GaN High Power Amplifiers: Optimal Solutions Addressing Pico to Macro BTS Demands

David Runton; Engineering Director, PBBU
David Aichele; Marketing Director, PBBU
Cellular Base Transceiver Station (BTS)

High efficiency, GaN high power amplifiers for 3G & 4G Networks

**BTS Market Drivers**
- Linear PA for 3G and 4G
- Increased data demand (more bandwidth)
- Reduce size and weight
- High reliability
- Lower system cost

**Why GaN?**
- High peak efficiency
  - Peak efficiency ~70%
  - Correlation with high power density
- High temperature operation
- Multi-band, multi-standard linear PA
- Wide signal bandwidth operation
- High efficiency PA techniques
- Small form factor

**Product Platforms**
- Cellular Base Transceiver Station (BTS)
  - High efficiency, GaN high power amplifiers for 3G & 4G Networks
Advantages & Benefits

- **Scale**
  - Build GaN in existing GaAs fabs—scale-driven cost

- **Linearity and Bandwidth**
  - Improved performance—especially for LTE/WiMAX

- **Green**
  - More power efficient per mW of RF power

- **Power and Size**
  - More RF power per mm²

- **Opex/Capex**
  - Lower BOM and operating costs = reduced total cost of ownership

---

GaN Offers Superior Output Power Capability

[Diagram showing the superiority of GaN in terms of output power capability compared to other technologies like SiC MESFET, Silicon, GaAs HBT, and GaAs HEMT at various frequencies.]
## RFMD® High Power GaN Products

<table>
<thead>
<tr>
<th><strong>UPT</strong></th>
<th><strong>PowerIC</strong></th>
<th><strong>MPT</strong></th>
<th><strong>BPT</strong></th>
<th><strong>Switch</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="RFMD RF393X" /></td>
<td><img src="image" alt="RFMD RF3826" /></td>
<td><img src="image" alt="RFMD RF3928" /></td>
<td><img src="image" alt="RFMD RFG1M20180" /></td>
<td><img src="image" alt="RFMD RFSW2100" /></td>
</tr>
<tr>
<td><strong>Product Update</strong></td>
<td><strong>Product Update</strong></td>
<td><strong>Product Update</strong></td>
<td><strong>Product Update</strong></td>
<td><strong>Product Update</strong></td>
</tr>
<tr>
<td>RF393X released</td>
<td>RF3826 released</td>
<td>RF3928 released</td>
<td>RFG1M20180 released</td>
<td>RFSW2100 Sampling</td>
</tr>
<tr>
<td>RF393XD Die released</td>
<td>RFHA1000 released</td>
<td>RF3928B released</td>
<td>RFG1M09180 released</td>
<td></td>
</tr>
<tr>
<td>RF394X Sampling</td>
<td>RFHA1001 released</td>
<td>RFHA1023 released</td>
<td>RFG1M20090 released</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RFHA1003 released</td>
<td>RFHA1020 released</td>
<td>RFG1M09090 released</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RFHA1006 released</td>
<td>RFHA1025 released</td>
<td>RFHA1042 released</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RF3833 Sampling</td>
<td>RFHA1043 released</td>
<td>RFHA1048 released</td>
<td></td>
</tr>
<tr>
<td><strong>Target Markets</strong></td>
<td><strong>Target Markets</strong></td>
<td><strong>Target Markets</strong></td>
<td><strong>Target Markets</strong></td>
<td><strong>Target Markets</strong></td>
</tr>
<tr>
<td>General Purpose</td>
<td>General Purpose</td>
<td>ATC Radar</td>
<td>BTS Cellular</td>
<td></td>
</tr>
<tr>
<td>UHF L</td>
<td>Military Comms</td>
<td>Civilian Radar</td>
<td>Commercial</td>
<td></td>
</tr>
<tr>
<td>S-Band Radar</td>
<td>PMR Comms</td>
<td>Military Radar</td>
<td>Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Military Comms</td>
<td>Electronic Warfare</td>
<td>L-Band Radar</td>
<td>Military Comms</td>
<td></td>
</tr>
<tr>
<td>Radar</td>
<td>Radar</td>
<td>S-Band Radar</td>
<td>PMR Comms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Electronic Warfare</td>
<td></td>
</tr>
<tr>
<td><strong>Summary</strong></td>
<td><strong>Summary</strong></td>
<td><strong>Summary</strong></td>
<td><strong>Summary</strong></td>
<td><strong>Summary</strong></td>
</tr>
<tr>
<td>30 to 140W CW 48V unmatched GaN FETs tunable DC to 3.5Ghz</td>
<td>10 to 40W input matched broadband amplifiers 28V to 48V, constant gain</td>
<td>250 to 500W PW 36V to 65V matched for L-Band and S-Band frequencies</td>
<td>50W to 180W input matched broadband amplifiers 48V</td>
<td>30W &amp; 50W P0.1dB DC to 6GHz SPDT GaN Switch</td>
</tr>
</tbody>
</table>
**Product Description**

The RF393X series consist of 48 V high power discrete GaN amplifier designed for commercial wireless, military, industrial, and general purpose applications. Ease of integration is accomplished through simple, optimized matching networks external to the hermetic, flanged package providing peak power, wideband gain and power performance in a single amplifier.

**Product Features**

- High Power Density > 6W/mm
- 48V bias operation (works 20V to 48V)
- High terminal impedance – tunable wide BW
- Peak Drain Efficiency ~65% @ 2.1GHz

**Specifications**

<table>
<thead>
<tr>
<th>UPT Part Number</th>
<th>Freq (GHz)</th>
<th>P3dB @ 900MHz (W)</th>
<th>SS Gain @ 0.9GHz (dB)</th>
<th>DE 0.9GHz (%)</th>
<th>P3dB 2.1GHz (W)</th>
<th>SS Gain @ 2.1GHz (dB)</th>
<th>DE 2.1GHz (%)</th>
<th>Vd (V)</th>
<th>Pkg</th>
<th>Prod Status</th>
<th>Export Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF3931</td>
<td>DC-3.5</td>
<td>50</td>
<td>20</td>
<td>70</td>
<td>45</td>
<td>15</td>
<td>65</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RF3932</td>
<td>DC–3.5</td>
<td>78</td>
<td>21</td>
<td>73</td>
<td>75</td>
<td>14</td>
<td>65</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>3A001b.3.a</td>
</tr>
<tr>
<td>RF3933</td>
<td>DC–3.5</td>
<td>116</td>
<td>21</td>
<td>70</td>
<td>100</td>
<td>14</td>
<td>60</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>3A001b.3.a</td>
</tr>
<tr>
<td>RF3934</td>
<td>DC-3.5</td>
<td>145</td>
<td>21</td>
<td>75</td>
<td>140</td>
<td>13</td>
<td>60</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>3A001b.3.a</td>
</tr>
</tbody>
</table>

RF393XD Die Version Available
RFMD® GaN Broadband Power Transistors (BPT)

**Product Description**

The BPT series is optimized for commercial infrastructure, military communication and general purpose amplifier applications. Designed for high peak-to-average ratio and pulsed applications, these high performance amplifiers achieve high efficiency and flat gain over a broad frequency range in a single amplifier design. Simple, optimized matching networks external to the ceramic flanged package provide wideband gain, efficiency, and linear performance in a single amplifier.

**Product Features**

- High terminal impedance, wideband performance
- Applicable for high efficiency techniques, such as Doherty & Envelope tracking
- High peak power and efficiency

**Specifications**

<table>
<thead>
<tr>
<th>BPT Part #</th>
<th>Freq (GHz)</th>
<th>Peak Power (W)</th>
<th>SS gain (dB)</th>
<th>ACP @ 7.5dB PAR (dBc)</th>
<th>Drain Eff (%)</th>
<th>Vd (V)</th>
<th>Package</th>
<th>Samples</th>
<th>Prod. Status</th>
<th>Export</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFG1M20090</td>
<td>1.8 - 2.2</td>
<td>90</td>
<td>15</td>
<td>-36</td>
<td>36</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFG1M20180</td>
<td>1.8 - 2.2</td>
<td>180</td>
<td>15</td>
<td>-38</td>
<td>31</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFG1M09090</td>
<td>0.7 - 1.0</td>
<td>90</td>
<td>20</td>
<td>-34</td>
<td>38</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFG1M09180</td>
<td>0.7 - 1.0</td>
<td>180</td>
<td>20</td>
<td>-33</td>
<td>40</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA1042</td>
<td>0.2 - 0.45</td>
<td>125</td>
<td>19</td>
<td>-35</td>
<td>35</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA1043</td>
<td>1.2 – 1.85</td>
<td>125</td>
<td>15</td>
<td>-35</td>
<td>35</td>
<td>48</td>
<td>RF465-2</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
</tbody>
</table>
**RFMD® GaN Optimized for Linearity**

**GaN 1**
- High power density - up to 8 W/mm
- High peak drain efficiency
- High breakdown voltage >400V

**GaN 2**
- High linearity - 6 dB improvement over GaN 1
- Low Cgd variation vs. drain voltage
- High breakdown voltage >300V

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GaN 1</th>
<th>GaN 2</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{D-MAX}$</td>
<td>1000</td>
<td>550</td>
<td>mA/mm</td>
</tr>
<tr>
<td>Gate Pinch off</td>
<td>-3.5</td>
<td>-1.4</td>
<td>V</td>
</tr>
<tr>
<td>$g_m$</td>
<td>225</td>
<td>250</td>
<td>mS/mm</td>
</tr>
<tr>
<td>$V_{BR(GD)}$</td>
<td>&gt;450</td>
<td>&gt;350</td>
<td>V</td>
</tr>
<tr>
<td>MIMCAP</td>
<td>135</td>
<td>135</td>
<td>pF/mm</td>
</tr>
<tr>
<td>$R_{TFR}$</td>
<td>100</td>
<td>100</td>
<td>Ω/□</td>
</tr>
<tr>
<td>$R_{ISO}$</td>
<td>460</td>
<td>800</td>
<td>Ω/□</td>
</tr>
<tr>
<td>$F_T$</td>
<td>11</td>
<td>9</td>
<td>GHz</td>
</tr>
<tr>
<td>$F_{MAX}$</td>
<td>18</td>
<td>&gt;20</td>
<td>GHz</td>
</tr>
</tbody>
</table>
RFMD® GaN-2 Unmatched Power Transistors (UPT)

Product Description
The RFHA394X series consist of 48 V high power discrete GaN amplifier designed for commercial wireless, military, industrial, and general purpose amplifier applications. Ease of integration is accomplished through simple, optimized matching networks external to the hermetic, flanged package providing linear power, wideband gain and power performance in a single amplifier.

Product Features
- High Power Density ~2.5W/mm
- 48V bias operation (works 20V to 48V)
- High terminal impedance – tunable wide BW
- Peak Drain Efficiency ~60% @ 2.1GHz
- Excellent linearity

Specifications

<table>
<thead>
<tr>
<th>UPT Part #</th>
<th>Freq (GHz)</th>
<th>P3dB @ 900MHz (W)</th>
<th>SS Gain 0.9GHz (dB)</th>
<th>DE 0.9GHz (%)</th>
<th>P3dB 2.1GHz (W)</th>
<th>SS Gain 2.1GHz (dB)</th>
<th>DE 2.1GHz (%)</th>
<th>Vd (V)</th>
<th>Pkg</th>
<th>Samples Status</th>
<th>Prod. Status</th>
<th>Export Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFHA3942</td>
<td>DC-4</td>
<td>35</td>
<td>22</td>
<td>65</td>
<td>35</td>
<td>15</td>
<td>60</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>Nov’12</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA3944</td>
<td>DC-4</td>
<td>65</td>
<td>22</td>
<td>65</td>
<td>65</td>
<td>15</td>
<td>60</td>
<td>48</td>
<td>RF360-2</td>
<td>Now</td>
<td>Nov’12</td>
<td>3A001b.3.a</td>
</tr>
</tbody>
</table>

RFHA1101D & RFHA3942D Die Version Available

RF3932 IM3 (40W @ -30dBc)

RF3932 IM3 (40W @ -30dBc)
RFMD® GaN Broadband PowerICs (PICs)

Product Description
GaN PowerIC devices are wideband Power Amplifier designed for CW and pulsed applications such as wireless infrastructure, RADAR, two way radios and general amplifiers. These amplifiers achieve high efficiency, flat gain and large instantaneous bandwidth in a single amplifier design. External output match offers flexibility of further optimizing power and efficiency for any sub-band w/in band.

Product Features
- 28V & 48V Operation
- 10 to 80W CW
- Small form factor package, 50ohm Input
- Broadband power/gain performance

Specifications

<table>
<thead>
<tr>
<th>PICs PN</th>
<th>Inst BW (GHz)</th>
<th>P3dB (W)</th>
<th>SS Gain (dB)</th>
<th>PAE (%)</th>
<th>Vd (V)</th>
<th>Idq (mA)</th>
<th>Package</th>
<th>Samples</th>
<th>Prod Status</th>
<th>Export</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF3826</td>
<td>0.03 - 2.5</td>
<td>10</td>
<td>11</td>
<td>40</td>
<td>28</td>
<td>55</td>
<td>AIN SOIC-8</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA1000</td>
<td>0.03 – 1.0</td>
<td>15</td>
<td>18</td>
<td>60</td>
<td>28</td>
<td>88</td>
<td>AIN SOIC-8</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA1003</td>
<td>0.03 - 0.512</td>
<td>10</td>
<td>19</td>
<td>70</td>
<td>28</td>
<td>55</td>
<td>AIN SOIC-8</td>
<td>Now</td>
<td>Now</td>
<td>EAR99</td>
</tr>
<tr>
<td>RF3833</td>
<td>0.03 - 2.0</td>
<td>25</td>
<td>13</td>
<td>45</td>
<td>48</td>
<td>88</td>
<td>RF270-10</td>
<td>Nov ’12</td>
<td>Jan ’13</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHA1004</td>
<td>0.7-2.5</td>
<td>23</td>
<td>12</td>
<td>45</td>
<td>48</td>
<td>88</td>
<td>RF270-10</td>
<td>Nov ’12</td>
<td>Feb ’13</td>
<td>EAR99</td>
</tr>
<tr>
<td>RFHAxxxx</td>
<td>0.05-1</td>
<td>80</td>
<td>12.5</td>
<td>50</td>
<td>48</td>
<td>300</td>
<td>RF320-8</td>
<td>Jan ’13</td>
<td>TBD</td>
<td>EAR99</td>
</tr>
</tbody>
</table>
Power Bandwidth Limit

- High power density (V, I) enables high impedance
- Low pF/W enables broadband Wideband HPA’s covering multiple communication bands

\[
\frac{F_{\text{high}} - F_{\text{low}}}{F_0} = \frac{\pi}{-Q_L \ln(\Gamma)}
\]
### Broadband topologies

<table>
<thead>
<tr>
<th>Topology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistive FB</td>
<td>- lumped implementation&lt;br&gt;- good S22</td>
<td>- Output not designed for Zopt&lt;br&gt;- Tuning Zload affects gain flatness and S11&lt;br&gt;- Rf Pdiss / leakage issues</td>
</tr>
<tr>
<td>RLC Lossy Match</td>
<td>- Simple/lumped design&lt;br&gt;- output optimized for Zopt&lt;br&gt;- Input optimized for gain&lt;br&gt;- All-pass network at input implies excellent S11</td>
<td>- Lumped circuit, so flatness thermal design is critical</td>
</tr>
<tr>
<td>Distributed Amp</td>
<td>- best bandwidth and gain&lt;br&gt;- dissipation spread out</td>
<td>- Zload optimization for each cell is complicated&lt;br&gt;- poor efficiency&lt;br&gt;- implementation feasibility issues</td>
</tr>
</tbody>
</table>
Design Example – Unmatched FETs

**Features**
- Broadband Operation DC to 3.5GHz
- Advanced GaN HEMT Technology
- Advanced Heat-Sink Technology
- Small Signal Gain=13 dB at 2GHz
- 48V Operation Typical Performance
- Output Power 140W at P3dB
- Drain Efficiency 60% at P3dB
- -40 °C to 85 °C Operating Temperature

**Applications**
- Commercial Wireless Infrastructure
- Cellular and WiMAX Infrastructure
- Civilian and Military Radar
- General Purpose Broadband Amplifiers
- Public Mobile Radios
- Industrial, Scientific, and Medical

**RF3934**
120W GaN WIDE BAND POWER AMPLIFIER
Lumped Element Match

- Single 50W matched amplifier
- Broadband design “generally” hitting target impedances.
- The challenge is to create this impedance

- Determine Target Impedances
  - Actual impedance from loadpull
  - Non-linear model simulation results

Z₀ = 10Ω
30W PA Module - 700-2400MHz Simulations

Simulated Performance
- Frequency: 700 – 2400 MHz
- Gain: >10dB
- Input return loss: <-12 dB
- Output power: 30W
- Efficiency: >25%

Output Impedance
S11 Match to 50Ω
30W PA Module - CW Performance

Performance
- Frequency: 700 – 2400 MHz
- Gain: >10dB
- Input return loss: <-12 dB
- Output power: 30W
- Efficiency: >28%
2x RFG1M09180 Doherty Demonstrator

- **Performance**
  - 865-895MHz optimized, 725-960MHz
  - Pout = 50 dBm
  - Efficiency > 50%
  - Gain > 17dB
  - ACP (DPD) < -55dBc

- **PCB Material**
  - Taconic RF60 (h=0.635mm)

- **Circuit Area Size**
  - 114 x 80 mm
  - PCB 127x127mm reference circuit
GaN Transistor Non-linear Simulator Models

High Power GaN Models

Download both ADS & AWR Non-Linear Models from RFMD website:

http://www.rfmd.com/products/gan/

High Power GaN Models

RFMD offers GaN non-linear packaged and die models in both Agilent ADS and Microwave Office AWR formats. These models are available for download – registration is required to gain access to RFMD’s GaN HEMT models.

Click the Request Access link on the left menu and follow the registration instructions for access to the GaN models.
RFMD® GaN Future/Conclusions

Next Generation Products?
- Linearity Optimized
- Integration where beneficial
- Size/Efficiency optimized for small cell designs
- Higher Frequency Designs

Why GaN?
- High peak efficiency
  - Peak efficiency ~70%
  - Correlation with high power density
- High temperature operation
- Multi-band, multi-standard linear PA
- Wide signal bandwidth operation
- High efficiency PA techniques
- Small form factor
Questions?

Thank you.