Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Millimeter-wave CMOS RFIC]
Date Submitted: [15 November, 2006]
Source: [Tian-Wei Huang]
Company [Department of Electrical Engineering, National Taiwan University]
Address [No.1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan, R.O.C. ]
Voice:[+886 2 2363 5251x342], FAX: [+886 2 3366 5084], E-Mail:[twhuang@cc.ee.ntu.edu.tw]
Re: []

Abstract: [Description of the current status of CMOS RFIC development]
Purpose: [Contribution to TG3c at November 2006 meeting.]
Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.
Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
Millimeter-wave CMOS RFIC

Tian-Wei Huang

National Taiwan University

November 15, 2006
Agenda

• Gbps CMOS Modulator/Transmitter

• CMOS Low-Noise Amplifier

• CMOS Active Mixer and VCO

• SiGe 60-GHz Transmitter with Integrated Antenna
A 60-GHz 2.5-Gbps CMOS BPSK Modulator

- Modified reflection-type
- 0.13 μm CMOS technology
- Chip size: 0.5 × 0.35 mm²

- Frequency: 15-75 GHz
- Phase Imbalance < 3°
- Amplitude Imbalance < 0.5 dB
- Modulation bandwidth > 1 GHz

Hong-Yeh Chang, Pei-Si Wu, Tian-Wei Huang, Huei Wang, Yung-Chih Tsai, and Chun-Hung Chen “An ultra compact and broadband 15-75 GHz BPSK modulator using 0.13-μm CMOS process,” 2005 IEEE MTT-S IMS Digest, Long Beach, CA, June 2005.
CMOS MMW IQ Modulator

- TSMC 0.13-μm CMOS Process
- Chip Size: 0.65 × 0.58 mm²
- Modified Reflection-type Modulator
- Frequency: 20-40 GHz
- Sideband Suppression > 20 dB
- LO Suppression > 30 dB
- Spurs Suppression > 30 dB
- $P_{1dB} > -5$ dBm
- Conversion Loss < 13 dB
- Modulation bandwidth > 1 GHz

Measured output spectrum of the IQ modulator
Conversion loss and LO suppression
A 0.13-μm mmW CMOS Transmitter

- Technology: 0.13 μm CMOS technology
- Chip size: 0.85 x 0.6 mm²
- Frequency: 44.8-45.8 GHz,
- Phase Imbalance < 1.8°,
- Amplitude Imbalance < 0.7 dB
- DC power consumption: 40mW

Hong-Yeh Chang, Tian-Wei Huang and Huei Wang, “A 45-GHz quadrature voltage controlled oscillator with a reflection-type IQ modulator in 0.13-μm CMOS technology,” 2006 IEEE MTT-S International Microwave Symposium Digest, San Francisco, CA, June 2006.
V-band 3-Stage Cascode LNA (0.13μm CMOS)

- Gain > 20 dB from 51 to 57.5 GHz
- NF < 8 dB from 50 to 57 GHz
- Input P_{1dB} : -22 dBm
- IIP3 : -12 dBm at 56 GHz

Q-band 3-Stage LNA (0.13μm CMOS)

- Gain > 17 dB from 34 to 44 GHz
- NF < 7 dB from 40 to 42 GHz
- OP_{1dB} : +4 dBm (Psat: +7 dBm)
- OIP3 : +14.5 dBm
- Power dissipation: 24 mA at +1.5 V

Q-band 3-Stage LNA (Noise Figure)
Q-band 3-Stage LNA (AM-AM & IP3)
**Q-band CMOS LNA (Comparison)**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>This work</th>
<th>[5]</th>
<th>[3]</th>
<th>[4]</th>
<th>[2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>0.13µm CMOS</td>
<td>0.13µm CMOS</td>
<td>0.18µm CMOS</td>
<td>90nm CMOS</td>
<td>90nm SOI</td>
</tr>
<tr>
<td>Circuit Topology</td>
<td>3-stage common source</td>
<td>3-stage cascode</td>
<td>3-stage cascode</td>
<td>2-stage common source</td>
<td>1-stage cascode</td>
</tr>
<tr>
<td>3-dB BW (GHz)</td>
<td>10 (34-44)</td>
<td>10 (34-44)</td>
<td>5 (37-42)</td>
<td>14 (32-46)</td>
<td>16 (26-42)</td>
</tr>
<tr>
<td>Peak Gain (dB)</td>
<td>20 @43GHz</td>
<td>19 @40GHz</td>
<td>7 @40GHz</td>
<td>7.3 @35GHz</td>
<td>11.9 @35GHz</td>
</tr>
<tr>
<td>Chip Area (mm²)</td>
<td>0.525</td>
<td>1.43</td>
<td>2.04</td>
<td>N/A</td>
<td>0.18</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>24mA @1.5V</td>
<td>24mA @1.5V</td>
<td>100mA @3V</td>
<td>7mA @1.5V</td>
<td>17mA @2.4V</td>
</tr>
<tr>
<td>NF (dB)</td>
<td>6.3 @41GHz</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3.6 @35GHz</td>
</tr>
<tr>
<td>OP1dB (dBm)</td>
<td>4</td>
<td>-0.9</td>
<td>5</td>
<td>-5.75</td>
<td>4</td>
</tr>
<tr>
<td>OIP3 (dBm)</td>
<td>14.5</td>
<td>11.6</td>
<td>N/A</td>
<td>7</td>
<td>N/A</td>
</tr>
</tbody>
</table>
0.3-25 GHz CMOS Gilbert-Cell Mixer

- 0.18-μm CMOS
- Gilbert-cell mixer with LC ladder matching network
- Conversion Gain: +11 dB from 0.3-25 GHz
- Isolation between LO and RF: > 20 dB
- LO power: -1 dBm
- IF: 10 MHz

0.8 mm x 1.0 mm

Ming-Da Tsai and Huei Wang, “A 0.3-25-GHz ultra-wideband mixer using commercial 0.18-μm CMOS technology,” *IEEE Microwave and Wireless Component Letters*, vol. 14, no. 11, pp. 522-524, Nov. 2004.
63 GHz CMOS VCO

- 0.25-μm bulk CMOS
- Push-push design using cross-couple pair
- 63 GHz output extracted through 50 ohm CPW and blocking capacitor
- \( V_{dd} \) fed through \( \lambda/4 \) line
- Chip size: 0.45 x 0.7 mm²
- -85 dBc/Hz @ 1 MHz offset
- Output frequency from 62 to 64.5 GHz
- Better than 25 dB rejection
- -4 dBm max. output power

114-GHz CMOS VCO

- Implemented in TSMC 0.13-μm CMOS
- Push-Push topology
- First CMOS VCO above 100 GHz

131-GHz VCO Using 90-nm CMOS

- 90-nm bulk CMOS technology
- Cross-coupled topology
- Coplanar waveguide (CPW) & asymmetric coplanar slot (ACPS)
- 0.55 x 0.65 mm²
- 1.2 V / 27.6 mW (core)
- Output power: -11.4 dBm
- Phase noise: -108.4 dBC/Hz @ 10 MHz offset (estimated)
- Tuning range: 2.2 GHz

60-GHz Transmitter with Integrated Antenna

- Technology: 0.18- \( \mu \)m SiGe BiCMOS process
- Chip size: 1.3 x 0.8 mm\(^2\)
- Conversion gain: 20.2 dB
- Output power: 15.8 dBm
- DC power consumption: 281 mW

Antenna Design

With antenna director

- E field mostly confined at surface
- Antenna gain increased: -10 dBi → 0 dBi (simulated)
- Results in narrow bandwidth

Without antenna director
60GHz Transmitter Module

- Antenna director fabricated using Duroid 5880
- Director placed at ~ half wavelength (at 60 GHz) away from taper-slot antenna
Transmitted IF signal generated using Agilent E4438C
Receiver consists of
- Standard horn antenna with 24dB gain
- Agilent 8565EC spectrum analyzer
- Agilent 11974V pre-selection harmonic mixer
Radiation Pattern

- Antenna gain improved by off-chip director
- Taper-slot antenna gain ~ -2 dBi with director
  ~ -15 dBi without director
- SSB isotropic conversion gain ~ 20.2 dB
Summary

- The mmW CMOS modulator/LNA/mixer/VCO are presented.

- A mmW CMOS broadband/compact (low-cost) direct-conversion digital transmitter is demonstrated. The 60-GHz CMOS transceiver is under development.

- A 60-GHz SiGe HBT transmitter with integrated antenna is measured with gain enhancement techniques.
Thank you!