A 20W GaN-on-Si Solid State Power Amplifier for Q-Band Space Communication Systems

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Outlines

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• SSPA Requirements & Selected GaN Technology
• SSPA Design
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Introduction

- Space applications require high performing and reliable electronic systems.

Long time mission & harsh environment  \(\rightarrow\) High Reliability  \(\rightarrow\) High Efficiency  \(\rightarrow\) Solar panels thus, limited energy

High cost per kilogram of the payload  \(\rightarrow\) Low Size & Weight
Motivations

- Broadband access services are bound to experience a x8 growth in the next 10 years.
- Ka-band today approaches up to 40% of the commercial telecom business.
- Such services are urging the need for new HTS systems, with Ka/K user segment but in many cases moving to Q/V band the feeder links to achieve more than a two-fold increase in bandwidth availability.
- In this context SSPAs could represent an attractive solution to replace Q-band TWTAs since, even if their efficiency is still lower than that of the tube amplifiers, aspects such as the lower cost, the graceful degradation, the selectable form factor etc., can introduce significant benefits at satellite level.
The RF line-up of the SSPA is composed by four subunits namely: **CAMP Hybrid**, Linearizer Hybrid, HPA Hybrid and HPA Bank.

### SSPA Architecture & Requirements

<table>
<thead>
<tr>
<th>Req.</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW</td>
<td>37.5-42.5</td>
<td>GHz</td>
</tr>
<tr>
<td>Gain</td>
<td>60-100</td>
<td>dB</td>
</tr>
<tr>
<td>Psat</td>
<td>&gt;20</td>
<td>W</td>
</tr>
<tr>
<td>Pout@NOP</td>
<td>&gt;10</td>
<td>W</td>
</tr>
<tr>
<td>NPR@NOP</td>
<td>&gt;16</td>
<td>dBc</td>
</tr>
<tr>
<td>PAE@NOP</td>
<td>&gt;15</td>
<td>%</td>
</tr>
</tbody>
</table>
Key Sub-circuits: CAMP Hybrid

- It is composed by the cascade of several LLAs and variable/fixed attenuators.
- They are properly chosen in order to assure the correct control of the uplink flux, either selected by ground telecommands (i.e., SSPA working in fixed gain mode) or by an automatic level control loop (i.e., SSPA working in ALC mode).
- The integrated DET provides the feedback signal to correctly govern the uplink flux.
- COTs components are used to assembly this sub-circuit

Pin
-56dBm
-16dBm

Pout
-3dBm
Key Sub-circuits: **Linearizer Hybrid**

- It is used to compensate for the non-linearities of the power stage.
- It includes some VVAs and MPAs before and after the actual LIN in order to be able to adjust the power levels along the line-up (SCA signal).

- **LIN:**
  - Balance conf.
  - Lange couplers
  - up to ±45° AM/PM
  - up to 7dB AM/AM
  - IL<20dB
  - Pout=7dBm

- The sum of the outputs of the linear and nonlinear arms results in a gain expansion characteristic associated with a either compression or expansion phase, depending on the setting of both the attenuator and phase shifter in the linear arm.
Key Sub-circuits: **Power Stage**

- The SSPA line-up is completed with the HPA Hybrid that drives, in a 1-to-16 ratio, the HPA Bank Hybrid power section.
  - Both implemented in WR-22 waveguide
  - Both based on ad-hoc MMIC PA developed on 100nm GaN-Si technology available at OMMIC
  - Each MMIC is with **input/output M-WG hermetic transition**

- **BW=37.5-42.5GHz**
- **Pout>2W**
- **PAE>24%**
- **Gain>21dB**
Key Sub-circuits: **Power Stage**

- Power sweep on one of the seventeen hybrid modules at 40GHz
  - $f=40\,\text{GHz}$
  - $P_{\text{out}}>2\,\text{W}$
  - AM/PM$<15^\circ$
  - Gain$>21\,\text{dB}$

![Image of hybrid module and circuit](image-url)
Key Sub-circuits: HPA Bank Hybrid

- MMICs in the HPA Bank have been connected by using a WR-22 waveguide network realized by cascading fifteen T-magic structures.
- A thermal and mechanical design has been carried out to guarantee that the hottest MMIC is kept lower than 160°C up to a $T_{BP} = 65 \degree C$.
Key Sub-circuits: Splitter/Combiner

- Splitter
- Input of the splitter
- Outputs of the splitter
- Output combiner
- Inputs of the combiner
- Output of the combiner
SSPA is powered with two positive voltages at 3.5V (GaAs devices) and 11.25V (GaN devices), and one negative voltage -8.0V (conditioned for the gates).

LxWxH: 45x22x7.2 cm$^3$

Weight = 5.5 Kg
Measurement Results

• Small signal performance of the complete SSPA have been measured at the nominal bias and over different temperature.

Broadband  S11 & S22 better than -20dB  In-band
Measurement Results

- Large Signal Measurement in Fixed gain mode.

From 37.5 GHz to 42.5 GHz
- $P_{out,sat} > 20$W
- PAE $> 15$
- Gain up to 100dB

40GHz Sweep
Measurement Results

- Measurements of the SSPA at $T_{BP}=65^\circ C$ and in fixed gain mode operation.
In order to evaluate the linearity of the SSPA, a two tone test was performed.

- $f = 40.75\, \text{GHz} \pm 5\, \text{MHz}$
- $P_{\text{out}} = 10\, \text{W}$ (i.e. 3dB OBO)
- PAE $> 13\%$
- $\text{IMD}_3 = 17.6/30.3$ dBc
- Estimated NPR $> 18\, \text{dB}$
Conclusion

• The design and experimental results of a Q-band SSPA suitable for modern HTSs have been presented.

• Combining/splitting structures have been realized in WR-22 waveguide and each MMIC PA, developed on a 100 nm GaN-Si technology, was made hermetic through a waveguide to microstrip transition system.

• The SSPA achieves a saturated output power in excess of 20W with a PAE, gain better than 15% and 65 dB, respectively.

• To the best of the authors’ knowledge, this is the first realization of a 20W SSPA in Q-band for space applications, at least in Europe.
The authors wish to acknowledge the Italian Space Agency (ASI) for funding this work in the context of project KALOS-DEVAQ within ESA’s ARTES C&G Technology Program. Particular thanks are due to Francois Deborgies from ESA/ESTEC for his expertise and technical support.