Indoor and Outdoor Millimeter Wave Systems and RF/BB SoCs

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Outline

• Tokyo Tech mm-wave project
• 60GHz indoor mm-wave system
• 38GHz outdoor mm-wave system
• Summary
Mm-wave project

Developing mm-wave systems and SoCs to address the future wireless big bang.

FY2007-FY2011

1. 60GHz, Indoor
   3-10 Gbps
   -- 10m

2. 38GHz, Outdoor
   0.6-1.0 Gbps
   1km – 4km
Project members and roles

Three labs. in Tokyo Tech. and five companies

Outdoor entrance systems (JRC)

Indoor wireless access system (Sony)

Mm-wave CMOS Rx/Tx chip and base band ADC/DAC. (Matsuzawa & Okada lab.)

GaN HPA (NEC)

Phase noise reduction by DSP (Suzuki lab. Tokyo Tech.)

Packaging, MMIC, RF-module (AMSYS)

High Gain Arrays (Ando Hirokawa lab.)

Antennas on PCB / Chip (Ando Hirokawa lab)

Propagation Test (Willcom)

The leader is Prof. M. Ando
60GHz indoor mm-wave system
Indoor system: Usage model

Giga bit ultra-fast data transfer systems
Low power and small size are important

Kiosk download  Peer-to-peer
System block diagram

Matsuzawa and Okada lab. developing

RF Front-end IC (65nm CMOS) Baseband IC (40nm CMOS)

- LNA
- 60GHz ILO
- 20GHz PLL
- 36MHz TCXO
- 3456MHz PLL
- DAC
- LPF
- Buffer
- VGA
- ADC
- Reg. bank addr/data
- DAC

By Sony
Equipment image

Two chips solution on one PCB with antenna

Low cost system

Gain: 5.6 dBi
60GHz CMOS transceiver chip

A direct conversion method is employed to reduce power and complexity.

Two 60GHz QILOs with 20GHz PLL
Die Photo

65nm CMOS
Rx: 3.8mm²
Tx: 3.5mm²
PLL: 1.2mm²

20GHz PLL

Die Photo 4.2mm

65nm CMOS
Rx: 3.8mm²
Tx: 3.5mm²
PLL: 1.2mm²

20GHz PLL
Communication test setup

Low gain antenna in package is used for the test

60GHz Rx
2dBi antenna

60GHz Tx
2dBi antenna

I/Q output (Rx)

20GHz PLL

I/Q input (Tx)
## Basic performance

Low power, low phase noise, and low NF

<table>
<thead>
<tr>
<th>Tx</th>
<th></th>
<th>Rx</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>18.3dB</td>
<td>CG</td>
<td>17.3dB (high-gain mode)</td>
</tr>
<tr>
<td>P1dB</td>
<td>9.5dBm</td>
<td>4.7dB (low-gain mode)</td>
<td></td>
</tr>
<tr>
<td>Psat</td>
<td>10.9dBm</td>
<td>NF</td>
<td>&lt;6.8dB (high-gain mode)</td>
</tr>
<tr>
<td>PAE</td>
<td>8.8% (only for PA)</td>
<td>IIP3</td>
<td>-5dBm (only for LNA)</td>
</tr>
<tr>
<td>PDC</td>
<td>186mW</td>
<td>PDC</td>
<td>106mW</td>
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</tbody>
</table>

### PLL

<table>
<thead>
<tr>
<th>Frequency</th>
<th>17.9-21.2GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Noise through Tx @60.48GHz</td>
<td>-94.2dBc/Hz @1MHz-offset</td>
</tr>
<tr>
<td>Ref. spur</td>
<td>&lt; -58dBc</td>
</tr>
<tr>
<td>Pout</td>
<td>-2dBm</td>
</tr>
<tr>
<td>PDC</td>
<td>66mW</td>
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</tbody>
</table>

The total Pd of system involving base band chip is about 500mW
Modulation Characteristics

Realizes every modulations for IEEE 802.15.3c.

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Modulation</th>
<th>Data rate 2.16GHz-BW</th>
<th>EVM</th>
<th>Distance (BER &lt; $10^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BPSK</td>
<td>1.76Gb/s</td>
<td>-18dB (-24dB with DFE)</td>
<td>0.5–274cm</td>
</tr>
<tr>
<td></td>
<td>QPSK</td>
<td>3.52Gb/s</td>
<td>-18dB (-28dB with DFE)</td>
<td>0.5–270cm</td>
</tr>
<tr>
<td></td>
<td>8PSK</td>
<td>5.28Gb/s</td>
<td>-17dB</td>
<td>0.5–20cm</td>
</tr>
<tr>
<td></td>
<td>16QAM</td>
<td>7.04Gb/s</td>
<td>-17dB</td>
<td>0.5–17cm</td>
</tr>
</tbody>
</table>

8Gb/s (QPSK) and 11Gb/s (16QAM) @ wider-BW
Progress of data rate in 60GHz

The transceiver attained over 10Gbps
Key technology: Quadrature ILO

Quadrature injection locked 60GHz oscillator with 20GHz PLL
Low phase noise of -96dBc/Hz @1MHz.
60GHz Quadrature PLL

Best phase noise is achieved.

58-63GHz, -96dBc/Hz-1MHz offset
38GHz outdoor mm-wave system
Role of outdoor mm-wave

**Current**
- Optical fiber
- Base stations for WiFi and WiMAX
- Not flexible

**Future**
- Optical fiber
- Connect with mm-wave
- Very flexible
38GHz outdoor mm-wave system

Already realized 1Gbps outdoor mm-wave systems
System configuration

Compatible with Gbit Ethernet
Hole system is integrated with planar antenna
A mixed signal SoC has been developed to realize 64QAM (1Gbps) with BW of 260MHz.

Base band SoC

90nm CMOS
40M Transistors
Developed new 10b ADC to address 64 QAM.

10b, 320 MSps, 40mW ADC

New ADC architecture

No interleaving
No double sampling
No OpAmp
No calibration
38GHz High gain planar antenna

Developed high: gain and isolation planer antenna

Gain: 34.58dBi@38.75GHz
Efficiency: 84.9%
Tx/Rx Isolation: 75 dB
BER vs. SNR

BER for 64QAM has been reduced to the ideal

C/N vs 64QAM_BER on B-B pair

- Measurement
- ENOB=6.0 (600Mbps version)
- ENOB=6.25
- ENOB=6.5 (1Gbps version 2009)
- ENOB=6.75
- ENOB=7.0
- ENOB=7.4
- ENOB=7.15 (1Gbps version 2010)
- ENOB=7.45 (ADC design target)

2008

2009

2010
Tokyo Tech. Model Network

Ten mm-wave base stations in our campus

Tokyo Tech. O-Okayama Campus
Expand the area to NEC (4km)

Challenge for 4km mm-wave communication
Model network in Tokyo

Outdoor mm-networks can cover the Tokyo metropolitan area
Weather variation and availability

Watch weather and mm-wave network condition

![Graph showing RX level variations over time with different weather conditions: Fine, Snow, and Rain. The graphs display RX level (dBm) against date and time, with different paths indicated by different colors.]
Future UHS network with mm-wave

Mm-wave will realize real high speed networks collaborating with optical and wireless technology
Summary

- Tokyo Tech now developing 60GHz indoor and 38GHz outdoor systems, CMOS RF and ADC/DAC for BB chips

- 60GHz CMOS direct conversion transceiver chip attained 11Gbps data rate

- 38GHz 1Gbps outdoor mm-wave system attained 1Gbps data rate with bandwidth of 260MHz for 4km distance communication
Acknowledgement

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Backup slides for questions