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

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IMAPS2019 - 05/7/2019

Talk Outline

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

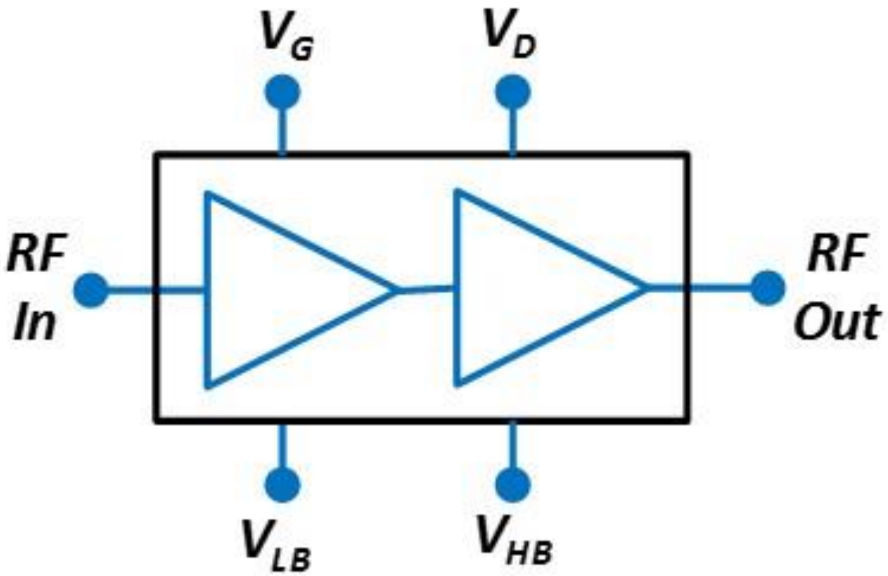
Introduction

- 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

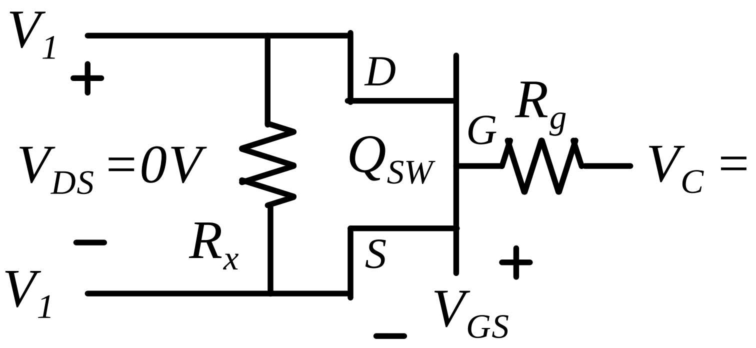
- Criteria for success compared to existing approaches
  - Better performance over the bands of interest
  - Smaller die area
  - Out of band rejection
- Amplifier design goals

Design Parameter	S-Band	X-Band
Frequency Bands (GHz)	3.0-3.5	9.0-11.0
Linear Gain (dB)	> 20	> 20
Output Power (W)	> 25 W	> 25 W
Efficiency (%)	> 60 %	> 55 %
Control Voltages (V)	0 / -30	-30 / 0



Reconfigurable Elements

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

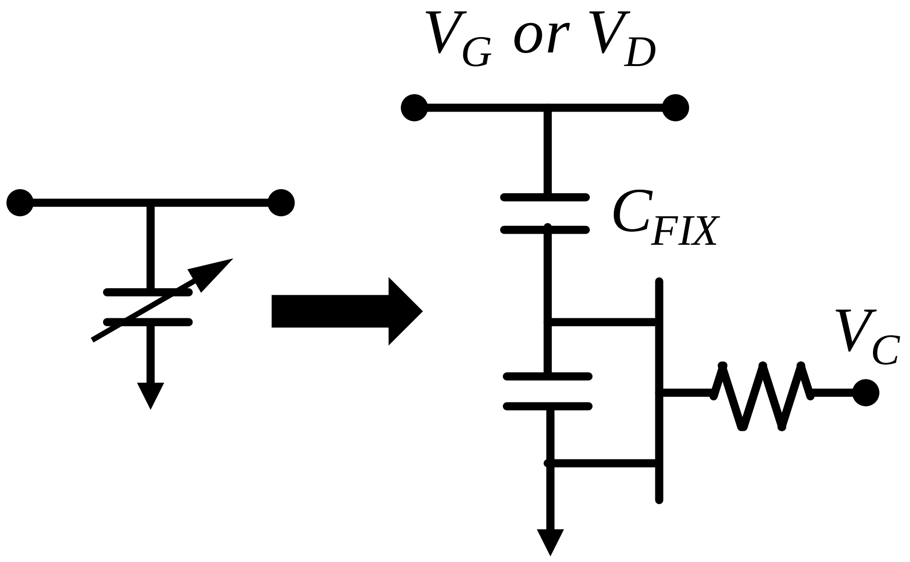


$$V_C = \begin{cases} V_{GS} = V_C - V_1 = 0\text{ V}, \textit{On-State} \\ V_{GS} = V_C - V_1 << V_P, \textit{Off-State} \end{cases}$$

- 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

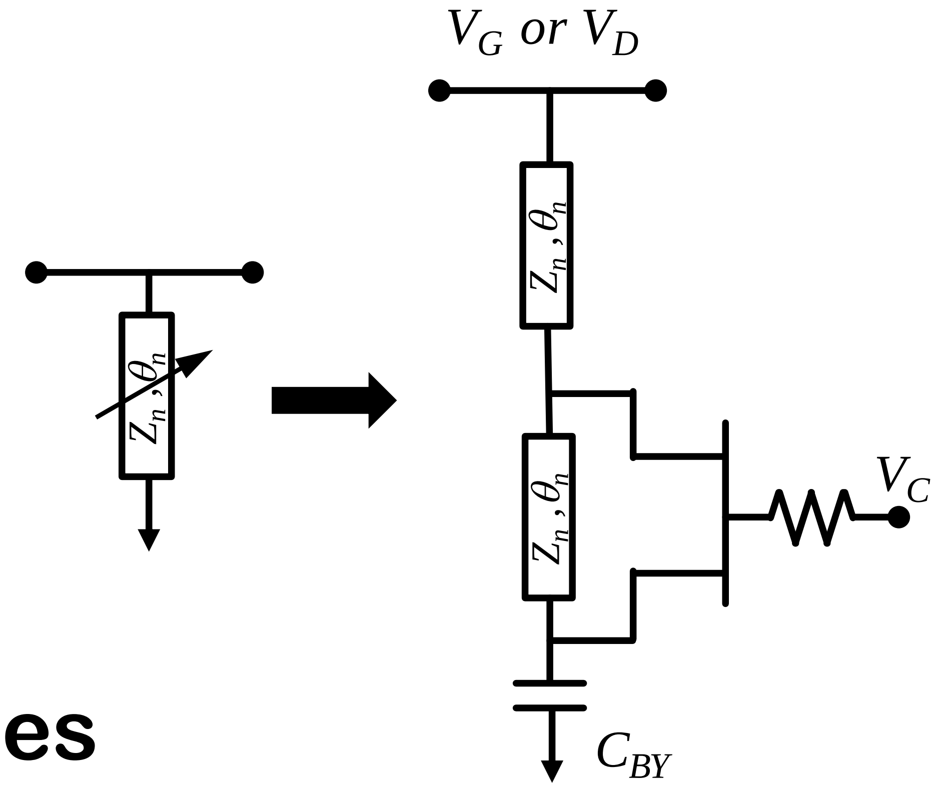
Reconfigurable Elements

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



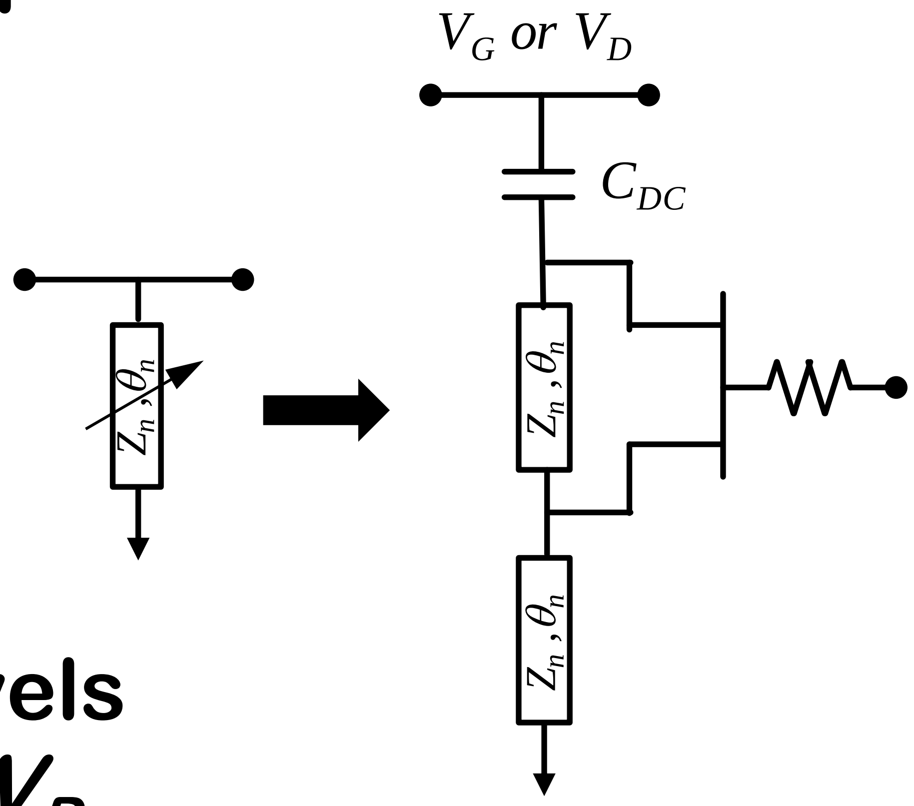
Reconfigurable Elements

- 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



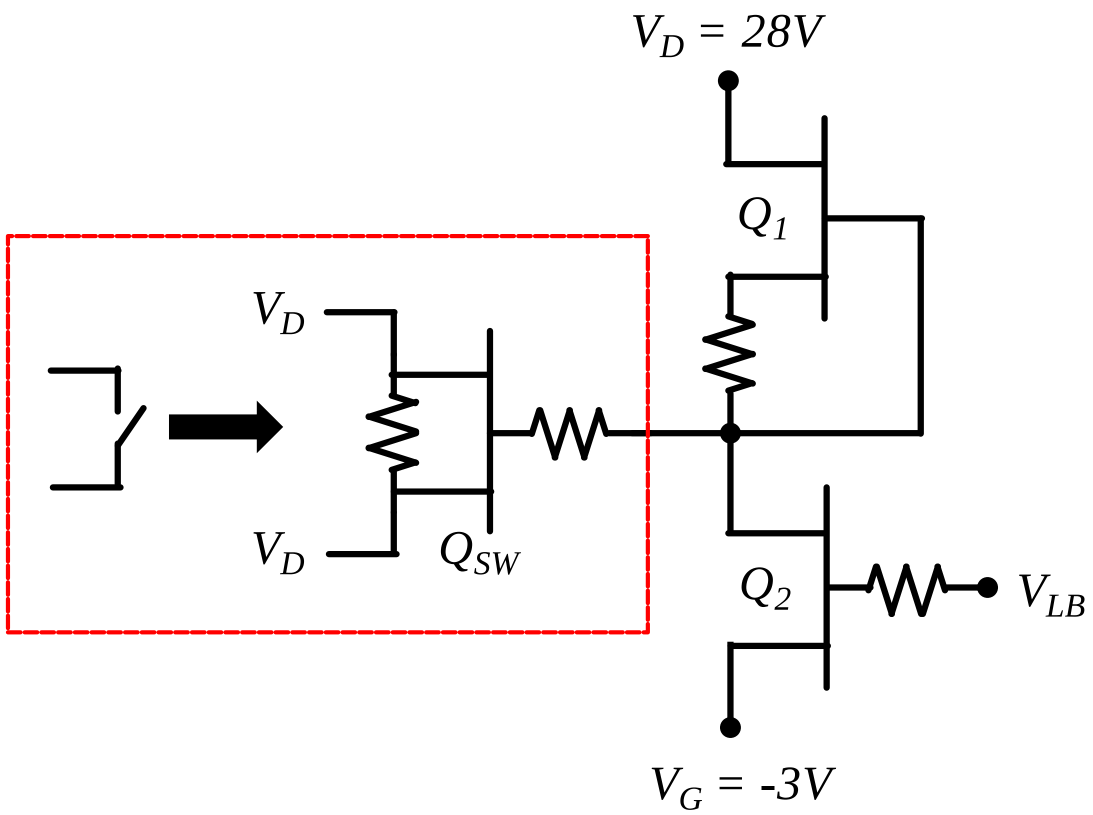
Reconfigurable Elements

- 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
  - $C_{DC} >>$ 53pF !!!!
- 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

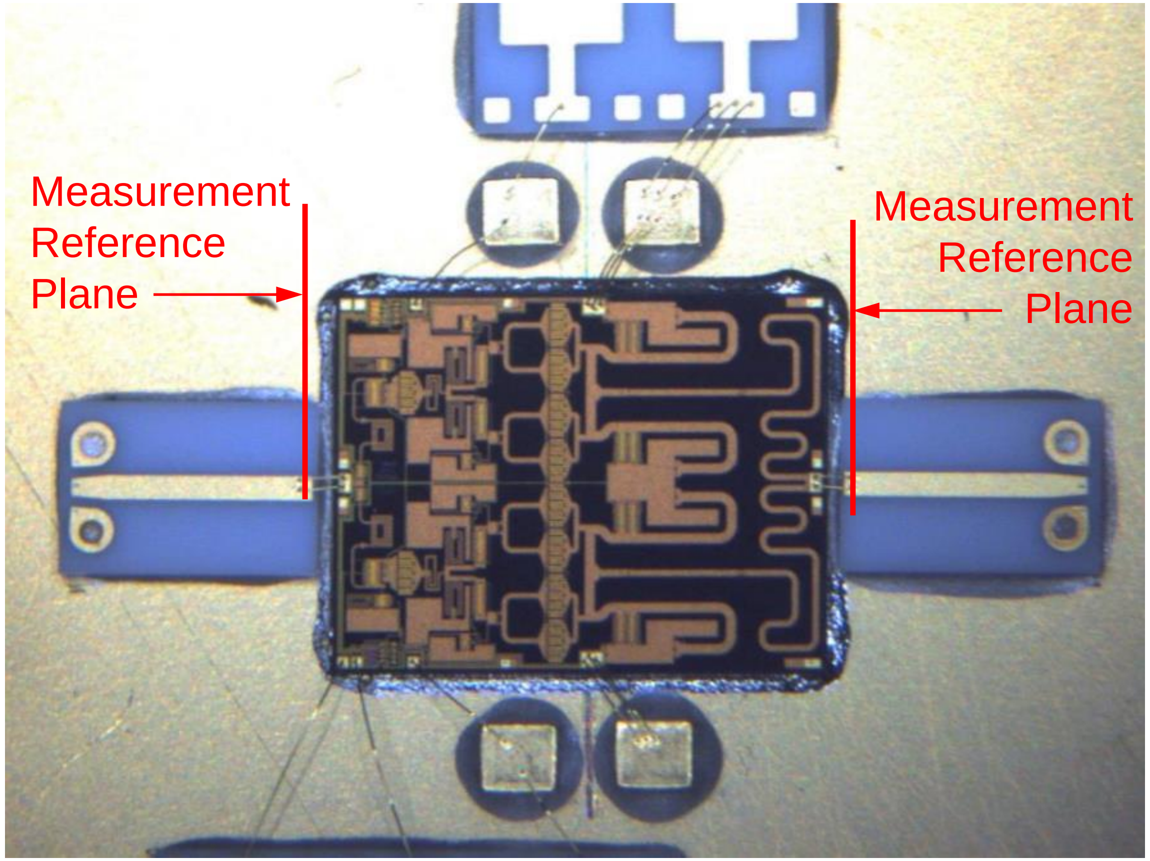


Circuit Design

- MMIC Technology – Qorvo's Production Released GaN15
  - 0.15μm Gate Length (Amp & Switch)
  - Up to 28V Operation
  - Ft / Fmax = 38GHz / 140GHz
  - R_{ON} = 1.6Ω-mm
  - C_{OFF} = 0.25pF/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

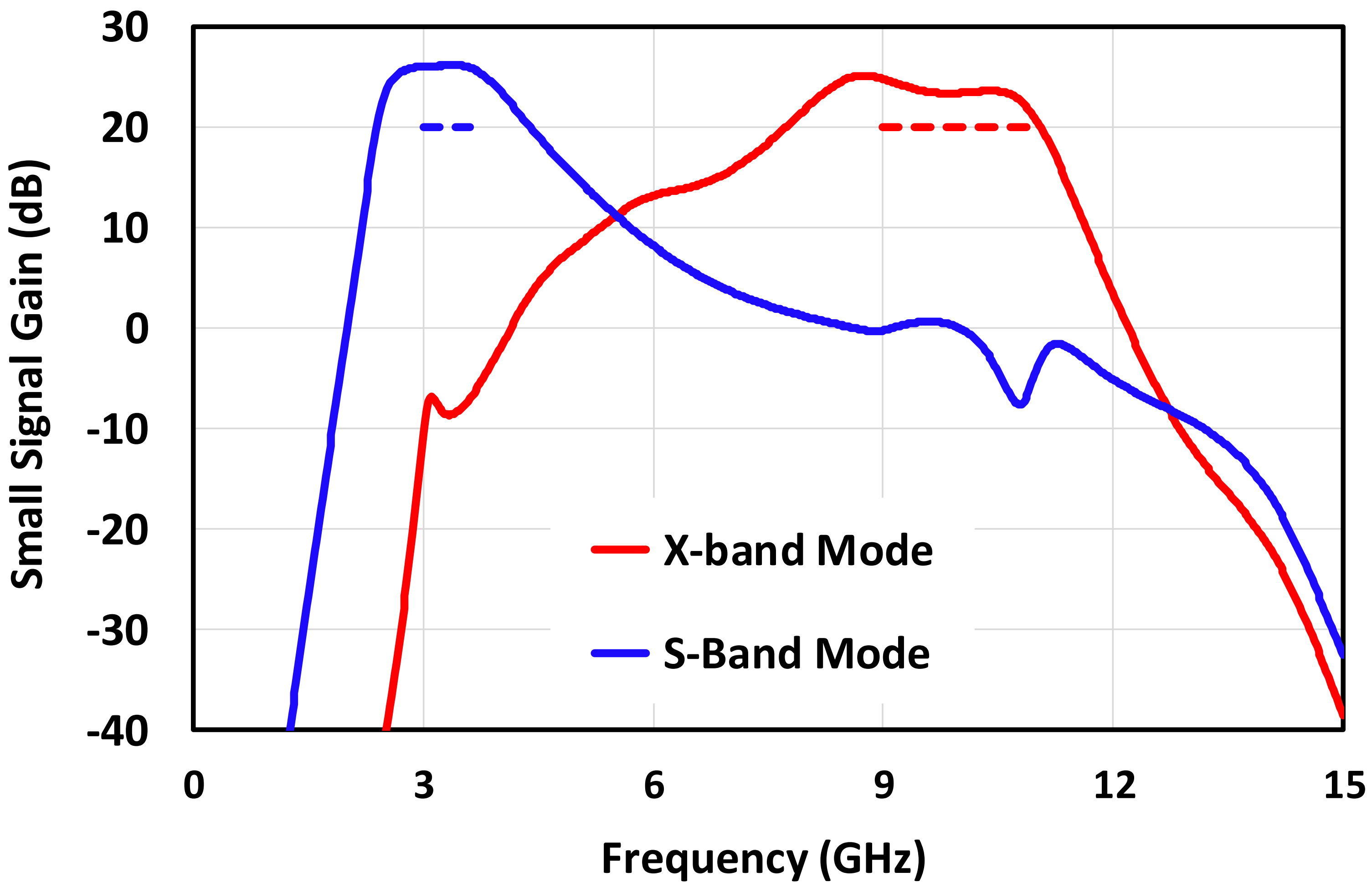
Circuit Design

- 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 mm^2
- Reconfigurable elements
  - Resistors
  - Capacitors
  - Line lengths



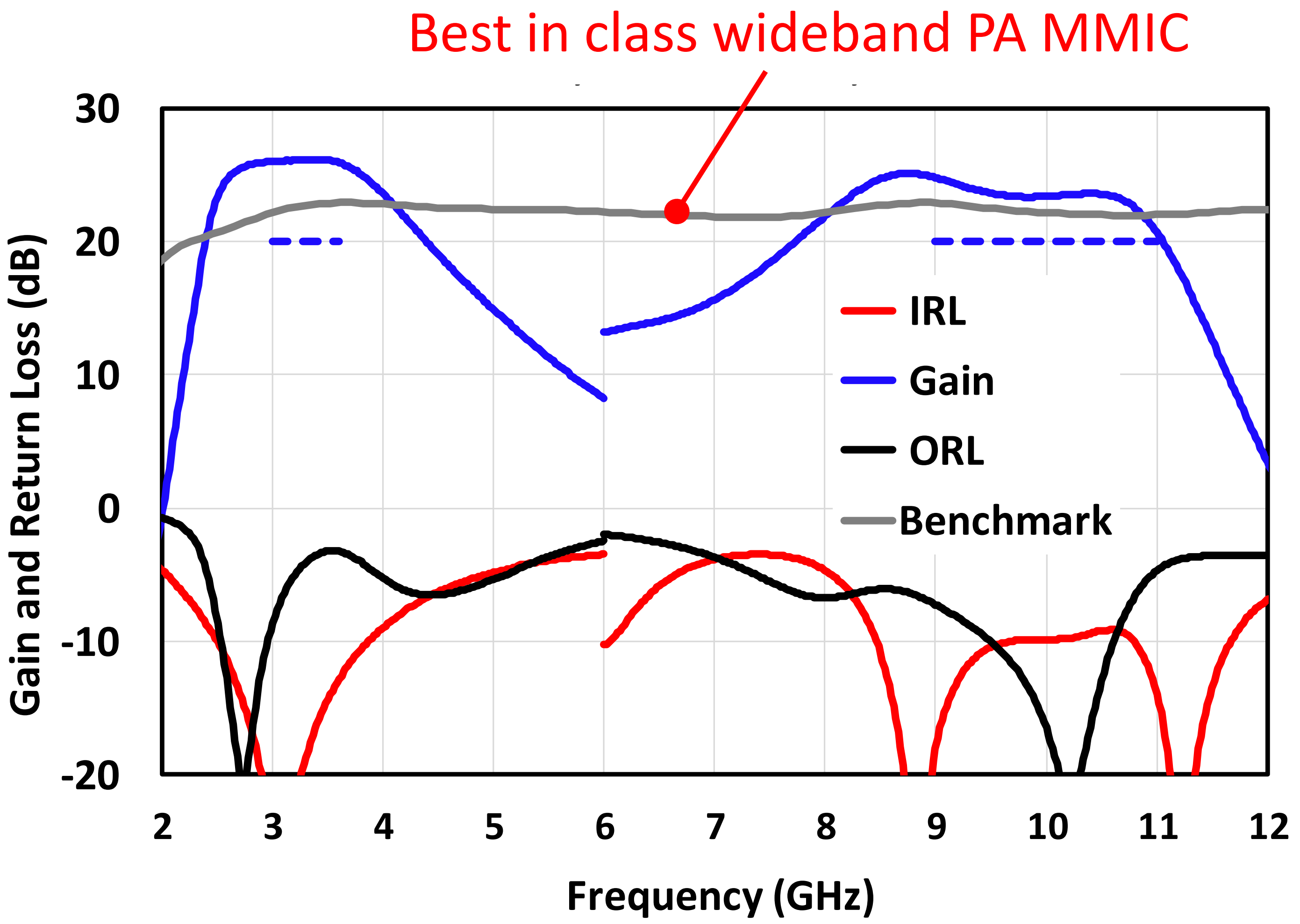
Measured Performance

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



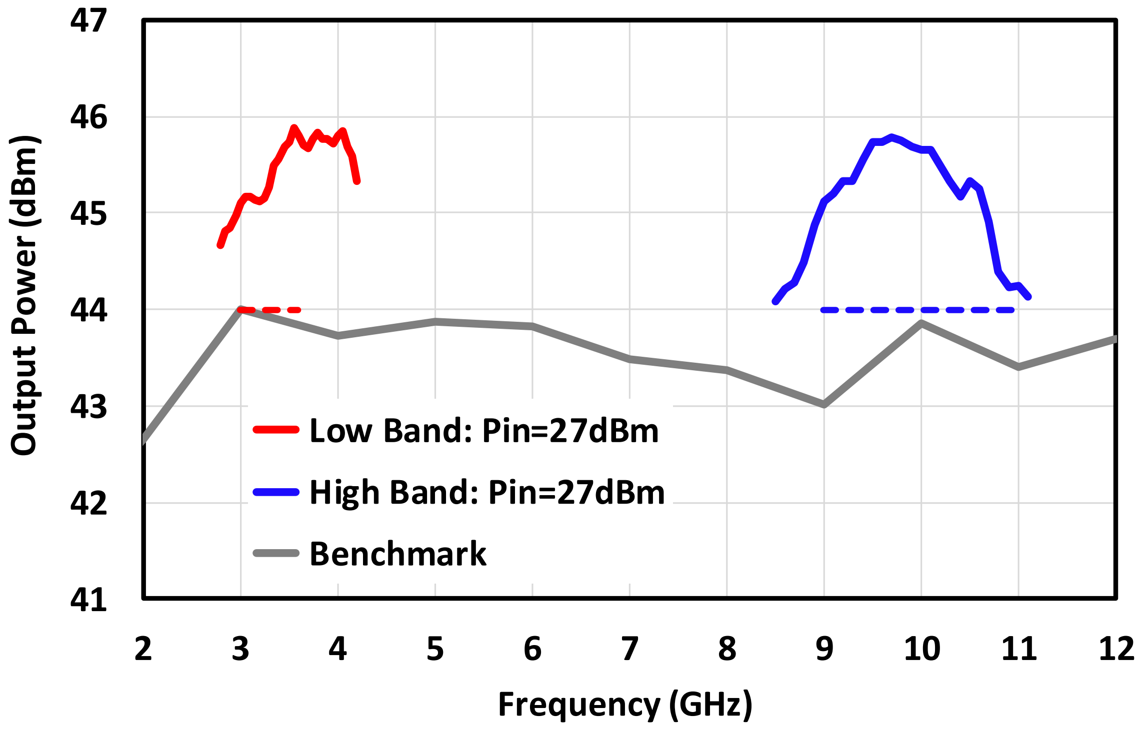
Measured Performance

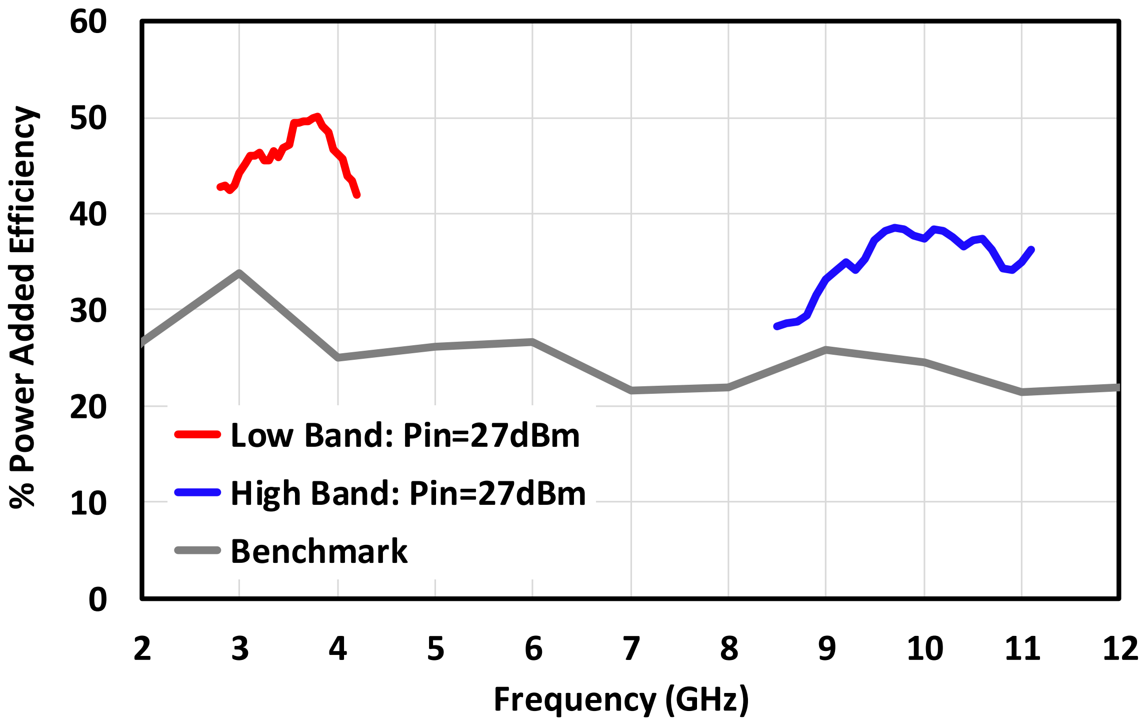
- **Linear Gain and return loss**
  - $V_D = 28V$
  - $I_{DQ} = 500mA$
  - $V_C = 0V / -30V$



Measured Performance

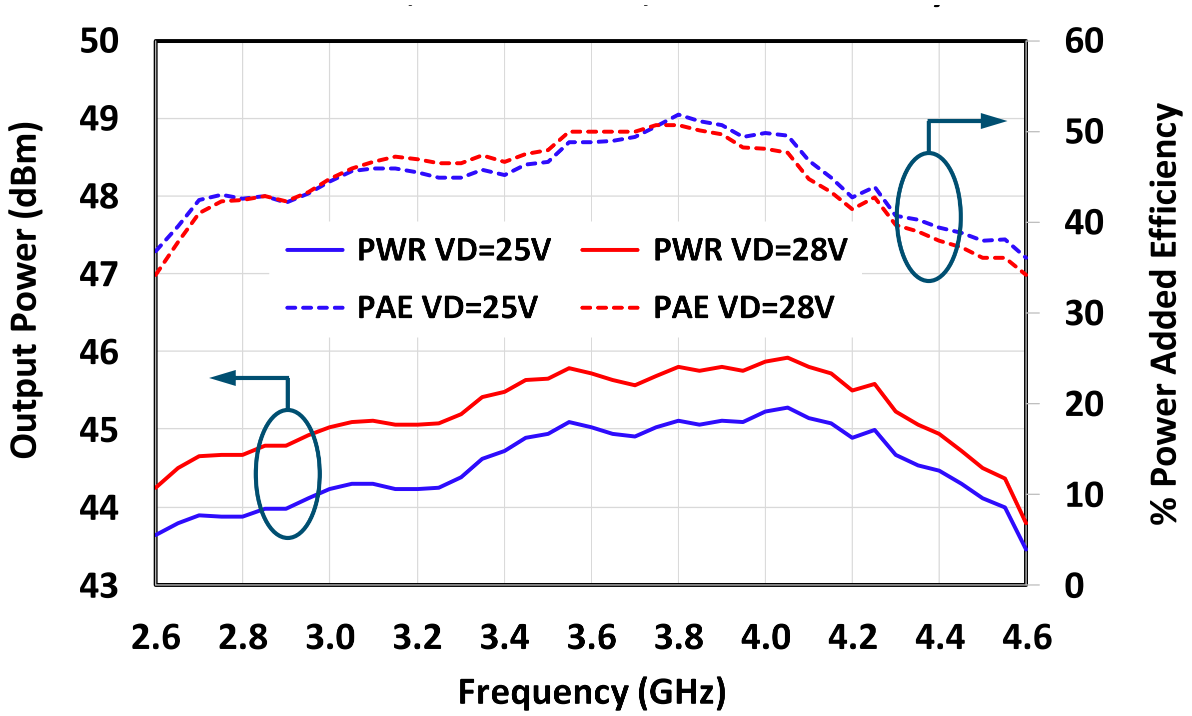
- Output Power and Efficiency: Pulsed V_D, 10μs / 10% duty

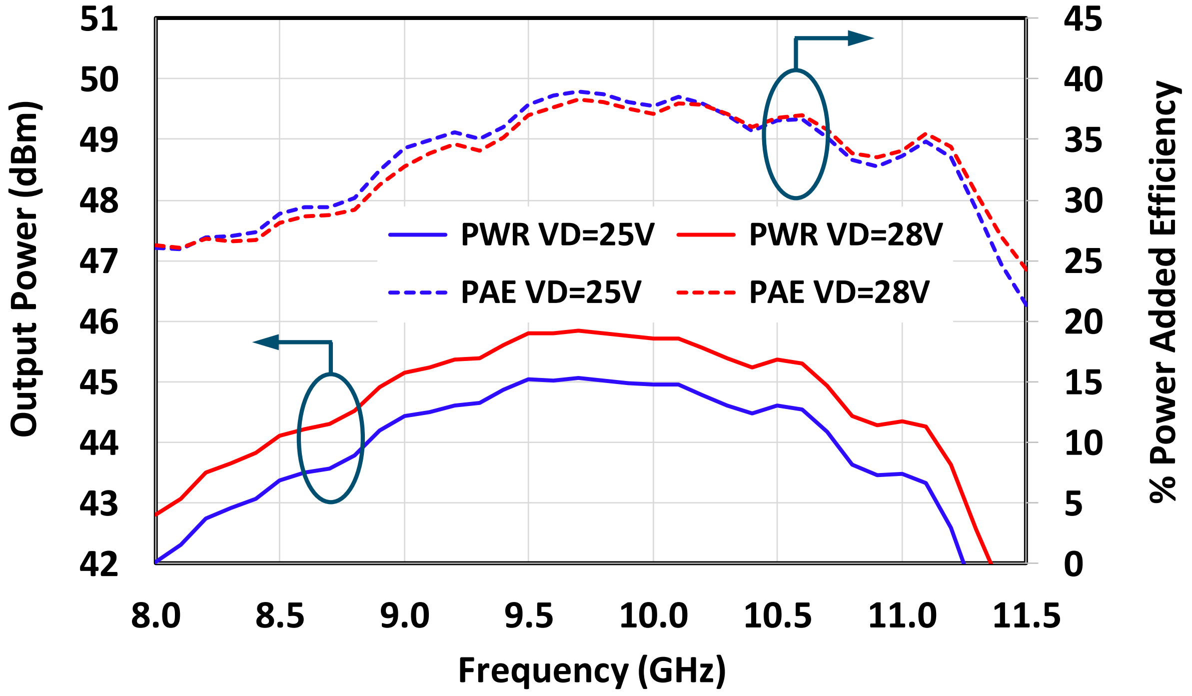




Measured Performance

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

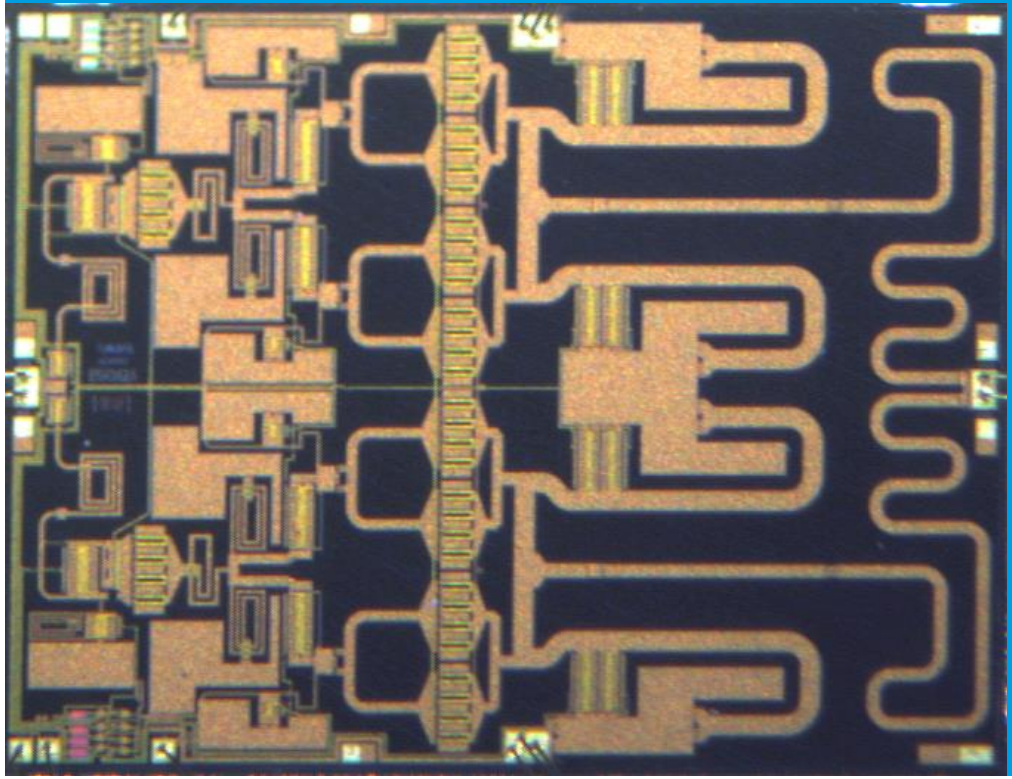




Measured Performance

- 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 mm^2



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