Design of an Ultra-High Efficiency GaN High-Power Amplifier for SAR Remote Sensing

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SweepSAR Technique

- increased swath and resolution
- TRM drives single feed array element
- digitally rcvrs + on-board cal ➔ on-orbit beamforming

Challenges:
- high rx duty cycle (near 100%)
- shorter, high peak power transmit pulse to achieve SNR

SweepSAR requires high-power and high efficiency PAs

GaN is a key enabling technology

On transmit, all feed array elements are illuminated creating the wide elevation beam
Proposed DESDynI SAR instrument

- Reflector
- Antenna feed array
- Notional TRM Block diagram
- 12 High power TRMs / pol
- HPA requirements:
  - > 100 W
  - > 60 % efficiency
  - compact
  - passive thermal management
  - reliable

GaN HEMT Technology

- Wide bandgap material
  - high breakdown (10 X GaAs)
  - high power density (5 X GaAs)
- Bandgap engineering with AlGaN / GaN layers
- SiC substrate – low thermal resistance
- Low parasitic capacitance – high efficiency amplifier modes
- Advanced GaN HEMTs
  - field plate to control electric field on gate
Large Signal Characterization

- Load-pull characterize non-linear device response
  - presents impedances to the DUT at fundamental and harmonics
- In large signal, linear approximation not valid
  \[ I_{DS}(V_{GS}) \approx i_{DS}(V_{GS}) + a_1 v_{gs} + a_2 v_{gs}^2 + a_3 v_{gs}^3 + \cdots \]
- Performance is non-linear (cannot use s-parameters) and depends on impedance presented to device
Load-pull Techniques

- Traditional passive Load-pull uses mechanical tuners to present reflection to device
- Active load-pull uses injection amplifiers to obtain $\Gamma$
  - closed loop uses signal from DUT
  - open loop uses synchronous AWG source
- Active open loop
  - complex modulated waveforms
  - harmonic control
  - high $\Gamma$
Open Loop Active Load-pull

- Mixed-Signal Active Load-pull (MSALPS) developed by Anteverta-mw and Maury Microwave
- 4 tuning loops – source $f_0$, load $f_0$, $2f_0$, and $3f_0$
- Measurement procedure:
  - samples $a$ and $b$ waves
  - iterates to achieve impedance
  - measures large signal performance
MSALPS capabilities

- **Real-time mode allows rapid characterization of multiple impedances**
  - reduces characterization time (hours to minutes)
- **Load-pull modulated signals**
  - AWGs allow for inject single tone or complex signals
  - simulate pulsed chirp waveform response
  - perform frequency dependent load-pull
- **Phase reference**
  - calculate dynamic voltage and current
  - determine class of operation, peak currents and voltages, optimize waveform
High-Power Test Fixture Design

- **Active load-pull requires high-power injection amplifiers**
  - 120 W device with a 50 Ω system impedance ➔ **700 W injection amp**!
  - 10 Ω transforming fixture ➔ **100 W injection amplifier**

- **Test fixture design requirements**
  - 50 Ω to 10 Ω transition - wide bandwidth
  - low-loss - integrated high-power bias

DUT Stability and Feedback

- Device stability a concern for high power devices
  - Large device $\rightarrow$ low impedance prone to oscillations
  - High-power could exceed thermal rating $\rightarrow$ catastrophic failures
- Feedback network to improve low frequency stability

Source match

- GaN HEMTs ➔ low input impedance
  - Trade-off between gain, stability, and bandwidth

\[ Z_0 = 10 \, \Omega \]
Load tuning

- Load-pull with no harmonic control
  - $P_{out} \sim 50 \text{ dBm}$
  - PAE $> 50\%$
  - Harmonic levels $\sim 30 \text{ dBm} (\sim 20 \text{ dBC})$

$F_0 = 1.25 \text{ GHz}$
$Z_0 = 50 \Omega$
Harmonic tuning

- swept harmonic at $\Gamma = 0.8$ over all phase angles
  - optimal harmonic impedances will be reflective
  - harmonic levels reduced to below 30 dBC
  - PAE improved to over 70 %
Proposed HPA Topology

- Transitioned to new GaN HEMT vendor
- Two-stage HPA design
  - 8-10 W GaN HEMT 1\textsuperscript{st} stage
  - 120 W GaN HEMT 2\textsuperscript{nd} stage
  - Input, interstage, and output matching networks on TMM 6
  - 10 $\Omega$ interstage matching
- Separate DC bias / control board
  - drain switching
  - gate dropout protection
8W to 100W interstage match

\[ Z_0 = 10 \, \Omega \]
100 W Output match

$Z_0 = 50 \, \Omega$

New part has slightly lower PAE
Thermal Design

Radiator Sizing for TRM

Estimated Power Dissipation = 22W

Total radiator Area = 65,381 sq mm
Conclusions

- **SweepSAR requires high peak power, high-efficiency HPA**
  - GaN HEMT technology
  - Active Load-pull system for high-efficiency design
- **Complexities of Load-pulling high power part**
  - Test fixture design
  - Stability enhancement techniques
- **Load-pull results on 100 W GaN HEMT**
  - ~50 dBm output power
  - ~70 % PAE
  - Harmonic levels improved to below 30 dBc with harmonic tuning
- **Rev 1 HPA measured results**
  - ~50 dBm Pout
  - ~60 % PAE
  - 30 dBc harmonic levels