Submission Title: A Japanese Activity on 300-GHz CMOS Transmitters

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Source: Iwao Hosako, contributors of the research are listed in “Contributors” slide

Company: NICT, Hiroshima University

Address 4-2-1, Nukuikita, Koganei, 184-8795, Tokyo, Japan

Voice: +81 42 327 6824, FAX: +81 42 327 6669, E-Mail: kasa@nict.go.jp

Re: []

Abstract: A 300GHz CMOS transmitters (TXs) in 40nm CMOS is presented. With the fmax being below 300GHz, it adopts a new PA-less QAM-capable architecture employing the “cubic mixer” and “square mixer”. The output powers of 300GHz CMOS TXs by cubic-mixer- and square-mixer-last architectures are −14.5 and −5.5 dBm, and the data rates of them demonstrate 17.5Gb/s/ch 16QAM transmission over 6 channels and 105Gb/s 32QAM transmission over a single channel, respectively.

Purpose: []

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Introduction

• Purpose of this talk is to introduce a Japanese activity on 300-GHz silicon CMOS transmitters and their wireless demonstrations.
• The introduced work was performed by contributors listed in the next slide and financially supported by the Ministry of Internal Affairs and Communications of Japan.
List of Contributors

- Kyoya Takano (Hiroshima University)
- Kosuke Katayama (Hiroshima University)
- Ruibing Dong (Hiroshima University)
- Shuhei Amakawa (Hiroshima University)
- Takeshi Yoshida (Hiroshima University)
- Minoru Fujishima (Hiroshima University)
- Shinsuke Hara (NICT)
- Akifumi Kasamatsu (NICT)
Outline

• Background of 300GHz wireless communication

• 300GHz CMOS TXs
  • 300GHz CMOS TX by cubic-mixer-last architecture
  • 300GHz CMOS TX by square-mixer-last architecture
    [2] K. Takano et al., ISSCC2017

• Performance comparison

• Wireless demonstration of the 300GHz CMOS TXs

• Conclusion
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• Conclusion
Atmospheric window and frequency allocation above 175 GHz

- Vast unallocated frequency band lying above 275 GHz

Atmospheric window

Allocated

Unallocated

Atmospheric loss (dB/km)

Frequency [GHz]

183  200  250  275  300  325

NICT Amaterasu:
https://smiles-p6.nict.go.jp/thz/jp/decay.html,

Possible applications of 300GHz wireless communication

- Enormous potential for THz wireless communication

Ultrahigh-speed wireless communications

THz communication with super computer in outer space

THz communication with cold storage center on outer space

M. Fujishima, Keysight world 2016 Tokyo (14 June, 2016)
300GHz CMOS transmitters (TXs)

☑ QAM-capable 300GHz CMOS TX with 17.5Gb/s/ch [1]
☑ 300GHz CMOS TX over 100Gb/s [2]

in 40nm CMOS (f_{max}: ~280GHz)


300GHz CMOS transmitters (TXs)

- QAM-capable 300GHz CMOS TX with 17.5Gb/s/ch [1]
- 300GHz CMOS TX over 100Gb/s [2]

In 40nm CMOS (\(f_{\text{max}}\): ~280GHz)

Ref. [1]

Ref. [2]
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• Conclusion
THz transmitters (TXs): State of the art

- TXs architecture depends on transistor $f_{\text{max}}$

**THz TX Architecture**

<table>
<thead>
<tr>
<th>PA-last</th>
<th>Multiplier -last</th>
<th>Mixer-last</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{\text{MAX}} &gt; RF$</td>
<td>$f_{\text{MAX}} &lt; RF$</td>
<td>$f_{\text{MAX}} &lt; RF$</td>
</tr>
<tr>
<td>III-V</td>
<td>CMOS</td>
<td>CMOS</td>
</tr>
</tbody>
</table>

$\Rightarrow$ III-V

**$f_{\text{max}}$: Unity-power-gain frequency**

**Spectrum**

- QPSK
- 16QAM

**Case of “$x 3$”**

- Low power
- QAM-incapable

**Complicated layout**

- Low power
- QAM-capable

- High power
- QAM-capable

THz transmitters (TXs): State of the art

- Technical challenges
  - 300GHz PA-less TX in CMOS operating beyond $f_{\text{max}}$,
  - QAM-capability for high data-rates
  - Without undue layout complication

- THz TX Architecture

- Multiplier-last
  - $f_{\text{MAX}} < RF$ → CMOS

- Mixer-last
  - $f_{\text{MAX}} < RF$ → CMOS

- Low power
  - QAM-incapable
  - Complicated layout

- Case of “x 3”

Design

- Cubic-mixer-last architecture (ISSCC2016)

- Cubic mixer is essentially a **tripler**
- It receives superposition of IF$_2$ (modulated) and LO (pure)

Power spectra and signal constellations

32QAM

RF power (dBm/MHz)

CH1 CH2 CH3 CH4 CH5 CH6

270 280 290 300 310

275 305GHz

30GHz

305GHz

32QAM 3.5Gbaud → 17.5Gb/s/ch (× 6)

Power spectra and signal constellations

### 32QAM

<table>
<thead>
<tr>
<th>Channel</th>
<th>CH1</th>
<th>CH2</th>
<th>CH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constellation (Equalized)</td>
<td>![Constellation]</td>
<td>![Constellation]</td>
<td>![Constellation]</td>
</tr>
<tr>
<td>EVM</td>
<td>8.9%rms</td>
<td>4.8%rms</td>
<td>7.0%rms</td>
</tr>
<tr>
<td>Data-rate</td>
<td>17.5Gb/s</td>
<td>17.5Gb/s</td>
<td>17.5Gb/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel</th>
<th>CH4</th>
<th>CH5</th>
<th>CH6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constellation (Equalized)</td>
<td>![Constellation]</td>
<td>![Constellation]</td>
<td>![Constellation]</td>
</tr>
<tr>
<td>EVM</td>
<td>7.1%rms</td>
<td>6.4%rms</td>
<td>5.9%rms</td>
</tr>
<tr>
<td>Data rate</td>
<td>17.5Gb/s</td>
<td>17.5Gb/s</td>
<td>17.5Gb/s</td>
</tr>
</tbody>
</table>

- Aggregate data-rate reaches 105Gb/s

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Design

- Square mixer + quasi-SSB mixer (ISSCC2017)

- Square mixer is essentially a **doubler**
- Quasi-SSB mixer includes filters for image suppression

Power spectra and signal constellations

32QAM

Power (dBm)

-40
-50
-60
-70

-40
-50
-60
-70

265 275 285 295 305 315

Frequency (GHz)

Power spectra and signal constellations

128QAM

Power (dBm)

-40
-50
-60
-70

-40
-50
-60
-70

265 275 285 295 305 315

Frequency (GHz)

32QAM 21Gbaud → 105Gb/s

128QAM 3.52Gbaud → 24.6Gb/s/ch (× 6)

## Power spectra and signal constellations

<table>
<thead>
<tr>
<th>Modulation</th>
<th>32QAM</th>
<th>128QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constellation (Equalized)</td>
<td><a href="#">32QAM constellation</a></td>
<td><a href="#">128QAM constellation</a></td>
</tr>
<tr>
<td>EVM</td>
<td>8.9%</td>
<td>3.3 ~ 4.1%</td>
</tr>
<tr>
<td>Data rate</td>
<td>105Gb/s</td>
<td>24.64Gb/s x6</td>
</tr>
</tbody>
</table>

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## Performance comparison

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>40nm CMOS</td>
<td>40nm CMOS</td>
<td>250nm InP</td>
<td>35nm GaAs</td>
<td>35nm GaAs</td>
<td>0.13µm SiGe</td>
<td></td>
</tr>
<tr>
<td>Freq. (GHz)</td>
<td>275-305</td>
<td>302</td>
<td>289–311</td>
<td>300</td>
<td>240</td>
<td>300</td>
</tr>
<tr>
<td>Modulation</td>
<td>32QAM</td>
<td>32QAM</td>
<td>128QAM</td>
<td>QPSK</td>
<td>8PSK</td>
<td>QPSK</td>
</tr>
<tr>
<td>Pout (dBm)</td>
<td>-14.5</td>
<td>-5.5</td>
<td>-</td>
<td>-3.5</td>
<td>-4</td>
<td>7</td>
</tr>
<tr>
<td>Pdc (W)</td>
<td>1.4</td>
<td>1.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.54</td>
</tr>
<tr>
<td>Data rate (Gb/s)</td>
<td>17.5 x 6</td>
<td>105</td>
<td>24.64 x 6</td>
<td>50</td>
<td>96</td>
<td>64</td>
</tr>
</tbody>
</table>

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Wireless demonstration

300GHz CMOS TX by cubic-mixer-last-architecture

300GHz CMOS TX by square-mixer-last-architecture

Video Contents

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Conclusion

• A Japanese activity on 300-GHz silicon CMOS transmitters and their wireless demonstrations were introduced.

• QAM-capable 300GHz TXs in 40-nm CMOS operating beyond $f_{\text{max}}$ were reported.
  • cubic-mixer-last architecture
  • square-mixer-last architecture

• For realizing 300GHz wireless communication, Si CMOS is one of possible technology.