A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS

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A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
Applications

AC-coupled receiver front end:

Serial link receiver front end:
Pre-amp Topology

Distributed Amplifier
- High bandwidth
- Large area
- High power consumption
- Difficult to achieve constant group delay

Cascode Amplifier
- Low power
- High VDD due to stacked transistors
- Bandwidth limited by node capacitances

A 19-GHz Broadband Amplifier Using a \( g_m \)-Boosted Cascode in 0.18-\( \mu \)m CMOS
Standard CMOS Cascode

3 time constants of simple cascode:

\[ \tau_{\text{out}} = \left( R_L \parallel r_0 \right) C_{\text{OUT}} \]

\[ \tau_{\text{cascode}} = \frac{C_{GS2} + C_{DB1} + C_{SB2} + 2C_{GD1}}{g_{m2}} = \frac{C_X}{g_{m2}} \]

\[ \tau_{\text{input}} = R_{\text{in}} C_{\text{in}} \]
$g_{\text{meff}} = \left[ 1 + A(s) \right] g_m$

- Increases output resistance
- Reduces time constant at $V_x$
- Ameliorates Miller effect at the input
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$g_m$-Boosted Cascode

Passive $g_m$-boosting:

\[ g_{meff} = \left[1 + A(s)\right] g_m \]

- $g_{meff} = g_m$ for $s = 0$
- $g_{meff} = 2g_m$ for $s = \infty$
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$g_m$-Boosted Cascode

$L_1$ separates $C_{\text{PAD}}$ and $C_{\text{IN}}$ [Sackinger’05]
$g_m$-Boosted Cascode

$L_2$ separates the $C_D$ of $M_1$ and $C_S$ of $M_2$  
[Analui’04]
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$g_m$-Boosted Cascode

L3 and L4 provide series and shunt peaking [Lee’04]
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$g_m$-Boosted Cascode

![Diagram of $g_m$-Boosted Cascode]

3-dB Bandwidth (GHz) vs. C (fF)

- $R = 500\Omega$
- > 30% improvement
Differential $g_m$-Boosted Cascode

$R_L$ is divided to improve the BW [Greshishchev’99]

Feedback sets the input resistance to 50 Ω

A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
Differential $g_m$-Boosted Cascode

Output Buffer

1.6 mm

0.7 mm
Measurement of $g_m$-Boosted Pre-amp

A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
Measurement of $g_m$-Boosted Pre-amp

$V_{DD} = 2.5 \text{ V}$

$BW = 22 \text{ GHz}$

6 dB was added to the $S_{21}$ measured on a 2-port network analyzer.
Measurement of $g_m$-Boosted Pre-amp

$V_{DD} = 2.2\, V$


$\text{BW} = 21\, \text{GHz}$

6 dB was added to the $S_{21}$ measured on a 2-port network analyzer.

A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
Measurement of $g_m$-Boosted Pre-amp

$V_{DD} = 2.5$ V

$P_{1dB}$ for 6-GHz input

Output Power (dBm) vs. Input Power (dBm) graph

$P_{output\ 1dB} = -9$ dBm

$P_{input\ 1dB} = -7.5$ dBm

1 dB Compression (dBm) vs. Frequency (GHz) graph

$P_{1dB}$ for 6-GHz input
Measurement of $g_m$-Boosted Pre-amp

$V_{DD} = 2.5 \, V$

Input power $= -8 \, \text{dBm}$
Full Front End Design

- Bandwidth > 20 GHz
- Constant group delay
- Gain > 6 dB
- 50-Ω Input Matching

- Bandwidth > 20 GHz
- Constant group delay
- Gain > 4 dB
- 50-Ω output driver
Post-amplifier

Used to cancel Miller capacitances
L₁, L₂ chosen for maximally flat frequency response
A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
Measurement of Full Front End

$V_{DD} = 2.5 \text{ V}$

$\text{BW} = 19 \text{ GHz}$

6 dB was added to the $S_{21}$ measured on a 2-port network analyzer.
Measurement of Full Front End

\[ V_{DD} = 2.2 \text{ V} \]

\[ \text{BW} = 17.5 \text{ GHz} \]

6 dB was added to the \( S_{21} \) measured on a 2-port network analyzer.
Measurement of Full Front End

$V_{DD} = 2.0\, V$

$BW = 16\, GHz$

6 dB was added to the $S_{21}$ measured on a 2-port network analyzer
Measurement Setup for Eye Diagrams

2^7 – 1 PRBS streams

Attenuator

4:1 Mux

Agilent 86100C ‘Scope
Eye Diagram Measurements

20 Gb/s, 270 mVpp input amplitude
Eye Diagram Measurements

24 Gb/s, 270 mVpp input amplitude
Sensitivity Testing

14 Gb/s, 27 mVpp input amplitude

55 mV

A 19-GHz Broadband Amplifier Using a $g_m$-Boosted Cascode in 0.18-μm CMOS
## Summary

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<th>This work</th>
<th>Analui’04</th>
<th>Bevilacqua’04</th>
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<tbody>
<tr>
<td>CMOS Technology</td>
<td>0.18 μm</td>
<td>0.18 μm</td>
<td>0.18 μm</td>
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<tr>
<td>Single ended (SE) or</td>
<td>Diff.</td>
<td>SE</td>
<td>SE</td>
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<tr>
<td>Differential (Diff)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 dB bandwidth (GHz)</td>
<td>19</td>
<td>9.2</td>
<td>7</td>
</tr>
<tr>
<td>DC $</td>
<td>S_{21}</td>
<td>$ (dB)</td>
<td>11</td>
</tr>
<tr>
<td>DC $</td>
<td>Z_{21}</td>
<td>$ (dB Ω)</td>
<td>52</td>
</tr>
<tr>
<td>Sensitivity (μW)</td>
<td>3.6 @ 14Gb/s</td>
<td>15.8 @ 10Gb/s</td>
<td></td>
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<tr>
<td>Input referred $P_{\text{1dB}}$ (dBm)</td>
<td>-7.5 @ 6 GHz</td>
<td></td>
<td></td>
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<tr>
<td>$P_{3\text{rd}}/P_{1\text{st}}$ (dB)</td>
<td>-31.8 @ 6 GHz</td>
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<td></td>
</tr>
<tr>
<td>Power (mW)</td>
<td>111</td>
<td>137</td>
<td>9</td>
</tr>
<tr>
<td>Supply Voltage (V)</td>
<td>2.5</td>
<td>2.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>1.4</td>
<td>.64</td>
<td>1.1</td>
</tr>
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Conclusions

- Passive $g_m$-boosting
  - Improves the time constant at cascode node
  - Reduces Miller effect at the input node
  - Does not reduce DC gain
  - Does not introduce peaking
  - No additional power consumption

- Pre-amplifier (only) achieves BW of 22 GHz in 0.18-μm CMOS

- Front end (pre-amp + post-amp) gain > 10 dB is achieved with BW of 19 GHz
Acknowledgements

- Shahriar Shahramian
- Canadian Microelectronics Corporation
- Intel Corporation
For example, assuming $R_{in} = 50 \, \Omega$, $R_L = 150 \, \Omega$, M1 & M2 are 20 x 2 $\mu$m, $I_D = 7.5 \, mA$, $C_{PAD} = 70 \, fF$, and $C_L = 40 \, fF$:

\[
\begin{align*}
\tau_{out} &= 15pS \\
\tau_{cascode} &= 12pS \\
\tau_{input} &= 9pS
\end{align*}
\]
### Time Constants of $g_m$-boosted Cascode

<table>
<thead>
<tr>
<th></th>
<th>Standard Cascode</th>
<th>$g_m$-boosted Cascode</th>
</tr>
</thead>
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<tr>
<td><strong>DC Gain</strong></td>
<td>$g_{m1} R_L$</td>
<td>$g_{m1} R_L$</td>
</tr>
<tr>
<td><strong>Input Time Constant</strong> ($\tau_{\text{Input}}$)</td>
<td>$R_S \left[C_{GS} + 2C_{GD}\right]$</td>
<td>$R_S \left[C_{GS} + 1.5C_{GD}\right]$</td>
</tr>
<tr>
<td><strong>Cascode Time Constant</strong> ($\tau_{\text{Cascode}}$)</td>
<td>$\frac{C_{\text{Tot}} + 2C_{GD}}{g_{m2}}$</td>
<td>$\frac{5C_{\text{Tot}} + 1.5C_{GD}}{g_{m2}}$</td>
</tr>
<tr>
<td><strong>Output Time Constant</strong> ($\tau_{\text{Output}}$)</td>
<td>$R_L \left[C_{GD} + C_{db} + C_L\right]$</td>
<td>$R_L \left[C_{GD} + C_{db} + C_L\right]$</td>
</tr>
</tbody>
</table>

- $R_S$: Source resistance
- $C_{GS}$, $C_{GD}$, $C_{db}$, $C_L$: Capacitances
- $g_{m1}$, $g_{m2}$: Transconductance
- $R_L$: Load resistance
- $C_{\text{Tot}}$: Total capacitance

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Differential $g_m$-boosted Cascode

$g_m$ boosting:

- Improves Input time constant
- Improves the time constant @ cascode node
- Do not reduce DC Gain
- No additional DC power consumption
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