Development of GaN SSPA for Satellite-Borne Application

November 10, 2010

MELOS: Mitsubishi Electric TOKKI Systems Corporation
Table of Contents

1. The high power amplifier for satellite use
2. GaN device characteristics
3. GaN Device: Achieved Performance
4. GaN SSPA: Achieved Performance
5. Conclusion and Next Target
1. High Power Amplifier

The present situation of the high power amplifier for satellite use

Figure 1-1  The present situation of the high power amplifier for satellite use
1. High Power Amplifier

Figure 1-2 Typical Communication Subsystem in the Communication Satellite

HPAs are applied to each communication channels

→ Applied many HPAs
→ Required
   { Light Weight
   { Small Footprint

Changes for the Better

TKE-2010-0906 A
1. High Power Amplifier

Equipment of High Power Amplification

The following two kinds of hardware take a part of high power amplification.
- **TWTA**: Traveling Wave Tube Amplifier
- **SSPA**: Solid State Power Amplifier

**Main Performance**:
- **Frequency**: L/S/C Band
- **Output Power**: L/S-band: 150 watts, C-band: 70 watts
- **Efficiency**: L/S-band: 55%, C-band: 50%
- **Mass**: L/S-band: 1200g, C-band: 1200g
- **Foot print**: 200 cm²

**Figure 1-3a**

**Main Performance**:
- **Frequency**: L/S/C Band
- **Output Power**: L/S-band: 70 to 150 watts, C-band: 2200g
- **Efficiency**: 60%
- **Mass**: L/S-band: 3400g, C-band: 2200g
- **Foot print**: 380 cm²

**Figure 1-3b**

The following two kinds of hardware take a part of high power amplification.
- **TWTA**: Traveling Wave Tube Amplifier
- **SSPA**: Solid State Power Amplifier

**Equipment of High Power Amplification**

**Figure 1-3a**

**Figure 1-3b**
Performance Comparison

**Figure 1-4a RF Output Power**

**TWTA:**
Higher Output Power, Efficiency

**Conventional GaAs SSPA:**
Light Weight

**Figure 1-4b Efficiency**

**Figure 1-4c Mass**
1. High Power Amplifier

Limit of the conventional GaAs SSPA

Limit of handling power (25W max)

Multiple power combining to achieve higher output power

Wider footprint / Heavier mass

More Powerful device is desired
## 2. Application of GaN to SSPA

### 2.1 What will be new and be improved with GaN?

#### Table 2-1  GaAs HEMT and GaN HEMT

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Device Type</th>
<th>SSPA RF Pout (W)</th>
<th>SSPA Efficiency (%)</th>
<th>SSPA Power Consumption (W)</th>
<th>SSPA Heat Dissipation (W)</th>
<th>Typical Mass (kg)</th>
<th>Figure of Merit #1 Pout/Pdissipation (W/W)</th>
<th>Figure of Merit #2 Pout/Mass (W/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Band</td>
<td>GaAs</td>
<td>40</td>
<td>37%</td>
<td>108</td>
<td>68</td>
<td>1.6</td>
<td>0.6</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>GaN</td>
<td>70</td>
<td>50%</td>
<td>140</td>
<td>70</td>
<td>1.2</td>
<td>1.0</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Ratio GaN/GaAs</td>
<td>175%</td>
<td>135%</td>
<td></td>
<td></td>
<td></td>
<td>170%</td>
<td>233%</td>
</tr>
<tr>
<td>L/S Band</td>
<td>GaAs</td>
<td>40</td>
<td>39%</td>
<td>103</td>
<td>63</td>
<td>1.7</td>
<td>0.6</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>GaN</td>
<td>150</td>
<td>55%</td>
<td>273</td>
<td>123</td>
<td>1.2</td>
<td>1.2</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Ratio GaN/GaAs</td>
<td>375%</td>
<td>141%</td>
<td></td>
<td></td>
<td></td>
<td>191%</td>
<td>531%</td>
</tr>
</tbody>
</table>
2.2 Expected GaN SSPA Performance

If GaN is applied to the SSPA...

Output Power | Efficiency | Mass
---|---|---
L/S-Band: 150 W | 55% | 1.2 kg
C-Band: 70 W | 50% | 1.4 kg
2.3 Issues to be solved

1. Development of GaN device for space application → SQT: Space Qualification Test

2. Applying GaN performance to SSPA design
   - Thermal performance
   - Prevent arcing in vacuum environment

3. Radiation effect confirmation
3. GaN Device: Achieved Performance

3.1 Device Electrical Performance

GaN for space application was developed by Mitsubishi Electric.

At device level, RF output power of over 50 dBm (at P2dB) is achieved. Power added efficiency (PAE) exceeds 60%.

Figure 3-1a  Input to Output Power and Gain completion.

Figure 3-1b  PAE(%) & I_{ds(RF)}(A)
(1) SQT Summary for GaN device

Table 3-1 SQT Result of GaN HEMT

<table>
<thead>
<tr>
<th>Group</th>
<th>Test Item</th>
<th>Test Condition MIL-STD-750 Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Test</td>
<td>Temperature Cycling</td>
<td>1051 -65/+175 deg.C, 210cycles</td>
<td>r/n=0/11</td>
</tr>
<tr>
<td></td>
<td>Shock</td>
<td>2016 1500G, 3 axis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vibration</td>
<td>2051 100-2000 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Constant Acceleration</td>
<td>2006 10000 G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seal Test</td>
<td>1071 Gross and Fine leak</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Internal Visual</td>
<td>2075</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>2077</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bond Strength</td>
<td>2037</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Die Shear Strength</td>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>Life Test</td>
<td>RF Life Test</td>
<td>1026 1000 hr</td>
<td>r/n=0/2</td>
</tr>
<tr>
<td></td>
<td>DC Life Test</td>
<td>1026 1000 hr</td>
<td>r/n=0/8</td>
</tr>
</tbody>
</table>

2 test results with Vds=47V are obtained.

→ Expected MTTF = 1.0x10^6 h at Tch=175 degC

Test Result with 270 degC, Vds 45V is obtained

→ MTTF with Vds=45 degC :1.3x10^6 hr at Tch=175 degC
3.2 (2) Arcing Test Results

Arcing test was performed with GaN device (100W class). There was no arcing at all from ambient pressure to high vacuum environment.

Figure 3-3 Test Set-up for Arcing Test

RF output power monitor remains stable during depressurization

Figure 3-4 Output Power Monitor
3.3 Device Radiation Hardness Tests

(1) Single Event Tests:
Radiation hardness test for single event effect (SEB, SEGR)
Test condition;
- Ion Beam : Br$^{+13}$ (145MeV)  (Br: Bromine)
- LET (Liner Energy Transfer): 31.2MeV/(mg/cm$^2$)
- Beam fluence : 1x10$^6$ ions/cm$^2$

Figure 3-5 Radiation Test Equipment

Figure 3-6 GaN Test Fixture
### 3.3 (1) Single Event

The device operating condition: $V_{ds}=50V, P_{out}=P_{13dB}$

#### Table 3-2 RF drive condition & irradiation result

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Drain Voltage [V]</th>
<th>Drain Current RF off [A]</th>
<th>Pin [dBm]</th>
<th>Pout [dBm]</th>
<th>Compression</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45.00</td>
<td>0.22</td>
<td>28.08</td>
<td>40.82</td>
<td>P2dB</td>
<td>Non-destruction</td>
</tr>
<tr>
<td>2</td>
<td>45.00</td>
<td>0.22</td>
<td>38.02</td>
<td>41.30</td>
<td>P12dB</td>
<td>↑</td>
</tr>
<tr>
<td>3</td>
<td>50.00</td>
<td>0.22</td>
<td>37.74</td>
<td>41.89</td>
<td>P10dB</td>
<td>↑</td>
</tr>
<tr>
<td>4</td>
<td>50.00</td>
<td>0.22</td>
<td>40.60</td>
<td>41.57</td>
<td>P13.2dB</td>
<td>↑</td>
</tr>
</tbody>
</table>

**Figure 3-7a**  
**Figure 3-7b**  
**Figure 3-7c**  

No degradation
3.3 (2) Total Ionizing Dose

Cobalt-60 gamma ray was irradiated on GaN device.
126kGy with RF input, bias Vds=45V,Ids=0.22A → No Degradation
86kGy with no RF, pinch-off bias Vds=45V,Vgs=-5V → No Degradation

Table 3-3 Bias condition & irradiation result

<table>
<thead>
<tr>
<th>Condition</th>
<th>Drain Voltage [V]</th>
<th>Gate Voltage [V]</th>
<th>Drain current [A]</th>
<th>Total Doze [kGy]</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>-</td>
<td>0.22</td>
<td>125</td>
<td>Non-destruction</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>-5</td>
<td>-</td>
<td>86</td>
<td>↑</td>
</tr>
</tbody>
</table>

The Result of Irradiation test after Vd=45V, Id=0.22A operation

Figure 3-8a
Figure 3-8b
Figure 3-8c
C-Band SSPA is developed by utilizing GaN device

- Single ended configuration for RF portion to minimize size
- The EPC (electrical power conditioner) is newly developed to drive GaN drain voltage (35V to 50V)

Performance Summary
- Frequency band : 3.95 GHz +/- 150MHz
- Output Power: >70 watts
- Spurious Output: <-50dBc/Inband
- Power consumption: 190 watts (Pout 84W)
- Efficiency : 45%
- Mass : 1370g
- Size : 265 x  95 x 125

Figure 4-1 GaN C-SSPA
4. GaN SSPA: Achieved Performance

**Frequency vs. Output Power characteristics**

The output power achieved 70W

**Figure 4-2 Output Power versus Frequency Characteristics**

**Figure 4-3 Liner Gain**

Linear Gain achieved 100dB
Figure 4-4 Output Power & Efficiency at CW

4. GaN SSPA: Achieved Performance

CW characteristics

- Pout>85W
- PAE>45% at P_{2dB}

45.93dBm=85W

Normalized with 2dB output power compression point (P_{2dB})
4. GaN SSPA: Achieved Performance

**Multi-carrier characteristics**

**Figure 4-5 Input to Output Power with Multi-Carrier**

**Figure 4-6 NPR: Noise Power Ratio**
4. GaN SSPA: Achieved Performance

Thermal Analysis Result

Thermal analysis is performed with the following thermal resistance:

- GaN package
- Thermal filer (GaN/Chassis)
- Chassis
- Thermal filer (SSPA/panel)

Result: $T_j=142.8$ deg.C

Enough margin to the rated channel temperature of 175 deg.C
Qualification Tests

Qualification test was performed successfully based on the following test items and test conditions

1. Thermal Vacuum Test:
   - Temperature : -10 deg.C to +60 deg.C
   - Vacuum condition : 1x10^-6 Torr
   - Test Cycle : 33 cycle
2. Vibration Test : Pass
3. Mechanical Shock Test : Pass
4. Electro Magnetic Compatibility : MIL-STD 462 applied

Table 4-1 Vibration & Shock Test condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Level</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sine</td>
<td>20G</td>
<td>all 3axis</td>
</tr>
<tr>
<td>Random</td>
<td>14.1 Grms</td>
<td>X, Y axis</td>
</tr>
<tr>
<td></td>
<td>19.7 Grms</td>
<td>Z axis</td>
</tr>
<tr>
<td>Shock</td>
<td>1000G</td>
<td>all 3axis</td>
</tr>
</tbody>
</table>
5. Conclusion and Next Target

5.1 Achieved Results

GaN SSPA was developed and achieve the following performance.

**GaN device**
- 100 Watts class GaN is developed
- Space Qualification Test is successfully completed
- No arcing from ambient pressure to high vacuum environment.
- Radiation Hardness is confirmed
  - No SEB, No SEGR with Vd 50V, P13dB condition
  - No TID degradation with operation condition (Vd 45V, Id 0.22A)

**SSPA Performance**
- 85 Watts RF output power with 45% efficiency is achieved
- Single stage configuration, without power combining
  - Slim and light weight is accomplished
- Qualification test is successfully completed
5.2 Target to Be Improved

Power added efficiency will be improved

![Graph showing efficiency improvement across different frequencies.]

**Figure 5-1 Efficiency Improvement**

The total efficiency at normal temperature is 45%.

- EPC have already realized efficiency 94% in other development.
- The efficiency in finale stage GaN will be achieved 65% by the improvement of device characteristics improvement.

For Next Model

- EPC efficiency: 94%
- Final Stage GaN efficiency: 65%

Total efficiency up to 50%

QT result

- EPC efficiency: 87%
- Final Stage GaN efficiency: 60%

Total efficiency: 45%
5. Conclusion and Next Target

Next Target

- Actual operation in the orbit

- Development for higher frequency operation
  …depends on the manufacturer