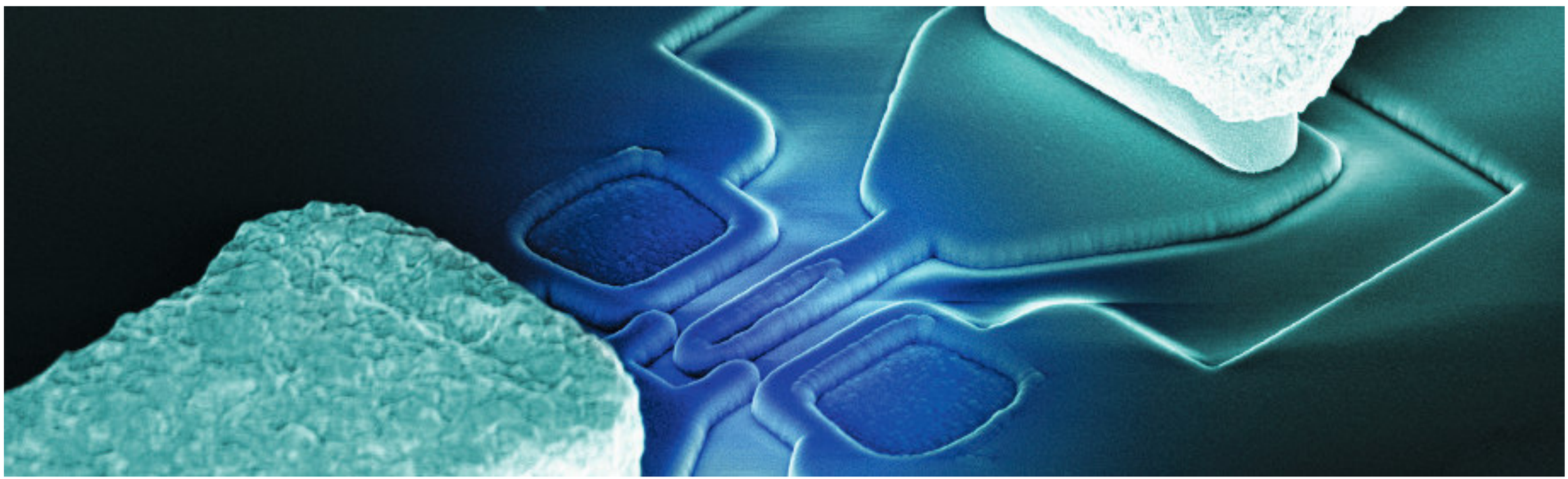
The ESA “Low Noise Amplifier at 600 GHz” Activity
Demonstration of State-of-the-Art Sub-Millimetre Wave MMICs and Modules for Radiometer Applications

Sébastien Chartier, Arnulf Leuther, Axel Tessmann, Laurenz John, Bersant Gashi, Rainer Weber, Mikko Kantanen, Mikko Varonen, Henrik Forsten, Jean-Christophe Angevain, Petri Piironen

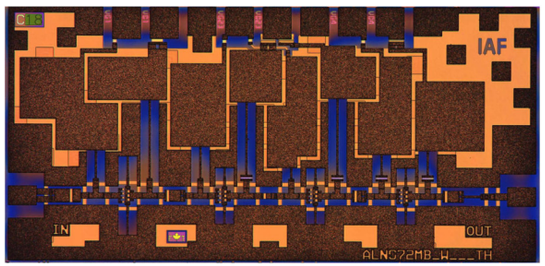


OUTLINE

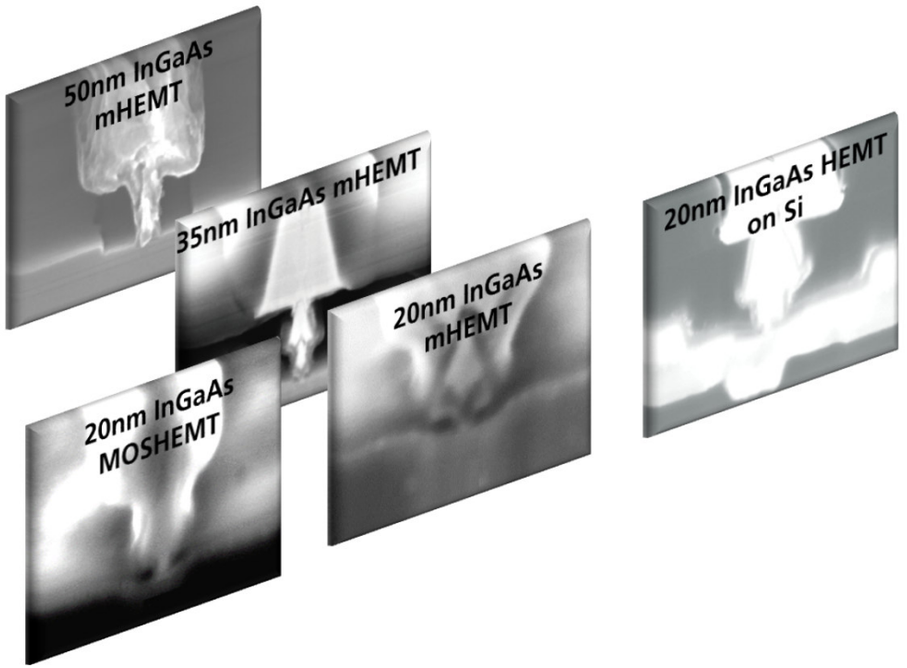
- Introduction/Motivation
- Fraunhofer IAF technologies for low-noise up to sub-millimetre wave applications
- Previous and on-going projects
- Sub-millimetre wave MMICs and modules examples
- Conclusion

Introduction / Motivation

- Satellite observations is a major source of information for numerical weather prediction (NWP) models.
- For the study of vertically integrated cloud mass, the radiometer needs to operate at frequencies exceeding 300 GHz since appropriate water vapour lines exist at e.g. 448 GHz and above
- Highest requirements for sensitivity
- Need of outstanding submillimeter-wave low-noise amplifier MMICs and modules based on state-of-the-art semiconductor technologies

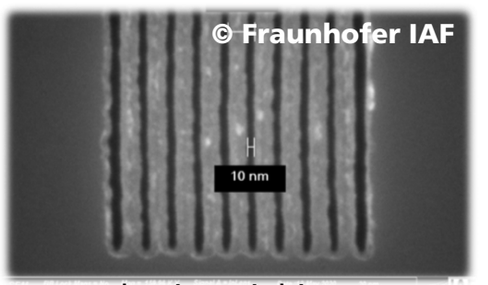


Fraunhofer IAF mHEMT Technology at a Glance



- State-of-the-art low noise figure performance
- Extremely high achievable bandwidth
- Multi-functional MMICs
- High performance on-chip wideband antennas
- Performance enhancement with:
  - Cryogenic operation
  - Superconducting materials (in development)
  - Indium micro-bumps for ultra-dense assembly (in development)

Indium micro-bumps



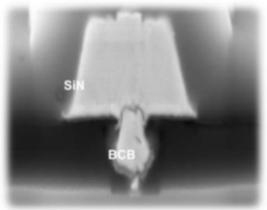
Superconducting niobium structures

Technologies	f_T	f_{MAX}
50nm mHEMT	380 GHz	600 GHz
35nm mHEMT	550 GHz	~1000 GHz
20nm mHEMT	660 GHz	>1000 GHz
20nm MOSHEMT	275 GHz	640 GHz
20nm HEMT on Si	>500GHz	>1000 GHz

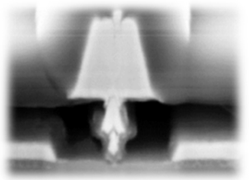
Low-Noise Amplifier MMICs (*) and Modules (**)				
Frequency [GHz]	94 (*)	183 (*)	243 (**)	300 (**)
Gain [dB]	>25	30	32	24
Noise Figure [dB]	1.9	3.2	5	6

Fraunhofer IAF mHEMT Technology at a Glance

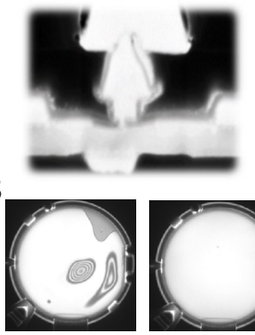
- **50 nm mHEMT**
- $In_{0.8}Ga_{0.2}As$
- Two interconnection metal layers
- f_T/f_{max}: 375 GHz / ≈ 670 GHz

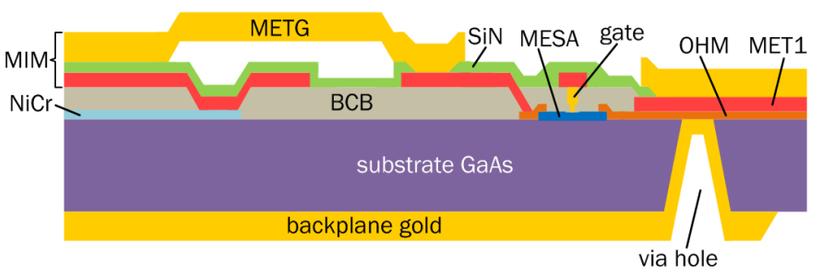


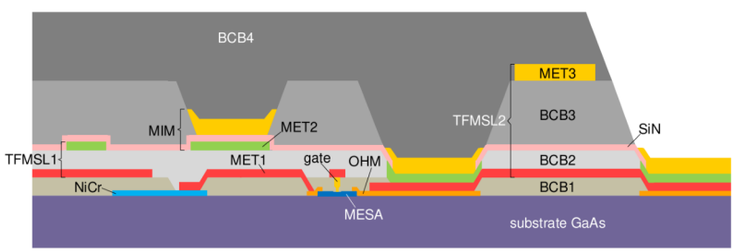
- **35 nm mHEMT**
- $In_{0.8}Ga_{0.2}As$
- Three interconnection metal layers
- f_T/f_{max}: 515 GHz / > 1000 GHz

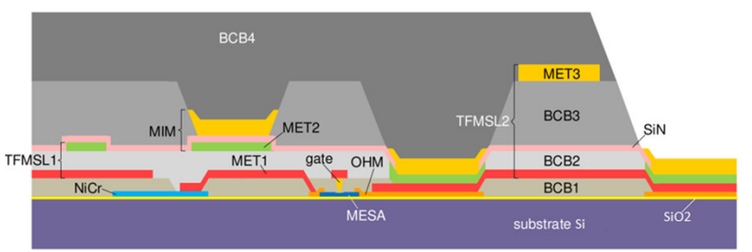


- **20 nm mHEMT on Insulator**
- Wafer bonding utilizing SiO2 interlayers for transfer process
- Backside field-plates
- $In_{0.8}Ga_{0.2}As$
- Three interconnection metal layers
- f_T/f_{max}: 515 GHz / > 1000 GHz







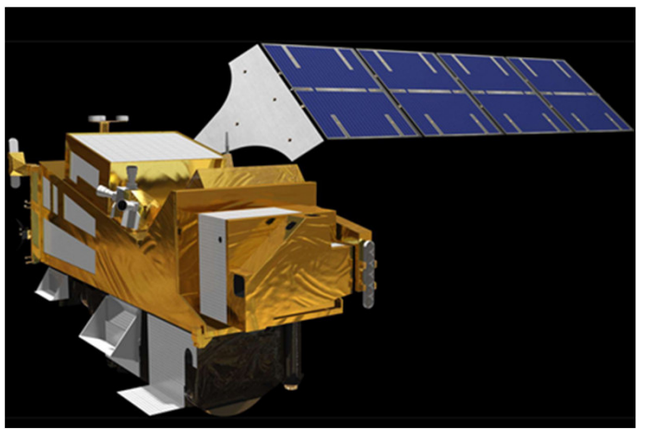


A. Leuther et al. "InGaAs HEMT MMIC Technology on Silicon Substrate with Backside Field-Plate" Proc. of the 50th EuMC, 2021

Meteorological Operational Satellite Second Generation

MetOp-SG A

- Microwave Sounder (MWS)
  - Atmospheric sounding: temperature and humidity



MetOp-SG B

- Microwave Imager (MWI)
  - Rainfall and clouds
- Ice Cloud Imager (ICI)
  - Ice clouds and snowfall

AIRBUS DEFENCE & SPACE

DA GROUP

OMNISYS INSTRUMENTS

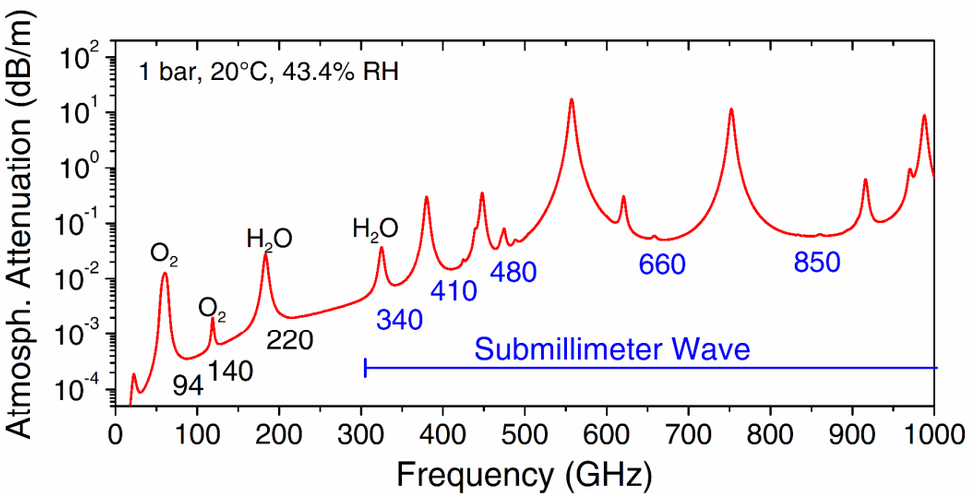
RAL Space

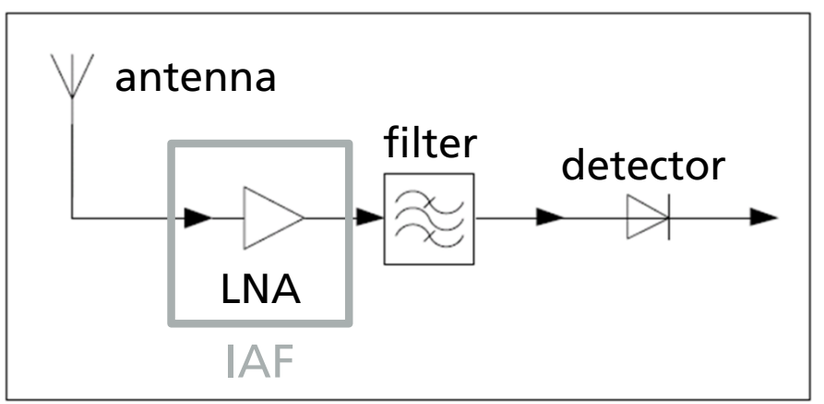
RPG Radiometer Physics GmbH

Fraunhofer IAF

MetOp-SG – Low-Noise Amplifiers: 54–229 GHz

Frequency (GHz)	Purpose
54	Temperature
89	Rainfall
118	Rainfall
165	Water vapor, rainfall
183	Water vapor, snowfall
229	Ice cloud

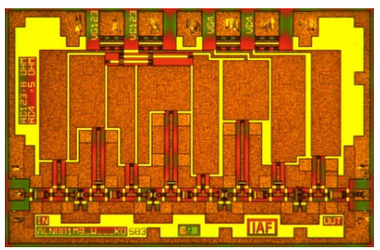




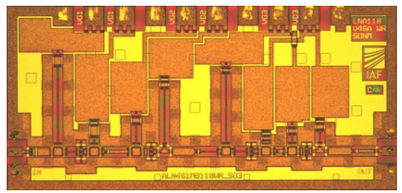
- Development of ultra-low-noise amplifier for high sensitivity
- **State-of-the-art** requirements for amplifiers

MetOp-SG – LNAs from IAF

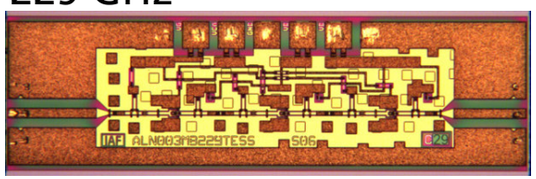
89 GHz

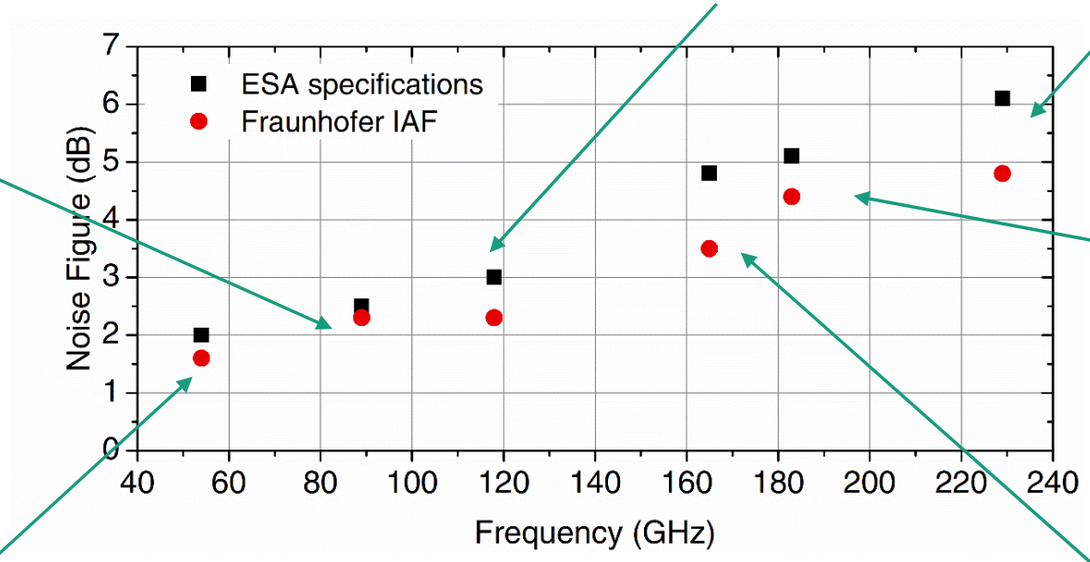


118 GHz

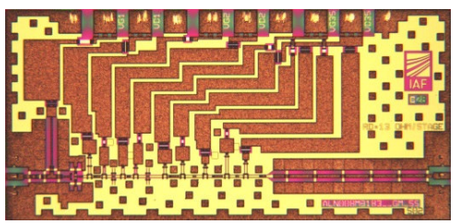


229 GHz

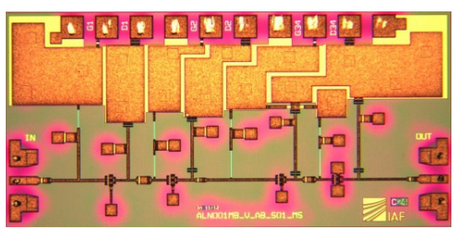




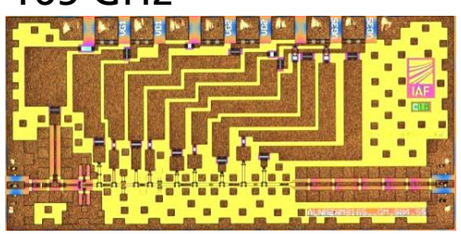
183 GHz



54 GHz

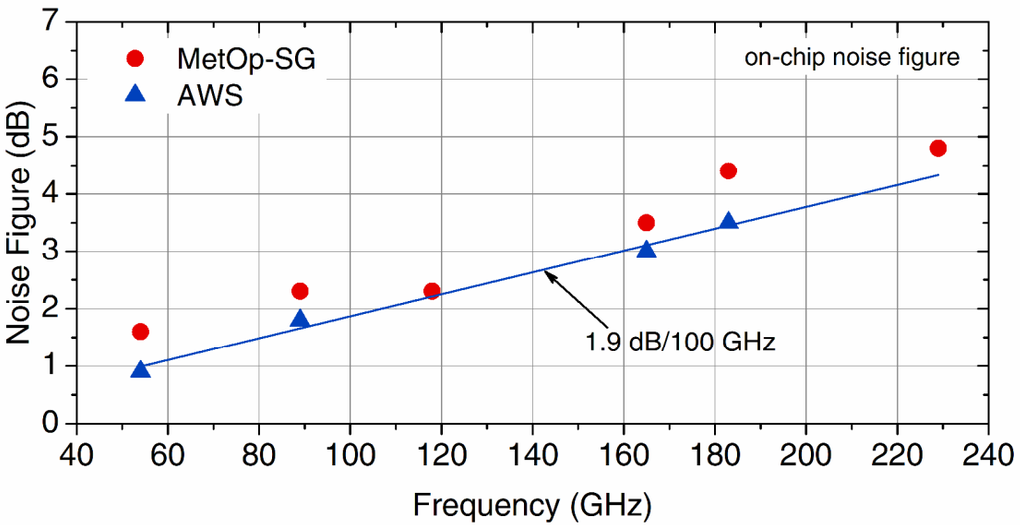


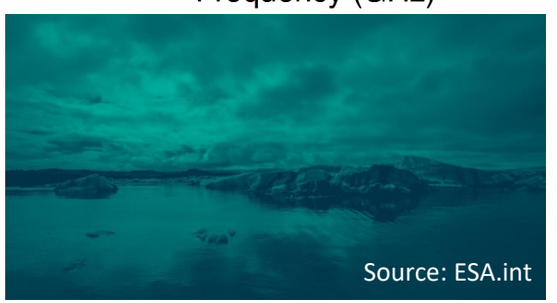
165 GHz



ESA Arctic Weather Satellite Mission: Improving Arctic and Global Weather Forecasts

- The **Arctic Weather Satellite** mission will provide frequent coverage of Earth for improved nowcasting and numerical weather prediction
- Multinational cooperation
- Fraunhofer IAF develops core components:
  - Low-noise millimeter-wave amplifier **MMICs** and **modules** based on our 50-nm mHEMT (54 , 89, 165, 183 GHz)





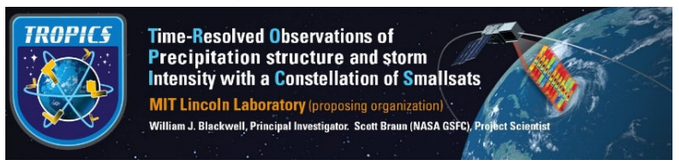
OHB SWEDEN

OMNISYS INSTRUMENTS

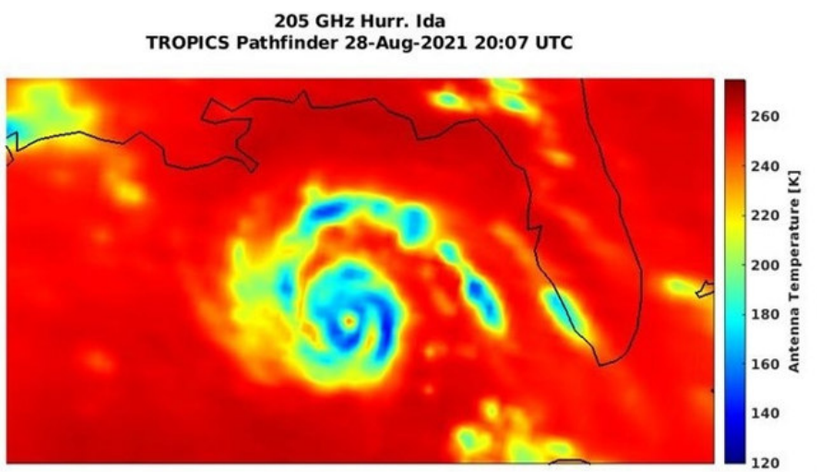
ACST Technology Solutions for Terahertz Electronics

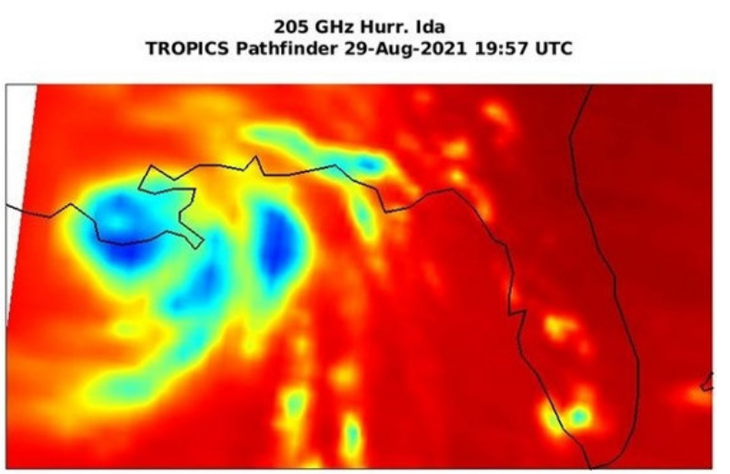
Fraunhofer IAF

TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats)



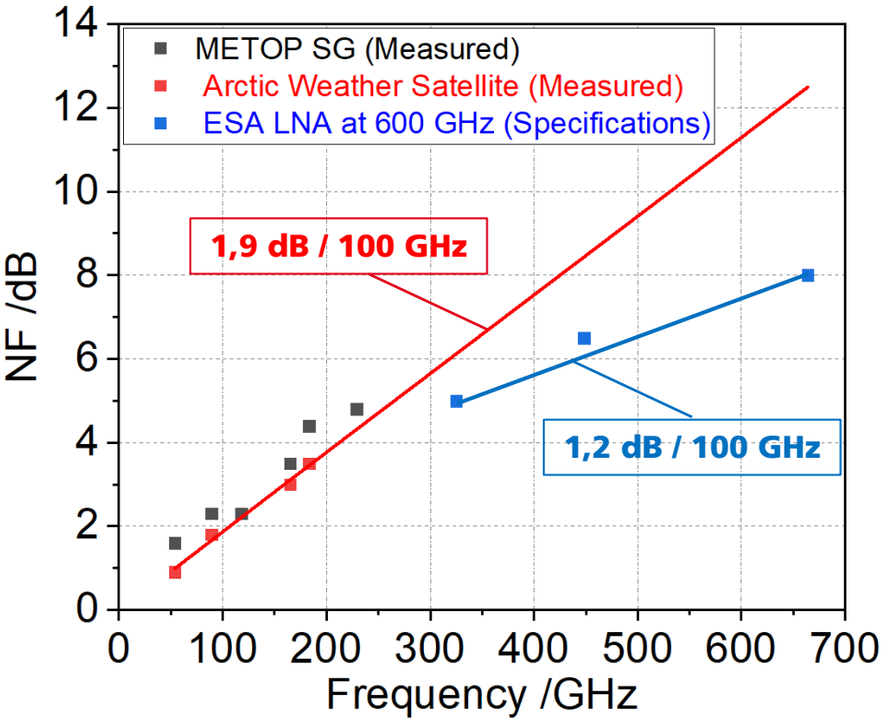
- Constellation of CubeSats in three low-Earth orbital planes
- Imagery in a single channel near 90 GHz for precipitation measurements
- 7 channels near the 118.75 GHz oxygen absorption line
- Water vapor profiles using 3 channels near the 183 GHz water vapor absorption line
- **Single channel at 205 GHz for cloud ice measurements**



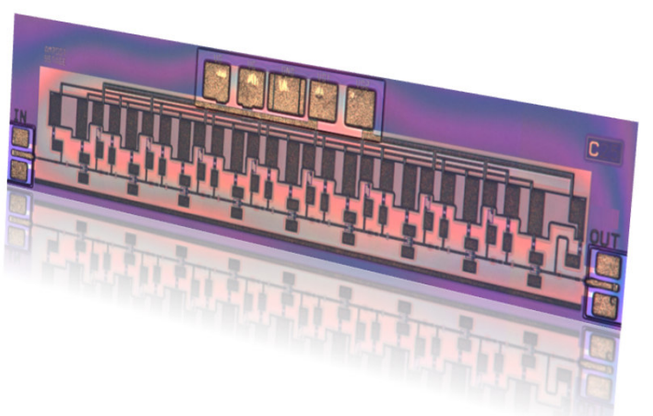


The “ESA LNA at 600 GHz” activity

Frequency	Purpose
325 GHz	Water Vapor absorption bands
448 GHz	Water Vapor absorption bands
664 GHz	Cloud ice water window channel

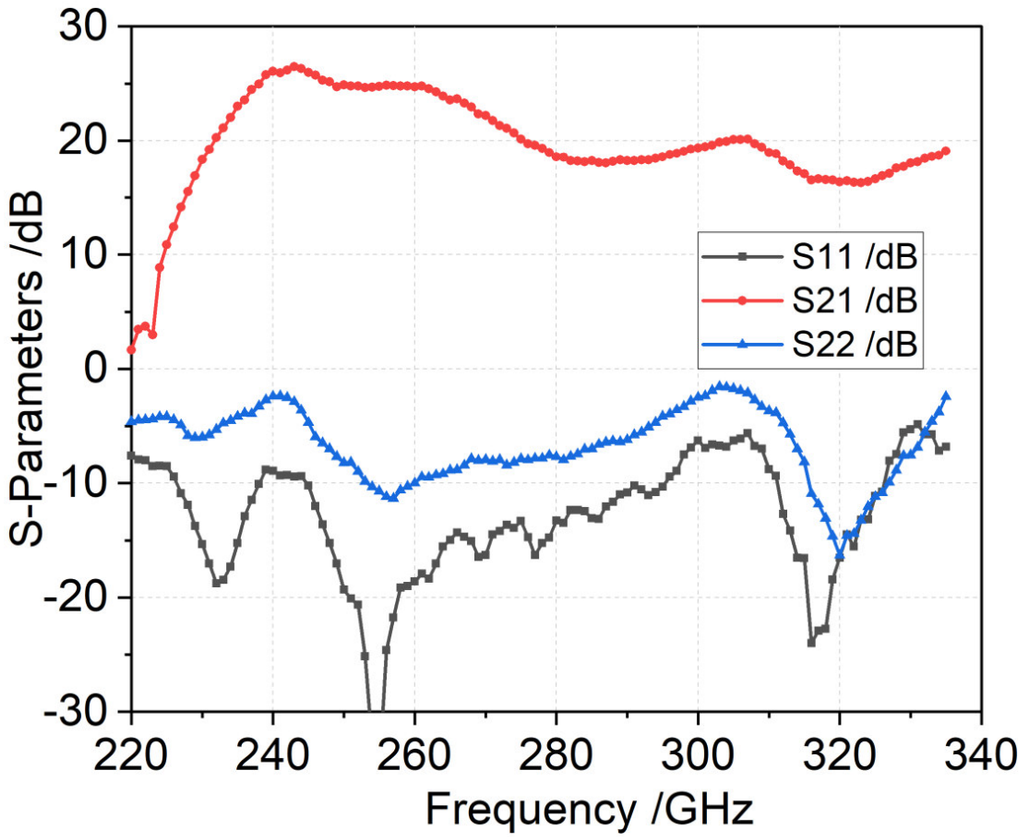


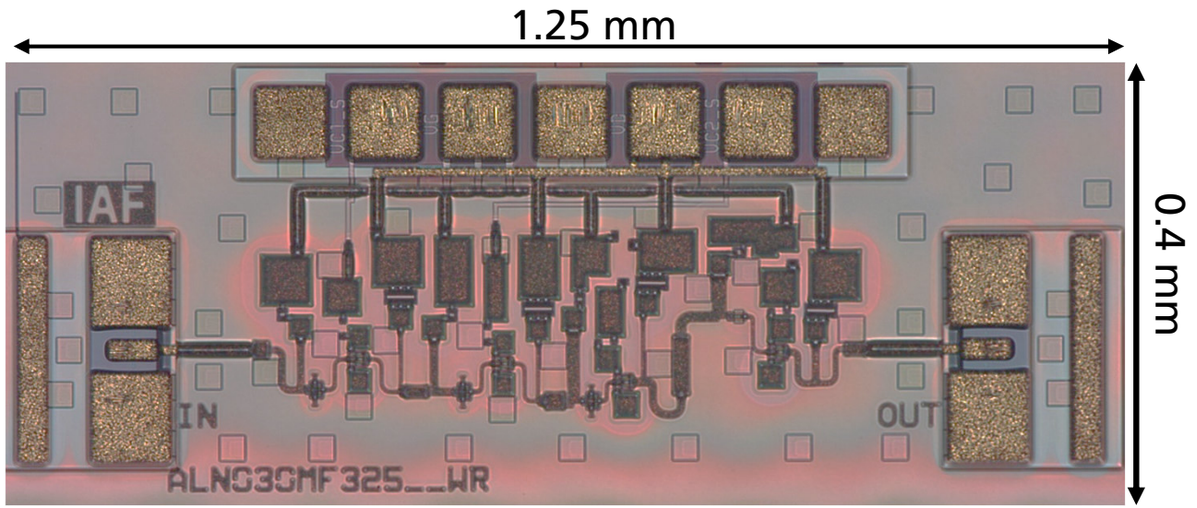
- Development of ultra-low-noise amplifier MMICs and modules for high sensitivity above 325 GHz
- **State-of-the-art** requirements for amplifiers



The “ESA LNA at 600 GHz” activity

325-GHz Low-Noise Amplifier MMIC

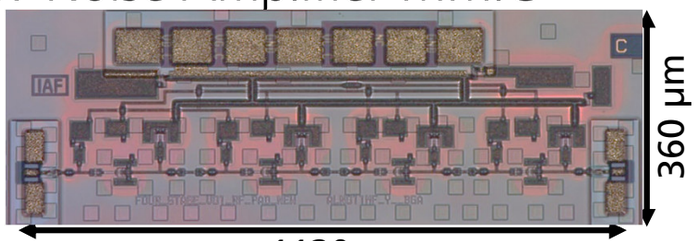


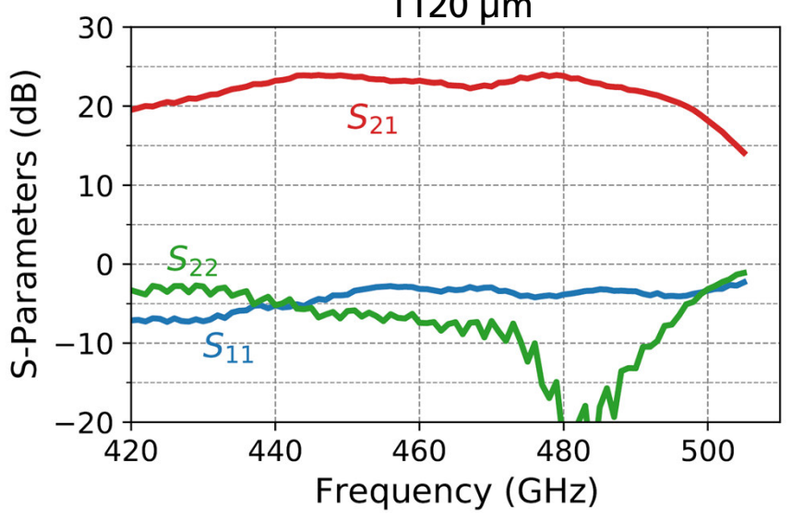


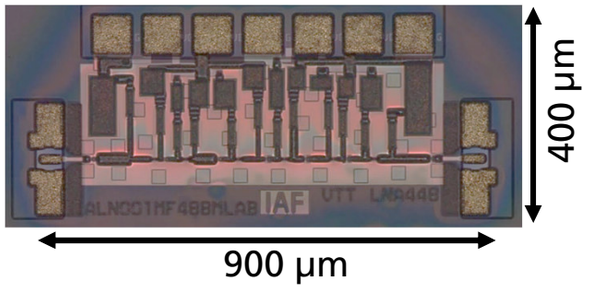
- 35 nm mHEMT technology
- 4-stage low-noise amplifier
- 2x10µm cascode stage
- Reactive matching network based on thin-film microstrip line
- Simulated noise figure: 6 dB

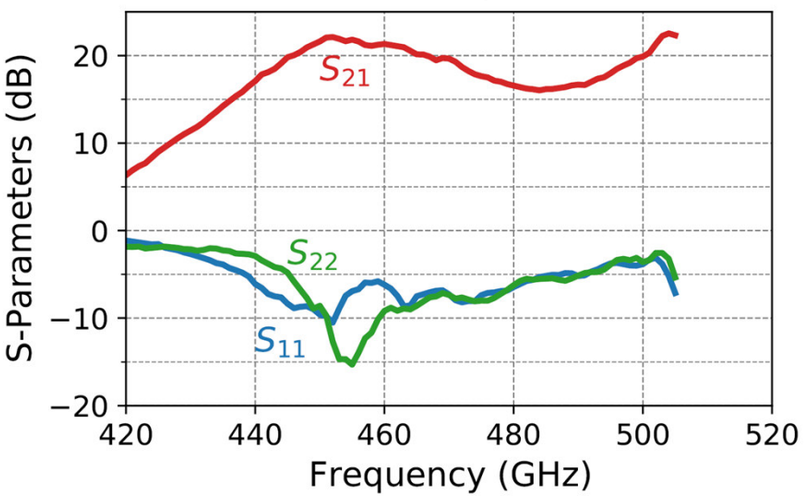
The “ESA LNA at 600 GHz” activity

448-GHz Low-Noise Amplifier MMIC







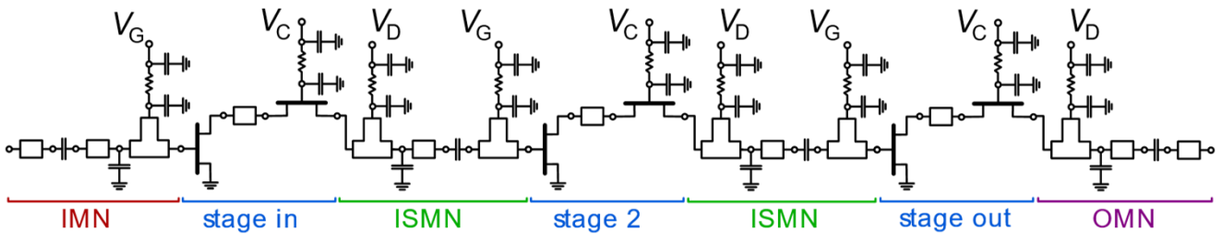


- 4-stage LNA (2x6µm cascode).
- More than 20-dB gain between appr. 420 to 500 GHz
- Simulated noise figure of 7.5 dB

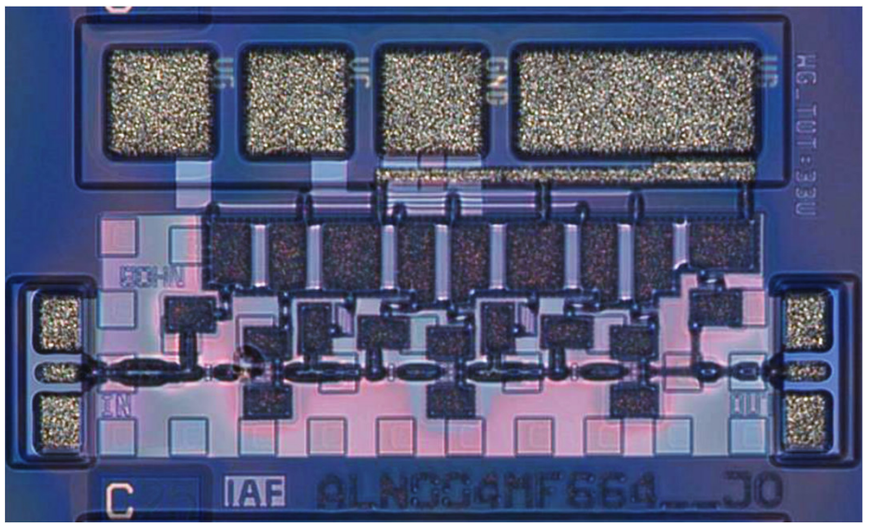
- 6-stage LNA (2x5µm Common-Source)
- 17 to 22-dB gain between 440 GHz and 470 GHz
- Simulated noise figure of 7 dB

The “ESA LNA at 600 GHz” activity

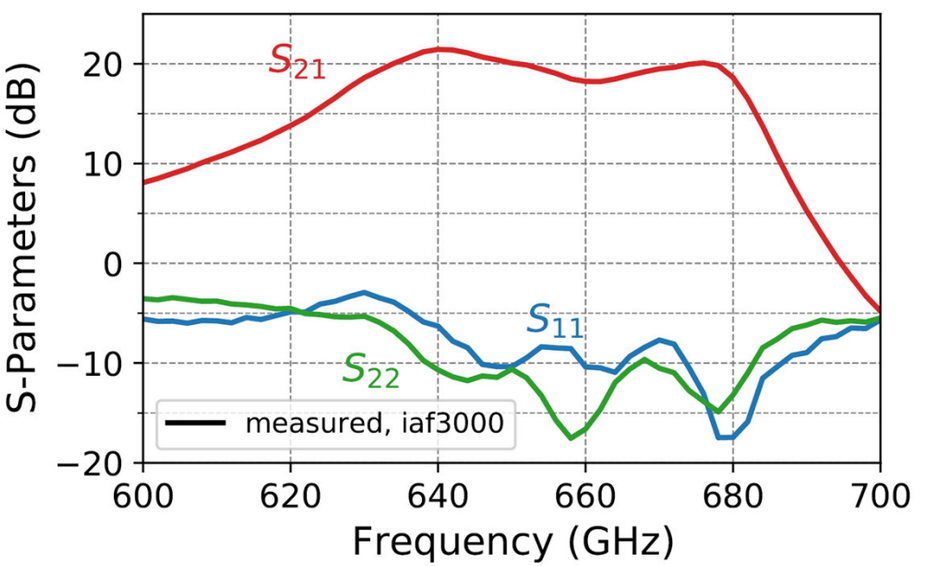
664-GHz Low-Noise Amplifier MMIC



600 x 320 µm²



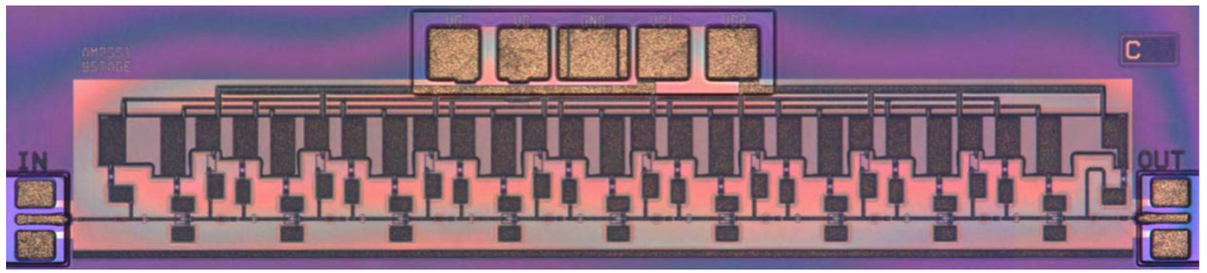
- Cascode topology permits high gain per stage
- New designs developed in this project:
  - 3-stage cascode
  - 20 dB of gain between 640 and 680 GHz
  - Thus significantly improved gain per cascode stage with mor than 6 dB
  - State-of-the-art performance with significantly improved gain in comparison to previous cascode circuits



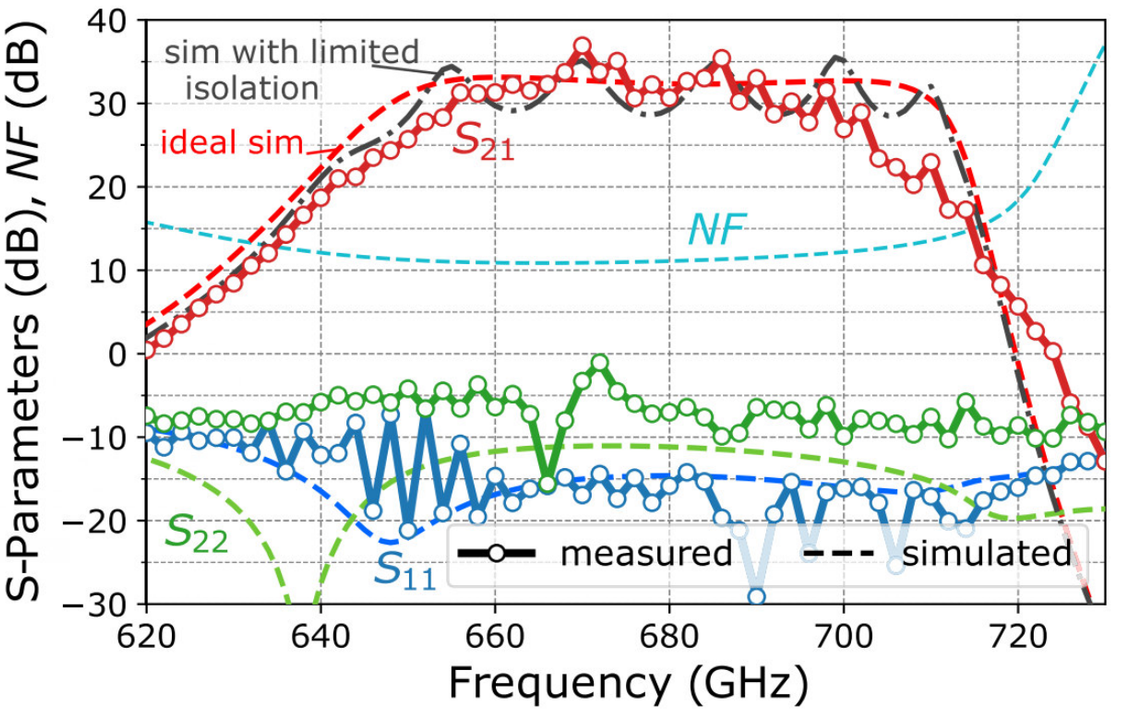
Fraunhofer IAF

The “ESA LNA at 600 GHz” activity

664-GHz Low-Noise Amplifier MMIC



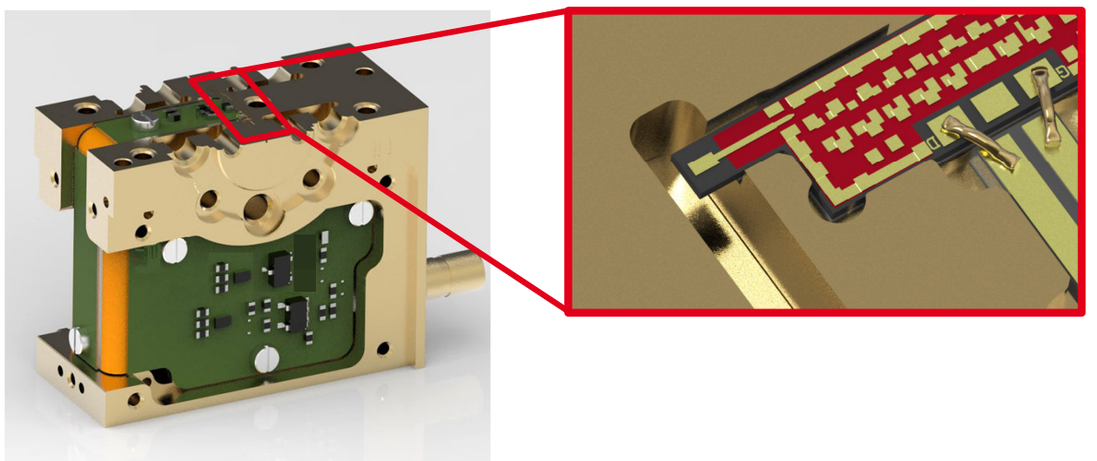
- 20-nm InGaAs-on-Si
- RF cascode with 2x5.5-µm HEMTs
- 9-stage reactively-matched TMIC
- Cascode design key design parameter
- Gain: **30–33 dB (660–700 GHz)**



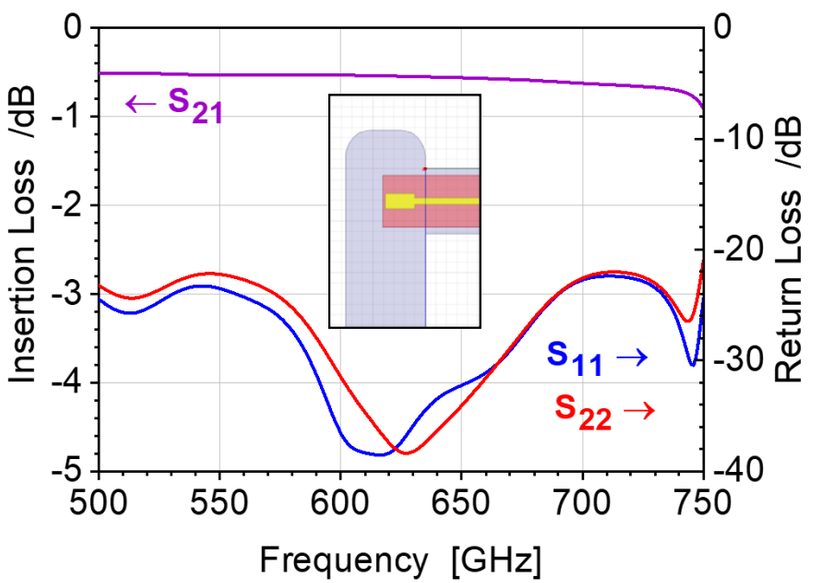
L. John et al.,
IEEE MWCL 2022

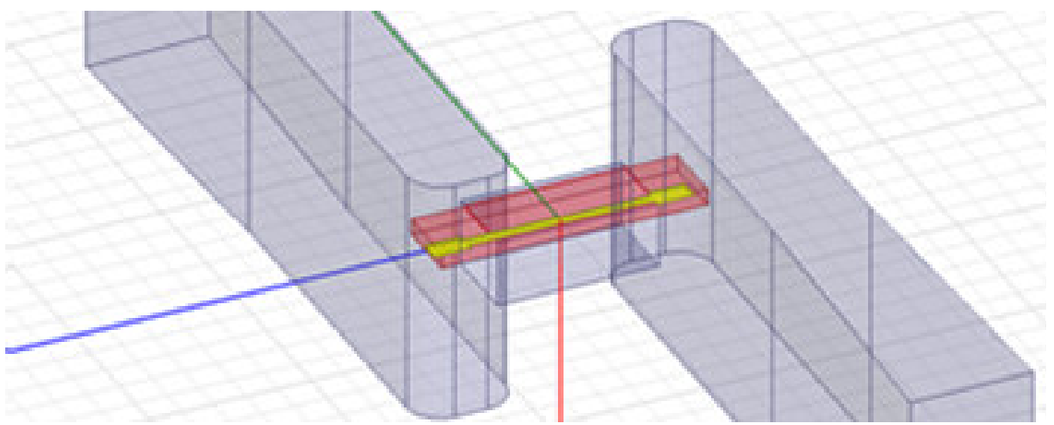
Fraunhofer IAF

Chip to waveguide transition



- Wirebonding too critical for the addressed frequencies
- Monolithic integration of the microstrip to waveguide transition
- 3D EM Field simulations (HFSS as EM Field solver)
- GaAs permittivity: 12.9 / gold conductivity: 4.1 x 10^7 S/m
- Back-to-back transition simulated with very good performance
- High sensitivity to placement
- The back-to-back structure was fabricated and tested
- Transmission loss of single transition: 1.0 dB up to 710 GHz





Fraunhofer IAF

Conclusion

- The most informative channel on cloud ice water is the window channels at 664 GHz and the water vapour absorption bands at 325 and 448 GHz
- The IAF 35 nm mHEMT and 20 nm mHEMT on Silicon technologies provide state-of-the-art performance ideally suited for the development of low-noise amplifier MMICs targeting this submillimeter-wave frequencies
- First MMIC generation shows excellent results.
- Next step is the assembly of the LNA MMICs in waveguide module for S-parameters and noise figure measurements

… To be continued !

Our warmest thanks to the European Space Agency for the continuous support in the frame of the ESA LNA at 600 GHz (ESA Contract: No. 4000132934/20/NL/FE)

THANK YOU FOR YOUR ATTENTION!

Fraunhofer IAF