A 40GHz to 67GHz Bandwidth 23dB Gain 5.8dB Maximum NF mm-Wave LNA in 28nm CMOS

K. Hadipour\textsuperscript{1,2}, A. Ghilioni\textsuperscript{1}, A. Mazzanti\textsuperscript{1}, M. Bassi\textsuperscript{1}, F. Svelto\textsuperscript{1}

\textsuperscript{1}University of Pavia, Pavia, Italy
\textsuperscript{2}Johannes Kepler University, Linz, Austria
Outline

• Introduction
• Bandwidth enhancement
• High gain amplification
• A high GBW amplifier
• Proposed low noise amplifier
• Measurement results
• Conclusion
Introduction

• **Mm-wave for high-data rate**

- Spectrum crowding in lower frequency bands
- The operation frequency of CMOS transistors is increased thanks to the technology scaling
- Wider bandwidths for higher data rate
Introduction

• Motivations

- Wireless HD Multimedia Sharing, Medical & Security Imaging, Automotive radars and Chip-to-Chip Communication
- Simpler modulation schemes ➔ Simpler transceiver system
Bandwidth enhancement

- Separation of load & source capacitances

- Maximum bandwidth improvement ($N$) is 4.9 based on Bode-Fano theorem

- High order inter-stage network with large amount of lossy components required to reach an improvement close to 4.9
Coupled resonators

- a) Capacitively coupled resonators
  
  - Pro: BW improvement without gain penalty
  
  - Con: Issue when very large bandwidth is targeted or the Q is low → Large coupling cap is required
Coupled resonators

b) Inductively coupled Resonators

- **Pro:** Larger bandwidth improvement can be achieved

- **Con:** Additional area consuming inductor is required
Proposed solution for inter-stage network

- Norton transformation of inductively coupled resonators

  - Simple topology and low losses
  - Reducing inductors’ count and values
  - Side effect: Upscaling of the impedance on the right side of the network by $N=\left(\frac{L_{P2}+L_S}{L_{P2}}\right)^2 \rightarrow$ smaller capacitance $C_P'$. 

\[ L'_{P2} = L_{P2}\sqrt{N} \quad C' = C_P/N \quad L'_{S} = L_{S}\sqrt{N} \quad R'_{P} = R_P N \quad N=\left(\frac{L_S+L_{P2}}{L_{P2}}\right)^2 \]
Optimization of active stages

• **Common source vs. Cascode**
  - Lower gain but better noise performance for CS
  - Stability issue in common source stages

But what if we compare two cascaded common source stages with a Cascode?!

• **Low power solution (Current Sharing)**
  - Pro: Same GBW for half the DC power
  - Cons: Another large capacitor is required for AC short → Larger area
Proposed amplification stage

- **Modified Current-Sharing architecture**

  - Wideband performance achieved by proper dimensioning of passive components in each resonant network
  - Lower impedance at node X compared to simple CS ➔ reduced Miller effect ➔ Higher stability, comparable to Cascode

RTU-2-B-3
Further bandwidth enhancement

- **Wideband stagger tuning**
  - Wider BW for each network at the cost of more in-band ripple
  - Stagger-tuning to compensate the in-band ripple and further extend BW
Proposed LNA

- T-type input matching network & source inductive degeneration for wideband input matching
- Open-drain buffer to connect to measurement instrument
Transmission line instead of Spirals

- Successful design relies on proper modeling of all the passive elements ➔ CPW transmission lines used to realize the inductances
  - Pros: Accurate modeling
    Scalable model
    Better ground current return path
  - Cons: Larger area
    Lower quality factor
Proposed LNA

Technology: ST 28nm CMOS LP
Chip area: 1150 µm x 730 µm
RTU-2-B-3
Performance Summary

Flat gain and smooth noise figure from 40 GHz to 70 GHz

RTU-2-B-3
Performance Summary

K > 10 and |Δ| < 1 in measured frequency band

OP-1dB > -4 dBm @ 60 GHz

RTU-2-B-3
Superior GBW compared to other CMOS LNAs
## Performance Summary

<table>
<thead>
<tr>
<th>Ref</th>
<th>Tech.</th>
<th>S21 (dB)</th>
<th>BW (GHz)</th>
<th>F&lt;sub&gt;center&lt;/sub&gt; (GHz)</th>
<th>NF (dB)</th>
<th>OP1-dB (dBm)</th>
<th>P&lt;sub&gt;DC&lt;/sub&gt; (mW)</th>
<th>Area</th>
<th>GBW (dB.GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFIC 08</td>
<td>90nm CMOS</td>
<td>15.0</td>
<td>6.0</td>
<td>58.0</td>
<td>4.4-5.0*</td>
<td>-3.0</td>
<td>4.0</td>
<td>440umx320um</td>
<td>90.0</td>
</tr>
<tr>
<td>TMTT 12</td>
<td>90nm CMOS LP</td>
<td>17.0</td>
<td>17.0</td>
<td>57.0</td>
<td>4.4-8.0*</td>
<td>-1</td>
<td>19.2</td>
<td>1000umx590um</td>
<td>289.0</td>
</tr>
<tr>
<td>TMTT 12</td>
<td>90nm CMOS LP</td>
<td>13.7</td>
<td>11.0</td>
<td>54.5</td>
<td>5.3-7.5*</td>
<td>+3.2</td>
<td>14.4</td>
<td>600umx480um</td>
<td>150.7</td>
</tr>
<tr>
<td>ESSCIRC 10</td>
<td>65nm CMOS</td>
<td>24.0</td>
<td>17.0</td>
<td>53.0</td>
<td>4.0-7.6</td>
<td>+2.1*</td>
<td>30.0</td>
<td>-</td>
<td>408.0</td>
</tr>
<tr>
<td>JSSCC 11</td>
<td>65nm CMOS</td>
<td>28.0</td>
<td>13.0</td>
<td>59.5</td>
<td>5.2-7.3</td>
<td>-</td>
<td>18.0</td>
<td>-</td>
<td>364.0</td>
</tr>
<tr>
<td>RFIC 12</td>
<td>65nm CMOS</td>
<td>17.0</td>
<td>14.0</td>
<td>54.0</td>
<td>6.5-8.1</td>
<td>+6.0*</td>
<td>5.0</td>
<td>170umx320um**</td>
<td>238.0</td>
</tr>
<tr>
<td>RFIC 12</td>
<td>65nm CMOS</td>
<td>26.0</td>
<td>9.0</td>
<td>60.0</td>
<td>4.0-5.5</td>
<td>-3.5</td>
<td>8.0</td>
<td>350umx140um</td>
<td>234.0</td>
</tr>
<tr>
<td>TMTT 13</td>
<td>65nm CMOS</td>
<td>17.5</td>
<td>7.0*</td>
<td>57.5*</td>
<td>5.3-6.5</td>
<td>-</td>
<td>18.0</td>
<td>703umx727um</td>
<td>122.5</td>
</tr>
<tr>
<td>JSSCC 10</td>
<td>40nm CMOS</td>
<td>18.0</td>
<td>11.0</td>
<td>57.5</td>
<td>7.0-8.2</td>
<td>-</td>
<td>14.3</td>
<td>200umx240um**</td>
<td>198.0</td>
</tr>
<tr>
<td>This Work</td>
<td>28nm CMOS</td>
<td>22.3</td>
<td>30.0</td>
<td>55.0</td>
<td>4.2-6.2</td>
<td>-4.0</td>
<td>25.3</td>
<td>1150umx730um</td>
<td>669.0</td>
</tr>
<tr>
<td>This Work</td>
<td>28nm CMOS</td>
<td>33.9</td>
<td>33.2</td>
<td>51.0</td>
<td>4.1-6.2</td>
<td>+3.0</td>
<td>20.6</td>
<td>1150umx730um</td>
<td>1125.5</td>
</tr>
</tbody>
</table>

*: Estimated from the Figure  **: Excluding the pads

**Widest bandwidth in CMOS technology with state of the art gain and noise figure**
Conclusion

- Significance of inter-stage networks to design wideband low noise amplifiers at mm-wave

- Common source stages in current sharing configuration for high gain & low power design

- 3rd order inter-stage networks & wideband stagger tuning common source stages for beyond state of the art GBW

- Very flat gain and GBW larger than 669 GHz for the LNA
Thank You!