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

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SweepSAR Technique

SweepSAR Technique

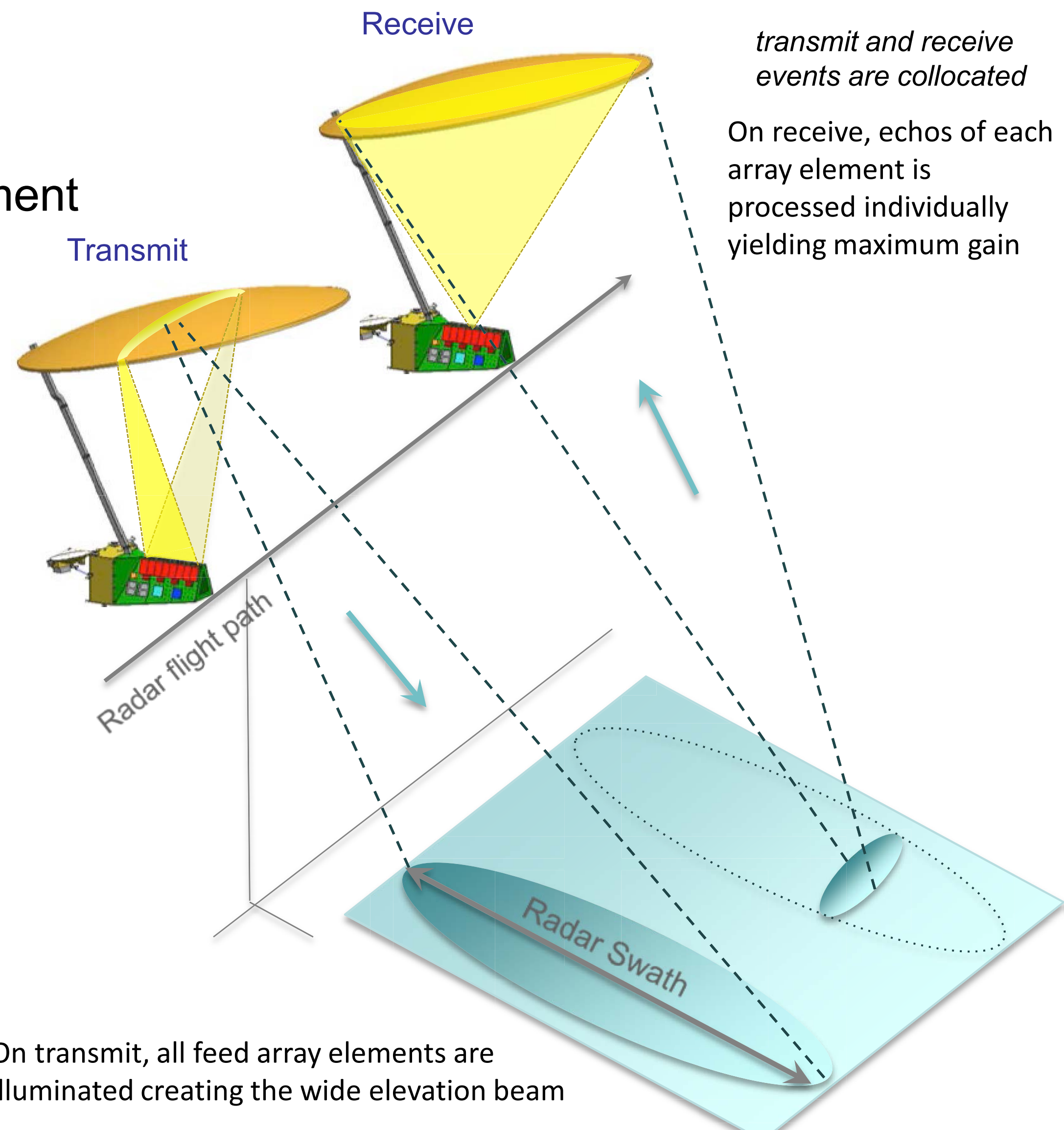
- increased swath and resolution
- TRM drives single feed array element
- digitally rcvrs + on-board cal ➔ on-orbit beamforming

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



Proposed DESDynI SAR instrument

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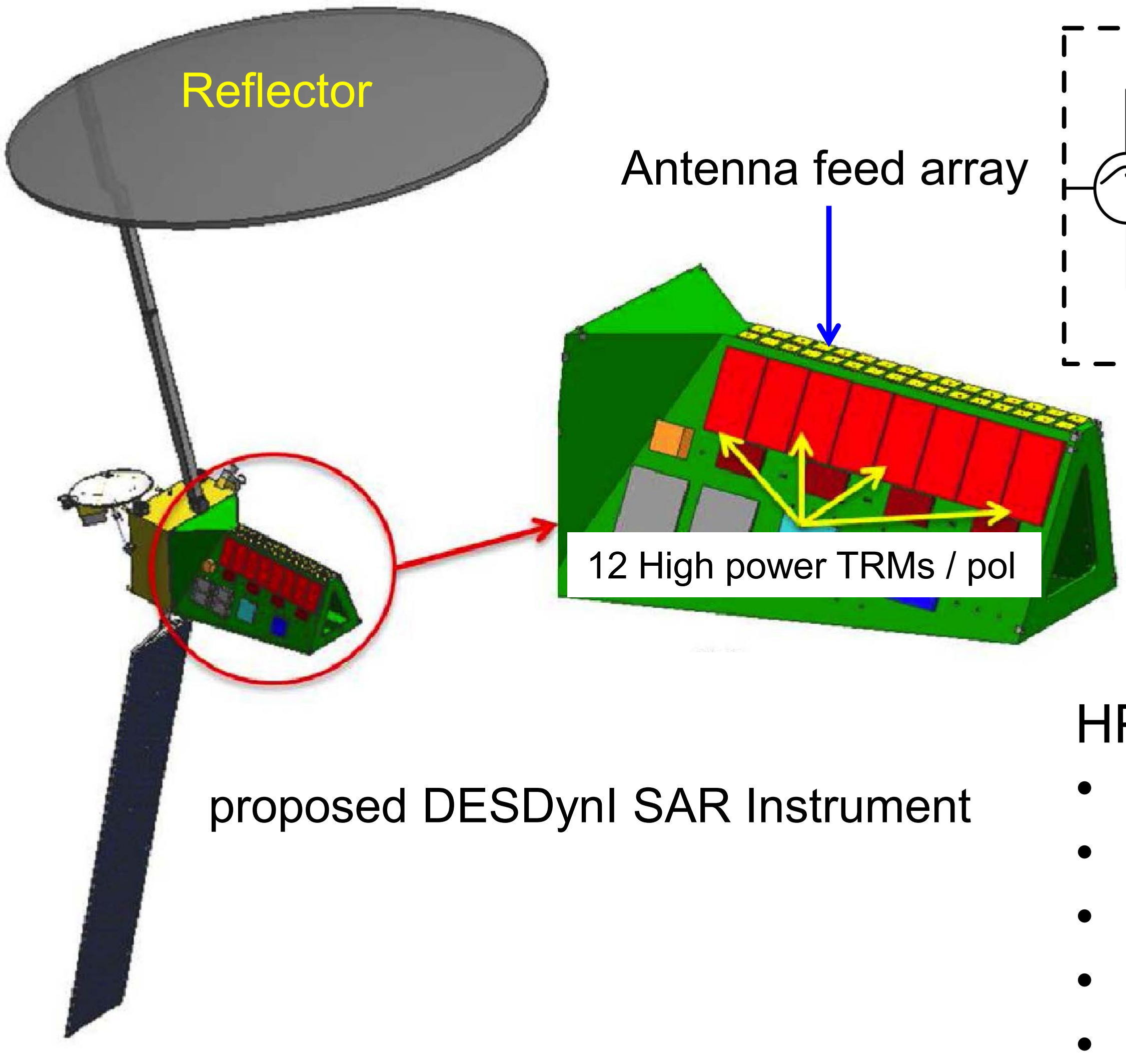
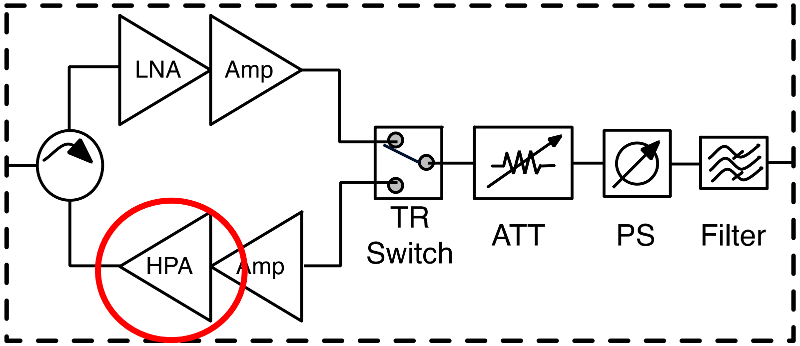


proposed DESDynI SAR Instrument



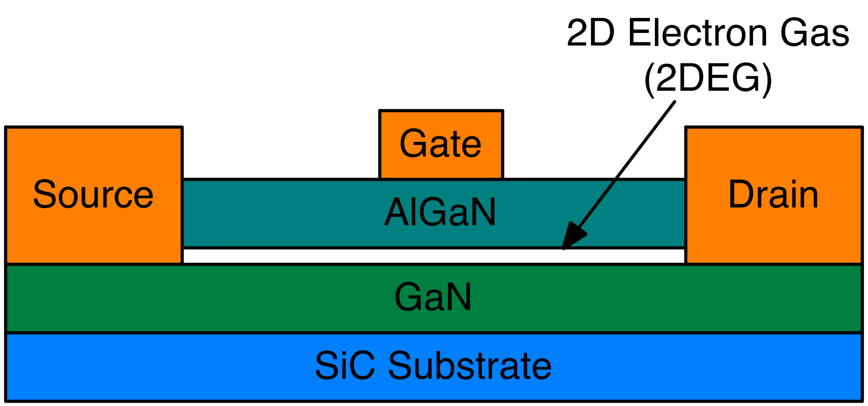
Notional TRM Block diagram

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

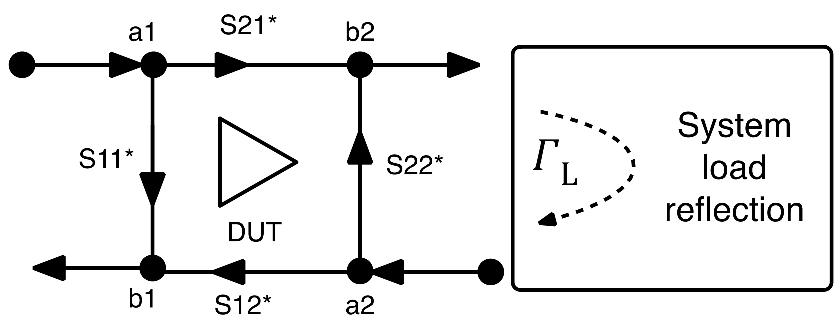


Large Signal Characterization

- **Load-pull characterize non-linear device response**
  - presents impedances to the DUT at fundamental and harmonics
- **In large signal, linear approximation not valid**

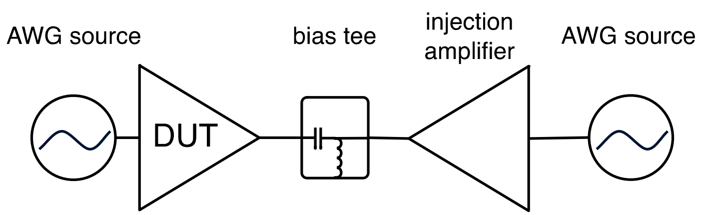
$$I_{DS}(V_{GS}) \simeq i_{DS}(V_{GS}) + a_1 v_{gs} + \underline{a_2 v_{gs}^2} + \underline{a_3 v_{gs}^3} + \cdots$$

- Performance is non-linear (cannot use s-parameters) and depends on impedance presented to device

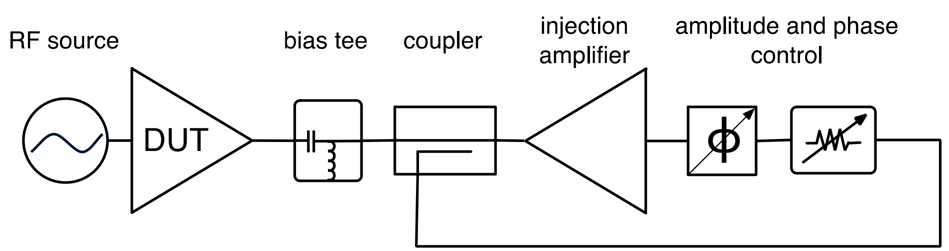


Load-pull Techniques

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



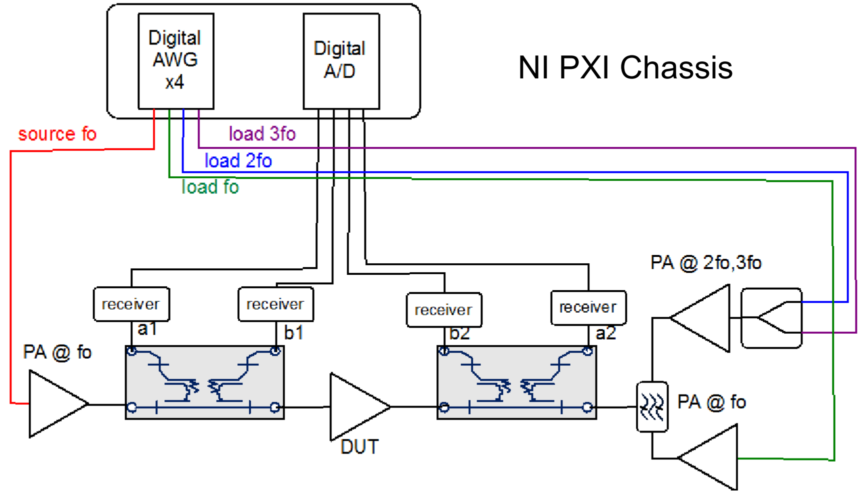
Open loop active load pull



Closed loop active load pull

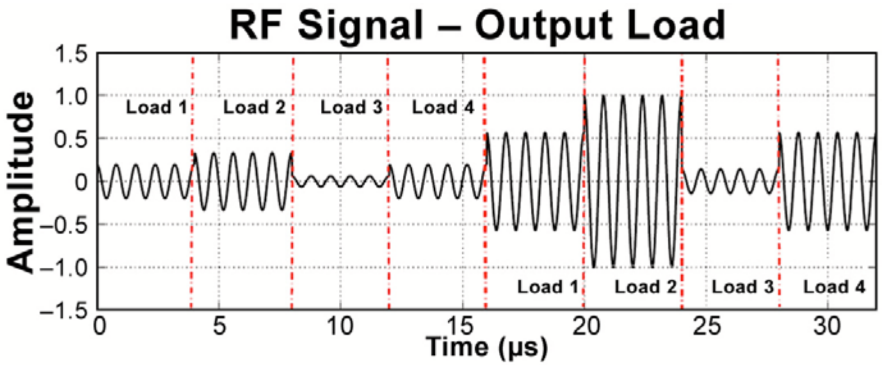
Open Loop Active Load-pull

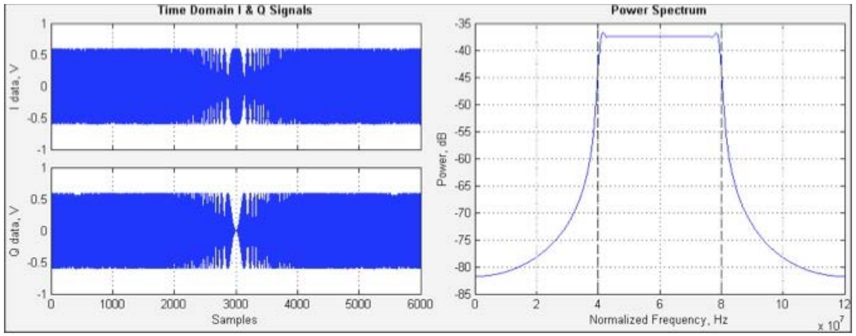
- Mixed-Signal Active Load-pull (MSALPS) developed by Anteverta-mw and Maury Microwave
- 4 tuning loops – source fo, load fo, 2 fo, and 3 fo
- Measurement procedure:
  - samples *a* and *b* waves
  - iterates to achieve impedance
  - measures large signal performance



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

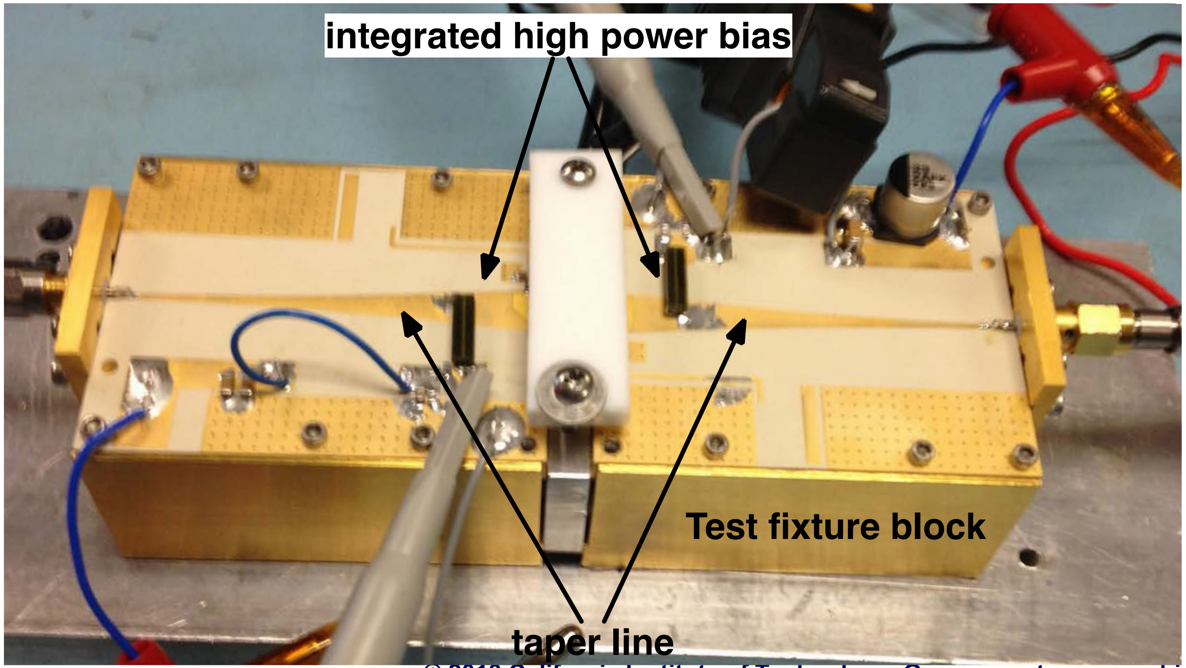


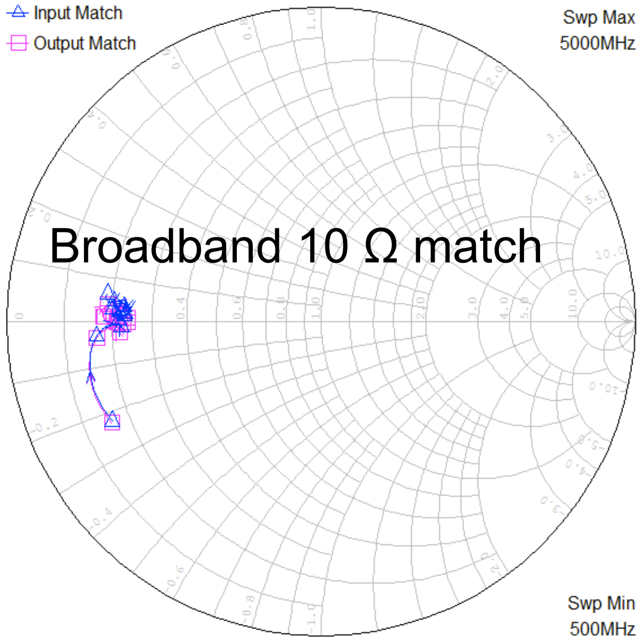


High-Power Test Fixture Design

- **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
  - low-loss
  - wide bandwidth
  - integrated high-power bias

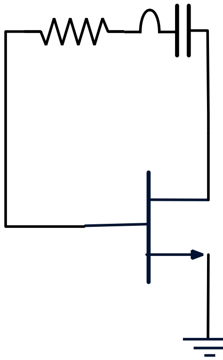
} **Klopfenstein taper**

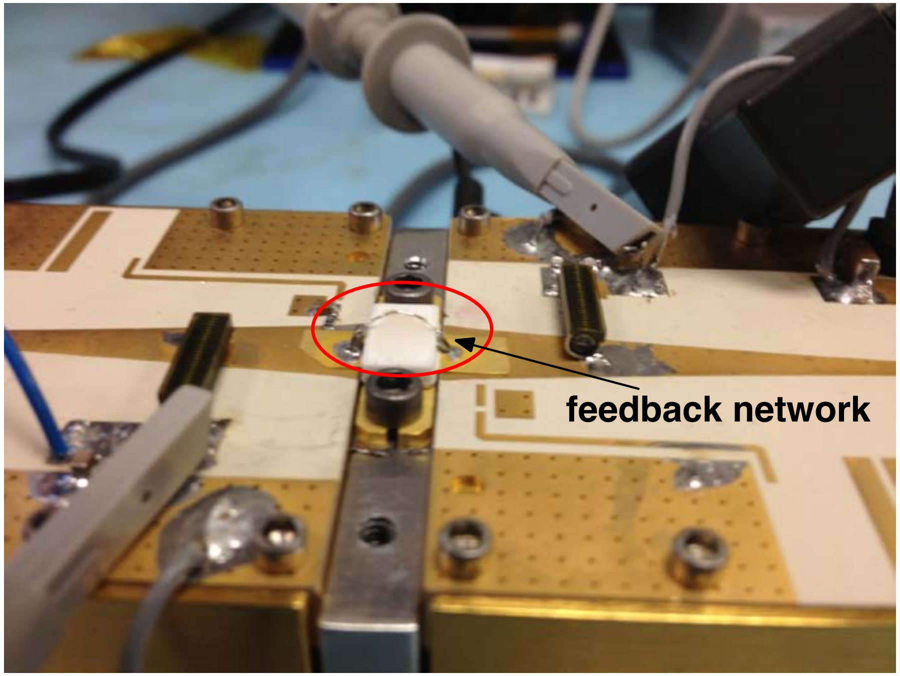


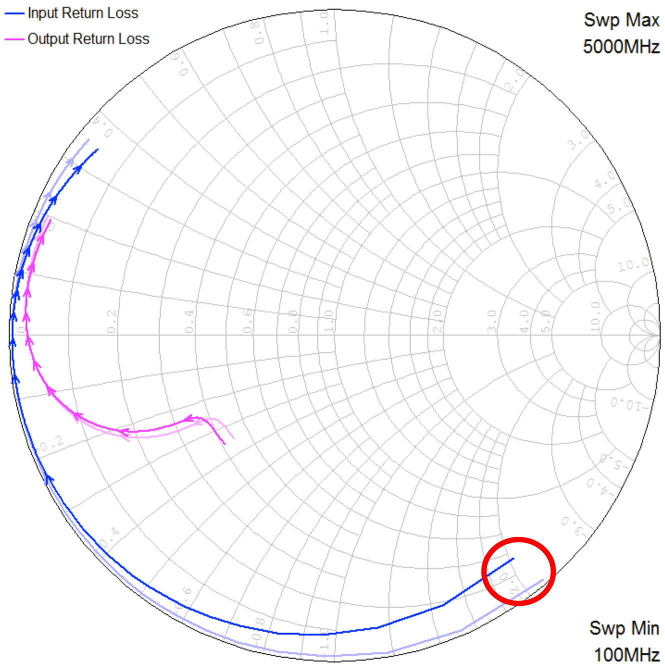


DUT Stability and Feedback

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

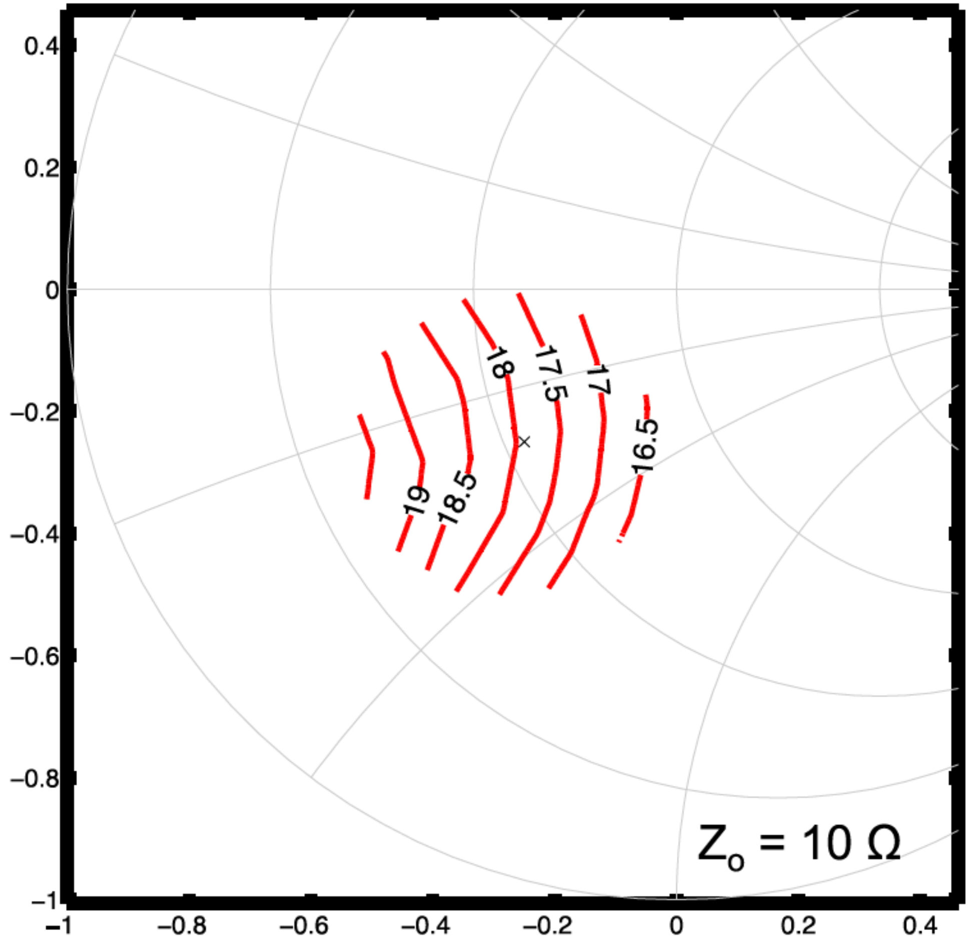






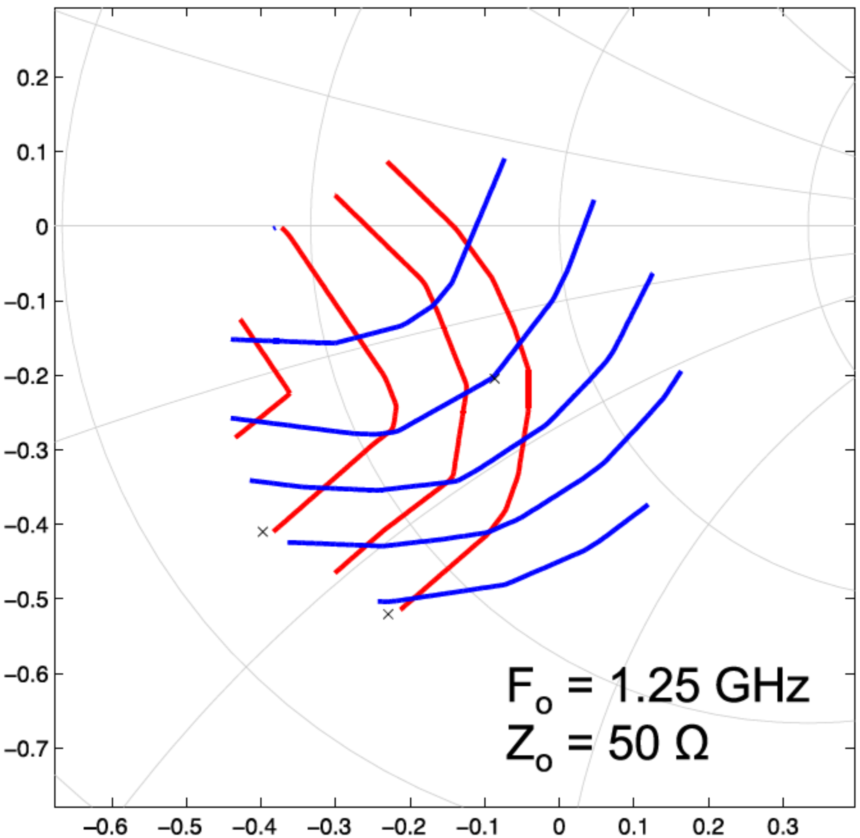
Source match

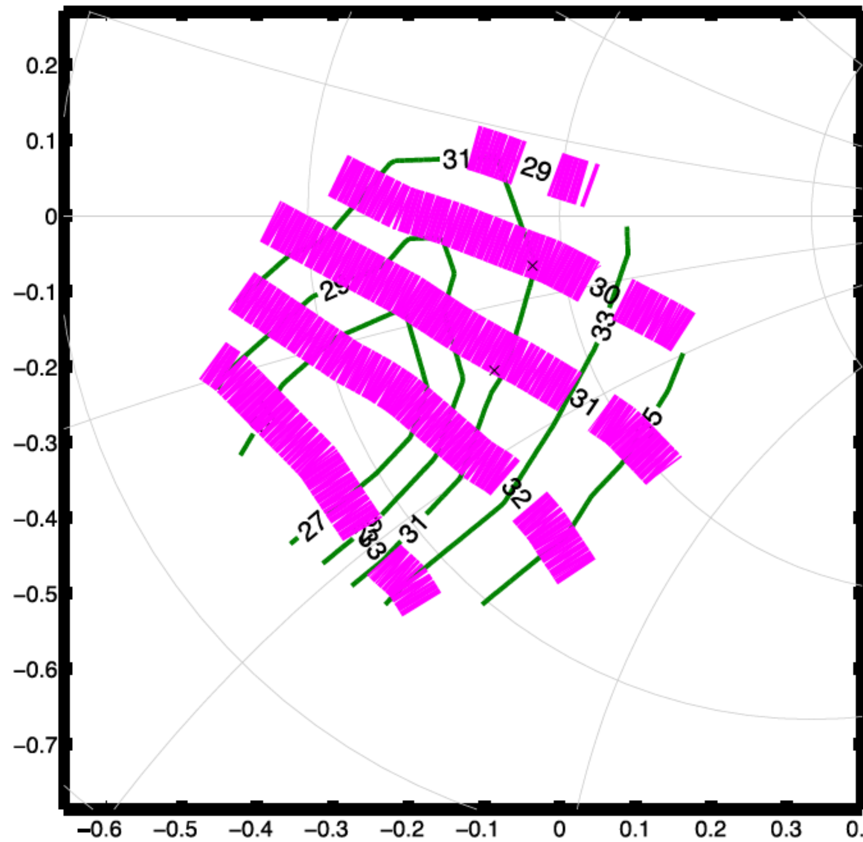
- GaN HEMTs ➔ low input impedance
  - Trade-off between gain, stability, and bandwidth



Load tuning

- Load-pull with no harmonic control
  - P_{out} ~ 50 dBm
  - PAE > 50 %
  - Harmonic levels ~ 30 dBm (~20 dBc)





Harmonic tuning

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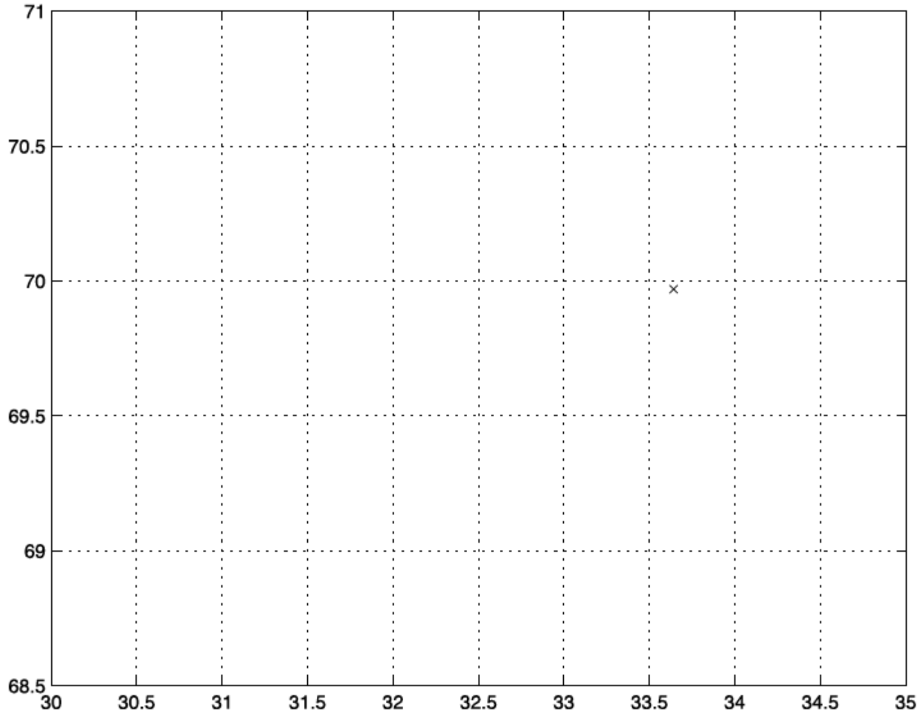
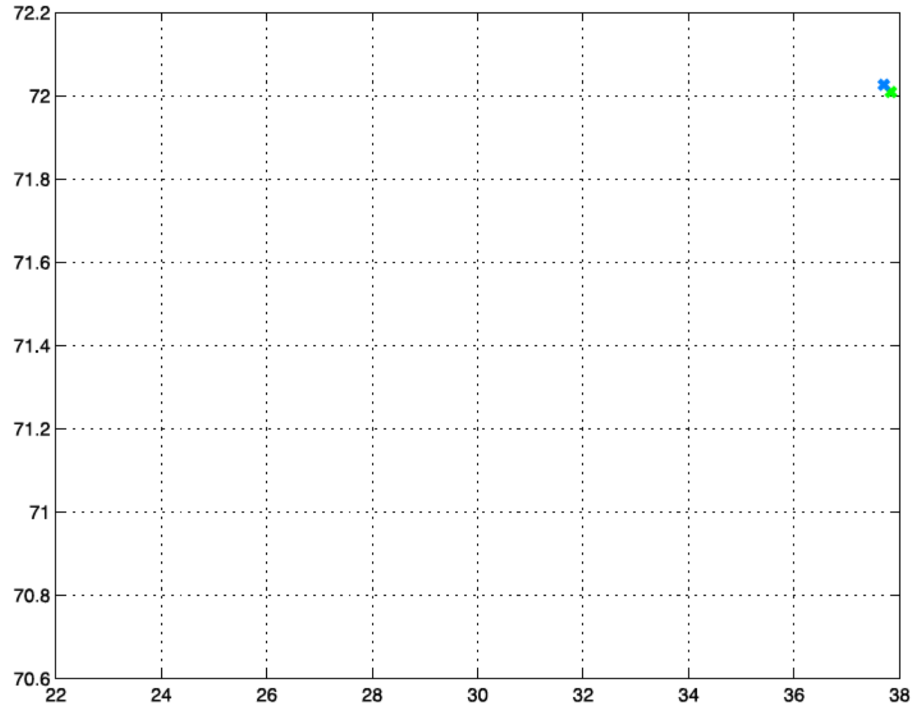
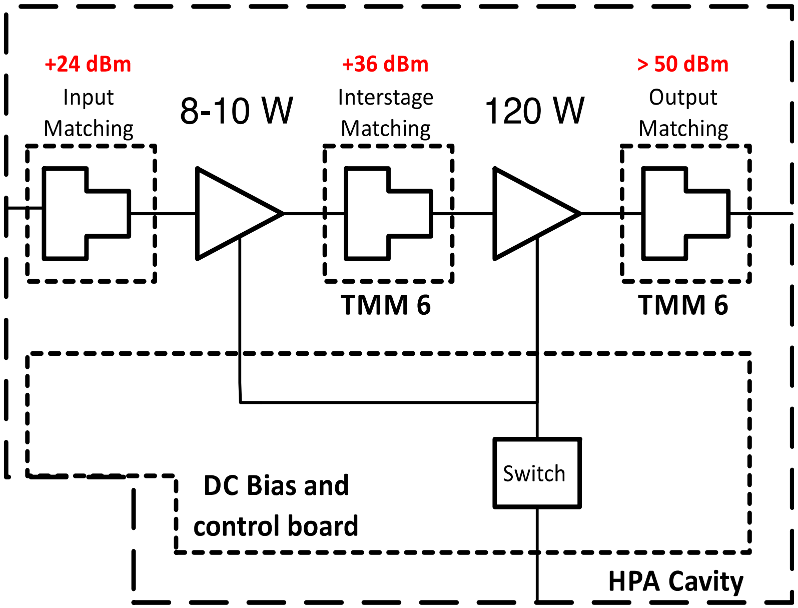
- swept harmonic at Γ = 0.8 over all phase angles
  - optimal harmonic impedances will be reflective
  - harmonic levels reduced to below 30 dBc
  - PAE improved to over 70 %





Proposed HPA Topology

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



8W to 100W interstage match

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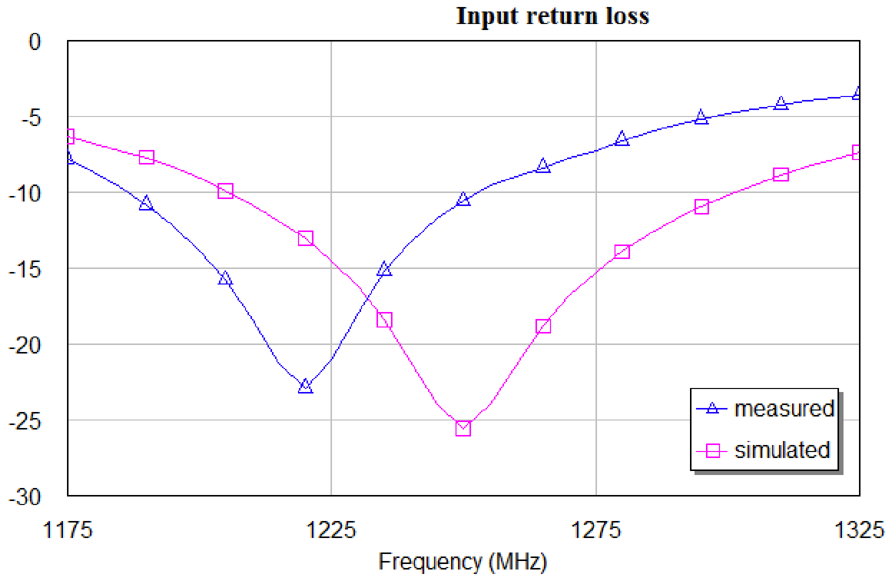
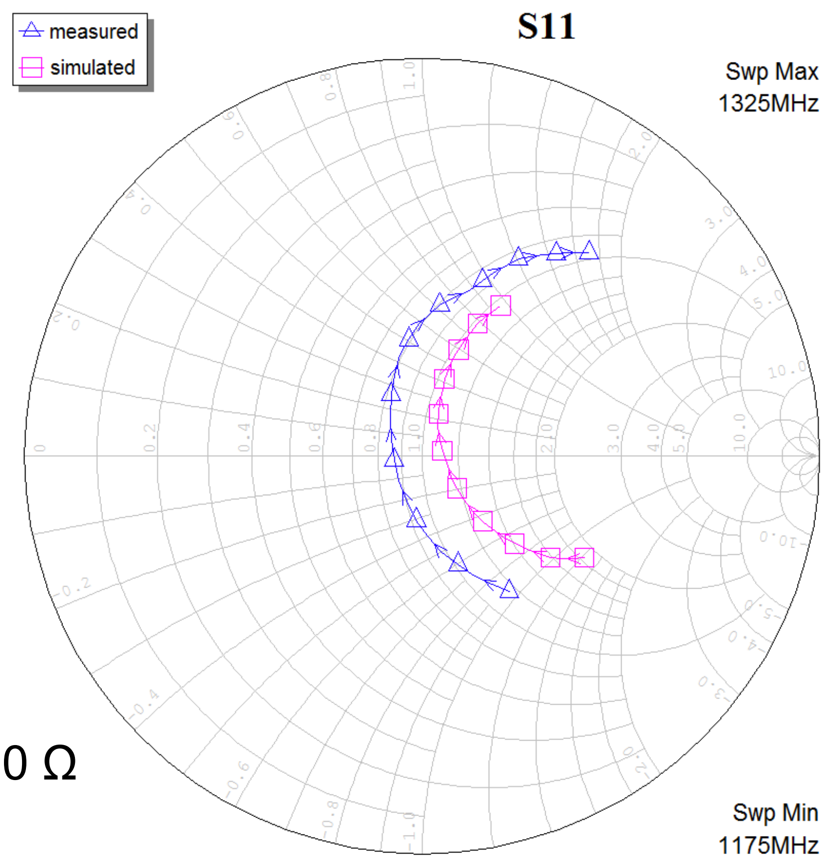
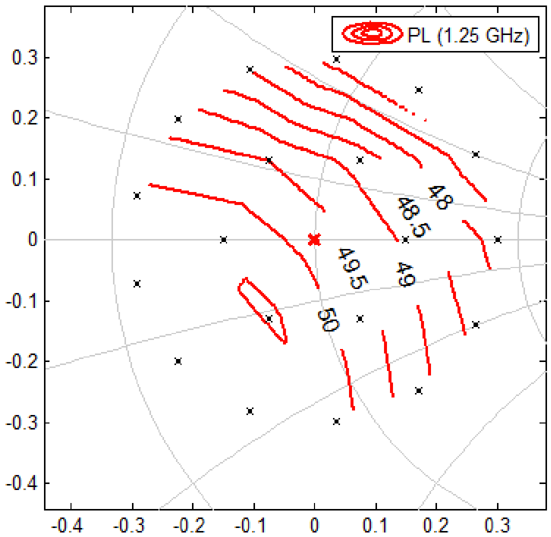
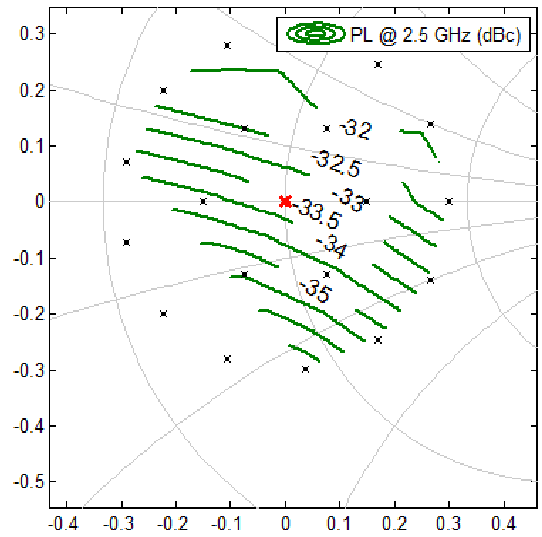


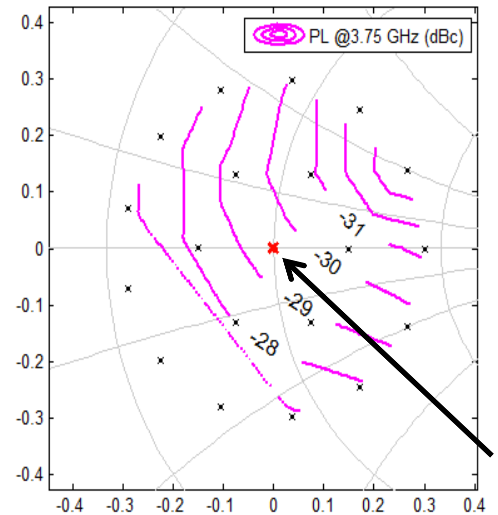


$Z_o = 10\ \Omega$

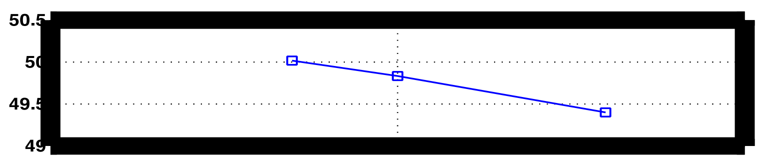
100 W Output match

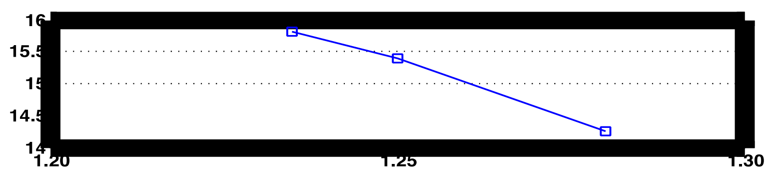


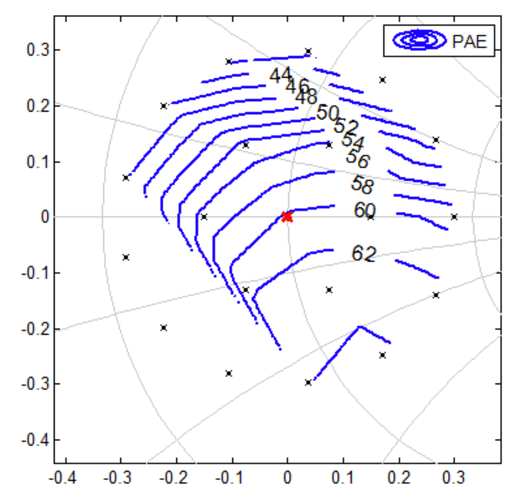




Z_o= 50 Ω

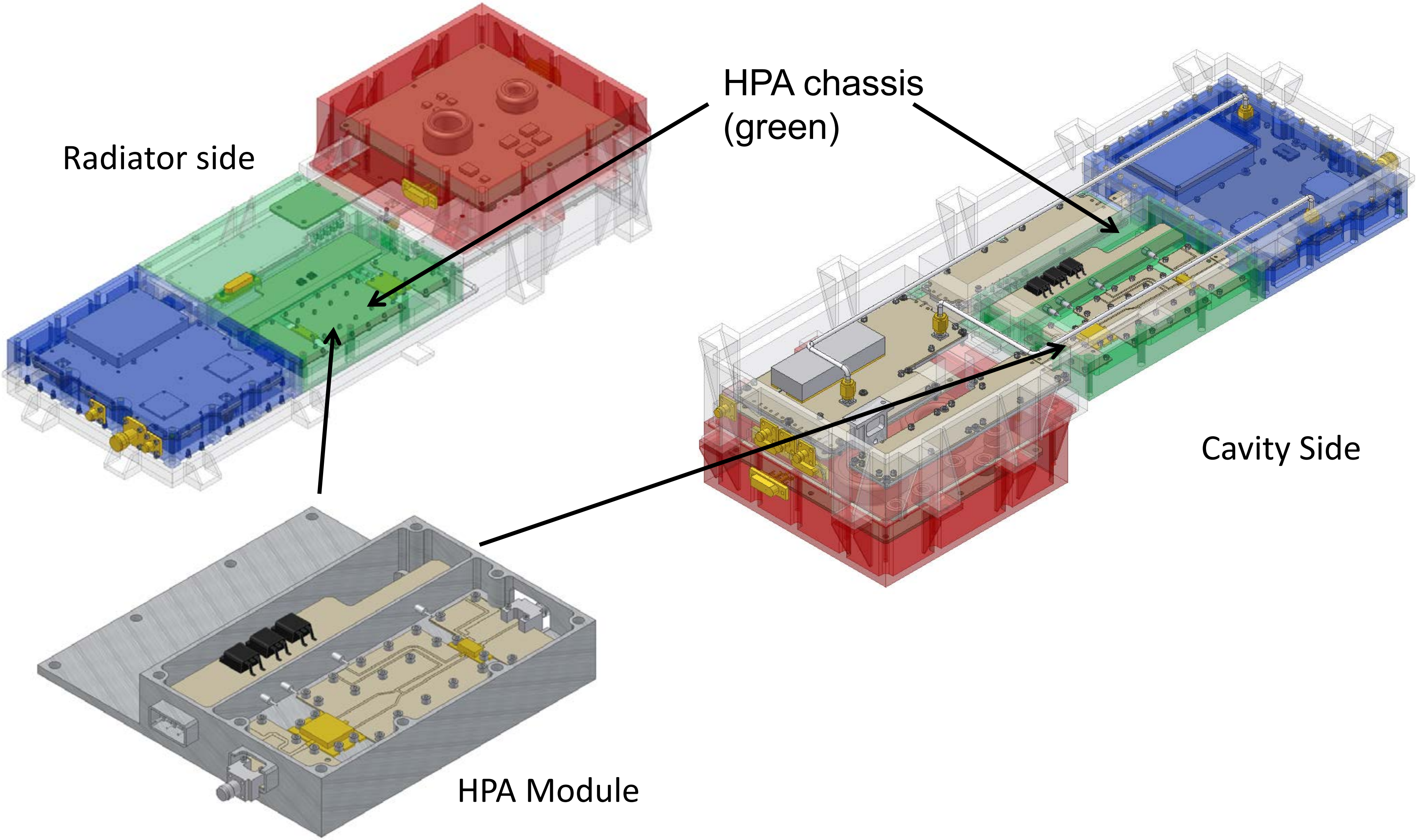




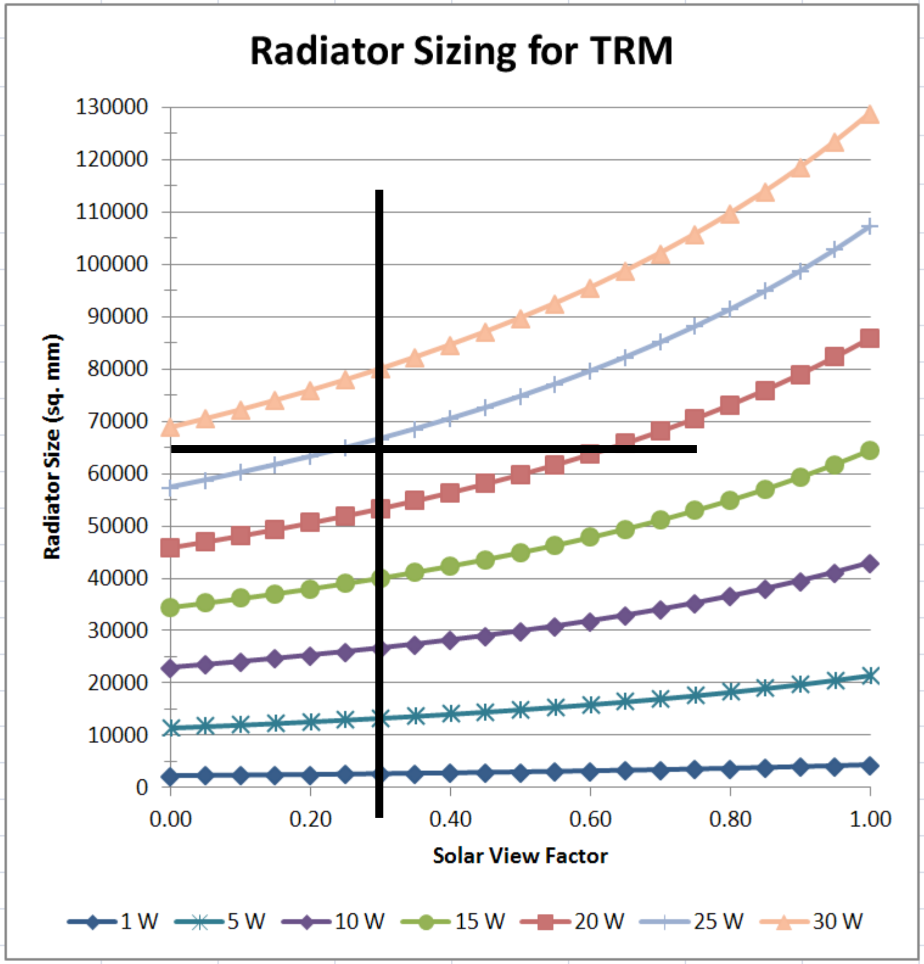


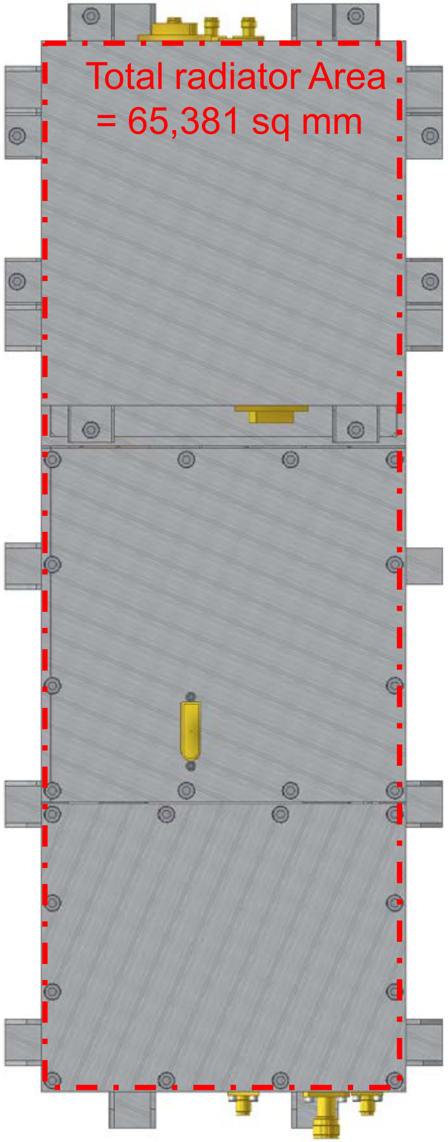
New part has slightly lower PAE

Overview TRM Configuration



Thermal Design





Estimated Power Dissipation = 22W

Conclusions

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- **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