Overview
Circuit Design Dept. & Projects

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Outline

• Overview Circuit Design (CD) Dept.

• SiGe BiCMOS IC Examples

• Projects

• Conclusion
• Advanced silicon technologies feature:
  \( f_T, f_{\text{max}} \) up to 200 to >300 GHz,
  \( \text{NF}_{\text{min}} \sim 0.5 \text{ dB} @1\text{GHz}, \)
  \( \text{NF}_{\text{min}} \sim 10 \text{ dB} @100\text{GHz} \)
  – Operating frequencies up to >100 GHz
  – Digital & RF integration
  – Simplified packaging
  – Low die cost

⇒ low-cost, reliable, high-frequency & broadband systems

**Research Focus of CD Dept.:**
High-frequency & broadband mixed-signal IC design in SiGe BiCMOS (CMOS)
Wireless Short Range Roadmap

Towards 100 Gbps in wireless communications

- Flash (NVM) scaling exponentially
- NVM is driver for mobile wireless short links
- Wireless short range data rates have to increase exponentially¹ (!)
- Technical solution for 100 Gbps needed by 2015

¹ Flash read/write time bottleneck has to be overcome
Fiber-optic communication system evolution

Towards 100 Gbps in fiber-optic communications

- Internet traffic drives fiber-optic data rates / data rates per $\lambda$
- Ethernet penetrating long-haul
- 100 GbE by 2012
- Retain legacy channel spacing while increasing data rates per $\lambda$
  => use spectrally efficient modulation schemes
- Novel systems with many similarities to wireless systems
Towards 100 Gbps Fiber-Optic & Wireless Comm.

OOK, QPSK, 16QAM, OFDM, other?

20 to 50 GHz 50 GSps Data Converters

BB Signal Processing: Equalization (Multi-Path/Dispersion), Error Correction

Power-reduction through analog or mixed-signal processing?

novel modulation schemes?
Towards 100 Gbps Fiber-Optic & Wireless Comm.

- TeraCom (250 GHz, Leibniz)
- Easy-A (60 GHz, BMBF)
- Benchmarking (>100 GHz, Intern)

100 Gbps

- 100 Gbps Wireless RF Frontends
- 100 Gbps fiber-optic communication Frontends

- Analog / mixed-signal processing GSps Data-Converters

- ECL-Projekt (intern)

- ViSiON (40G, BMBF)
- HiTRANS (40G, Ind.)

- 100 Gbps Datenentscheider (DFG)
- 100GET project (EUREKA / Celtic)

- HaLoS UKoLoS (DFG)
IHP Circuit Design Dept.

- 0.13 µm RFCMOS w. added features: HBT, RF MEMS, on-chip SAW, novel devices ??
  - high-Q passive filters
  - high-Q tanks
  - low standby current
  - integration of RF & digital
  ⇒ Ultra-low-power RF frontends using 130 nm RFCMOS and „More than Moore“

New Research Focus of CD:
Ultra-low-power RF frontends for wireless sensor networks
**CD Groups**

**Dept.-Head (Scheytt)**
- mm-Wave Wireless (Scheytt)
- Broadband Mixed-Signal (Gustat)
- Ultra-Low-Power Wireless (Fischer)

**RF Protolab (N.N.)

mmWave-RF Frontends & Synthesizer
~30 to 300 GHz

Ultra-Low-Power RF Frontends
("10 years lifetime from battery")

ultra-fast ADCs & DACs and logic,
100 Gbps fiber-optic communication ICs
CD Groups

### Cooperation inside IHP

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<td>High-Perf. WLANs, (1-100 Gbps)</td>
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<td>130 nm CMOS, MEMS, Integrated SAW</td>
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#### Projects

- **60 GHz 6 Gbps WLAN** (Easy-A, BMBF)
- **60 GHz 1 Gbps WLAN** in Home Network (Omega, EU FP7)
- THz communication (250 GHz / 100 Gb/s), (TeraCom, Leibniz Excellence)
- **10 & 19 GHz** fractional-N frequency-synthesizer PLLs (SISSI, 3020 ESA, DLR)
- Benchmarking Circuits (internal proj.)
- Multi-standard basestation synthesizer (MxMobile, BMBF)
- Unfortunately no radar project anymore

- **100 Gbps** carrier-grade Ethernet (100GET, EUREKA / BMBF)
- **30 GS/s** 8 bit DAC (internal)
- **12 GSps** 4 bit ADC, (UKoLos, DFG)
- **1 GSps** 12 bit DAC (BBDAC, ESA)
- ECL/CML library and Design Automation (internal, plus partners)
- **12 GS/s 8 bit ADC** (1.5 GHz ERBW) (internal)
- **9 GSps** Bandpass Delta-Sigma ADC (mobileGaN, BMBF)
- **40 Gbps** TIAs and Modulator Drivers (HiTrans, Industry & ViSiON, BMBF)
- **12 Gbps** Modulator Driver and Si Photonics Integration (BOOM, EU)

- **3 to 10 GHz Ultra-Wide-Band Frontend** (Pulsers, EU)
- Ultra-Low Power UWB Frontend (TANDEM, InnoProfile)
- Glukosensor (BMBF) concluded
- **5 GHz** WLAN Transceiver 802.11a/p (Homeplane, BMBF)
- GPS LNA, NF 1.4 dB, gain 17 dB (industry, terminated)
- Analog MIMO, (MiMAX, EU, started Jan. 2008)
- SAW-Funkmodule (BMBF) started Oct. 2008
RFIC and microwave IC design (currently 32 scientists)
- Technologies: SiGe Bipolar and BiCMOS (CMOS), LDMOS
- Applications: Wireless communication, radar, fiber-optic, data converters, ultra-fast logic
- Frequency range up to > 100 GHz
- Competence:
  - Frontends
  - Synthesizers
  - Broadband design / ultra-fast logic
  - ADC, DAC, mixed-signal

- Complex mixed-signal IC designs possible (collaboration w. system department)

- Close link to Semiconductor Technology
• Design environment
  – Cadence Virtuoso
  – Agilent ADS
  – Ansoft HFSS
  – (AWR microwave office, Catena)

• Comprehensive testing capabilities for wireless applications
  – S-Parameters (up to 110 GHz, soon 300 GHz)
  – Phase noise (up to 60 GHz)
  – Noise figure (up to 26 GHz)
  – Real-time oscilloscopes
  – Communication signal generators, analyzers
  – …
Assembly & Packaging Plans

RF ProtoLab

- Fast-prototyping in-house
  - Laser structuring (FR4, PTFE, Ceramics), 2-layer (LPKF S900), via processing etc.
  - flip-chip bumping, wire-bonding
  - packages (QFN, etc.), ceramic (Stratedge)
  - Bare die assembly: wire-bonding and flip-chip
  - Package assembly: using Rework-Station (Fine-placer)
  - EM-simulation & PCB design
  - Antenna-on-board integration schemes

- For more advanced packaging & assembly: cooperation w. external partners

- Co-design of IC and package is essential => find new solutions w. best of both worlds
SiGe BiCMOS Demonstrated IC Examples

mm-Wave/RF Components
- 200 GHz VCOs, Amp.'s
- 60...100 GHz wireless components
- 10...30 GHz Low-noise VCOs
- UWB LNA
- 0.9 dB NF LNA

Broadband Mixed-Signal
- 40 Gbps ICs
- 30 GSps DAC
- 30 Gbps ECL
- 16 GSps ADC
- 10 Gbps ECL

Frequency Synthesizers
- 56 GHz Synth.
- 48 GHz Synth.
- 19 GHz Synth.
- 10 GHz Synth.
- 0.7 – 4.4 GHz Synthesizer

mmWave/RF Frontends
- 120 GHz Radar
- 77 GHz Radar
- 60 GHz WLAN
- 24 GHz Radar
- IR-UWB
- 5 GHz WLAN

Integration-Level

High-Performance SiGe:C BiCMOS
Low-Cost SiGe:C BiCMOS
mm-Wave Wireless: 60 GHz

- **WIGWAM (BMBF, ended Q2 / 2007)**
  - 60 GHz 1 Gbps SiGe Wireless Frontend
  - Short range communication, Wireless PAN
  - Complete RF chip set plus FPGA baseband

- **Easy-A (BMBF, started Jan. 2008)**
  - 60 GHz 2…6 Gbps SiGe Wireless Frontend
  - Short range communication, WLAN/WPAN, IEEE 802.15.3c

- **Omega (EU FP7, started Jan. 2008)**
  - 60 GHz WPAN demonstrator
  - Gbps home networking
Projects

mm-Wave Wireless: 100 GHz and beyond

- **Benchmarking (internal)**
  - Communication building blocks up to 200 GHz
  - Feasibility of communication building blocks in SiGe technologies
  - Operating frequencies up to > $\frac{1}{2} f_T, f_{\text{max}}$

- **TeraCom (Leibniz excellence project, started Jan. 2008)**
  - Wireless frontend for THz communication 100 Gbps@250 GHz
  - Short range communication, WPAN, wireless data sync

115 GHz to 200 GHz VCO
94 to 180 GHz LNAs
Slow-wave transmission line
122 GHz RX Frontend
Projects

mm-Wave Radar

- **KOKON (BMBF, ended Q2 / 2007)**
  - 77...81 GHz VCO, PA, Radar RX Frontend in SiGe
  - Automotive Radar, Adaptive Cruise Control

- **24 GHz Radar (internal & industry, ended Q2 / 2007 transferred to spin-off)**
  - 24 GHz radar components, radar frontend
  - Automotive radar, ultra-low cost radar for security applications
Projects

Integrated Frequency Synthesizers

- **SiMS, 3020 (ESA), SiSSi (DLR)**
  - 10 GHz, 19 GHz DSM fractional-N synthesizer PLLs
  - Fully-integrated, radiation-hard
  - Broadband satellite communication

- **MxMobile (BMBF)**
  - Fully-integrated synthesizer in SiGe BiCMOS for 0.7 … 4.4 GHz
  - Multi-standard / multi-band basestations, software-defined radio (SDR)

- **Easy-A, WIGWAM (BMBF)**
  - Fully-integrated 56 GHz Synthesizer
  - Fully-integrated 48 GHz Synthesizer
  - 60 GHz WPAN
Projects

Broadband mixed-signal IC design: fiber-optics and fast logic

• 100GET (EU/BMBF, started Oct. 2007)
  – High-speed electronics for 100 Gbps fiber-optic coherent receiver
  – App.: 100 Gbps carrier-grade Ethernet

• 100 Gbps Datenentscheider (w. Uni Paderborn, DFG, started Oct. 2007)
  – 100 Gbps data regenerator with Decision Feedback Equalizer
  – App.: 100 Gbps fiber-optic communication, dispersion compensation

• ECL/CML BIB (internal funding & cooperation)
  – ECL/CML standard cell libs, VHDL design & automated logic synthesis,
    Synopsys support, ECL / CML / CMOS co-simulation
  – App.: Ultra-fast logic, broadband signal processing

• HiTrans (industry, started May 2008)
  – 40 Gbps Modulator Driver and TIA in SiGe BiCMOS
  – App.: 40 Gbps LAN applications

• BOOM (EU, started May 2008)
  – III-V- and SiGe ICs on optical SOI motherboard
  – App.: Terabit Internet router
Projects

Broadband mixed-signal IC design: Data Converters

- **HaLoS, UKoLoS (DFG)**
  - ADC 4 bit, BW 5 to 15 GHz, 12 to 28 GSps
  - UWB radar, fiber-optic communications

- **Ultra-fast DAC**
  - 30 GS/s 4 bit and 8 bit DAC
  - Software-defined radio, measurement equipment, fiber-optic communications

- **HMOS, mobile-GaN (BMBF)**
  - 2 - 2.2 GHz, 9 GSps Delta-sigma modulator for class-S PA
  - Modulator and driver for switched mode PA
  - High-efficient PAs for mobile basestations
Low-Power Wireless Frontends

- **Pulsers II (EU FP6)**
  - 3 to 10 GHz Impulse Ultra-Wide-Band Frontend with localization
  - Sensor networks, localization
  - Complete frontend realized

- **Homeplane (BMBF)**
  - 5 GHz WLAN Transceiver 802.11a/p
  - WLAN, car-2-car communication

- **GPS LNA (industry)**
  - Low-cost, low-noise GPS LNA
  - GPS in cell phones

- **MiMAX (EU FP7, started Jan. 2008)**
  - MIMO Frontend with analog combining
  - High-performance low-power WLAN
Conclusions

• Overview Circuit Design (CD) Dept. & Projects

• SiGe BiCMOS IC Examples
  – focused on high-frequency / broadband in silicon
  – New focus: ultra-low power RF frontends
  – demonstrate IHP‘s vertical competence from systems down to materials

• Thank you!