A Reconfigurable S/X-Band 25W GaN Power Amplifier MMIC

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Talk Outline

• Introduction
• Reconfigurable Elements
• Circuit Design
• Measured Results
• Conclusion
Introduction

• Some applications utilize multiple relatively narrow frequency bands with greatly differing center frequencies
  • Radar systems
  • Future 5G systems

• Some existing approaches for the power amplifier
  • Switch between individual PA MMICs
  • Wideband PA covering both bands. i.e. NDPA
  • Dual passband power amplifier design

• Objective: Develop a power amplifier MMIC that is electronically reconfigurable between S-band and X-band
Introduction

• Criteria for success compared to existing approaches
  • Better performance over the bands of interest
  • Smaller die area
  • Out of band rejection

• Amplifier design goals

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>S-Band</th>
<th>X-Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Bands (GHz)</td>
<td>3.0-3.5</td>
<td>9.0-11.0</td>
</tr>
<tr>
<td>Linear Gain (dB)</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Output Power (W)</td>
<td>&gt; 25 W</td>
<td>&gt; 25 W</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>&gt; 60 %</td>
<td>&gt; 55 %</td>
</tr>
<tr>
<td>Control Voltages (V)</td>
<td>0 / -30</td>
<td>-30 / 0</td>
</tr>
</tbody>
</table>
Reconfigurable Elements

- The circuit elements are reconfigured with D-mode GaN RF switch FETs placed throughout the amplifier circuit.

- In a typical RF switch circuit, $V_1 = 0V$ and the FET is switched with $V_C = 0V / -30V$.

- Here is $V_1 = V_G (~ -3V)$ or $V_1 = V_D (15-40V)$ depending on the location of the switch FET within the amplifier circuit.
Reconfigurable Elements

• Reconfigurable shunt capacitors are straightforward
  • Reconfigurable between 2 values
  • $C_{\text{FIX}}$ DC blocks the switch FET
  • FET is grounded forcing $V_{DS} = 0\text{V}$
  • Reconfigured with $V_C = 0\text{V} / -30\text{V}$
Reconfigurable Elements

• Reconfigurable shunt lines (inductors) are more complex
  • Reconfigurable between 2 values
  • $C_{BY}$ DC blocks the switch FET
  • Line forces $V_{DS} = 0V$

• Now $V_D$ or $V_G$ at FET source/drain
  • On State $V_C = V_D$ or $V_G$
  • Off State $V_C = V_D$ or $V_G - 30V$

• Need 4 to 6 different control voltages
• $V_D$ or $V_G$ aren’t typically fixed for known
Reconfigurable Elements

• Could try to DC block the switch FET
• Reactance small compared to $R_{ON}$
  - $C_{DC} >> 1/\omega R_{ON}$
  - Assume $R_{ON} = 1\Omega$ at 3GHz
  - $C_{DC} >> 53\text{pF}$ !!!!
• Need additional bias circuitry to translate -30V / 0V to the correct levels and self adjust for different $V_G$ and $V_D$
Reconfigurable Elements

- Patented reconfigurable bias circuit (US 10,164,587)

- When $V_{LB} = 0V$ $Q_2$ is “on”
  - $Q_{SW}$ gate connected to $V_G$
  - Switch bias is $-3V - 28V = -31V$
  - $Q_{SW}$ is in the “off” state

- When $V_{LB} = -30V$ $Q_2$ is “off”
  - $Q_{SW}$ gate connected to $V_D$
  - Switch bias is $28V - 28V = 0V$
  - $Q_{SW}$ is in the “on” state
Circuit Design

• MMIC Technology – Qorvo’s Production Released GaN15
  • 0.15μm Gate Length (Amp & Switch)
  • Up to 28V Operation
  • $F_t / F_{\text{max}} = 38\text{GHz} / 140\text{GHz}$
  • $R_{\text{ON}} = 1.6\Omega\cdot\text{mm}$
  • $C_{\text{OFF}} = 0.25\text{pF/mm}$

• Matching network design methodology
  • Assume series lines are not reconfigurable
  • Assume that series resistors and capacitors are reconfigurable
  • Assume that all shunt elements are reconfigurable
Circuit Design

• MMIC design summary
  • Two stage amplifier
  • Output stage: 8-way combining
  • Input stage: 4.8:1 staging ratio
  • Die Size: 5.10 x 3.92 mm²

• Reconfigurable elements
  • Resistors
  • Capacitors
  • Line lengths
Measured Performance

- Small Signal Gain
  - $V_D = 28V$
  - $I_{DQ} = 500mA$
  - $V_C = 0V / -30V$
- Provides 20-30dB of out of band rejection
Measured Performance

- Linear Gain and return loss
  - $V_D = 28\text{V}$
  - $I_{DQ} = 500\text{mA}$
  - $V_C = 0\text{V} / -30\text{V}$

![Diagram showing gain and return loss vs frequency](image)

Best in class wideband PA MMIC
Measured Performance

- Output Power and Efficiency: Pulsed $V_D$, 10$\mu$s / 10% duty
Measured Performance

- Demonstration of the self adjusting switch FET bias circuit for two different drain power supply voltages.
Measured Performance

• Die Size: 25% Reduction
• Linear Gain
  • More Linear Gain at S-Band
  • More Linear Gain most of X-Band
• Output Power
  • S-Band: 1.1 to 2.1dB increase
  • X-Band: 0.7 to 2.1dB increase
• Power Added Efficiency
  • S-Band: 10 to 20 point increase
  • X-Band: 8 to 15 point increase

2-18GHz 20W NDPA Die Size:
5.34 (X) x 5.00 (Y) = 26.7 mm²
Conclusion

• A reconfigurable power amplifier MMIC has been presented
• The circuit is reconfigurable between S-band and X-band
• A self adjusting bias circuit that allows series and shunt elements to be reconfigured without the use of DC blocks
• The amplifier operates with 2 complementary control lines and 2 power supply lines
• Demonstrated improved performance over the operating bands and reduced die compared to a state of the art wideband PA MMIC with similar gain and output power