Wideband Reconfigurable Harmonically Tuned GaN SSPA for Cognitive Radios

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Outline

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Benefits & Challenges

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

Power Variability
  • Hybrid Coupler
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Introduction - Motivation

- Congestion, caused by a growing user community at the X-Band space-to-ground data link frequency range, is creating the need for cognitive radio capabilities.

What capabilities do we need from a transmit power amplifier to enable a cognitive communication system?

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

II. Linearity
Benefits

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

Our proposed innovation has the potential to enable low cost
Cognitive Communication Systems:
• 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 when backed off from saturation

GaN Transistor Frequency Limitation
• Achieving max PAE with Class-F type amplifiers requires $F_T > 3^{\text{rd}}$ harmonic
• Current commercially available transistors have an $F_T$ of 18 GHz ($\approx 2^{\text{nd}}$ Harmonic at X-Band)
• High $F_T$ of GaN HEMTs comes at the expense of feature size and power density
Wide-Band Reconfigurable Harmonically Tuned PA

Circuit Within this area can be realized using low cost CMOS technology

Design to provide wideband high efficiency using multi-network tuning
Inverse Class-F GaN SSPA at X-Band

X-Band is selected because the 8.0-8.5 GHz frequency range is designated for NEN space-ground links

Our target is $P_{\text{out}} > 4\text{-W}$ with PAE $> 35\%$

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

Measured $P_{out}$ and PAE vs. $P_{in}$: $V_{DS} = 40$ V, $V_{GS} = -3.2$ V and frequency = 8.45 GHz.

Measured gain and VSWR vs. $P_{in}$: $V_{DS} = 40$ V, $V_{GS} = -3.2$ V, and frequency = 8.45 GHz.

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 $V_{DS} = 40$ V, $V_{GS} = -3.2$ V; $P_{in}$ ranges 21.5-30.35 dBm, VSWR ranges 2.4 -33
**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>
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</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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CW operation required direct contact between transistor belly and heat sink.

**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

Input Port #1

Output Port #4

Isolated Port #2

Isolated Port #3

Hybrid Couplers

MMIC Amplifiers
Mini-Circuits
GVA-123+, GaAs HBTs

Substrate height, $h = 0.02$ inch & $\varepsilon_r = 3.0$
Balanced amplifier provides a 3dB increase in output power over a single MMIC.

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 of a transmit power amplifier at X-band

• A reconfigurable harmonically tuned SSPA has been proposed as being a solution to enabling wideband high efficiency needed for a cognitive system

• An inverse Class-F GaN SSPA operating at 8.4 GHz has been shown to achieve 5.14-W of output power with 38.6% PAE and a 70 MHz bandwidth of $P_{\text{out}} > 36$ dBm and PAE $>35%$.

• A balanced amplifier has been presented for additional consideration in reconfigurable power topologies.