A Packaged 135GHz 22nm FD-SOI Transmitter on an LTCC Carrier

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Outline

- Motivation
- Ceramic interposer design/ transition loss
- On package Antenna design
- Integrated Transmitter module on an LTCC carrier
- Link measurement
- Conclusion
Packaging technologies at sub-THz frequencies

IC technologies

- 22FDSOI [Farid et. al.]
- 45SOI [Siwei et. al.]
- 55nm SiGe [Sawaby et. al.]
- GaAs HEMT [Ito et. al.]

Packaging technologies

- High performance laminate
  - IL= 2.5dB @140GHz

- Radio on Glass
  - IL= 1dB @140GHz
Transmitter IC design

- Direct conversation transmitter using GF 22FDSOI
- Tx chip is flipchip bonded to LTCC interposer using 50μm diameter copper pillar
- Copper pillars are equally spaced at 175μm distance
Ceramic Interposer design

- 3 dielectric layers of Kyocera GL771
- 4 metal layers (ME3 for I/Q routing and LO signal)

How to secure landing copper pillars precisely?
- Ceramic coat with 75μm opening
- SOP on the ceramic carrier
CMOS/Interposer transition

- Simulated transition loss=1.15dB at 135GHz
- Transition loss includes
  - Copper pillar
  - 220μm CPW section

- Measured transition loss~0.85dB
Series Fed Patch Antenna on LTCC carrier

- 8-elements series fed patch antenna
- $\frac{\lambda}{4}$ transmission line matches antenna to the transmitter 50Ω impedance
- Copper pillar transition is part of the impedance matching network
Measured Antenna performance

- 11dB gain, 5.5GHz bandwidth
- 12° E-plane 3-dB beam width
- Sidelobes suppressed by 12-dB
Integrated Transmitter module testing

- Tx Input signal swept from 0.1G to 10GHz (either I or Q)
- LO signal fixed at 135GHz
- Tx upper sideband captured using Harmonic mixer and spectrum analyzer
Integrated Transmitter module

- Module has 6GHz 3-dB modulation BW
- Conversion gain=24dB
- EIRP at Psat =12.8dB / EIRP at P1dB=8.4dB
Module Link Measurement

- Transmitter (I,Q) data driven by AWG at 2GHz IF
- EVM measurements with equalization at DSO.

### 16QAM (6dB-BO)

<table>
<thead>
<tr>
<th>Baud Rate</th>
<th>EVM (%)</th>
<th>EVM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1GBaud</td>
<td>5.44% RMS</td>
<td>9.2% RMS</td>
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<tr>
<td>4GBaud</td>
<td>5.44% RMS</td>
<td>9.2% RMS</td>
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### 64QAM (8dB-BO)

<table>
<thead>
<tr>
<th>Baud Rate</th>
<th>EVM (%)</th>
<th>EVM (%)</th>
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</thead>
<tbody>
<tr>
<td>1GBaud</td>
<td>5.6% RMS</td>
<td>7.4% RMS</td>
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<tr>
<td>2GBaud</td>
<td>5.6% RMS</td>
<td>7.4% RMS</td>
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## Comparison with state of the art

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>Package</strong></td>
<td>RO4350</td>
<td>Radio on Glass</td>
<td>Astra MT77</td>
<td>LTCC GL771</td>
</tr>
<tr>
<td><strong>IC Tech</strong></td>
<td>55nm SiGe HBT</td>
<td>0.13μm SiGe-BICMOS</td>
<td>45nm CMOS SOI</td>
<td>22nm FDSOI</td>
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<tr>
<td><strong>Antenna</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td><strong>Integration</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Frequency (GHz)</strong></td>
<td>110-150</td>
<td>115-155</td>
<td>142-147</td>
<td>131-137</td>
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<tr>
<td><strong>EIRP at Psat</strong></td>
<td></td>
<td></td>
<td>14dBm/ channel</td>
<td>13dBm</td>
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<tr>
<td><strong>Tx-Psat</strong></td>
<td>-0.5dBm</td>
<td>13dBm</td>
<td>2dBm</td>
<td>1.95dBm</td>
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<tr>
<td><strong>Tx Pdc (mW)</strong></td>
<td>220</td>
<td>1350</td>
<td>2100</td>
<td>210</td>
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<tr>
<td><strong>Package Loss</strong></td>
<td>3dB</td>
<td>1dB</td>
<td>2.5dB</td>
<td>0.85~1.1dB</td>
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<tr>
<td><strong>Supported</strong></td>
<td>QPSK</td>
<td>256QAM</td>
<td>BPSK</td>
<td>64QAM</td>
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<td><strong>Modulation</strong></td>
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Conclusion

- High performance package with loss transition loss <1dB at 135GHz
- Transmitter module has 6GHz 3-dB BW limited by series fed patch antenna BW
- EIRP at psat=13dBm (limited by the CMOS TX output power of 2dBm)
Acknowledge

• Kyocera Japan for LTCC carrier fabrication
• Kyocera San Diego for module assembly
• GF for free access to 22FDX technology and free access to GF advanced copper pillars
Questions?