‘System on chip solutions for future high speed communication’

Gigabit Wave project objectives:

Hardware solutions for future
- ✓**short and medium range wireless communication links**
- ✓**high data rate**

60-300 GHz, with bit rates up to and above 10 Gb/s

Project partners Chalmers, ERICSSON and Teledyne Thousand oaks

Linköping University, Sivers IMA, Bitsim, Gotmic, Altera in MODEM-project
NXP on 60 GHz RX/TX 45 nm CMOS
TU-Berlin, HHI (Heinrich Hertz Institute) on 60 GHz NLOS-MIMO

Outline

1. Motivation
2. RFIC/MMIC processes for frequencies beyond 100 GHz
3. Some circuit results
4. Some system demonstrations
5. Summary

CHALMERS

Gigabit Wave Project Team

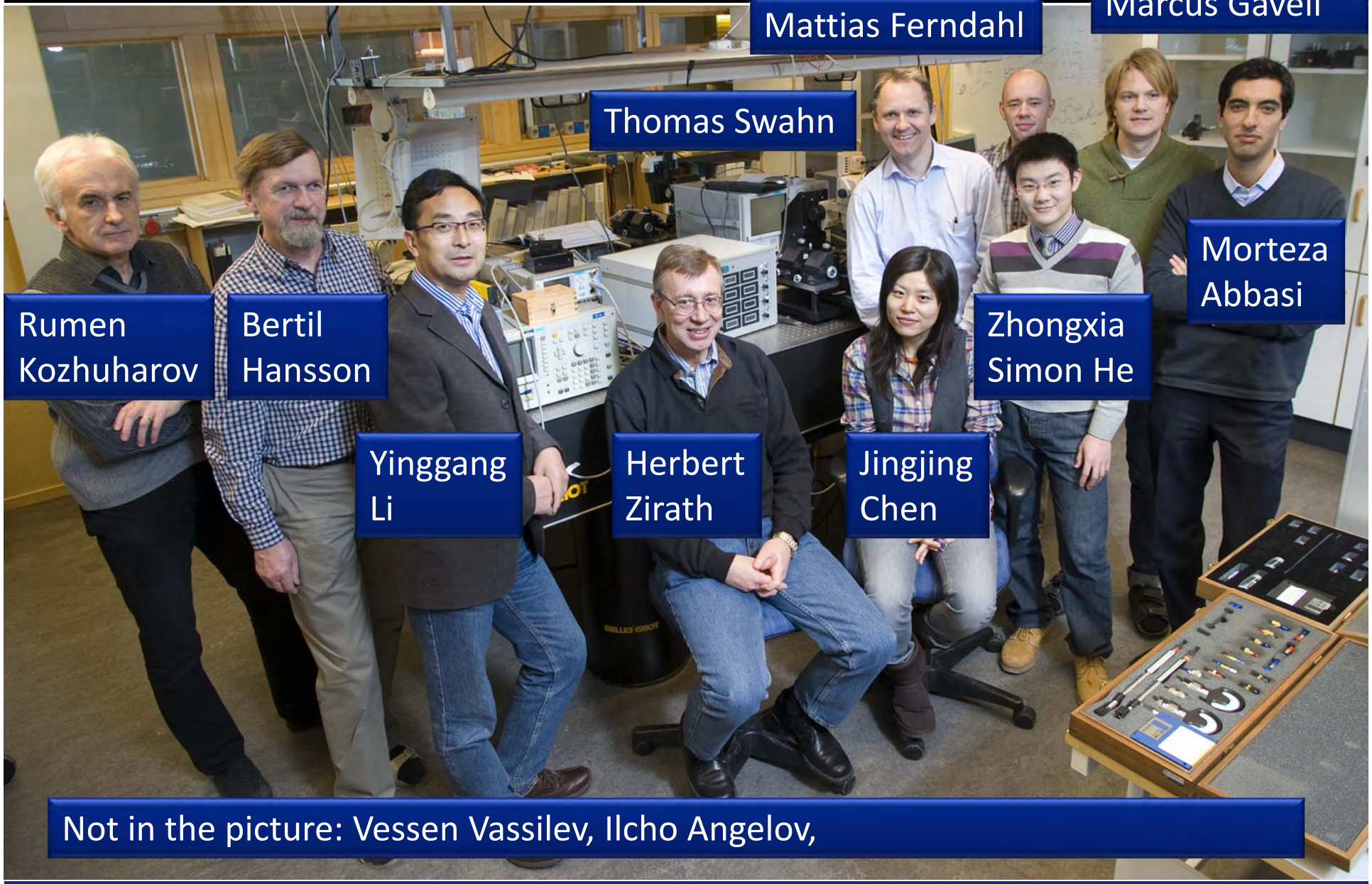
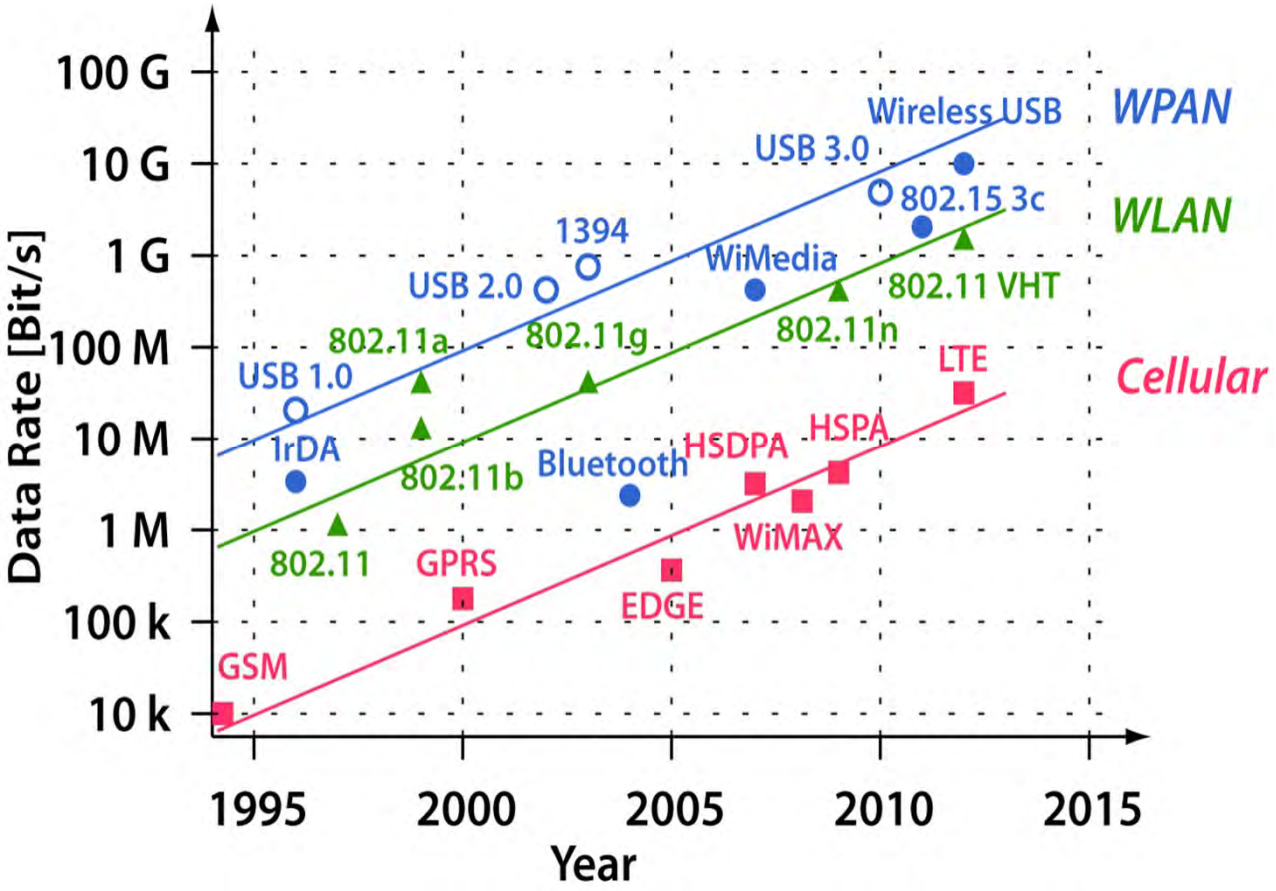


Photo: Jan-Olov Yxell, Chalmers

MC2 Microtechnology and Nanoscience

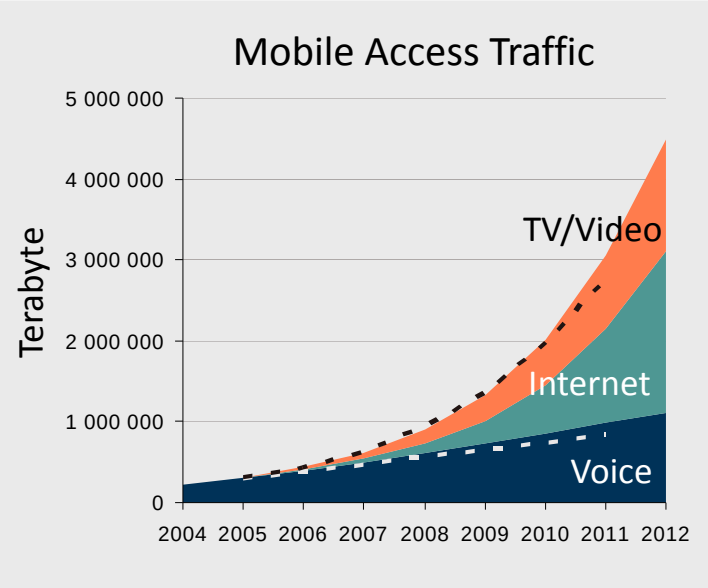
Evolution of Wireless Multimedia Services



- Wireless data rates **increase tenfold every five years**
- WLANs and WPANs demand for rates beyond 1 GBit/s in the near future

Courtesy Georg Boeck, boeck@tu-berlin.de, Berlin University of Technology

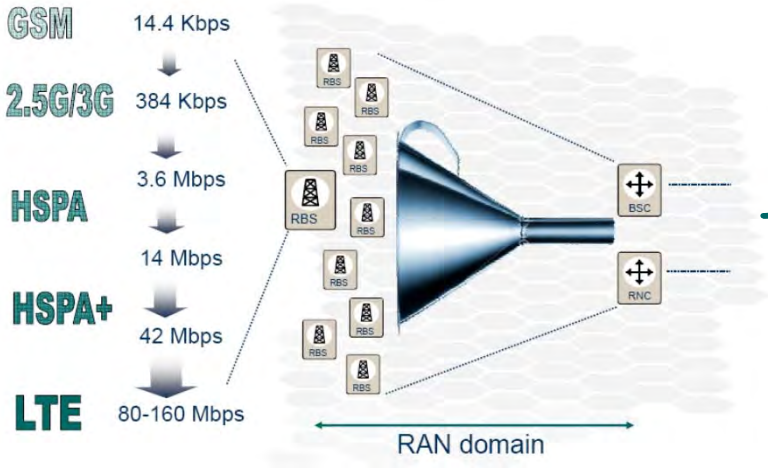
Develop future-proof solutions



Circuits and systems:

- High speed
- High frequency
- Highly integrated

Challenge to operators: $/bit



Mobile Backhaul:

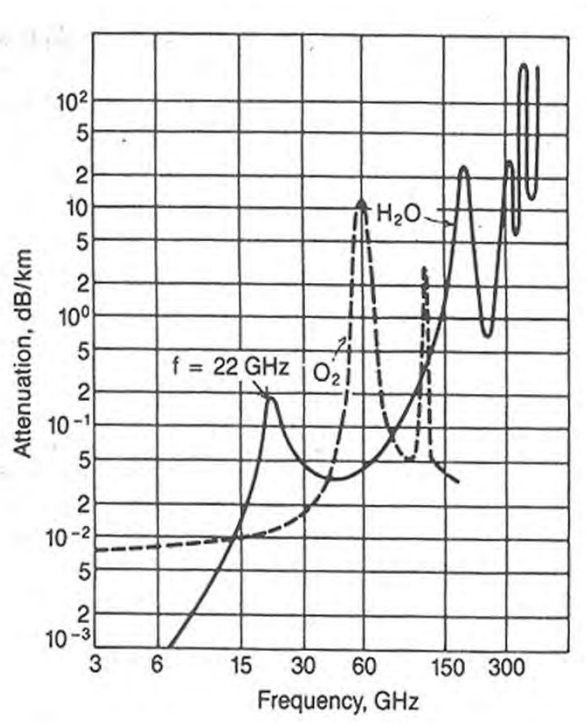
- Gbps capacity needed for LTE (2010)
- 2.5Gbps in a few years ahead
- 10Gbps as fiber extension

Challenges….

high datarate ->high bandwidth ->high frequency:

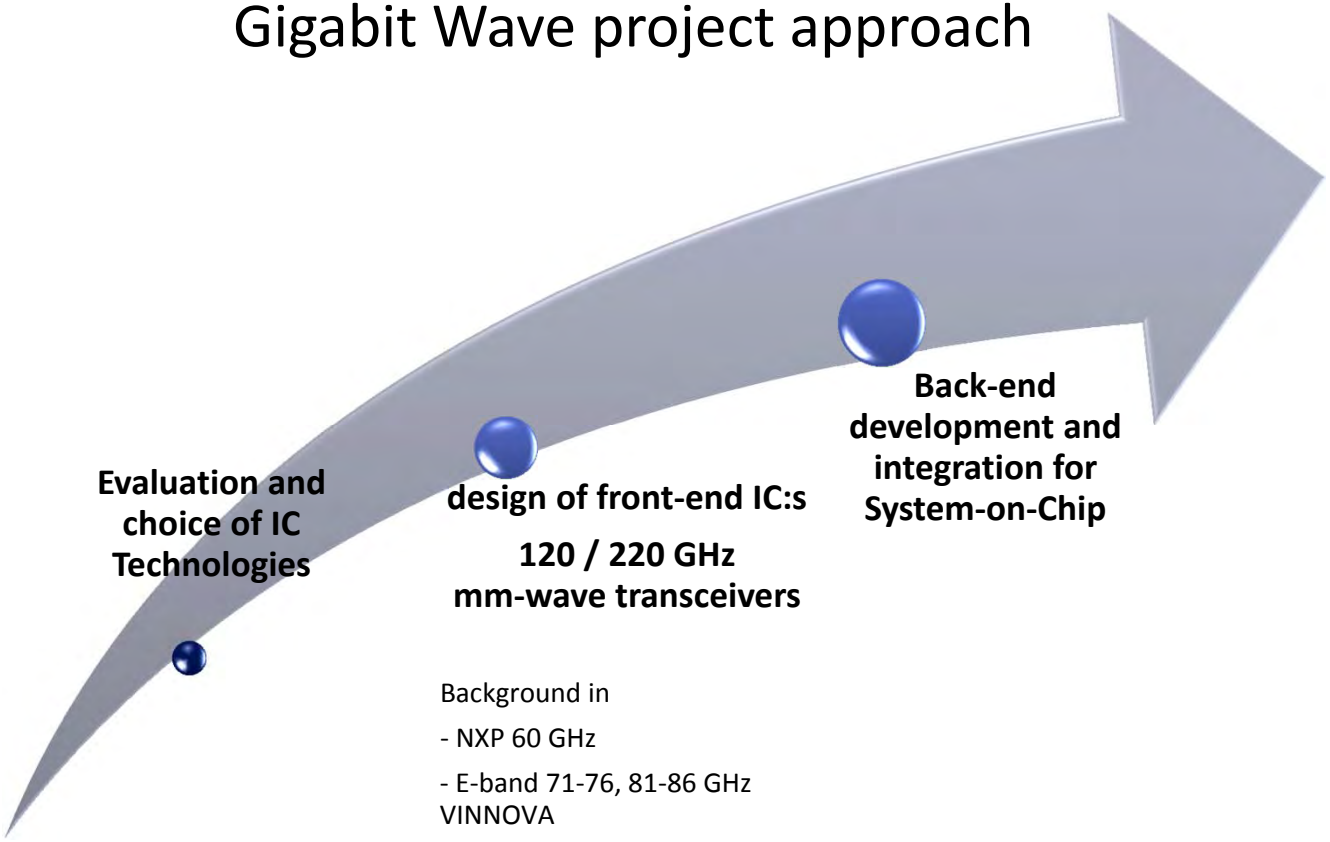
-60 GHz: unlicenced band 5 GHz, high attenuation, small distance, secure comm
-E-band: 71-76, 81-86 licenced band for PtP 10 GHz BW
-120 GHz: 20 GHz no standard today
-220 GHz: 40 GHz no standard today

- Very few commercial circuits exist for the front-end like LNA, mixer, LO, modulator, demodulator etc
- Today's most advanced semiconductor processes are needed for the realization of the hardware
- No commercial back-end electronics exists
- Spectrum efficiency
- System simulation a challenge
- Packaging



System on chip solutions for future high speed communication

Gigabit Wave project approach



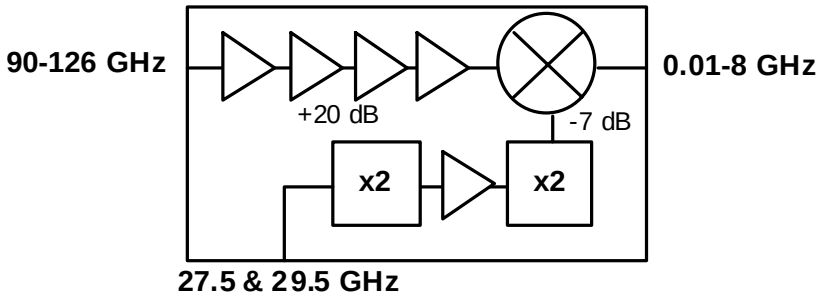
Background in

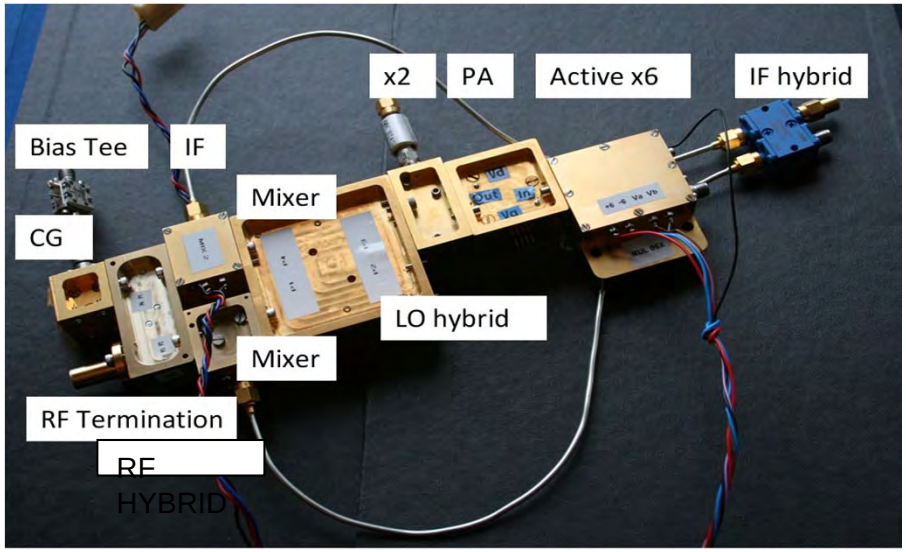
- NXP 60 GHz
- E-band 71-76, 81-86 GHz VINNOVA

Goal

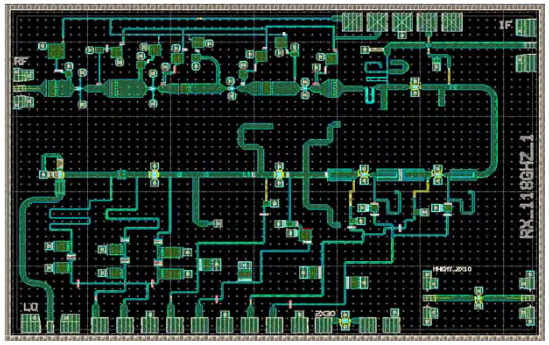
Demonstration of 2 fully integrated and packaged wireless 10 Gb/s Ethernet-compatible chipsets working in two bands: 120 GHz and 220 GHz.

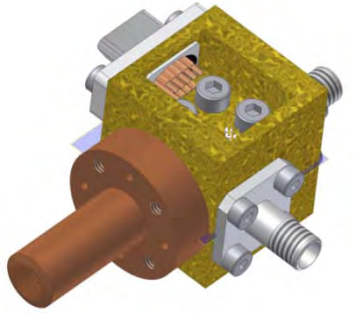
Integration of mmW/THz-Electronics…



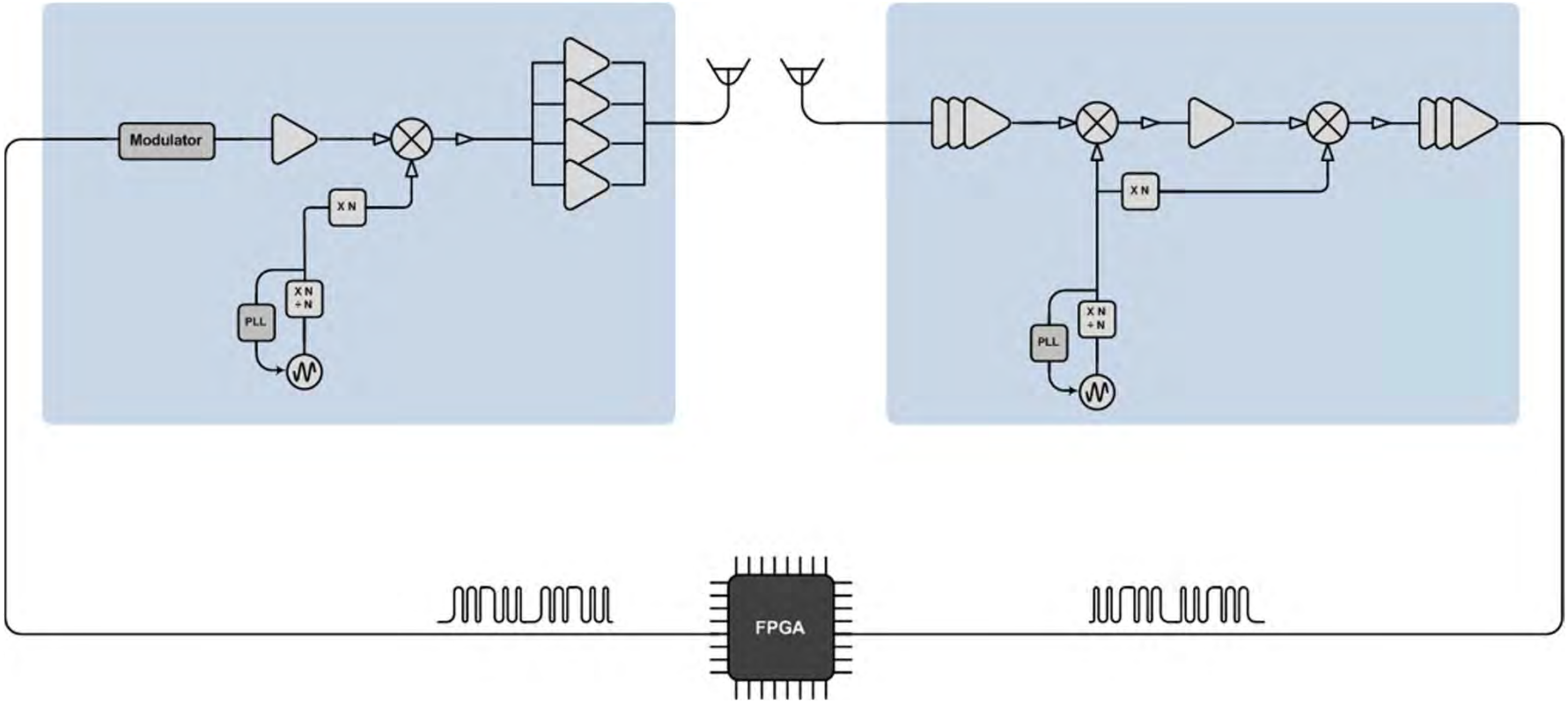


Single side band mixer





Generic demonstrator block diagram



The backend electronics is developed in a VINNOVA-project, called MODEM

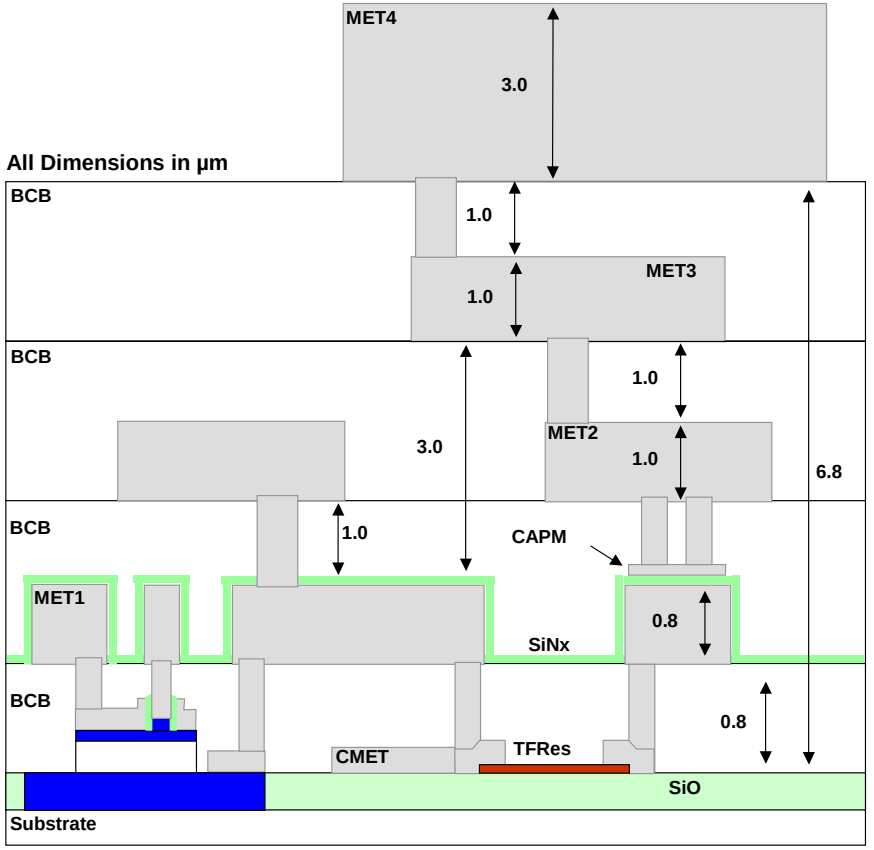
Processes used at present in the program

	Teledyne	Teledyne	Teledyne	TSMC
Technology	InP DHBT	InP DHBT	InP HEMT	CMOS
Feature size	500 nm	250 nm	50 nm	45 nm
No. met.layers	5	5	2	9
Complexity	MSI - LSI	MSI - LSI	10 – 50	VLSI
f_T/f_{MAX}	330/360 GHz	400/700 GHz	600/600 GHz	300/300 GHz
V_{BR}	VB_{CE0} = 4 V	VB_{CE0} = 4 V	1 V	1 V
	120 GHz 220 GHz	120 GHz 220 GHz 340 GHz	120 GHz 220 GHz 340 GHz	60 GHz+

Teledyne: TSCHBT 0.5/0.25 μm InP DHBT Dielectric layers in BCB

Denser integration possible, because the dielectric layers are 50 times smaller ➔ 5-10 times denser integration possible as compared to standard MMIC technology! Each layer is 2 μm thick

First design round, including 29 circuits and test structures, was completed during autumn 2009. Evaluated during spring 2010.
Second design round, including >100 circuits and test structures, was completed during spring 2011.
2-3 more tapeouts planned



Representative cross-section of TSCHBT IC technology. Drawing is not to scale. f_t *= 400 GHz, and* f_{max} *= 700 GHz @* $J_E = 5\ mA/\mu m^2$

3D MMIC technology

Pioneering work was done by NTT since beginning of 1990....

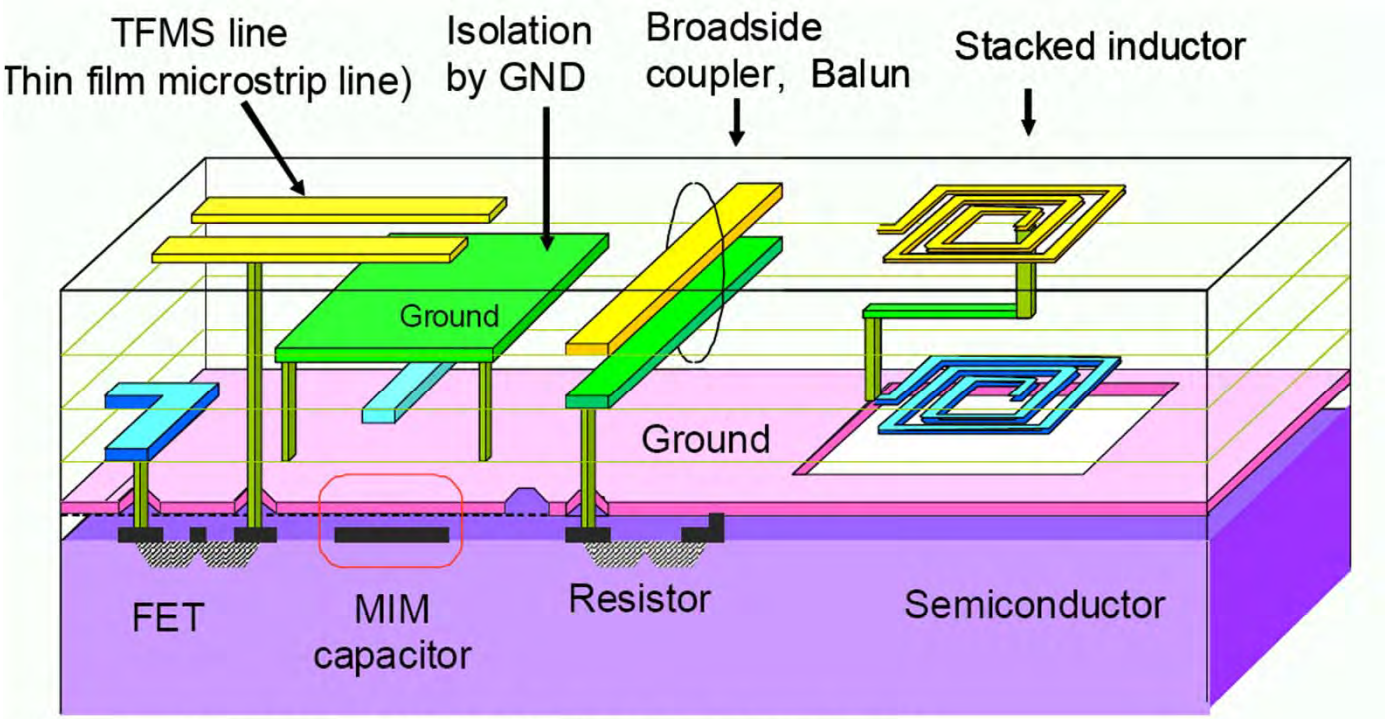
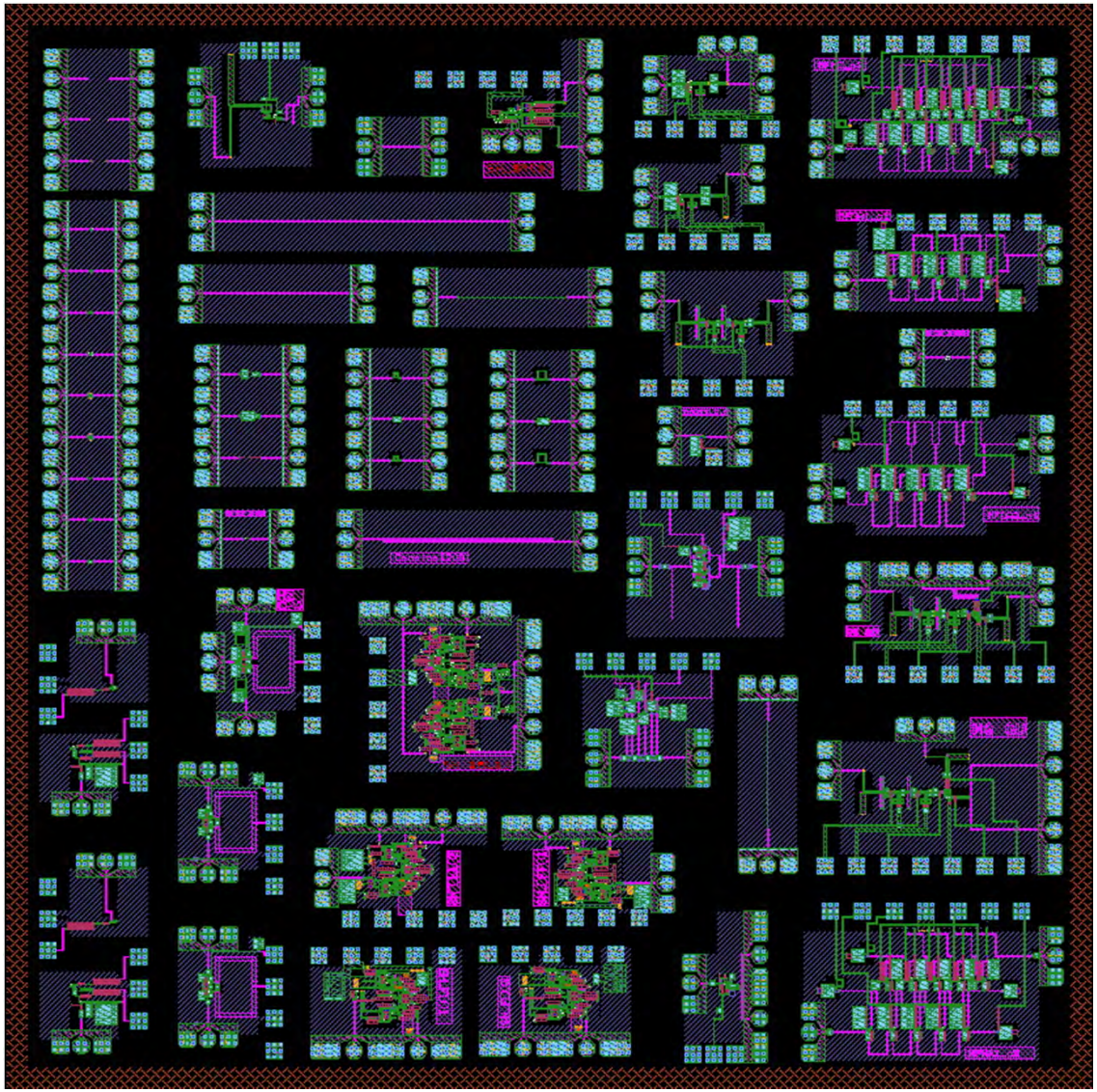


Fig. 1. Structure of 3D MMIC and passive circuits

Teledyne 500 nm InP DHBT, tapeout #1

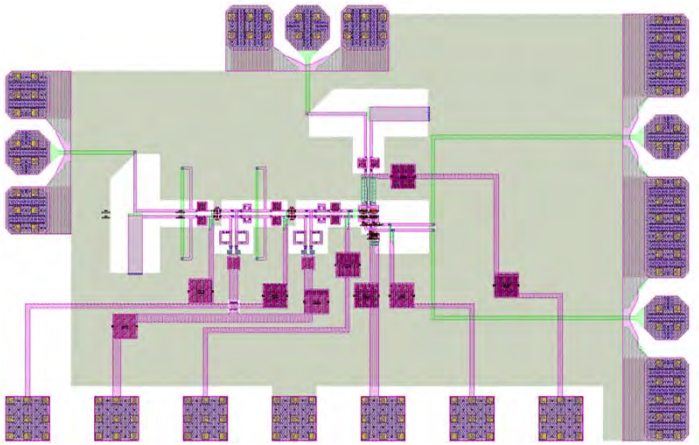
Reticle taped-out autumn 2009

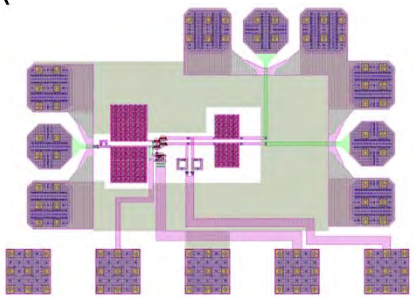
First design round, including 29 circuits and test structures, was completed during the autumn 2009.

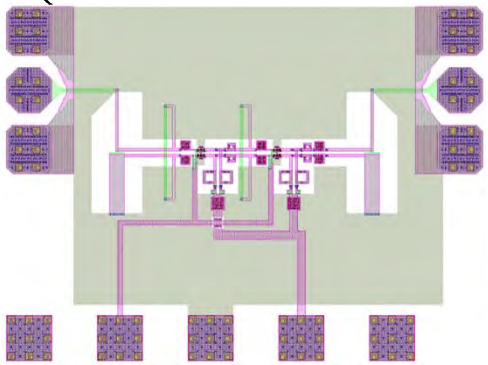


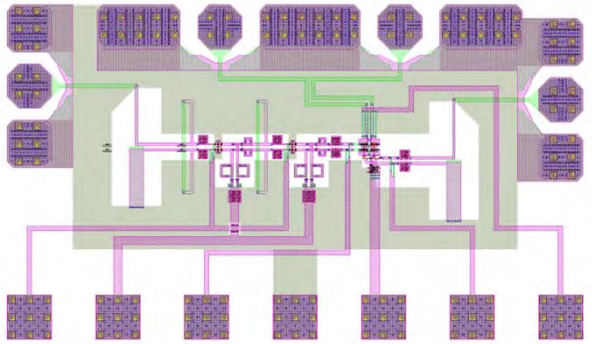
Some MMICs in Teledyne tapeout #1

- **Up converting Gilbert mixer**
  (CG =11 dB, BW = 85-100 GHz)
- **Down converting Gilbert mixer**
  (CG =2 dB, BW = 85-100 GHz)
- **Active balun**
  (CG= 0-8 dB, BW = 15-120 GHz)
- **Differential buffer amplifier**
  (A = 10 dB, BW = 90-130 GHz, OP1dB = 10 dBm)









Marcus Gavell, et al,' A fundamental upconverting Gilbert mixer for 100 GHz wireless applications, 32nd IEEE COMPOUND SEMICONDUCTOR IC (CSIC) SYMPOSIUM , 3-6 October 2010, Monterey, USA.

Teledyne tapeout #2
50 nm InP HEMT Tapeout May 2010 test round

- Test devices for modeling and designkit
- Single-ended resistive mixers
- W- and G-band LNAs
- 120 GHz OOK-modulator
- 220 GHz OOK-modulator
- Frequency Tripler - 30 to 100 GHz
- 220 GHz Antenna-Integrated mixers
- 100-220 GHz power detector
- 100-220 GHz envelope detector (10 Gbps)

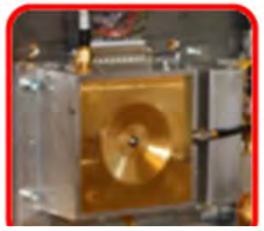
A designkit was made for this process including scalable nonlinear HEMT model

Majority of circuits works well, several publications ahead
One possible patent on antenna integrated mixer

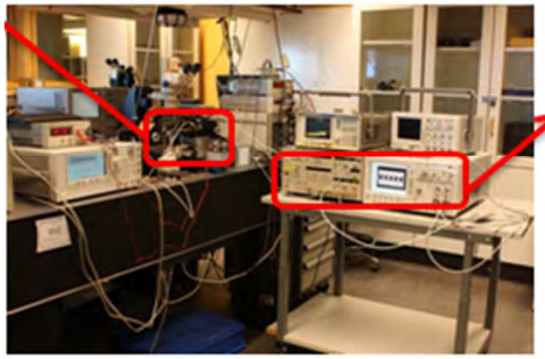
Wireless system demonstrations

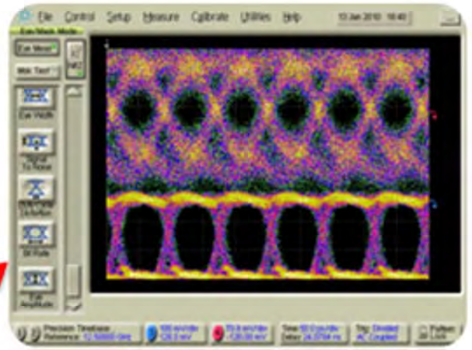
1. 12.5 Gbps OOK short range link at 220 GHz
2. NLOS MIMO at 60 GHz 500 Mbps
3. 5 Gbps at E-band with D-QPSK

System level experiments are made on our latest receiver module (IAF 100nm mHEMT) to demonstrate the feasibility of 12.5Gbps wireless data transmission at 220GHz.



220 GHz Single-Chip Heterodyne TX-RX with integrated antenna





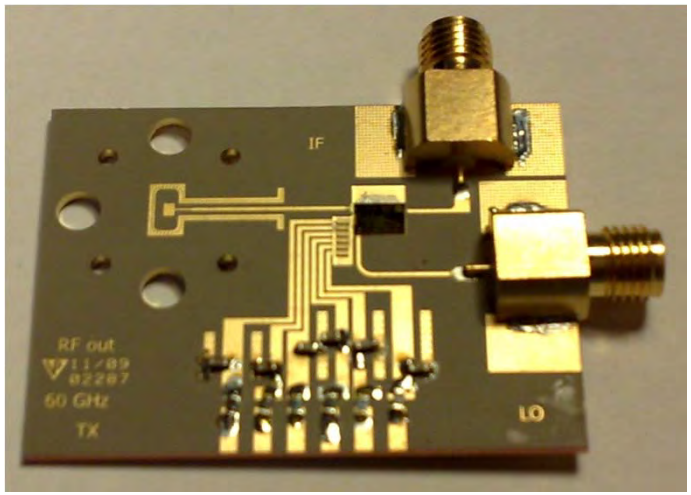
12.5Gbs

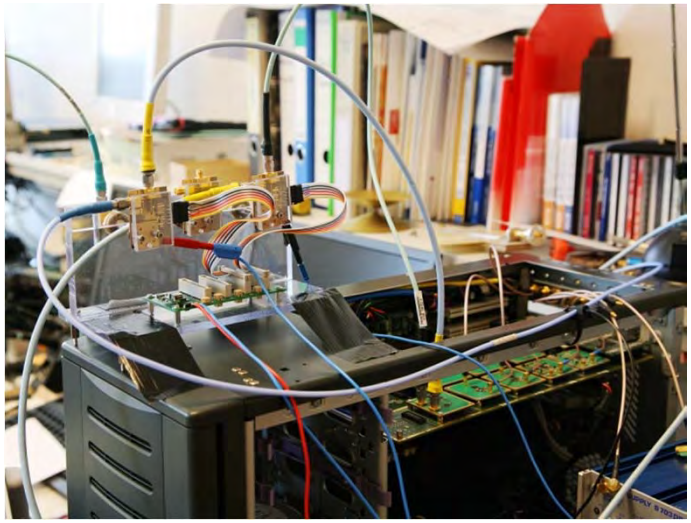
System Level Experiments

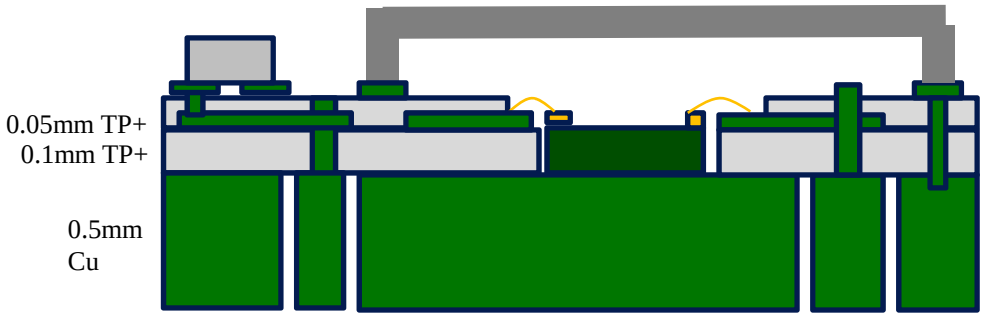
Morteza Abbasi, et al,, Single-Chip 220 GHz Active Heterodyne Receiver and Transmitter MMICs with on-Chip Integrated Antenna, IEEE Trans. MTT 2011

Advanced mm-wave module for 100+ GHz MMICs

- **Verified performance up to 110 GHz**
- High performance Waveguide to microstrip transitions
- Possibility to integrate multiple chips
- **First demonstion of 60 GHz MIMO NLOS** in collaboration with Heinrich Hertz Institute/TUB using these modules







World 1st Demo of 60GHz NLOS STC-MIMO System

We demonstrated world 1st
Non-Line-Of-Sight MIMO System on ICC'09 with HHI

- 2x2 MIMO with Space-time-coding
- Transmitting continue when direct path is blocked
- Data rate: 250 Mbps
- Real time HDTV video transmission
- Transmission distance: 10m

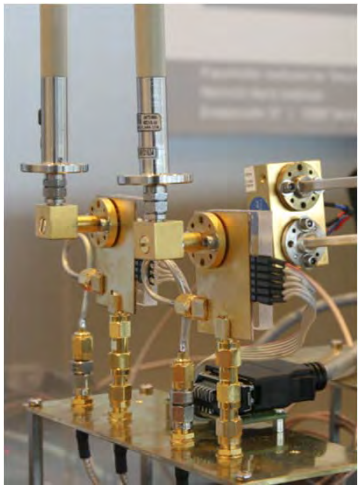
Cooperating Partner:

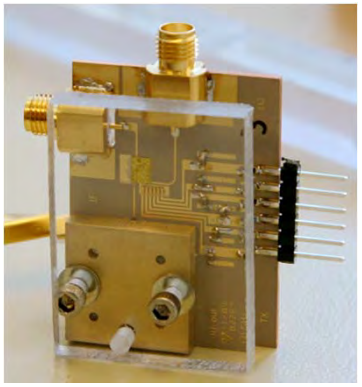
- Heinrich Hertz Institute (HHI): Signal Processing

Fraunhofer Heinrich Hertz Institute

- MEL, Chalmers
  60GHz MMIC-chipset and RF module design

- TU Berlin
  CMOS multifunction RFIC



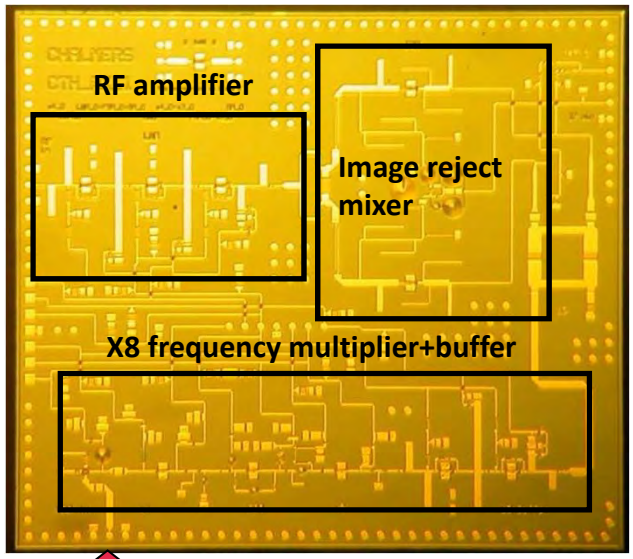


International Conference on Communication 2009

Dresden Germany

1st chip set for **60 GHz radio** made at Chalmers University in pHEMT technology (WIN PP-15)

Image reject receiver



RFin
56-64 GHz

Baseband out
2.5 GHz CF

5.7x5 mm

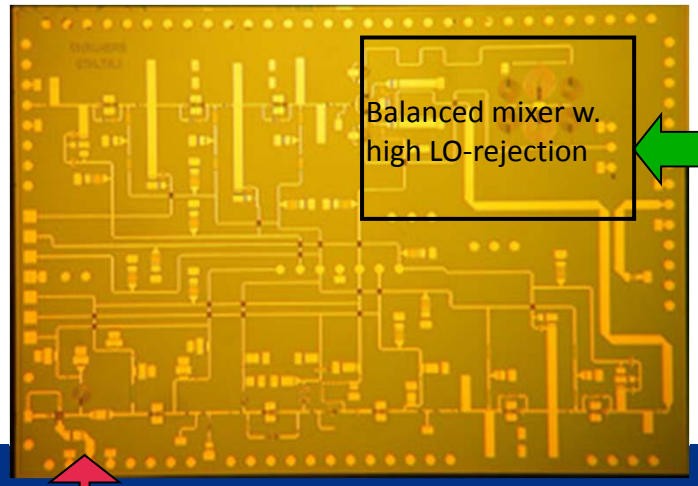
LO 6.7-7.7 GHz

Experimental data

8 dB RF-IF gain
>25 dB image rejection
56-64 GHz RF bandwidth
>1.5 GHz IF bandwidth

Transmitter

RFout
56-64 GHz



Baseband in
2.5 GHz CF

5x3.5 mm

LO 6.7-7.7 GHz

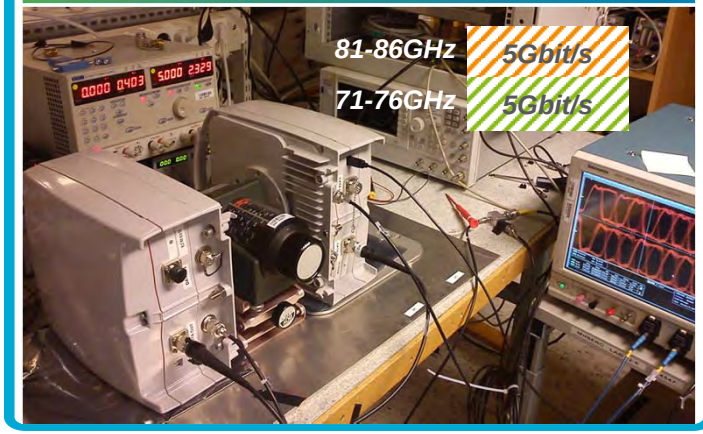
See IEEE JSSC Nov 2005

5Gbps demonstrator

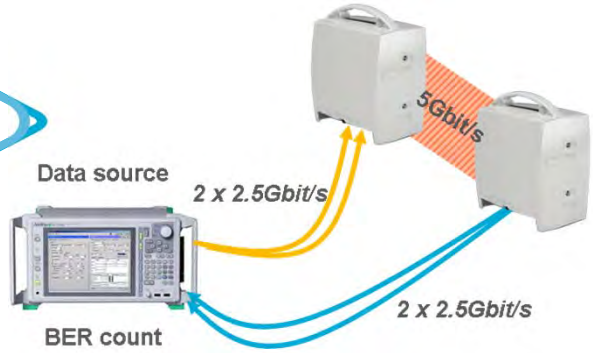
5GB E-band radio demonstrator

- Joint-research with MEL, Chalmers
- Demonstrator Technology
  - Link capacity: *5Gbit/s full-duplex*
  - Frequency: *71-76GHz & 81-86GHz (E-band)*
  - Modulation: *Differential-QPSK*
  - All-outdoor unit with dual-channel STM-16/OC-48 optical interface
- Future-proof microwave backhaul solution for LTE and beyond

Lab test-bench

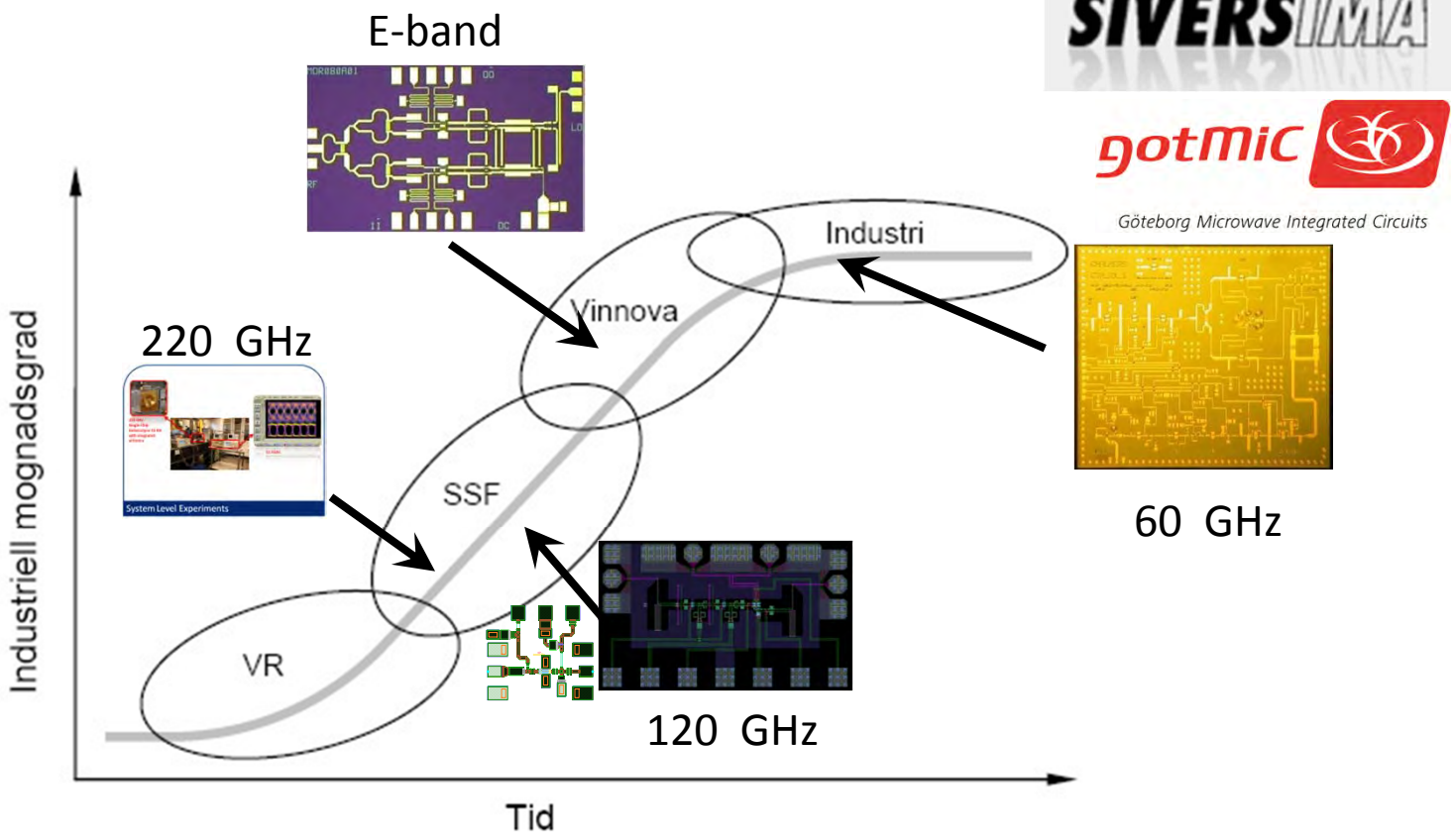


Public Demo at MWC2011 Mobile World Congress, Barcelona



Simon He, Jingjing Chen

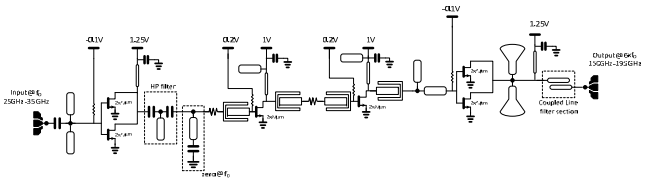
Mapping of our activities onto SSF's evolution plot

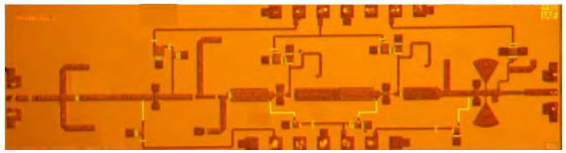


Figur 2. Illustration av svenska forskningsfinansiärers prioriteringsområden.

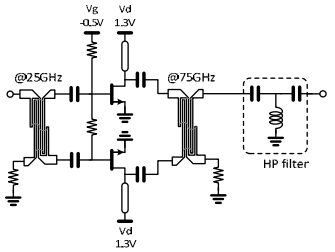
Summary

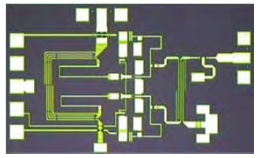
Circuit Design and Fabrication up to 340 GHz



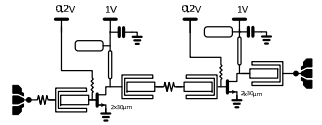


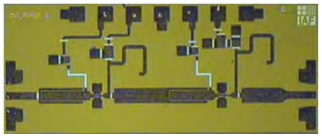
3.5 mm x 1 mm

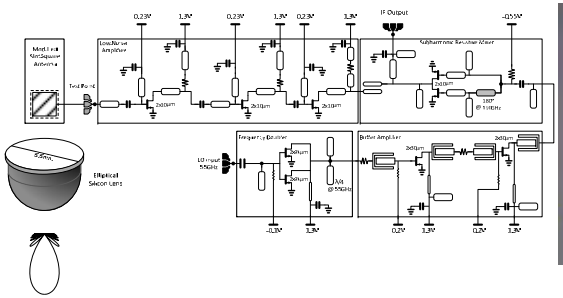


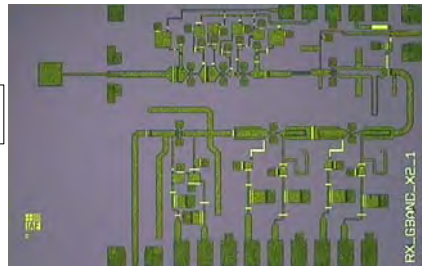


1.5 mm x 1 mm

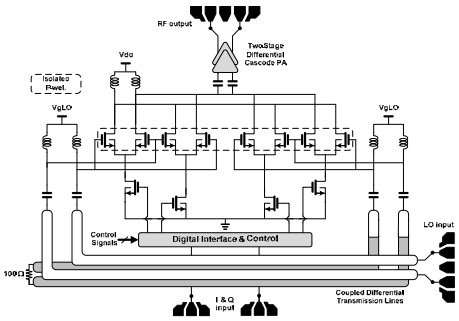


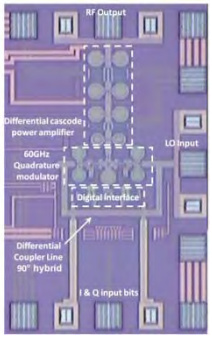




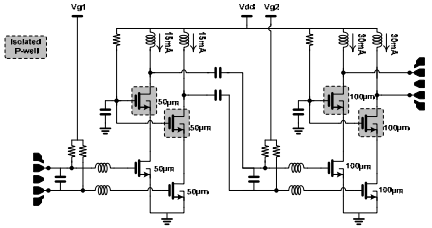


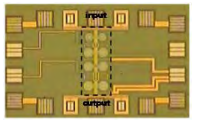
2.75 mm x 1.75 mm





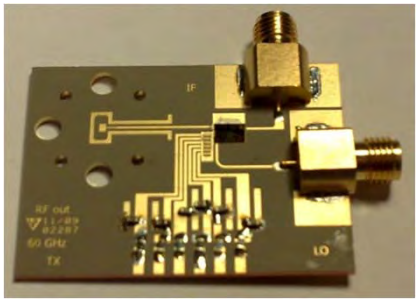
350µm x 650 µm

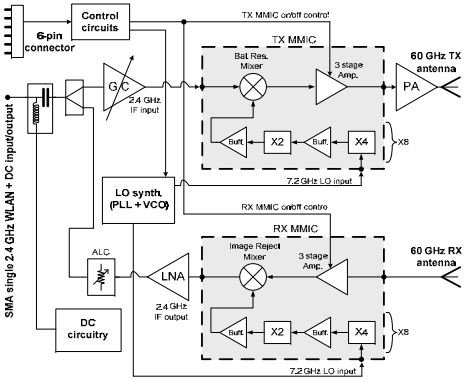




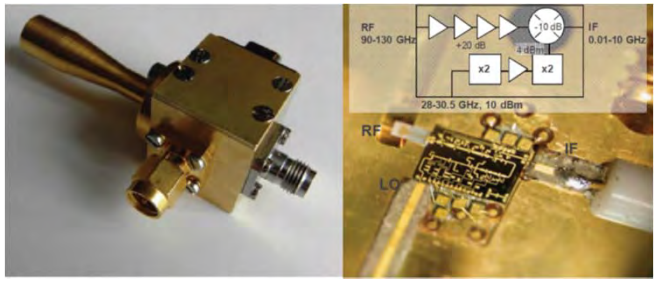
130µm x 300 µm

Packaging and Interfacing

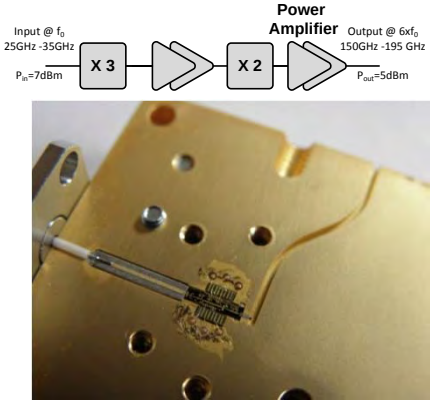




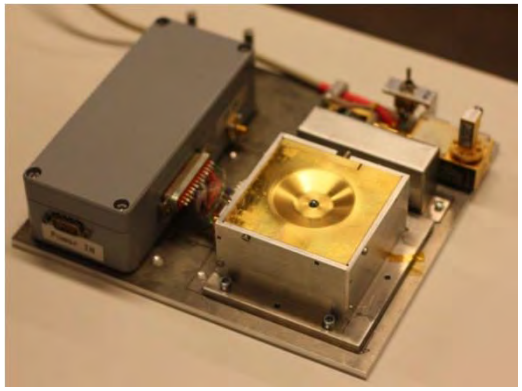
60GHz receiver / transmitter

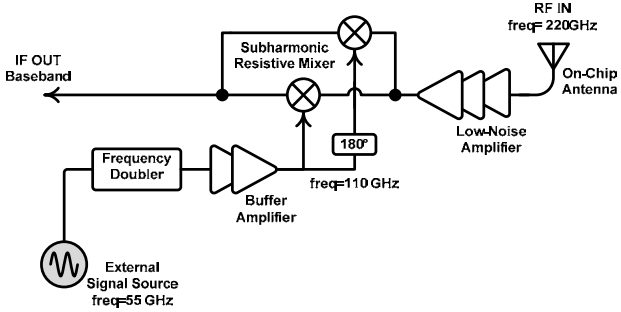


118GHz low-noise heterodyne receiver



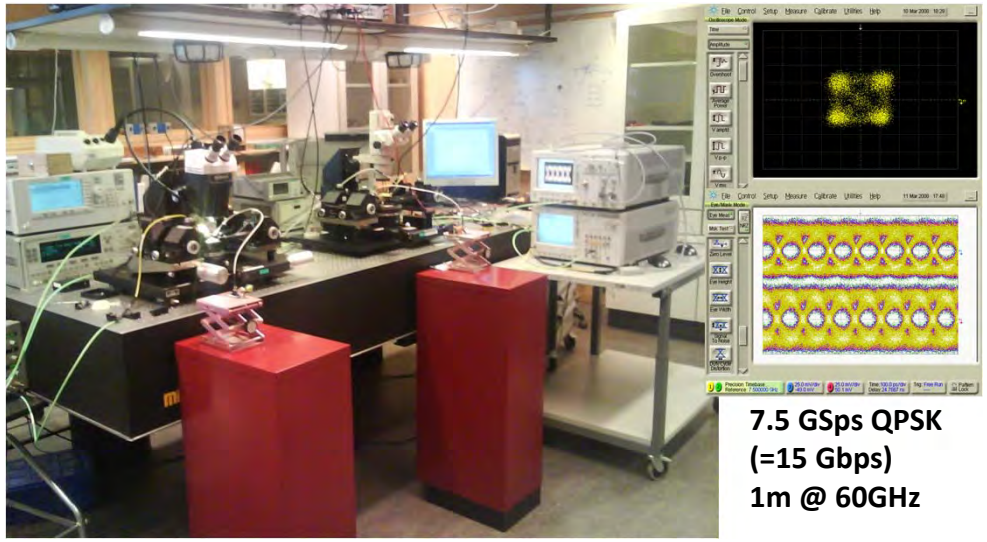
180GHz integrated signal source



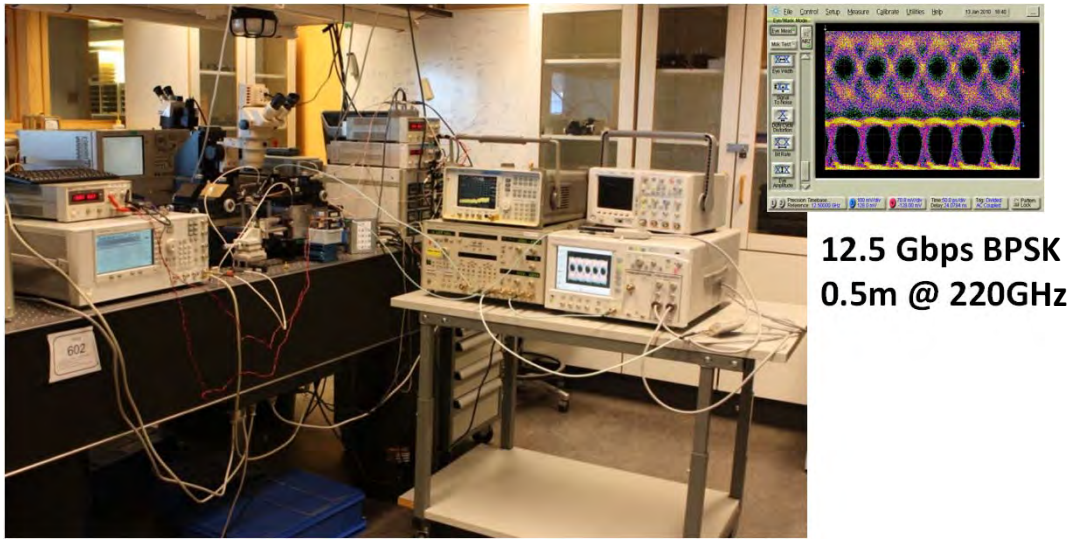


220GHz low-noise heterodyne receiver / transmitter with integrated antennas

System Level Measurements & Demonstrations



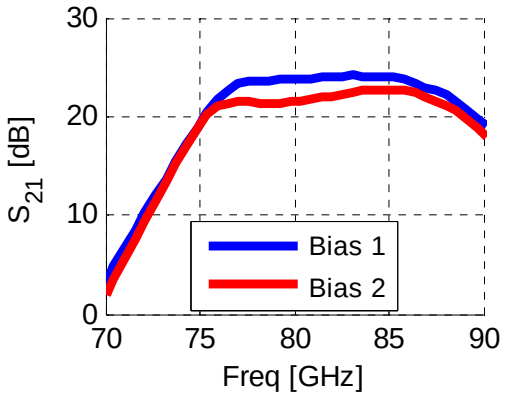
7.5 GSps QPSK
(=15 Gbps)
1m @ 60GHz



12.5 Gbps BPSK
0.5m @ 220GHz

Thank You for listening !

WIN 150nm mHEMT



E-band circuits

- Low Noise Amplifiers

NF=4.5 dB, Gain=23 dB,

- **IQ modulator (Accepted IMS 2010)**

Side-band suppression >= 20 dB, IIP3=20dBm

- **Image Reject Mixer (Presented CSICS 2009)**

Image-Rejection Ratio >= 20 dB

- Multipliers (x8)
- **Gotmic AB** (spin-off 2008) uses WIN for E-band circuits