Wideband Reconfigurable Harmonically Tuned GaN SSPA for Cognitive Radios

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Outline

Introduction - Motivation

Benefits & Challenges

Wide-Band Reconfigurable Harmonically Tuned Power Amplifier
  • Inverse Class-F Design
  • Amplifier Fabrication and Results
  • Thermal Management
  • Dual-Band Multi-Network Design

Power Variability
  • Hybrid Coupler
  • Balanced Amplifier

Conclusions and Acknowledgements
What do we need from transmit power amplifiers in a cognitive communication system?

I. Re-configurability
   • High output power; without sacrificing efficiency
   • Operating frequency; without sacrificing efficiency

II. Linearity

Introduction - Motivation

• Spectrum management issues due to growing user community
  – Congestion in the X-Band space-to-ground data links is creating the need for cognitive radio capabilities
Benefits

Higher Efficiency Means
- Saved DC power
- Decreased Heat
  - Efficiency is lost primarily through power dissipation within the transistor junction and conductor losses.
  - Improved Thermal Reliability

Potential to Enable Low Cost Cognitive Telemetry:
- Avoids the need for multiple $T_x$ and $R_x$ modules

Applications include:
- NASA Missions
- Small Satellites and Spacecraft
- Military Unmanned Air Vehicles
- Commercial/Amateur Cubesats
Challenges

Efficiency
- High Efficiency SSPA’s require harmonic tuning - such as Class-F and Inverse Class-F designs. Matching circuit is complex and inherently narrow band.

Wideband Devices
- Class-F type wideband harmonic tuning techniques used at lower frequencies are unrealizable at X-band

Power Variability
- Amplifiers efficiency drops off when operating below saturation

GaN Transistor Frequency Limitation
- Achieving max PAE with Class-F type amplifiers requires $F_T > 3^{rd}$ harmonic
- Current commercially available transistors have an $F_T$ of 18 GHz
- High $F_T$ of GaN HEMTs comes at the expense of feature size and power density
Wide-Band Reconfigurable Harmonically Tuned PA

Design to provide wideband high efficiency using multi-network tuning

Realized in CMOS chip form
Inverse Class-F GaN SSPA at X-Band

Harmonics are reflected to reshape the voltage and current waveform at the drain.
Fabricated Inverse Class-F Amplifier

Transistor: Cree CGHV1F006S 6W, DC-18 GHz, 40V, GaN HEMT

Substrate height, $h = 0.02$ inch & $\varepsilon_r = 3.0$
Tuning of Inverse Class-F Amplifier

Simulated and Measured ($\Gamma_{\text{opt-in}}$) parameters of IMN after tuning from 8.4 to 16.8 GHz.

Simulated and Measured ($\Gamma_{\text{opt-out}}$) parameters of OMN after tuning from 8.4 to 16.8 GHz.
Inverse Class-F $P_{out}$, PAE, Gain and VSWR

Maximum $P_{out} = 5.14$-W, PAE = 38.6%
with DE = 48.9%
Inverse Class-F Bandwidth

70 MHz bandwidth where P_{out} > 36 dBm and PAE > 35%

8.315 - 8.385 GHz

PAE and P_{out} vs. Frequency \( V_{DS} = 40 \text{ V}, V_{GS} = -3.2 \text{ V}; P_{in} \) ranges 21.5-30.35 dBm, VSWR ranges 2.4 -33
CW operation required direct contact between transistor belly and heat sink

### Thermal Management

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>$P_{in}$ (dBm)</th>
<th>$V_{DS}$ (V)</th>
<th>Gain (dB)</th>
<th>PAE (%)</th>
<th>Temp (°C)</th>
<th>$P_{out}$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.36</td>
<td>29.9</td>
<td>32</td>
<td>6.3</td>
<td>37.3</td>
<td>95</td>
<td>4.2</td>
</tr>
</tbody>
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**Operating conditions of measured package temp = 95°C:**

- DC Power Dissipation ≈ 7 W
  - Data sheet indicates for package temperature of 95°C, the max allowed power dissipation is ≈ 9 W.

Hence, achieved thermal safety margin of ≈ 22%.
Dual Band Multi-Network Design

Reconfigurable concept can be applied to dual-band transmitters
Power Variability - Balanced Amplifier

Balanced Amplifier Circuit Topology
Microstrip Branch Line 3-dB Hybrid Coupler

Input Port #1

Isolated Port #2

Output Port #3

Output Port #4

Substrate height, \( h = 0.02 \) inch & \( \varepsilon_r = 3.0 \)

Measured vs Simulated Results
Fabricated Balanced Amplifier

Substrate height, $h = 0.02$ inch & $\varepsilon_r = 3.0$
$P_{in}$ vs. $P_{out}$ for Single & Balanced MMIC Amplifiers

Frequency = 8.546 GHz

Balanced amplifier provides a 3dB increase in output power over a single MMIC.

Balanced Amplifier

Single Amplifier

Measured $P_{out}$ vs. $P_{in}$ with $V_D = 5$ V and frequency = 8.546 GHz.
Conclusion

- Challenges have been presented for achieving the desired high efficiency wide-band operation needed for a cognitive system at X-band.
- An inverse Class-F GaN SSPA operating at 8.4 GHz has been shown to achieve 5W of output power at 40% PAE with a 70 MHz bandwidth of Pout > 36 dBm and PAE >35%.
- A reconfigurable harmonically tuned SSPA has been proposed and justified to provide wideband high efficiency.
- A balanced amplifier has been presented for additional consideration in reconfigurable power topologies.