f=20 GHz



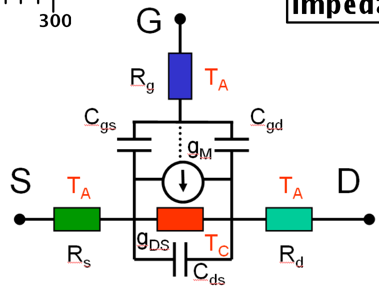








m2
freq=20.00GHz
Sopt=0.898 / 51.870
TEMP=15.000000
impedance = Z0 * (0.278 + j2.



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On-Going Cryo-mHEMT-Programs

- RADIONET
  - AMSTAR+
  - APRICOT

RadioNet

CAY | UC UNIVERSIDAD DE CANTABRIA | iram | MANCHESTER 1824 | *MPIfR* | *INAF*

Fraunhofer IAF

- Cooperation Projects with European Partners
  - IRAM, MPIfR
  - IGN,CAY

CHALMERS MC2 | iram | Max-Planck-Institut für Radioastronomie | esa

- Max-Planck-Fraunhofer Cooperation Project:
  - Optimization of the mHEMT Process for Cryo-Applications
  - dedicated Cryo-Runs

MAX-PLANCK-GESELLSCHAFT | Fraunhofer

Summary Infrastructure

- IAF
  - Institution for Applied Research (not a foundry!)
  - Quality Management ISO 9001:2000
  - Quasi-Industrial Standards

- MMIC Design
  - ADS Designkits
  - (Cryo-)Model Library
  - Autolayout

- MMIC Processing
  - Epitaxy
  - mHEMT Processing for 100, 50, 35 nm Gates
  - Wafer-Mapping of Transistors and Circuits

- MMIC Packaging
  - Laser Dicing and „Pick and Place“ Instrumentation
  - Waveguide Module Design and Fabrication

Summary and Outlook

- State of the art RT mHEMT process
  - NF=2 dB(TN=177 K) @94 GHz (300 K)
- Promising Cryo MMIC results
  - TN=5K @ 8 GHz (15 K)
- Potential to further process-optimization for cryo applications
- Improvement/Refinement of Cryo-Models

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