Broadband Wireless Communication
The world is going wireless!

- Wireless LANs experience a growing success in enterprises.
- Wireless home gateways are the missing piece in fast internet and video access.
- Wireless personal networks will open new service opportunities.
Wireless Requirements

- Cost < 10$
- Power consumption < 100 mW
- Network capacity > 100 Mbps
- Range > 50 m

⇒ IMEC’s Mission: “To enable low cost and low power integrated solutions for the next generation broadband communication networks”
Long term strategy executed in a phased approach

- **phase 1**: enterprise WLAN
- **phase 2**: home gateway with extended range and capacity
- **phase 3**: high datarate terminals

**OFDM**

- Turbo coding
- SDMA
- QoS MAC
- 5 GHz FE SIP

**MIMO**

- personal area network
- Scalability
- SIP
OFDM Modem Architecture

Mapper → IFFT → Symbol reorder

CFO Comp → Time Sync & Gain Comp

Demapper → Equalizer
Improved equalizer for better performance with QAM

QAM64 BER performance

- Improved equalizer
- Standard equalizer
Second generation OFDM Modem

- 0.18m CMOS 5LM
- 20MHz
- 160 PQFP
- 431 kgates
- 19 RAMs
- 20.8mm2
- Ptx = 199mW
- Prx = 212mW
Wireless set-up at 5.2 GHz
Long term strategy executed in a phased approach

- **Enterprise WLAN**
  - OFDM
  - phase 1

- **Home gateway with extended range and capacity**
  - Turbo coding
  - SDMA
  - QoS MAC
  - 5 GHz FE SIP
  - phase 2

- **High datarate terminals**
  - MIMO
  - Scalability
  - SIP
  - personal area network
  - phase 3
IMEC’s solution: WLAN-in-a-package

- BiCMOS RF ASIC

- Mixed-signal CMOS ASIC(s):
  - OFDM modem, memory,
  - microprocessor, peripherals,
  - FPGA

- MCM-D interconnect technology
  - glass substrate
  - Cu interconnections
System model includes 4 most important front-end impairments
PA can be operated with only 15 dB back-off (IIP3 - Pin)
Phase noise must be $K < -32 \text{dBc}$ for a Lorentzian model.
Demonstrator: Single-package 5 GHz receiver RF module

5 GHz WLAN

Two 5 GHz MCM Bandpass Filters

LNA with bare die pHEMT transistor (EC2612)

GaAs (pHEMT) bare die downconversion mixer (TGC1411)
Single-package 5 GHz receiver
RF module

Mixer:
conv. gain: 15 dB
power: 25 mA @ 3V

BPF-LNA-BPF-mixer:
gain: 22.4 dB
NF: 7.8 dB
P-1dB: -25 dBm (input)
size: 6.5 x 7 mm²
Co-Design of ASIC and MCM allows optimal trade-offs

Chip-package co-design trade-offs in VCO design

MCM-D technology

0.35 μm BiCMOS
24 GHz ft
3.3 Volt supply
Better VCO performance with high-Q MCM passives

3 versions with constant output power

<table>
<thead>
<tr>
<th>Inductors</th>
<th>Varactors</th>
<th>Phase Noise (dBc/Hz @ 100 kHz)</th>
<th>Power (mW)</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>on-chip Q=5.5</td>
<td>on-chip Q=17</td>
<td>-86</td>
<td>17.8</td>
<td>167</td>
</tr>
<tr>
<td>MCM Q=50</td>
<td>on-chip Q=17</td>
<td>-90</td>
<td>9.5</td>
<td>173.7</td>
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<tr>
<td>MCM Q=50</td>
<td>off-chip Q=40</td>
<td>-92</td>
<td>7.9</td>
<td>176.5</td>
</tr>
</tbody>
</table>

(simulated results)

\[
S_\Phi \propto \frac{1}{Q^2} \left( \frac{f_{osc}}{f_m} \right)^2 \cdot \frac{2kT \cdot F}{P_S}
\]

\[
FOM = 10 \log \left[ \left( \frac{f_0}{\Delta f} \right)^2 \frac{1}{L(\Delta f)P_{dc}} \right]
\]
4.7 GHz VCO with MCM-D inductors
Complete RF Transceiver in a single package

Size:
16 x 16 mm²
Next step: from antenna to DC in a single package

- Direct downconversion
- Polar upconversion
- power amp in the package
- eventually, antenna in the package
Transmitter architecture exploration

Polar upconversion

- Amplitude (envelope) signal
- Modulated phase signal
- Phase feedback

Blocks:
- Fractional-N Synthesizer
- VCO
- Digital divider
- Switching power supply
- PA

Outputs:
- Radiating wire
Single-package implementation and demonstration

Optimization of power amplifier chain
Long term strategy executed in a phased approach

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  - personal area network
  - Scalability
  - SIP

- **Technologies:**
  - OFDM
  - Turbo coding
  - SDMA
  - QoS MAC
  - 5 GHz FE SIP
  - SIP
Turbo Decoding Scheme

- Iterative decoding: $D_1 \rightarrow D_2 \rightarrow D_1 \rightarrow D_2 \rightarrow ...$
- A decoder module ($D$) for each encoder ($C$)
- Increasingly good solution:
  closer to maximum likelihood decoding
Turbo coding significantly improves performance

BER

\[ \frac{E_b}{N_0} \text{ (dB)} \]

OFDM
QPSK carrier modulation
ETSI Channel A

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Systematic memory optimizations reduce power consumption

- **Systematic optimization improves:**
  - power
  - decoding delay
  - data rate

- **At the cost of area**

*3.9  /20.9  /568  *323
Spatial Division Multiple Access (SDMA)

- Improves bandwidth efficiency. System capacity increases with number of antennas
- By exploiting spatial diversity
- Antenna array processing at basestation for Tx and Rx
- OFDM reduces the complexity of baseband SDMA processing
OFDM / SDMA Architecture with Per-carrier Processing

SDMA

OFDM modem

RF Front End

SDMA

OFDM modem

RF Front End

SDMA

OFDM modem

RF Front End

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OFDM/SDMA Multiplies Network Capacity

- 1 user @ 25 Mbps
- 4 users @ 25 Mbps
- Same bandwidth!
- Better performances!

U = 1
A = 1

U = 4
A = 4

5 dB

BER

EbNo
Multimedia home gateway requires a QoS MAC

- 155 Mb/s WLAN 5 GHz
- Reconfigurable appliances
- Broadband satellite access
- MPEG 4
  - >100 Gop/s
  - 5 Gtr/s
  - 10 Watt

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Wireless Personal Network enables new applications
Multiple Antennas: Scalability of Link Capacity

Total Transmitted power is the same

Link Capacity x n
SC-CP offers OFDM performance with low PAPR
Scalability with Hybrid OFDM

Small and Low cost

Rich and fancy
Capacity search: link adaptation to avoid fading margin

- Capacity
- Throughput
- SNR
- Bits/s/Hz
- 20 dB
Substrate noise coupling is a problem for integrated radio’s.
Substrate noise spectral peaks 40 dB larger than noise floor
Applying the analysis to the WLAN OFDM baseband chip

- Mixed-signal IC in 0.35 um digital CMOS
- Embedded 8-bit ADC
- Digital up/down-converter and complex filter
- WLAN modem
- Noise sensors
Our Goals

▷ Mid term goals:
  • demonstrate a high performance wireless home gateway: turbo coding, SDMA, QoS MAC.
  • Demonstrate an integrated 5GHz front-end.

▷ Long term goals:
  • single-package radio for personal area networks.
  • High datarate multi-antenna terminals.