High Power GaN HEMTs for WiMAX BTS

Norihiko Ui, Kaname Ebihara and Seigo Sano
Eudyna Devices Inc.

January 16, 2006
Contents

• Introduction
• DC Characteristics and Load-Pull Results
• 3.5GHz 40W GaN HEMT
• 3.5GHz 200W GaN HEMT
• 3.5GHz 2-stage Amplifier
• Summary
Requirement of WiMAX BTS Amplifier

- High Power, High Efficiency and High Gain
- High Frequency with Broad Band
  200MHz Band Width at 2.6GHz and 3.5GHz
- High Linearity
  Low EVM Characteristics

Our Target: EVM<3.0% at Pave=10W(40dBm)
3.5GHz, PAR12dB OFDM Signal
Psat>52dBm
### Material Property of GaN

<table>
<thead>
<tr>
<th>Material</th>
<th>Bang Gap Energy (eV)</th>
<th>Critical Breakdown Field (MV/cm)</th>
<th>Thermal Conductance (W/cm/K)</th>
<th>Mobility (cm²/V/s)</th>
<th>Saturated Velocity (*10⁷ cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.1</td>
<td>0.3</td>
<td>1.5</td>
<td>1300</td>
<td>1.0</td>
</tr>
<tr>
<td>GaAs</td>
<td>1.4</td>
<td>0.4</td>
<td>0.5</td>
<td>6000</td>
<td>1.3</td>
</tr>
<tr>
<td>SiC</td>
<td>3.2</td>
<td>3.0</td>
<td>4.9</td>
<td>600</td>
<td>2.0</td>
</tr>
<tr>
<td>GaN</td>
<td>3.4</td>
<td>3.0</td>
<td>1.5</td>
<td>1500</td>
<td>2.7</td>
</tr>
</tbody>
</table>

#### Key features of GaN
- High breakdown voltage
- Wide Band gap
- High thermal conductivity (SiC Substrate)
- High current density
  - High electron velocity
  - High sheet carrier density

### Benchmark

<table>
<thead>
<tr>
<th>Term</th>
<th>unit</th>
<th>Si-LDMOS</th>
<th>GaAs MESFET</th>
<th>SiC MESFET</th>
<th>GaN HEMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Voltage</td>
<td>V</td>
<td>28</td>
<td>28</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Brakedown Voltage; Vgdo</td>
<td>V</td>
<td>75</td>
<td>75</td>
<td>(150)</td>
<td>350</td>
</tr>
<tr>
<td>Power Density</td>
<td>W/mm</td>
<td>0.7</td>
<td>0.7</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Gain @2.17GHz</td>
<td>dB</td>
<td>15.5</td>
<td>14</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Source <a href="mailto:Impedance@2.17GHz">Impedance@2.17GHz</a> *1</td>
<td>Ω</td>
<td>0.3</td>
<td>0.3</td>
<td>?</td>
<td>3</td>
</tr>
<tr>
<td>Load Impedance @2.17GHz *1</td>
<td>Ω</td>
<td>1.5</td>
<td>2.9</td>
<td>?</td>
<td>45</td>
</tr>
<tr>
<td>Drain efficiency; ηd @2.17GHz*</td>
<td>%</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Thermal Resistance *1</td>
<td>deg.C/W</td>
<td>1.2</td>
<td>1.6</td>
<td>?</td>
<td>(1.2)</td>
</tr>
<tr>
<td>Die size</td>
<td>------</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
</tr>
</tbody>
</table>

Note: *1: 10W Chip
Contents

• Introduction
• DC Characteristics and Load-Pull Results
• 3.5GHz 40W GaN HEMT
• 3.5GHz 200W GaN HEMT
• 3.5GHz 2-stage Amplifier
• Summary
High Breakdown Characteristics

IV Characteristics

2 terminal Gate-Drain reverse

Vth : -1.7V
Ifmax : 600mA

a) Vgs=+2V

b) Vgs=+0V

c) Vgs=-1V

Vgdo : 350V

Good pinch-off characteristics up to 200V

Enough high fT of 14GHz to be operated at 3.5GHz
Loadpull Measurement Results

GaN HEMT Unit-cell; Wg=2.25mm, Vds=50V

Psat=40.4dBm at 3.6GHz

Higher Output Load Impedance

- Broad Band Characteristics
- Simple Matching Circuit
Contents

• Introduction
• DC Characteristics and Load-Pull Results
• 3.5GHz 40W GaN HEMT
• 3.5GHz 200W GaN HEMT
• 3.5GHz 2-stage Amplifier
• Summary
40W Device Design

Wg=11.25mm GaN HEMT

Simple Matching Circuit with Small Package
40W Device Pin-Pout and Efficiency

Vds=50V, Idsq=200mA, freq.=3.5GHz

- **Output Power [dBm]**
  - Range: 28 to 48

- **Input Power [dBm]**
  - Range: 18 to 40

- **Drain Efficiency [%]**
  - Range: 0 to 100

The graph shows the relationship between input power and output power, along with the drain efficiency, for a device under specified conditions.
**40W Device Pin-Pout**

*Vds=50V, Idsq=200mA*

![Graph of 40W Device Pin-Pout with Vds=50V, Idsq=200mA](image-url)

- Frequency [GHz]: 3.35, 3.4, 3.45, 3.5, 3.55, 3.6, 3.65
- Output Power [dBm]: 20dBm, 22dBm, 24dBm, 26dBm, 28dBm, 30dBm, 32dBm, 34dBm, 36dBm, 38dBm, 40dBm, 42dBm, 44dBm, 46dBm, 48dBm
40W Device EVM

Vds=50V, Idsq=200mA, freq.=3.5GHz

Single Carrier OFDM 64QAM3/4
3.5MHz channel bandwidth
PAR=11.6dB(0.01%, CCDF)
Contents

• Introduction
• DC Characteristics and Load-Pull Results
• 3.5GHz 40W GaN HEMT
• 3.5GHz 200W GaN HEMT
• 3.5GHz 2-stage Amplifier
• Summary
200W Device Design

- Wg=36mm GaN HEMTs
- Close to 50 ohm matching
- Single End Small Package

- Input Matching
- Output Matching
- 50ohm
200W Device Pin-Pout(1)

Vds = 50V, Idsq = 1.0A, freq. = 3.5GHz

Input Power [dBm]

Output Power [dBm]

Drain Efficiency [%]

Pout

Drain Effi.
200W Device Pin-Pout(1)

Vds=50V, Idsq=1.0A

![Graph showing the relationship between frequency and output power for different input powers.](image-url)
Contents

- Introduction
- DC Characteristics and Load-Pull Results
- 3.5GHz 40W GaN HEMT
- 3.5GHz 200W GaN HEMT
- 3.5GHz 2-stage Amplifier
- Summary
GaN HEMT 2-stage Amplifier

40W GaN HEMT

200W GaN HEMT
GaN HEMT 2-stage Amplifier Pin-Pout

Vds=50V, Idsq=1.0A(final) and 220mA(driver), f=3.5GHz

Pulse Condition: width/period
6uSec/60uSec(10% Duty Cycle)
GaN HEMT 2-stage Amplifier EVM

Vds=50V, Idsq=1.0A(final) and 220mA(driver), f=3.5GHz

Single Carrier OFDM 64QAM3/4
3.5MHz channel bandwidth,
PAR=11.6dB(0.01%, CCDF)

Drain Efficiency [%]

EVM [%]

Pout [dBm]
Contents

- Introduction
- DC Characteristics and Load-Pull Results
- 3.5GHz 40W GaN HEMT
- 3.5GHz 200W GaN HEMT
- 3.5GHz 2-stage Amplifier
- Summary
Summary

- High power 40W and 200W GaN HEMTs for WiMAX BTS was developed.

  40W: $P_{sat}=46.2\,\text{dBm}$, Drain Effi.$=51\%$, $GL=14\,\text{dB}$
  
    $EVM=2.0\%$ at $P_{ave}=35\,\text{dBm}$, Drain Effi.$=20\%$

  200W: $P_{sat}=53\,\text{dBm}$, Drain Effi.$=51\%$, $GL=11.5\,\text{dB}$

- High power 2-stage (40W and 200W GaN HEMTs) Amplifier was demonstrated.

  $P_{sat}=53.2\,\text{dBm}$, $GL=28\,\text{dB}$

  $EVM=3.0\%$ at $P_{ave}=40\,\text{dBm}$, Total Effi.$=15\%$
Eudyna
Eudyna Devices Inc.