Workshop about Opportunities for dual-use technologies: Components

A Micromachined Heterogeneous Integration Platform for THz Systems

Franz Dielacher
Infineon Technologies Austria AG
Franz.dielacher@infineon.com
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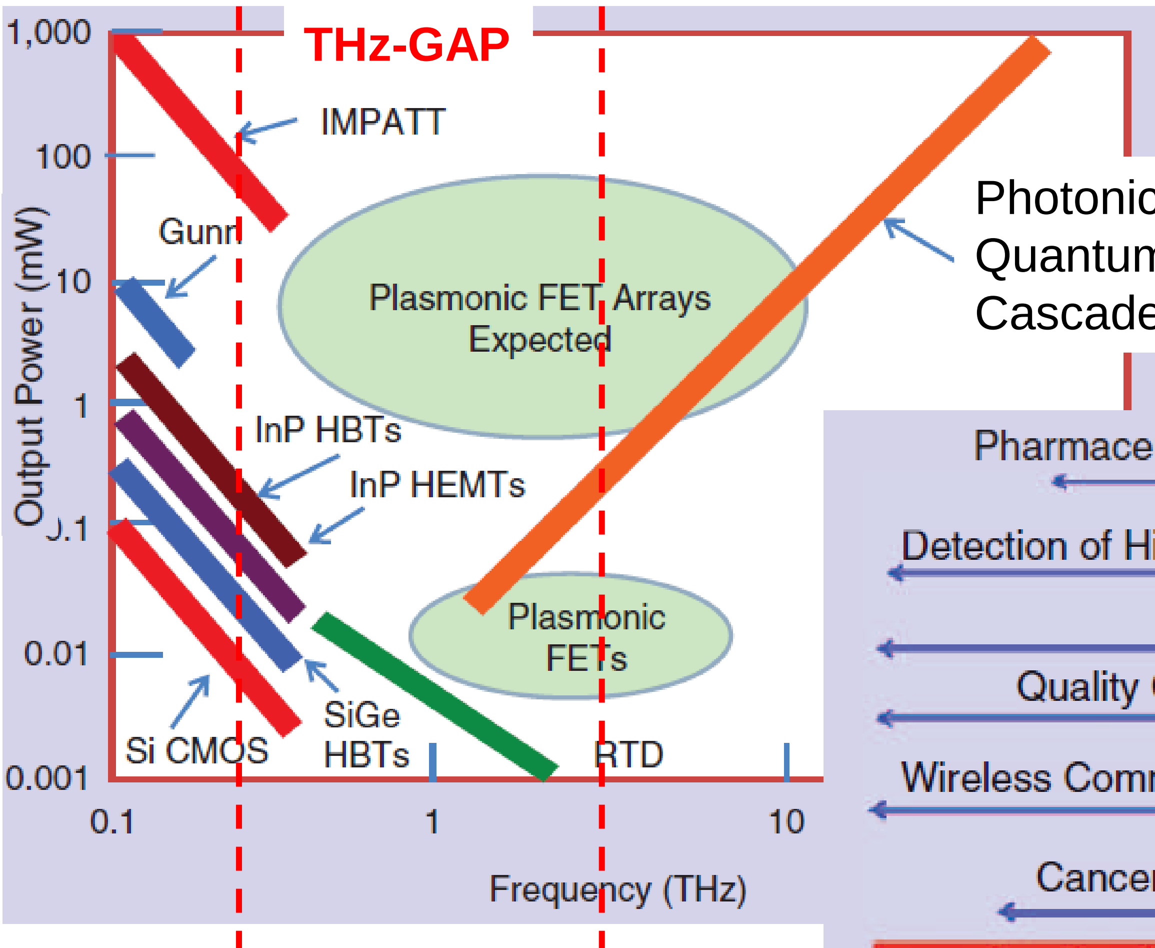
MOTIVATION:

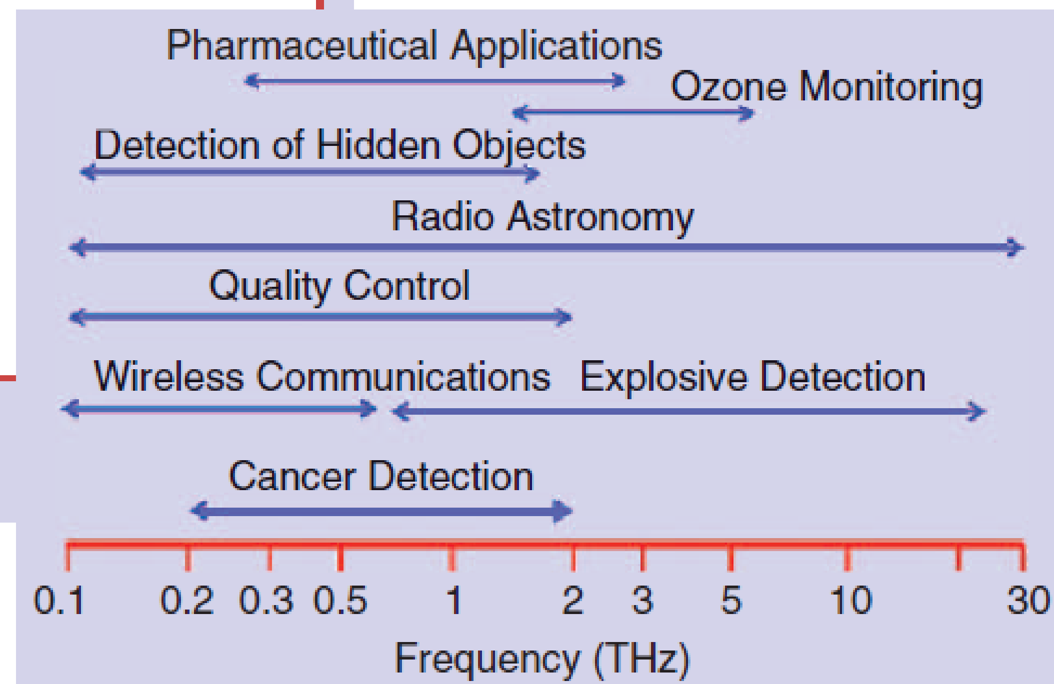
THz applications and the need for new ways of building THz systems

Opportunities in the THz gap



Photonics Quantum Cascade Lasers

Spectral Fingerpring



Source:
IEEE Microwave Magazine
November/December 2014

mm-Wave and Terahertz (THz) Systems

Low-cost THz technology in our society
Enabled by micromachined heterogeneous integration platform

Industrial-sensing
Food control
Medical
Thickness

800M€ in 2020

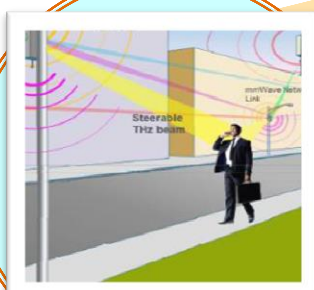
300M€ today

Wireless-backhaul
Small-Cells
5G

Security,
Radar
Avionics
Scanning

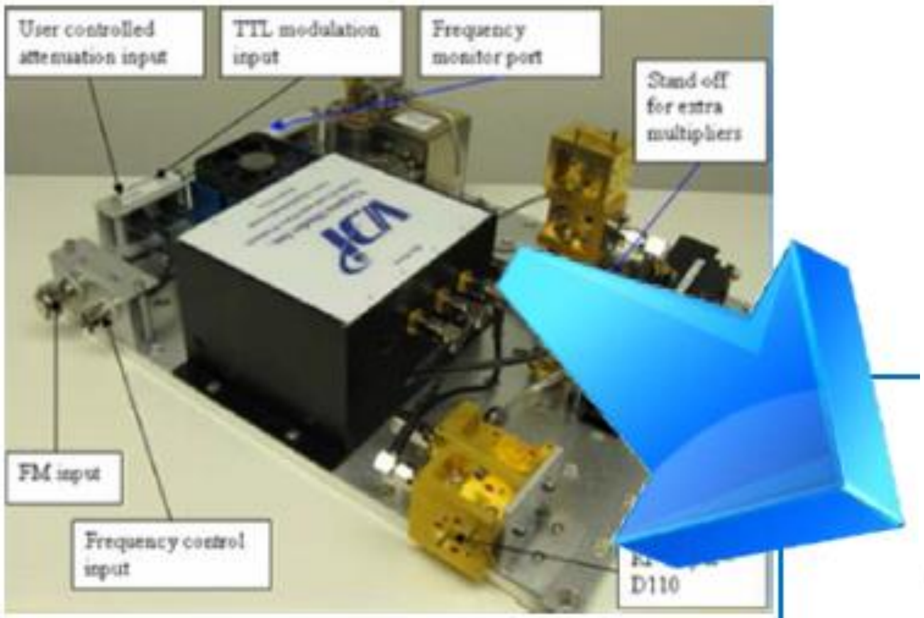
Astrophysics
Atmospheric chemistry

>20 % CAGR



2014 2016 2018 2020 2022

Micromachined THz Systems



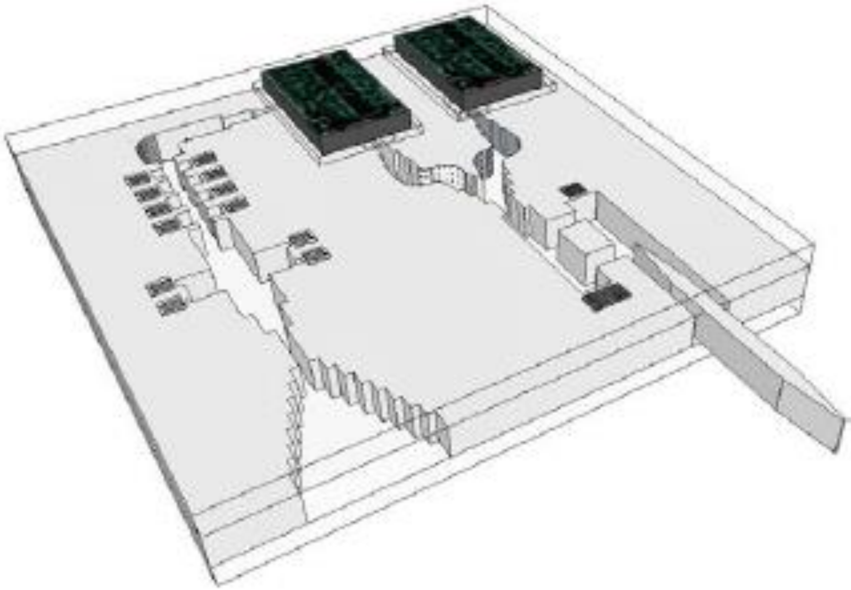
sub-mm-wave system by VDI

Conventional THz system

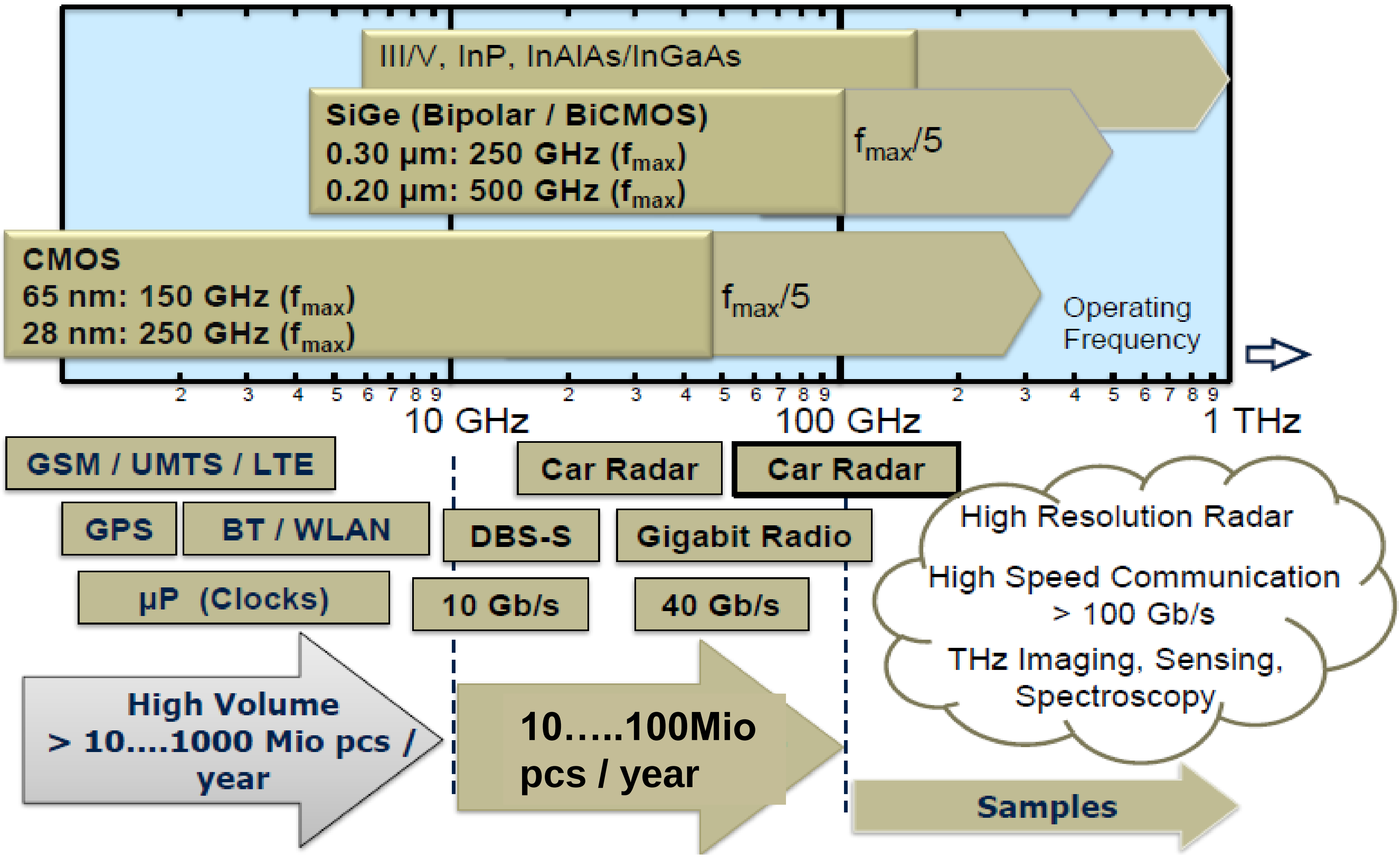
- Bulky
- Heavy
- Manually assembled
- Expensive
- Only for scientific instruments

Highly-integrated THz system

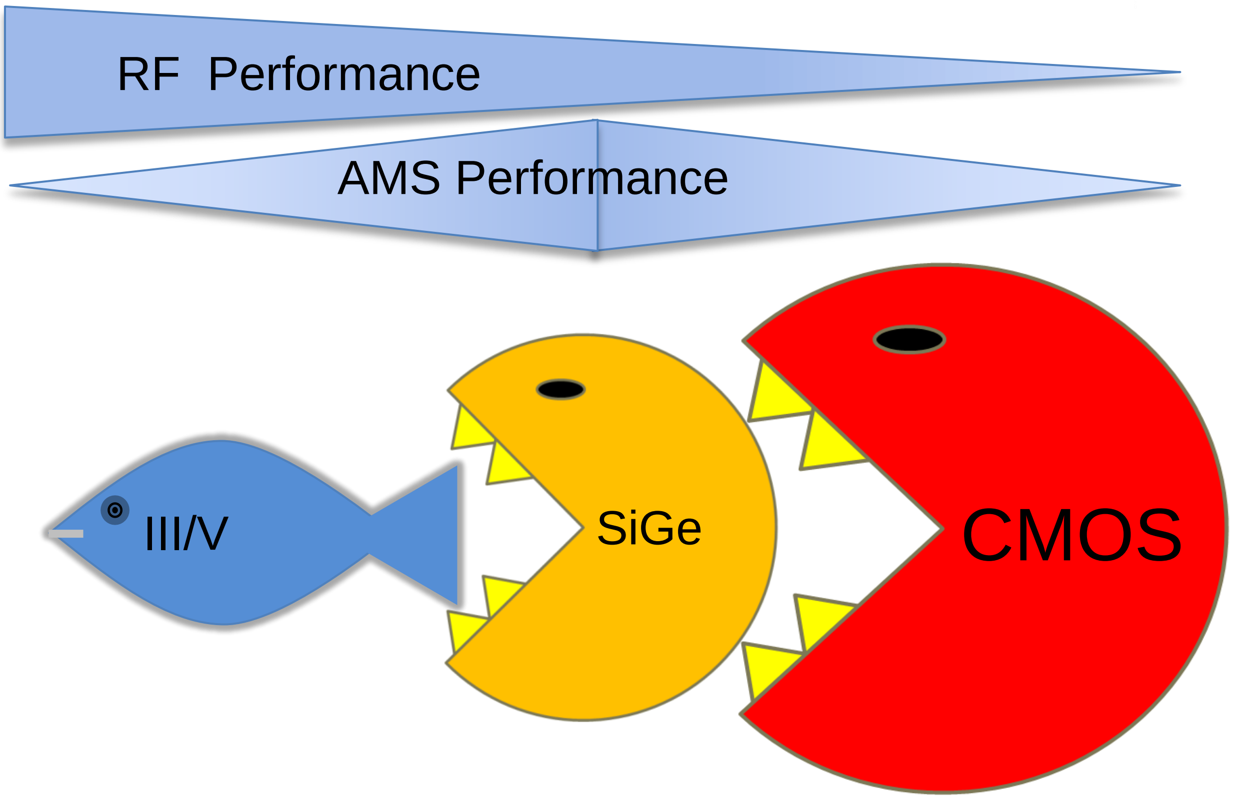
- 1000x smaller
- 1000x lighter
- 10x less power
- reconfigurable
- 100x lower cost
- High volume manufacturable



Technology Choice versus Application



Technology Decision



1st Law:
What can be done in Silicon, will be done in Silicon

2nd Law:
What can be done in CMOS, will be done in CMOS

…if there is a business case

MMIC Processes for f>100GHz

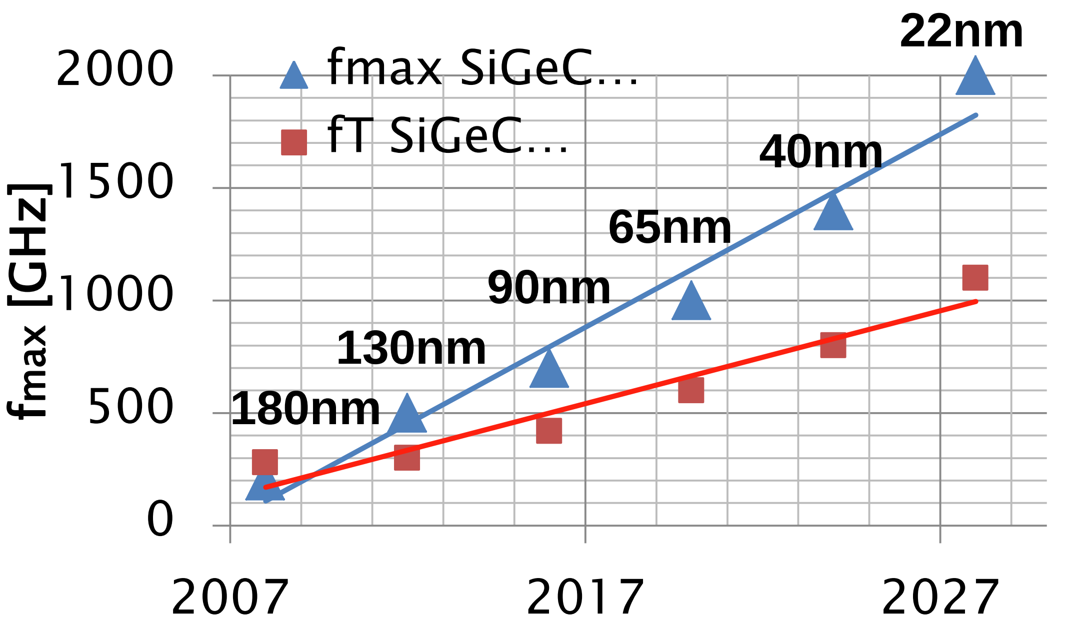
M3TERA

	Infineon	Teledyne	Teledyne	WIN	TSMC
Technology	SiGe HBT	InP DHBT	InP HEMT	pHEMT	CMOS
Feature size	180 nm 120 nm	250 nm	50 nm	100 nm	45 nm
No. met.layers	4 5	5	2	2	9
Complexity	VLSI	MSI - LSI	10 – 50	10 – 50	VLSI
f_T/f_{MAX}	200/250 GHz 250/400 GHz	370/650 GHz	600/600 GHz	120/180 GHz	300/300 GHz
V_{BR}	VB_{CE0} = 1.8 V VB_{CE0} = 1.5 V	VB_{CE0} = 4 V	1 V	7 V	1 V

Source: Herbert Zirath, EuMW-2015, WS07 RF-technologies on the move…

SiGE and CMOS Trends

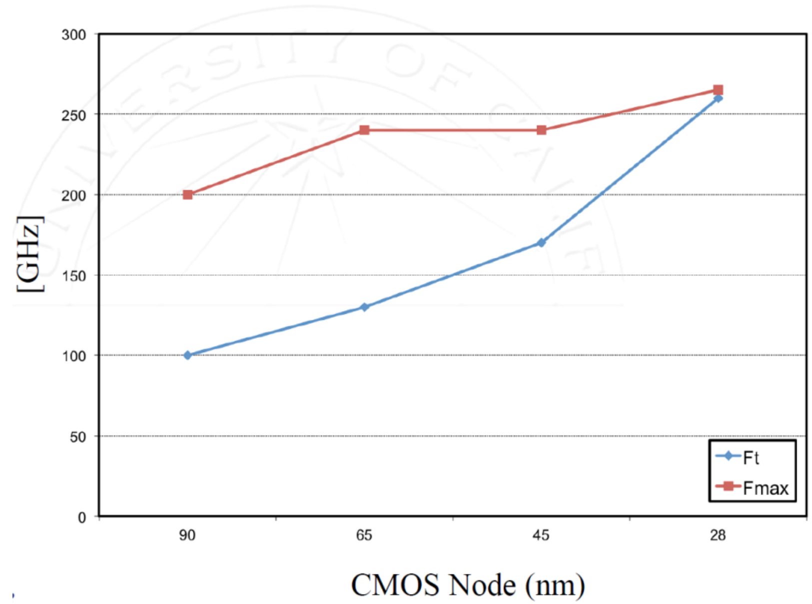
SiGeC



Available | **R&D** | **Predictions based on Simulation**

Source: SiGeC HBT technology roadmap, IMS2015, Phoenix, AZ, 17-22 May, 2015

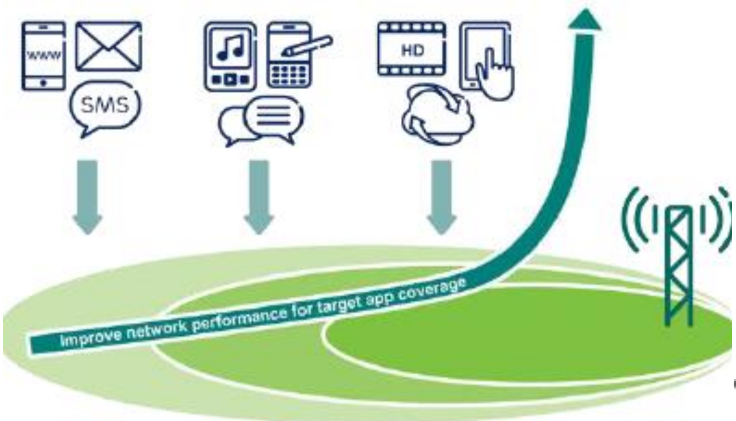
CMOS



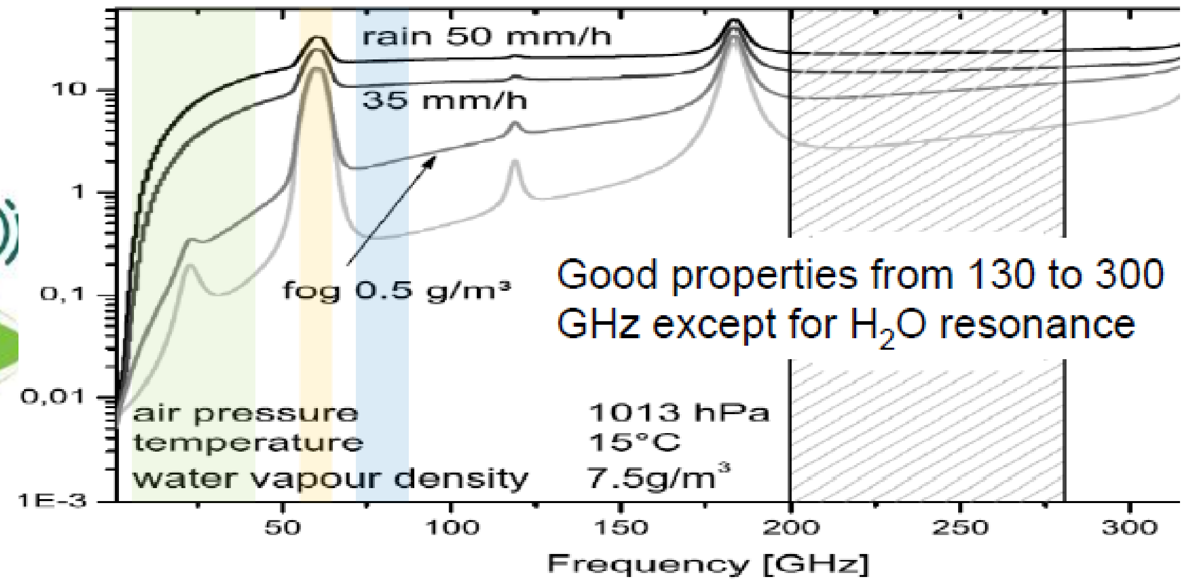
CMOS: fmax is flattening

Source: Ali Niknejad, Brooklyn5Gsummit April 2015

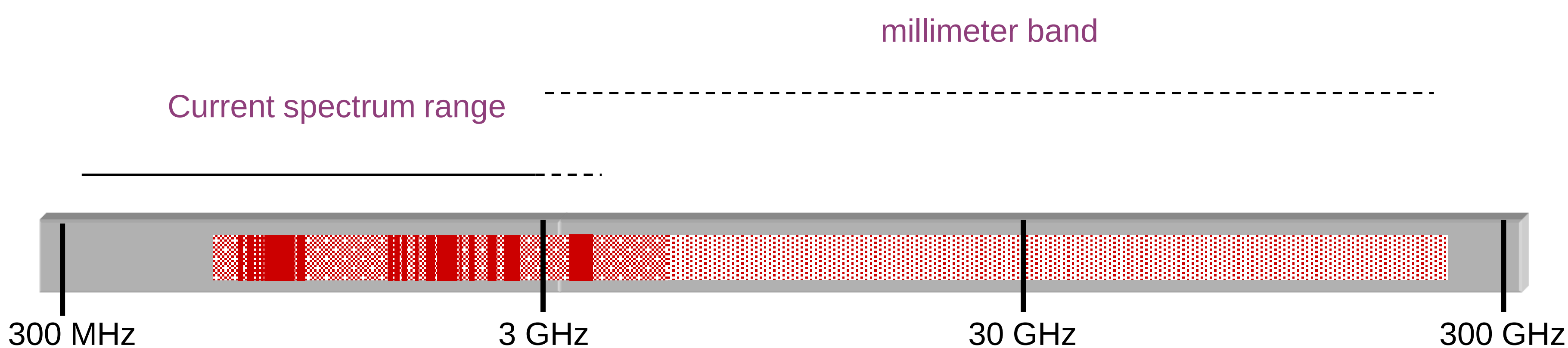
Telecommunication in the THz gap



Increasing demand for high QoS and Speed by mobile users

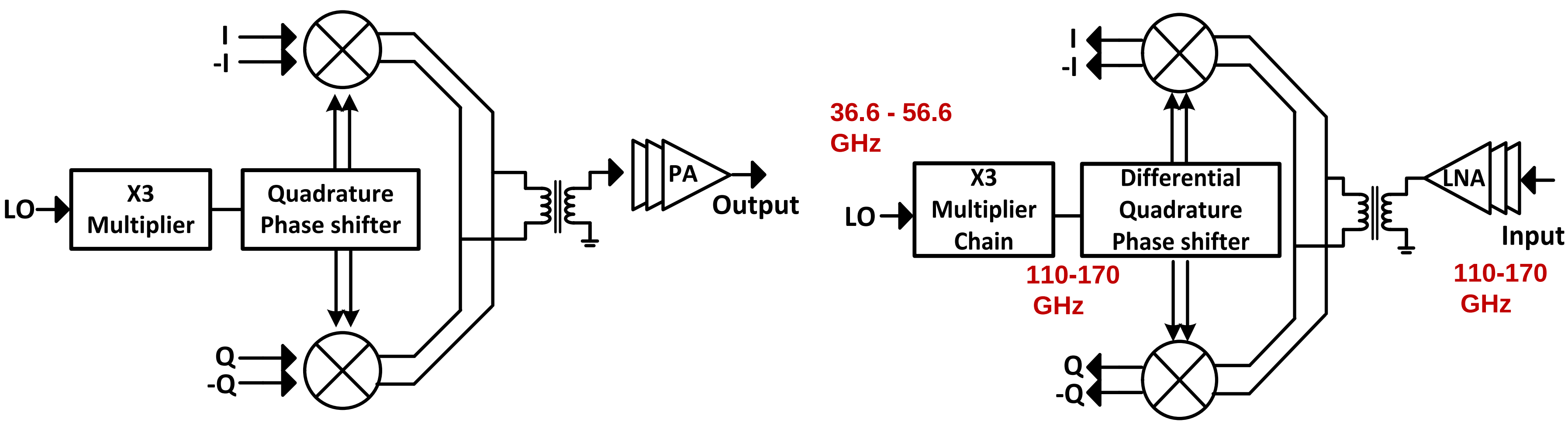


Good properties from 130 to 300 GHz except for H_2O resonance

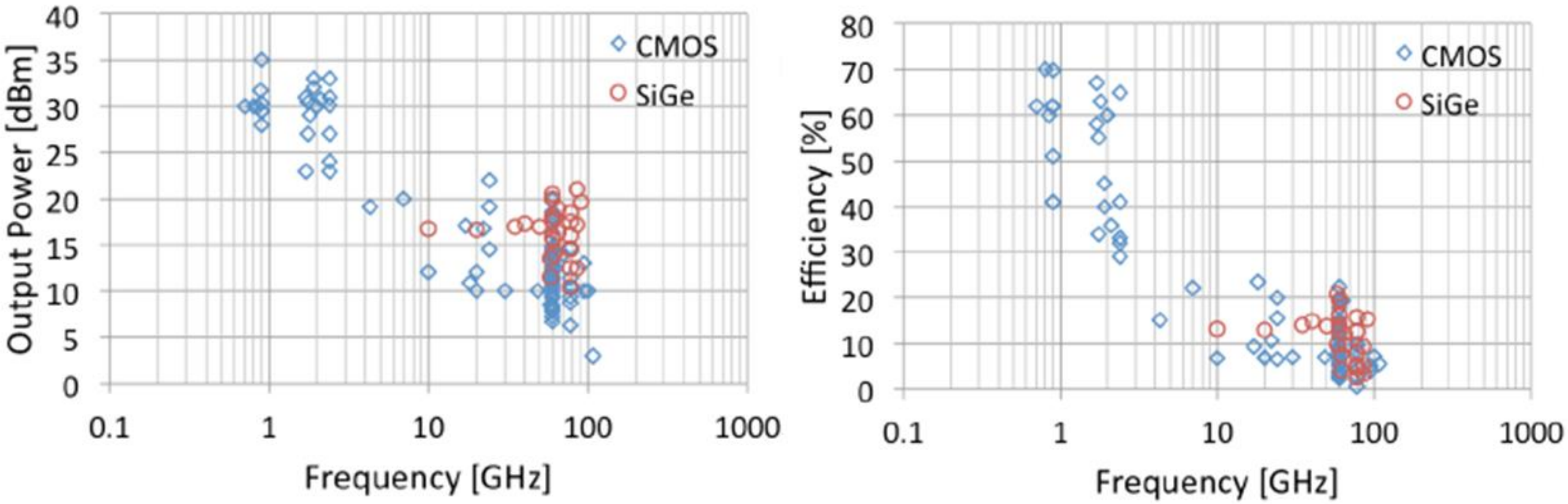


Transmitter

Receiver

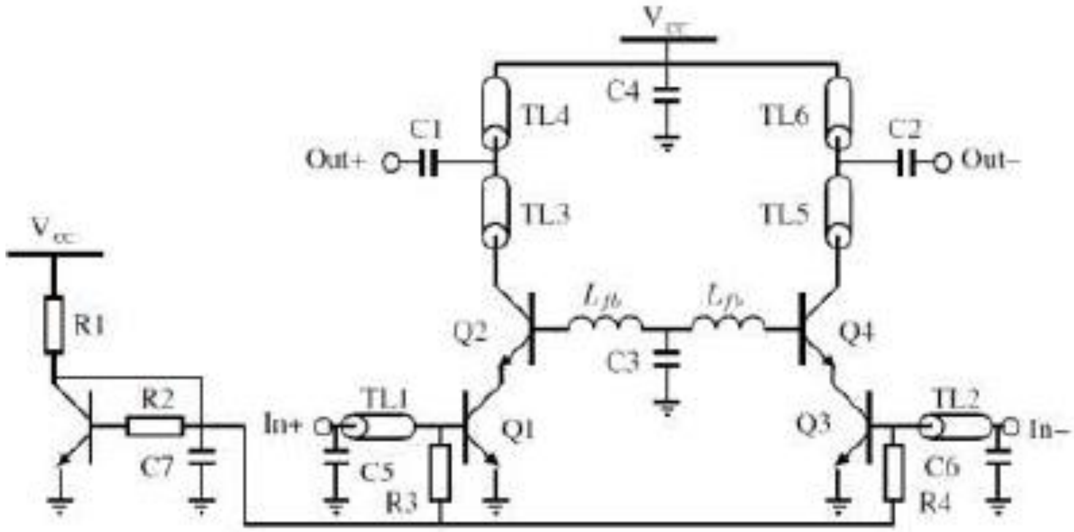


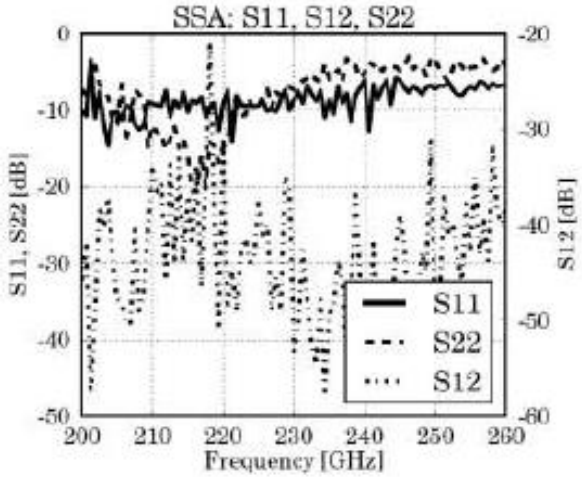
Silicon Power Amplifier Design



- Power and Efficiency drop with frequency
- SiGe mainly used at frequencies > 10 GHz
- In SiGe > 20 dBm @ 100 GHz is reported but efficiency is an issue

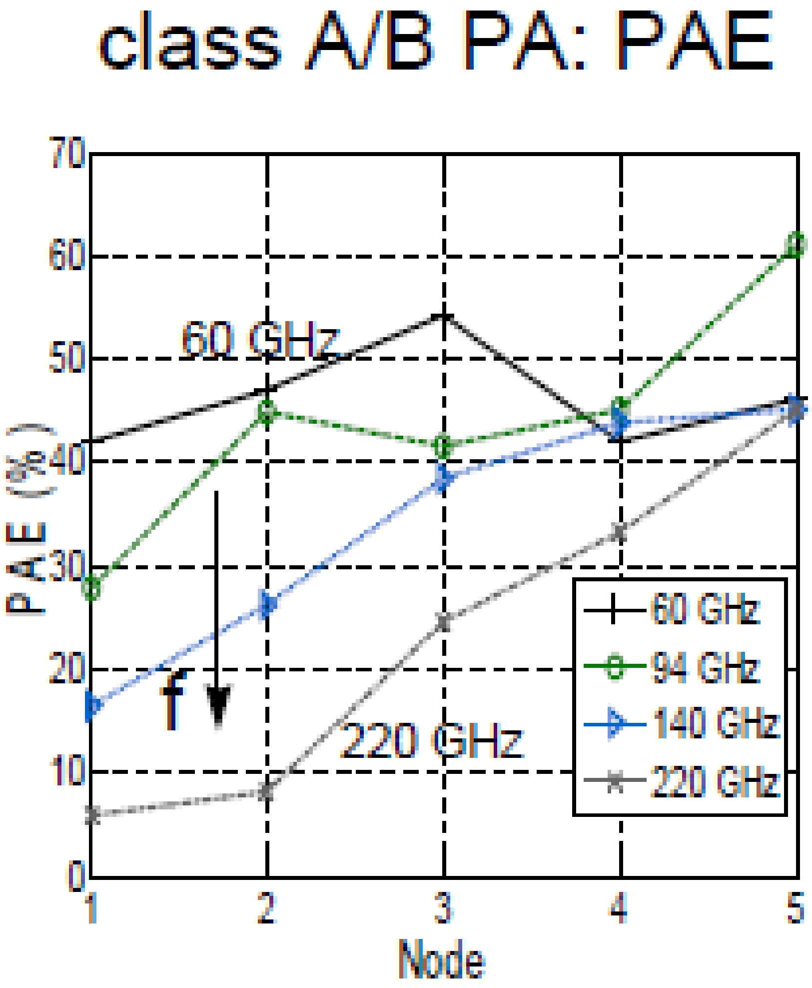
212 GHz PA Design in 130nm SiGe





212 GHz 4-stage Amplifier in SiGe $fT/fmax$ = 250/400 GHz

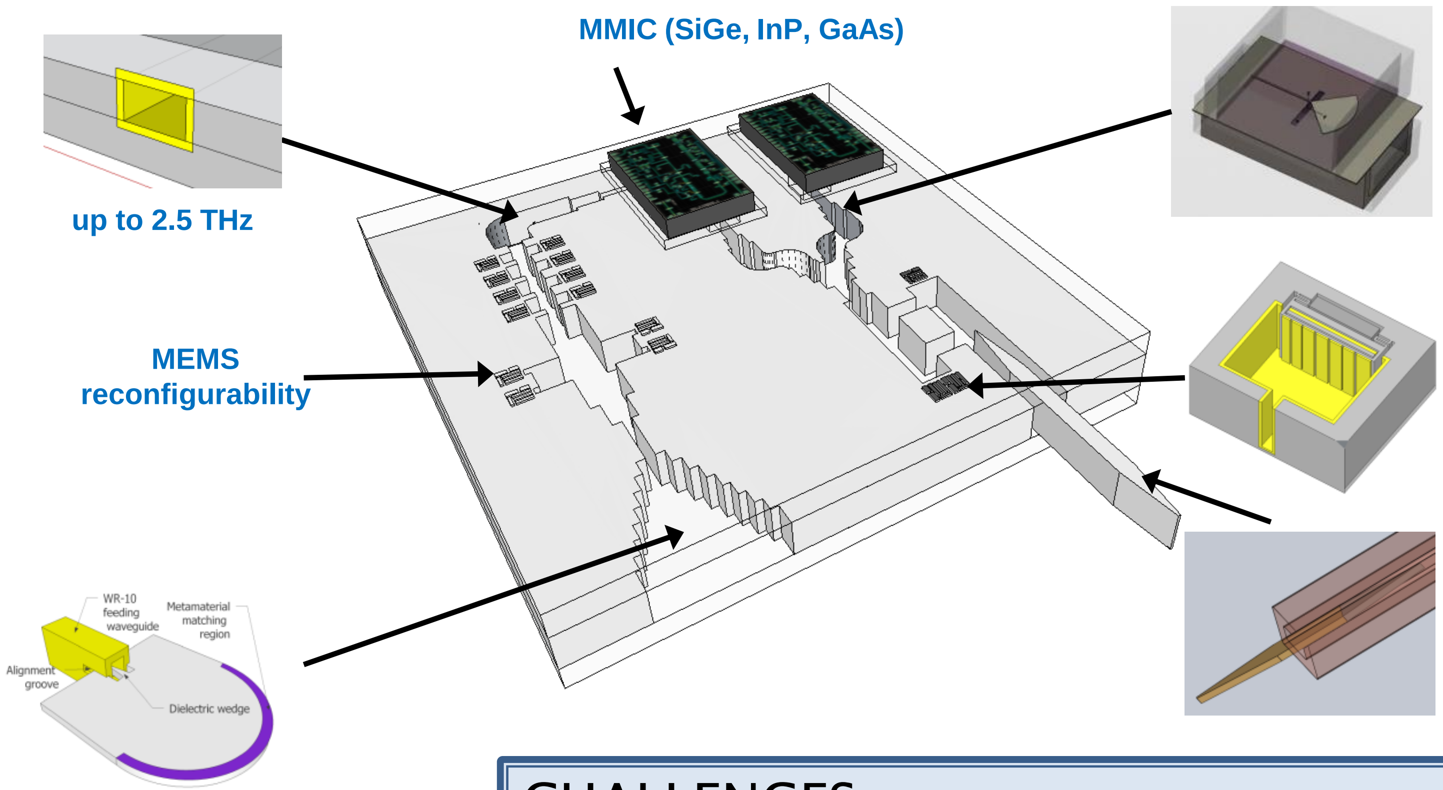
- Gain: 19.5 dB
- BW: 21 GHz
- 65 mA @ 3.3 V
- Marchand baluns at input and output
- Pads tuned with short circuit stub to resonate the pad capacitance
- T-match at the output (for wide bandwidth)



Calculated from HICUM/L2
With all known physical and
Parasitic effects
(incl. Self-heating)

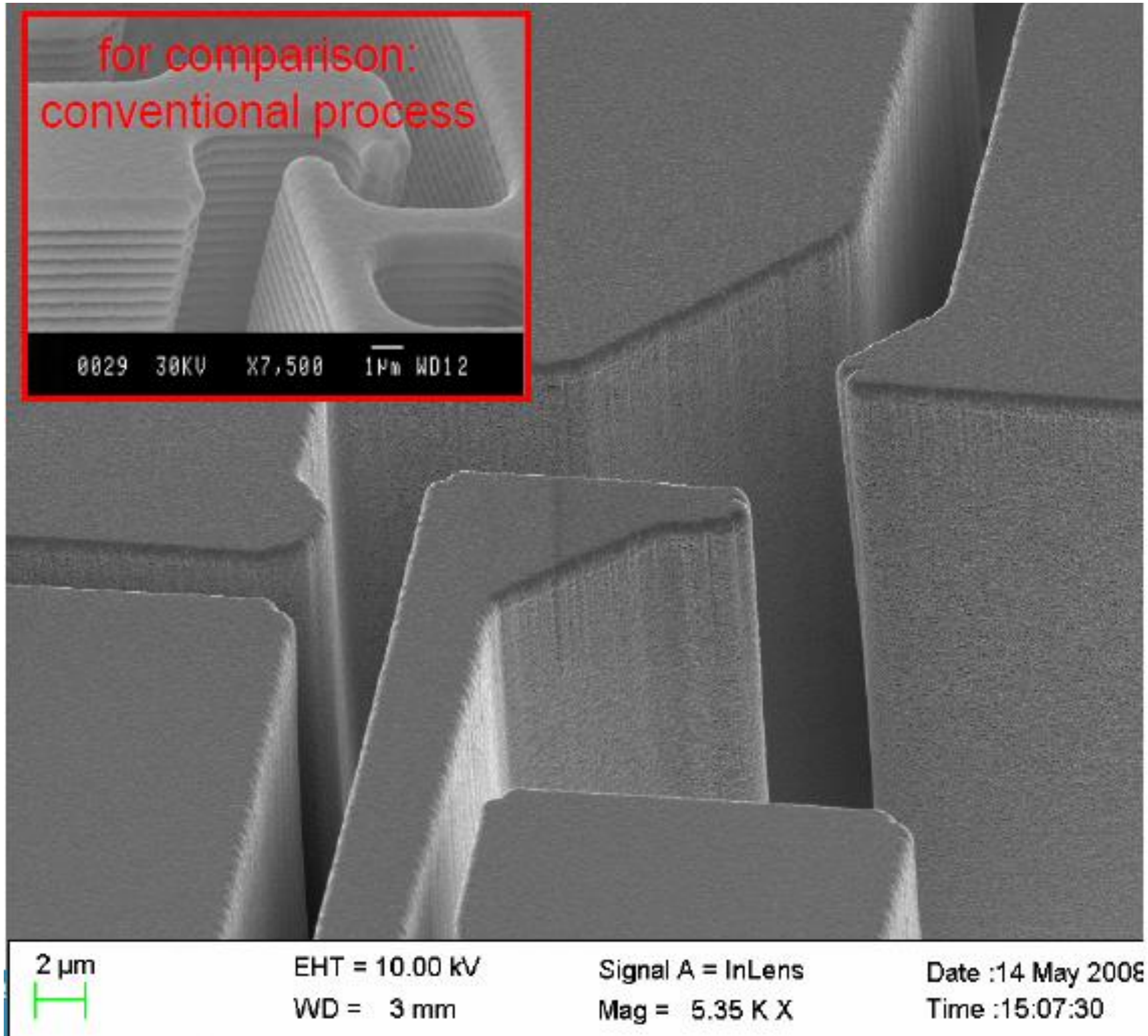
Node-1: 130nm
Node-2: 90nm
Node-3: 65nm
Node-4: 40nm
Node-5: 22nm

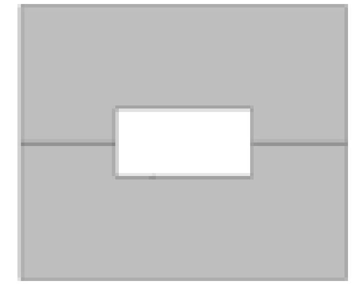
Source: M. Schroeter, SiRF2014



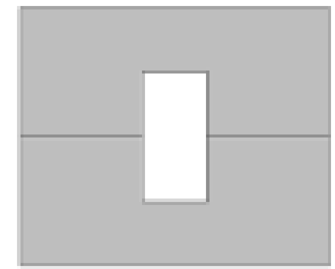
CHALLENGES

- Micromachining
- Silicon wafers bonding
- Metallic coating
- MMIC to MEMS waveguide interface

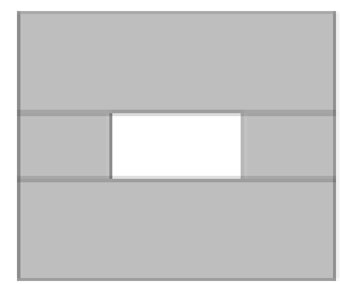




- 1 E-plane split

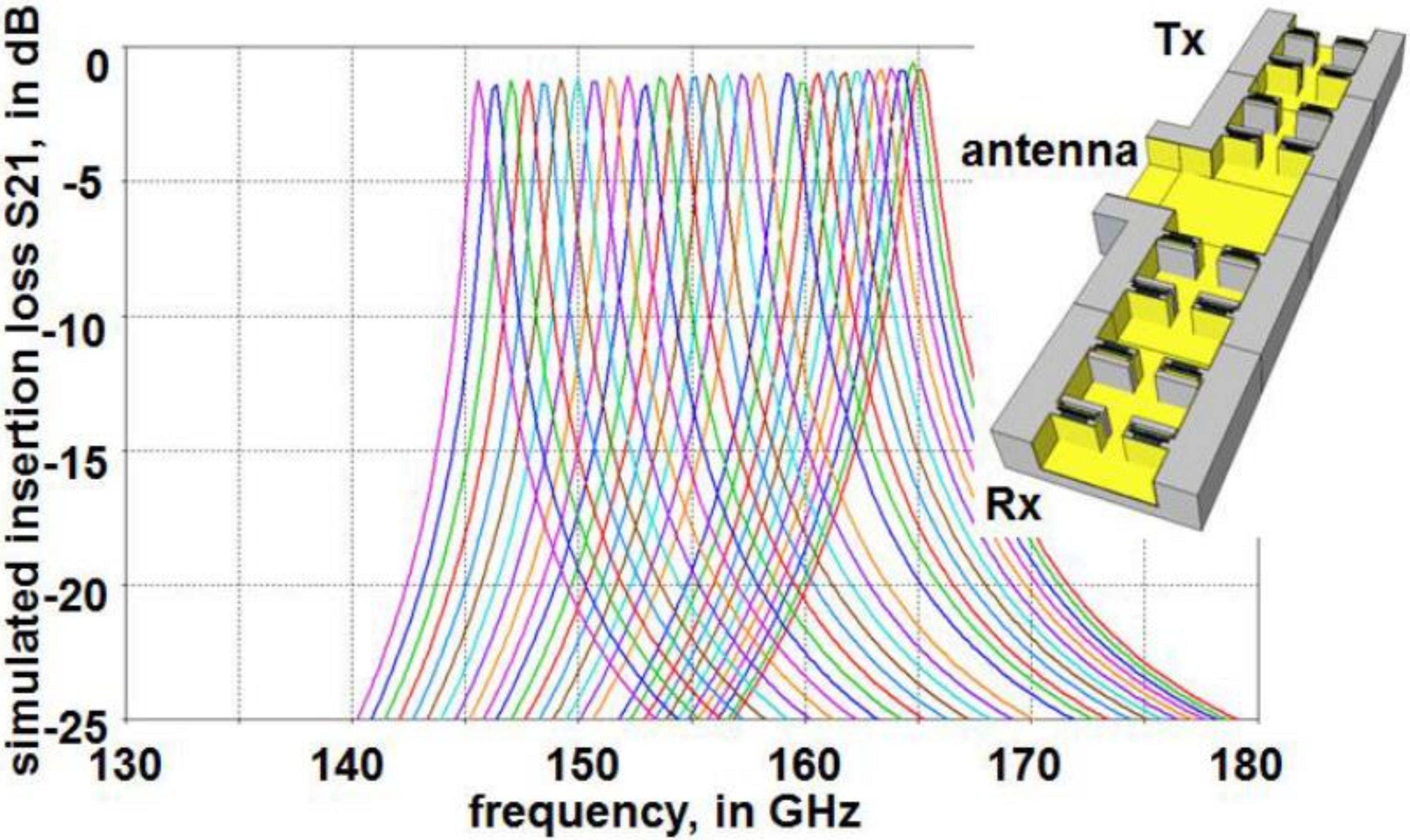


- 1 H-plane split



- 2 E-plane split

3-cavity based diplexer-filter example



- Waveguides (~0.01 dB/mm loss @ D-band)
- Tunable filters (~15% tuning, 0.4 dB IL @ D-band)

M3TERA

KTH and NASA JPL are pioneering THz micromachining

500-750 GHz Submillimeter-Wave MEMS Waveguide Switch

U. Shah[1], T. Reck[2], E. Decrossas[2], C. Jung-Kubiak[2], H. Frid[1], G. Chattopadhyay[2], I. Mehdi[2], and J. Oberhammer[1]

[1]KTH Royal Institute of Technology, Stockholm, Sweden

[2]Jet Propulsion Laboratory, Pasadena, CA, 91109 USA

500-600 GHz Submillimeter-Wave 3.3 bit RF MEMS Phase Shifter Integrated in Micromachined Waveguide

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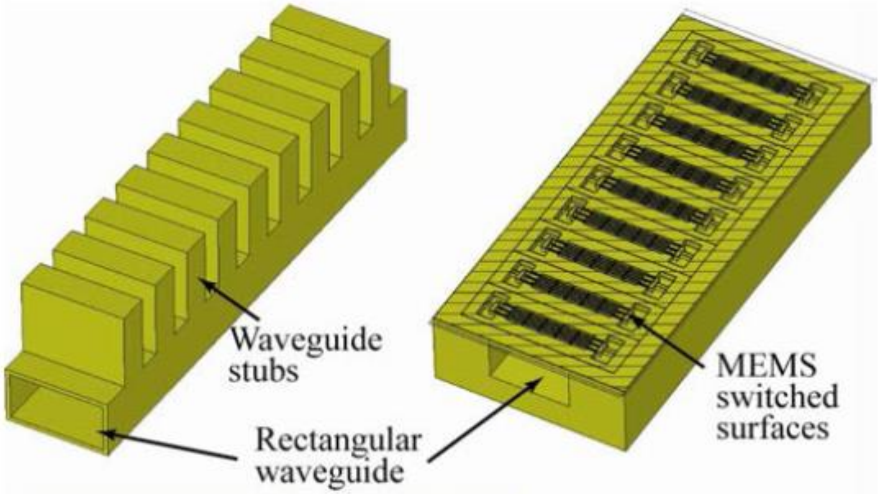
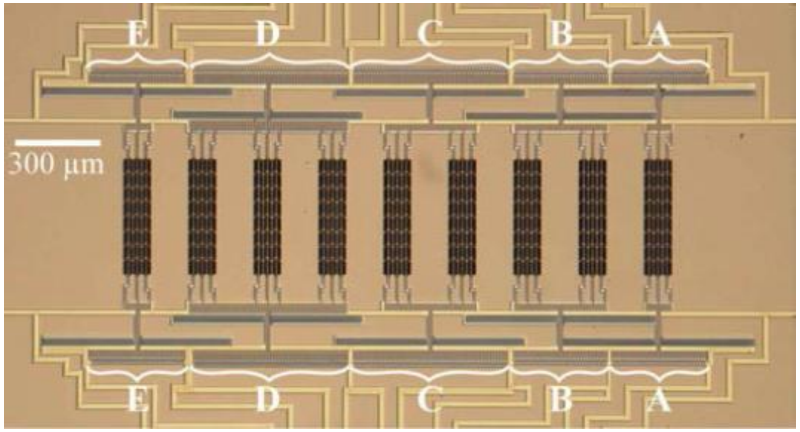
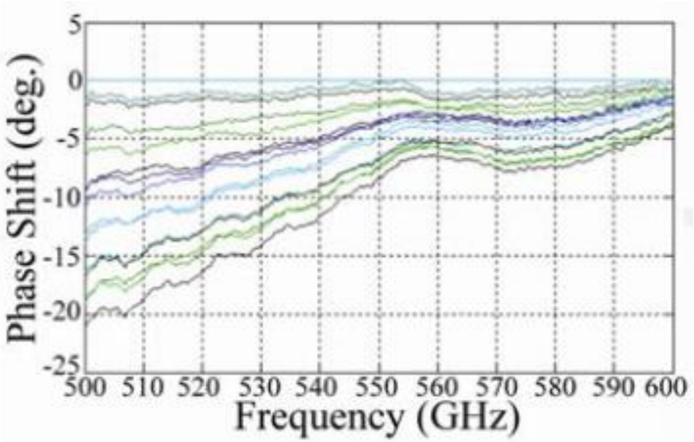
First RF MEMS above 200GHz, First MEMS phase-shifter above 110GHz, …

Resently published example 2

500-600 GHz Submillimeter-Wave 3.3 bit RF MEMS Phase Shifter Integrated in Micromachined Waveguide







Submillimeter-wave MEMS phase-shifter design using 9 E-plane stubs

Normalized phase-shift of the 500-600GHz phase-shifter
Linear phase-shift of 20deg in 10 steps
Return-loss < 15dB, insertion-loss < 3dB

SUMMARY

M3TERA

-> Mm-wave and THz frequencies are playing an important role in current and emerging applications like

- Communications (Microwave backhaul, 5G, …)
- Medical, Security, Industrial, Food control, Astronomy, ….

-> Low-cost THz technology will be enabled by the micromachined heterogeneous integration platform

-> The major innovation and design issues are

- Development of the micromachined multisubstrate platforms
- Integrated circuit design in cost efficient SiGe-BiCMOS technology
- Mm-wave and THz suited packaging of the ICs

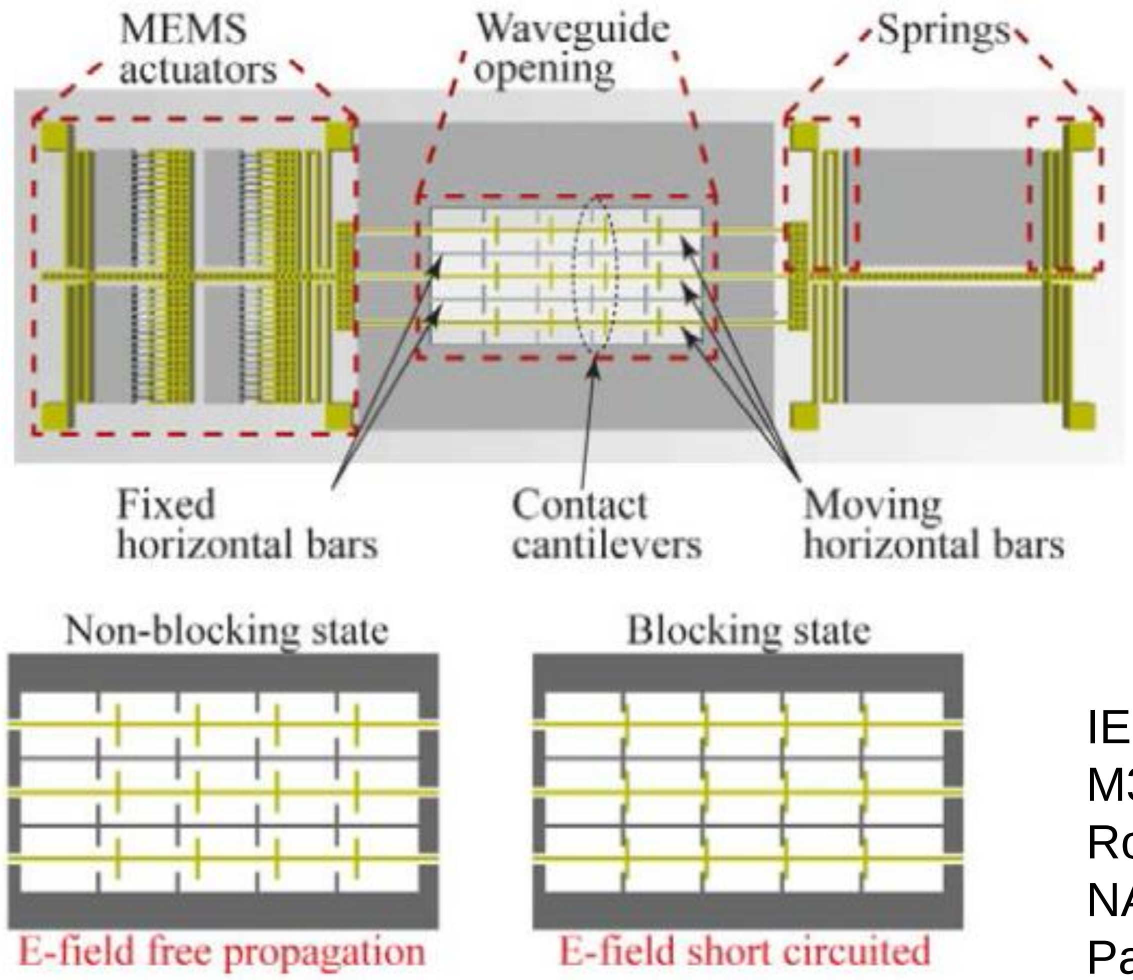
-> The platform will initiate an important transition in industrial microwave-systems manufacturing and will enable the large-scale commercialization

Thank you for your attention

Back-up

Resently published example 1

500-750 GHz Submillimeter-Wave MEMS Waveguide Switch



MEMS waveguide switch
a.) Schematic cross-section of the switch and
b.) Non-blocking and blocking state of the switch

Measurement:
Better 15dB isolation in blocking
Better 3dB insertion-loss
in non-blocking for 500-750GHz

IEEE IMS-2016 Conference Paper
M3TERA partner KTH
Royal Institute of Technology and
NASA Jet Propulsion Laboratory
Pasadena, CA

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If you need further information, please contact the coordinator:
TECHNIKON Forschungs- und Planungsgesellschaft mbH
Burgplatz 3a, 9500 Villach, AUSTRIA
Tel: +43 4242 233 55 Fax: +43 4242 233 55 77
E-Mail: coordination@m3tera.eu

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