We04B-#1

220-to-320-GHz Fundamental Mixer in 60-nm InP HEMT Technology Achieving 120/152/168-Gbps Data Transmission in Three Bands

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Outline

- Background
- Proposed mixer
- Measurement results
- Summary
6th Generation Mobile Communication System (6G)

This graph is based on the picture from NICT.

Data rate [b/s]

Year


Analogue: 9.6 kb/s
PDC: 28.8 kb/s
cdmaOne: 64 kb/s
W-CDMA: 384 kb/s
HSPA: 14.4 Mb/s
LTE: 100 Mb/s
LTE-Advanced: 1 Gb/s (~ 2.1 GHz)
10 Gb/s mmW
100 Gb/s ~ 2.1 GHz

100 Gb/s – 1 Tb/s mmW / THz

This graph is based on the picture from NICT.
300-GHz-band for 6G

- 300-GHz-band (around 220-325 GHz): Wideband & low-loss
  - Suitable for 6G high-speed wireless communications

ex.) IEEE802.15.3d floor plan
Maximum Bandwidth: 69 GHz
Our previous work (300GHz band TRX)

➢ Our previous work [1]: 300GHz band TRX achieving 9.8m, 120 Gbps wireless data transmission
➢ Need mixer with wider bandwidth for higher data rate

Outline

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Mixer topology selection (1)

(a) Single end  
(b) Single balanced  
(c) Double balanced

<table>
<thead>
<tr>
<th></th>
<th>(a) Single end</th>
<th>(b) Single balanced</th>
<th>(c) Double balanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>☹</td>
<td>☺</td>
<td>☹</td>
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<tr>
<td>Rejection</td>
<td>☹</td>
<td>☺ (IF or RF)</td>
<td>☺ (IF &amp; RF)</td>
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</tbody>
</table>
## Mixer topology selection (2)

### Diagrams:
- **(a)** Resistive mixer
- **(b)** Gate mixer
- **(c)** Drain LO injection mixer

### Table:

<table>
<thead>
<tr>
<th>Feature</th>
<th>(a) Resistive mixer</th>
<th>(b) Gate mixer</th>
<th>(c) Drain LO injection mixer</th>
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<tbody>
<tr>
<td>Linearity</td>
<td>😞</td>
<td>😊</td>
<td>😊</td>
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<tr>
<td>Conversion gain</td>
<td>😞</td>
<td>😊</td>
<td>😊</td>
</tr>
<tr>
<td>Direction</td>
<td>Bi-direction (up and down conversion)</td>
<td>Uni-direction (up or down conversion)</td>
<td>Uni-direction (up or down conversion)</td>
</tr>
</tbody>
</table>
Conventional RF matching network

MN: matching network
CG: conversion gain

- Conventional RF MN: matching frequency is designed around LO frequency
- CG degrades away from LO frequency → bandwidth degradation

![Diagram showing RF return loss and normalized CG over frequency range](image)
Proposed bandwidth extension technique using WSF-MN

WSF: wide split frequency

- Proposed RF WSF-MN: matching frequency is designed around edges of desired band
- Large attenuation far from LO frequency can be avoided → bandwidth extension
IF / RF isolation for CG improvement

- IF isolation capacitor and RF isolation stubs are placed for high isolation of IF/RF and high CG.
Simulation results of CG improvement

Conversion gain (dB)

ZIF @ 30GHz

- IF isolation capacitor
- w/ IF isolation capacitor
- w/ RF isolation stubs
- RF frequency (GHz)
- ZRF @ 30GHz
- ZRF @ 270GHz
- ZIF @ 270GHz
- Conversion gain (dB)
- w/ IF isolation capacitor
- Wo RF isolation stubs
Outline

- Background
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- Measurement results
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Mixer IC fabrication

- Technology: 60-nm InP-HEMT [1]
- Chip size: 1 mm * 1 mm
- Power consumption: ~0 mV

Mixer IC on-wafer measurement setup

VNA (Keysight PNA-X)

Frequency extender
Probe (-8dB)
Mixer IC
LO path
Probe (-8dB)
X18 multiplier
Synthesizer

RF path
IF path
Down conversion
Up conversion

DC Supply
Vbias

-1 dBm
7 dBm
➢ RF matching frequency is widely split
➢ Conversion gain: -15 dB
➢ -6 dB RF bandwidth: 220-320 GHz
➢ Mixer IC was implemented to WR3.4 waveguide module
➢ Conversion gain: -16 dB
➢ Output 1dB-compression power: -16 dBm
Use two mixer modules for back-to-back transmission experiment at 3 bands.
Back-to-back transmission experiment setup (2)

<table>
<thead>
<tr>
<th>LO* freq. [GHz]</th>
<th>1st band</th>
<th>2nd band</th>
<th>3rd band</th>
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<tbody>
<tr>
<td></td>
<td>252.5</td>
<td>282.5</td>
<td>282.5</td>
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<tr>
<th>Filter**</th>
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<th>3rd band</th>
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<tbody>
<tr>
<td>Low pass filter (f_{cut} = 247.5 GHz)</td>
<td>227</td>
<td>257</td>
<td>307</td>
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<tr>
<td>Low pass filter (f_{cut} = 277.5 GHz)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>High pass filter (f_{cut} = 287.5 GHz)</td>
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<table>
<thead>
<tr>
<th>RF signal center freq. [GHz]</th>
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<th>3rd band</th>
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<tbody>
<tr>
<td></td>
<td>20</td>
<td>42</td>
<td>38</td>
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<table>
<thead>
<tr>
<th>Symbol rate [GHz]</th>
<th>1st band</th>
<th>2nd band</th>
<th>3rd band</th>
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<tbody>
<tr>
<td>64 QAM</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>16 QAM</td>
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<thead>
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<tr>
<td>64 QAM</td>
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</table>

<table>
<thead>
<tr>
<th>Data rate [Gbps]</th>
<th>1st band</th>
<th>2nd band</th>
<th>3rd band</th>
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<tbody>
<tr>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>168</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>152</td>
<td></td>
<td></td>
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</tbody>
</table>
Back-to-back transmission experiment result

20 GBaud, 64QAM
120 Gbps

42 Gbaud, 16QAM
168 Gbps

38 Gbaud, 16QAM
152 Gbps

SNR = 22.8 dB (>FEC limit 22.5 dB)

SNR = 17.1 dB (>FEC limit 16.5 dB)

SNR = 16.6 dB (>FEC limit 16.5 dB)
<table>
<thead>
<tr>
<th>Ref</th>
<th>f&lt;sub&gt;center&lt;/sub&gt;</th>
<th>-3dB BW (6dB BW)</th>
<th>CG (dB)</th>
<th>OP1dB (dBm)</th>
<th>Technology</th>
<th>Symbol rate (GBaud)</th>
<th>Max. Datarate (Gbps)</th>
<th>IC implementation</th>
<th>Link distance (m)</th>
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<tbody>
<tr>
<td>2</td>
<td>270</td>
<td>32 (50)</td>
<td>-15 (up &amp; down)</td>
<td>-16</td>
<td>80-nm InP HEMT</td>
<td>25 (16QAM)</td>
<td>100</td>
<td>Waveguide module</td>
<td>2.2</td>
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<tr>
<td>3</td>
<td>270</td>
<td>47 (60)</td>
<td>-15 (up &amp; down)</td>
<td>-16.5</td>
<td>80-nm InP HEMT</td>
<td>30 (16QAM)</td>
<td>120</td>
<td>Waveguide module</td>
<td>9.8</td>
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<tr>
<td>4</td>
<td>300</td>
<td>~30 (~50)</td>
<td>-15 (up) -5 (down)</td>
<td>N.A.</td>
<td>250-nm InP-HBT</td>
<td>25 (QPSK)</td>
<td>50</td>
<td>On-board</td>
<td>On-board back-to-back</td>
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<tr>
<td>5</td>
<td>230</td>
<td>26 (30)</td>
<td>16.5 (up) 8 (down)</td>
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<td>130-nm SiGe</td>
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<td>On-board</td>
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<td>6</td>
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<td>-2 (up) 2 (down)</td>
<td>N.A.</td>
<td>40-nm CMOS</td>
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<td>Chip with probe</td>
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<tr>
<td>7</td>
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<td>26.5 (55)</td>
<td>-19 (down)</td>
<td>N.A.</td>
<td>40-nm CMOS</td>
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<td>Chip with probe</td>
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<td>8</td>
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<td>~20 (~30)</td>
<td>-20 (down)</td>
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<td>9</td>
<td>135 (~2)</td>
<td>25 (~35)</td>
<td>-11.4 (up)</td>
<td>-7.5</td>
<td>65-nm CMOS</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
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<tr>
<td>10</td>
<td>265</td>
<td>30 (~35)</td>
<td>26 (down)</td>
<td>N.A.</td>
<td>40-nm CMOS</td>
<td>19 (16QAM)</td>
<td>76</td>
<td>On-board</td>
<td>0.06</td>
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<tr>
<td><strong>This work</strong></td>
<td>270</td>
<td>60 (100)</td>
<td>-15 (up &amp; down)</td>
<td>-16</td>
<td>60-nm InP HEMT</td>
<td>Three bands</td>
<td>20 (64QAM) @ 1&lt;sup&gt;st&lt;/sup&gt; band 42 (16QAM) @ 2&lt;sup&gt;nd&lt;/sup&gt; band 38 (16QAM) @ 3&lt;sup&gt;rd&lt;/sup&gt; band</td>
<td>120 @1&lt;sup&gt;st&lt;/sup&gt; band 168 @2&lt;sup&gt;nd&lt;/sup&gt; band 152 @3&lt;sup&gt;rd&lt;/sup&gt; band</td>
<td>Waveguide module</td>
</tr>
</tbody>
</table>
Summary

- We proposed a resistive mixer with a widely split frequency matching network.
- The mixer IC is fabricated in 60-nm InP HEMT technology and achieved bandwidth from 220-320 GHz, the widest ever reported.
- Two mixer modules were used in TX and RX for back-to-back transmission experiment at 3 bands. 120/168/152 Gbps were achieved at 3 different frequency bands.

ACKNOWLEDGEMENT

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Appendix
LO reflection

LO port return loss (dB) vs frequency (GHz)