A Decade Bandwidth
90 W GaN HEMT Push-Pull Power Amplifier for VHF / UHF Applications

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Agenda

1. Motivation
2. RFMD GaN Technology overview
3. Multi-decade band PA topologies
4. 45 W Unit Amplifier design and performance
5. 90 W Module design and performance
6. Summary
Motivation

Milcom and Public Mobile Radio Amplifiers

PMR Portable Radio

JTRS Radio

Market Drivers

- Improve battery life
- Multi-standards for inter-operability
- Wide-band architecture
- Improve reliability
- Leverage COTS components

Why GaN?

- Higher efficiency
  - Reduce heatsink requirements, smaller size
  - Increase battery life
- Wide bandwidth
  - Replace 3 or more amplifiers with 1 amplifier
  - Improve engineering efficiency
Power Frequency ($PF^2$) Limit

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>GaAs</th>
<th>GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_g$ (eV)</td>
<td>1.1</td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td>$v_s \times 10^7$ (cm/s)</td>
<td>0.7</td>
<td>0.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

$P_{\text{max}} \propto \frac{E_g^4 v_s^2}{F^2}$
Power Bandwidth Limit

- High power density (V, I) enables high impedance, high power density
- Low pF/W enables broadband

Wideband HPA’s covering multiple communication bands

\[
\frac{F_{\text{high}} - F_{\text{low}}}{F_o} = \frac{\pi}{-Q_L \ln(\Gamma)}
\]
RFMD GaN HEMT Process

Process Details:
- AlGaN/GaN HFET on 3” SiC
- 0.5µm gate length
- Dual field plate technology
  - Gate connected
  - Source connected
- Ti / Al / Ni / Au ohmic contact
- Ni / Au Gate

For additional detail: Shealy et al., IEEE BCTM 2009, p146-153
GaN Transistor Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idss</td>
<td>800</td>
<td>mA/mm</td>
</tr>
<tr>
<td>Id-max</td>
<td>900</td>
<td>mA/mm</td>
</tr>
<tr>
<td>Peak gm</td>
<td>225</td>
<td>mS/mm</td>
</tr>
<tr>
<td>Vp</td>
<td>-4</td>
<td>V</td>
</tr>
<tr>
<td>V_{br(GD)}</td>
<td>&gt;150</td>
<td>V</td>
</tr>
<tr>
<td>f_t</td>
<td>10.5</td>
<td>GHz</td>
</tr>
<tr>
<td>f_{max}</td>
<td>16</td>
<td>GHz</td>
</tr>
<tr>
<td>Power Density</td>
<td>8.4</td>
<td>W/mm</td>
</tr>
<tr>
<td>Peak Power</td>
<td>18.6</td>
<td>W</td>
</tr>
<tr>
<td>Peak Drain Eff</td>
<td>71</td>
<td>%</td>
</tr>
<tr>
<td>Optimum load</td>
<td>31.4+j46.1</td>
<td>Ω</td>
</tr>
</tbody>
</table>

[1] Class AB Bias: Vds=48V, Ids = 20 mA/mm
[2] frequency = 2.14 GHz;
# Broadband PA Topologies

<table>
<thead>
<tr>
<th>Topology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Resistive FB        | - lumped implementation  
                      - good S22                                                                  | - O/P not designed for Zopt  
                      - Tuning Zload affects gain flatness and S11  
                      - Rf Pdiss / leakage issues  
                      - Rf Layout issues                                                             |
| RLC Lossy Match     | - Simple / lumped design  
                      - output optimized for Zopt  
                      - Input optimized for gain flatness  
                      - All-pass network at input implies excellent S11 | - Lumped circuit, so thermal design is critical |
| Distributed Amp     | - best bandwidth and gain  
                      - dissipation spread out                                                    | - Zload optimization for each cell is complicated  
                      - poor efficiency  
                      - implementation feasibility issues                                       |
45W Amplifier Performance

- Uses 6.6mm device periphery
- Designed for 25Ω source and load impedance
- Frequency target is 30-1000MHz
- Multi-chip module approach with GaAs passive die and GaN HEMT active die.
- This minimizes SiC die area as the matching circuits are large at low GHz frequencies and below.

- Dies are packaged in a Cu package
- Performance
  - \( V_{dq} = 50V, I_{dq} = 130mA \)
  - Bandwidth: \( 20 – 1000 \text{ MHz} \)
  - Gain: \( 17.5 \pm 1 \text{ dB} \)
  - Input return loss: < 11 dB
  - Output power: 50.3 W at 512 MHz
  - PAE: 70% at 512 MHz
PA Module Topology

- Two 25Ω matched unit amplifiers are combined together.
- Broadband 45W amplifiers are first designed for operating in a 25Ω system.
- Two such PAs are combined using a broadband 1:1 Balun at input and output to convert the differential 25Ω impedance to a 50Ω system.
- Gate bias feeds isolated through a resistor, and connected together.
- The high-Q bias feed inductors at drain of each device are connected together.
- 300Ω ferrite (at 100 MHz) at the drain bias feed to extend low frequency performance.
Balun Design

- Broadband coiled balun is formed by winding a rigid coax around a ferrite rod.
- Coiling increases self-inductances and the ferrite improves low frequency cut-off.
- Advances in low-loss ferrites make them suitable for GHz range.
- A 43 material ferrite rod from Fair-Rite corp with 5mm diameter is used - provides high permeability at low frequency and low loss at high frequency.
- 50Ω coax with 0.22dB/ft loss, that can handle 124W at 500MHz is used.
- The center and outer conductor are connected to unbalanced signal and ground at one end and to the differential balanced signal at the other.
- The ferrite forces equal and opposing current at the inner and outer conductor and isolates the 180° signal from the input ground at low frequency.
- For high frequency isolation the coax length is quarter wave long at the upper cut-off frequency.
- This results in a 4 turn coil for the chosen ferrite diameter.
Balun performance

- Measured performance
  - Insertion loss (back-back) : 0.34 dB
  - Insertion loss per balun : 0.17 dB
  - Return loss: better than 20 dB
PA Module

- 2 x 2 inch size
- Uses 2 x 45W devices in push-pull configuration
- Each device is matched to 25Ω at the input and drives a 25Ω load
- Drain is biased separately through a 160nH high current air coil inductor and a 300Ω ferrite.
- 25Ω microstrip traces with broadband capacitors for DC blocking connect the devices to the differential end of the balun.
- A similar coaxial balun is used at the input to split the signal to the two devices.
- The backside of the devices and PCB are soldered to the Copper carrier and mounted on an Aluminum heatsink with fins for improved thermal performance.
90 W Module Small Signal performance

- Bandwidth: 20 – 1100 MHz
- Gain: 17 – 19 dB
- Input return loss: 12 dB
- $V_{dq} = 50V$
- $I_{dq} = 265mA$ (class-AB)
90 W Module CW performance

- Vdq = 50V, Idq = 265mA
- Frequency: 100 – 1000 MHz
- Gain over band: 15.1 – 16.3 dB
- Output power: 82 – 107.5 W
- Efficiency: 51.9 – 73.8 %
90 W Module CW performance

- $V_{dq} = 50V$, $I_{dq} = 265mA$
- Frequency: 512 MHz
- $P_{out} : 104.2$ W
- PAE: 67.4%
- Drain efficiency: 69.4%
Two Tone Linearity Performance

- Pout : 52 W
- IMD3 : 35 dBc
- Drain efficiency : 41 %

- Vdq = 50V
- Idq = 540 mA
- Fc = 512 MHz
- Tone spacing = 1MHz
Summary

• Emerging SDR architectures require wideband, high power amplifiers with high efficiency, compact size and low cost

• GaN-on-SiC technology adoption continues for high power commercial and military applications

• We’ve demonstrated a 90W, 100 – 1000 MHz, 50V GaN HEMT PA module with >51% drain efficiency over the band

<table>
<thead>
<tr>
<th>Output power (W)</th>
<th>Bandwidth (MHz)</th>
<th>Gain (dB)</th>
<th>Supply Voltage (V)</th>
<th>Drain Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>82–107.5</td>
<td>100-1000</td>
<td>15.1-16.3</td>
<td>50</td>
<td>51.9-73.8</td>
</tr>
</tbody>
</table>

• Future work:
  - improving efficiency and linearity performance
Q & A
Thank You