



The University Of Cincinnati College of
Engineering

National Aeronautics and
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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

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

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

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

Decrease in Heat Sink Mass



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

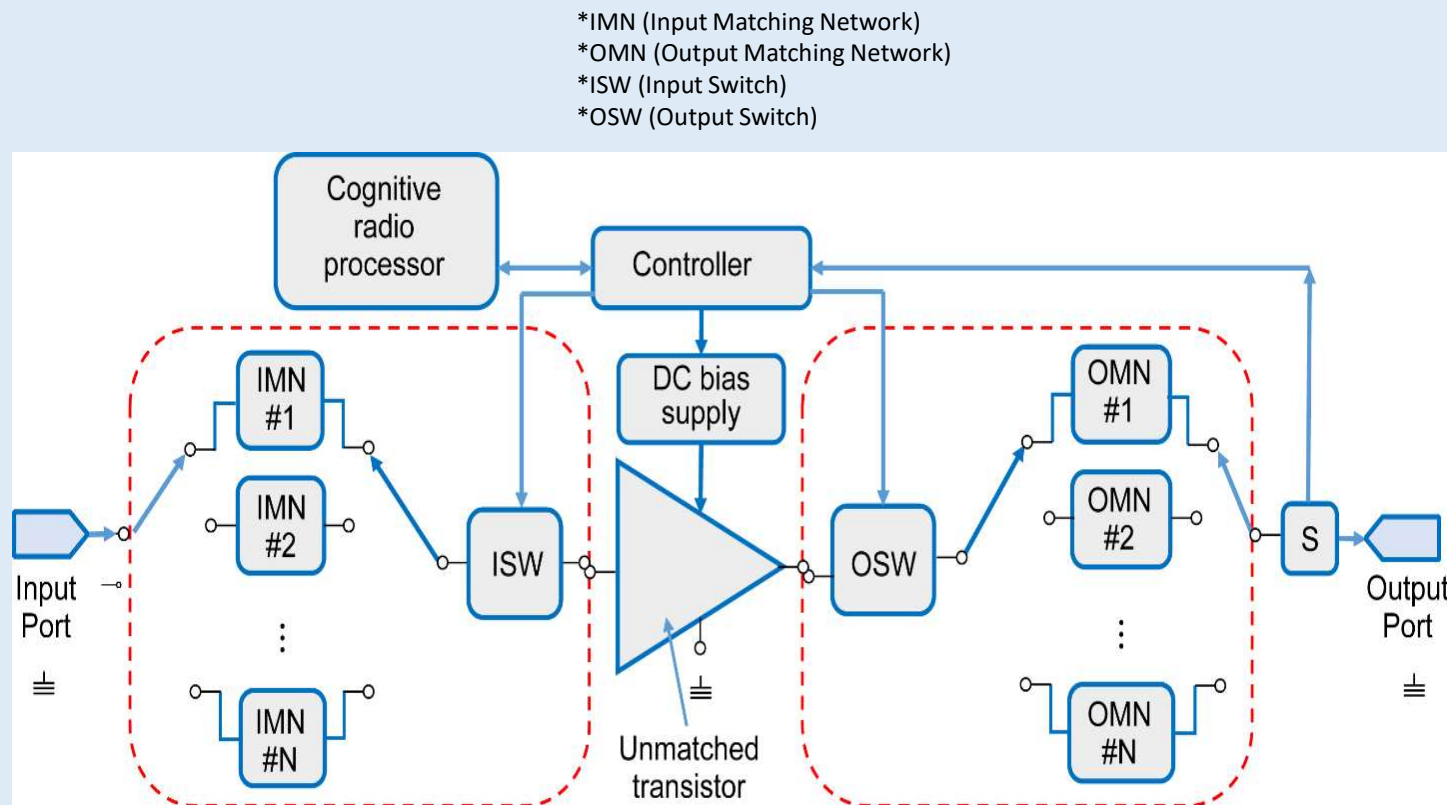
Power Variability

- Amplifiers efficiency drops off when operating below saturation

GaN Transistor Frequency Limitation

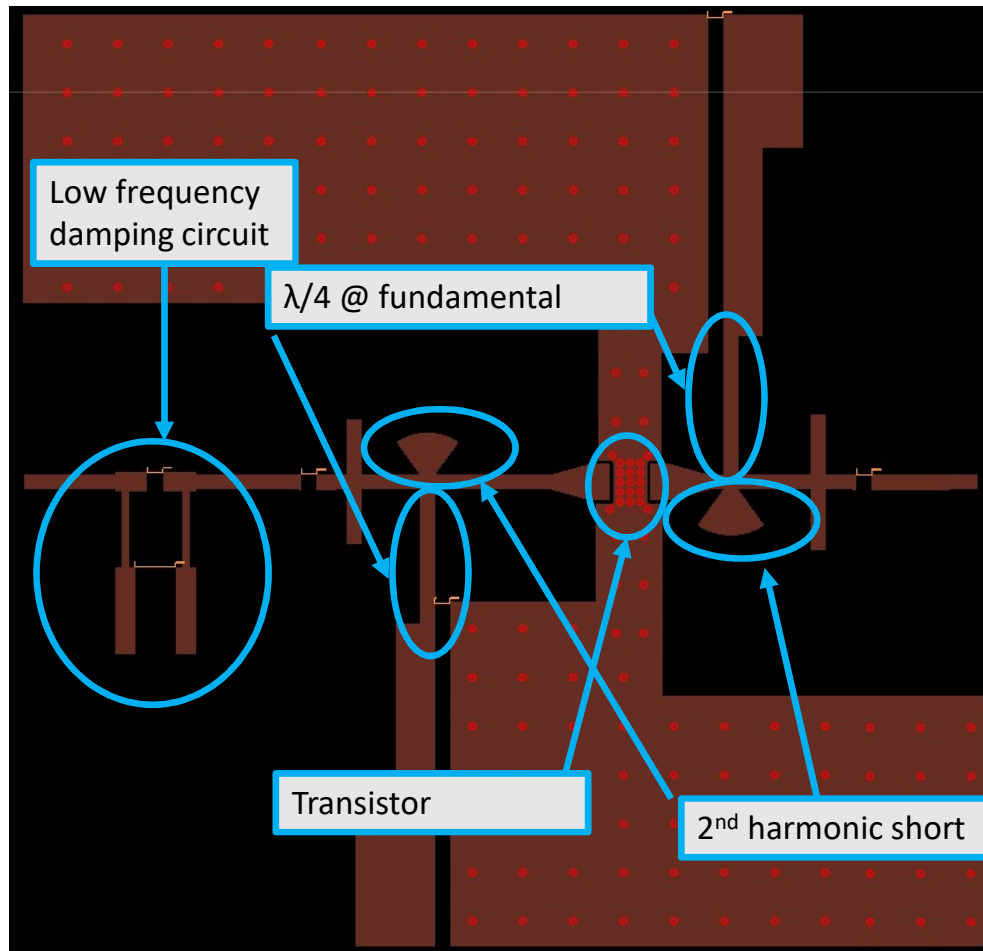
- Achieving max PAE with Class-F type amplifiers requires $F_T > 3^{\text{rd}}$ harmonic
- Current commercially available transistors have an F_T of 18 GHz
- High F_T of GaN HEMTs comes at the expense of feature size and power density

Wide-Band Reconfigurable Harmonically Tuned PA

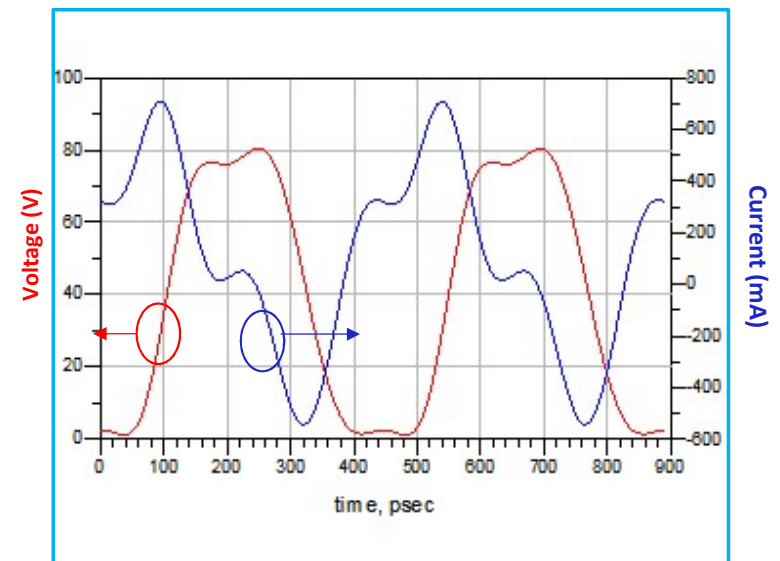


Design to provide wideband high efficiency using multi-network tuning

Inverse Class-F GaN SSPA at X-Band

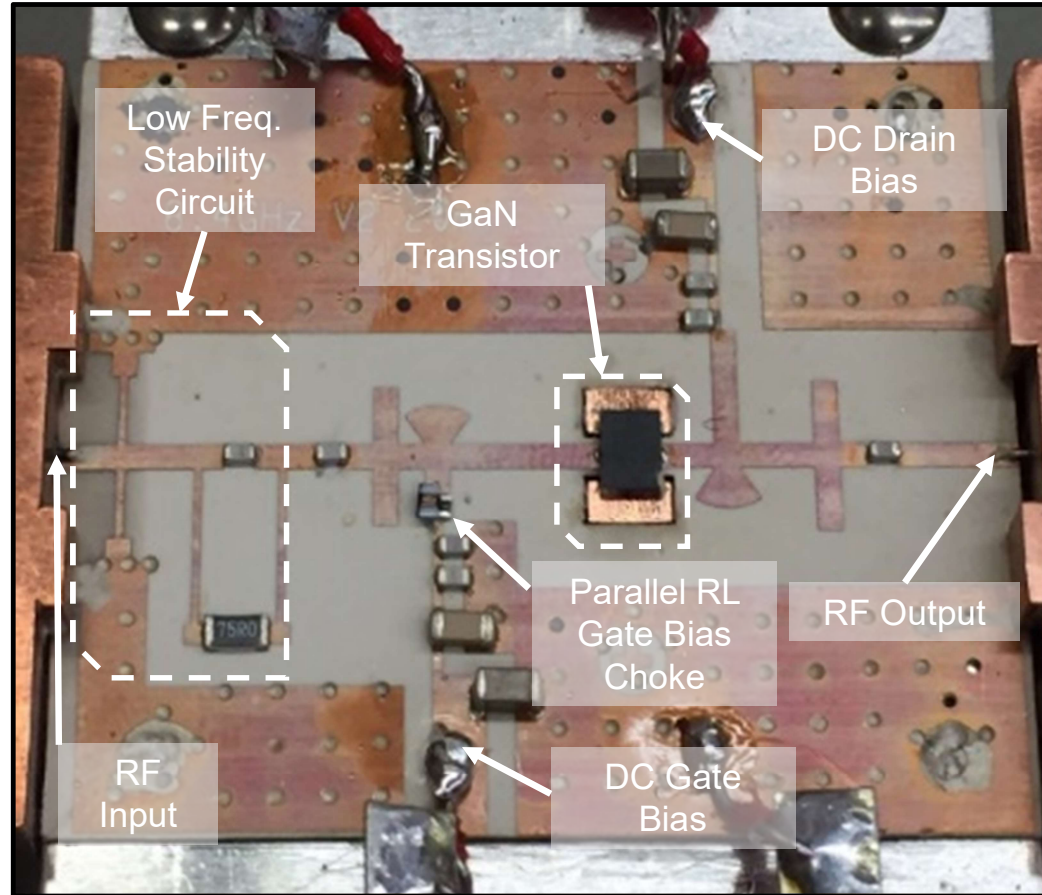


Harmonics are reflected to reshape the voltage and current waveform at the drain



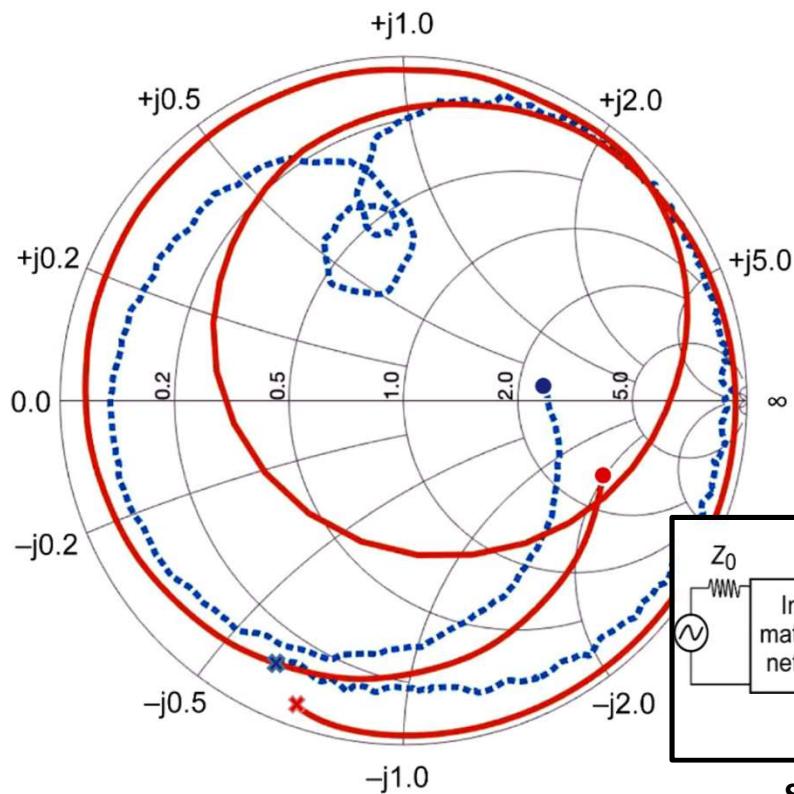
Fabricated Inverse Class-F Amplifier

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



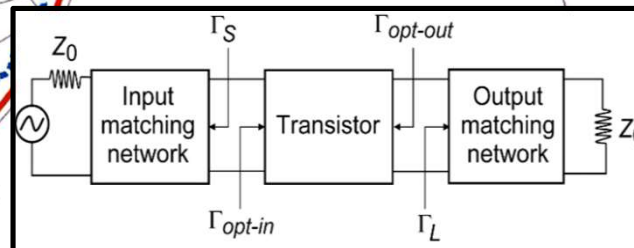
Substrate height, $h = 0.02$ inch & $\epsilon_r = 3.0$

Tuning of Inverse Class-F Amplifier

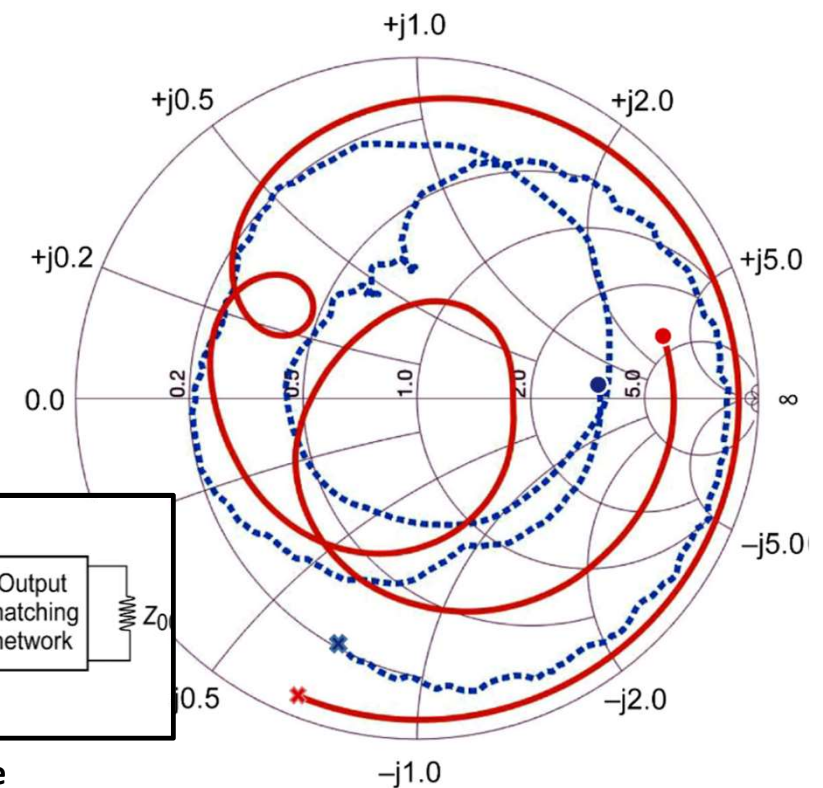


Measured —•— 8.4 GHz * 16.8 GHz
Simulated — 8.4 GHz * 16.8 GHz

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



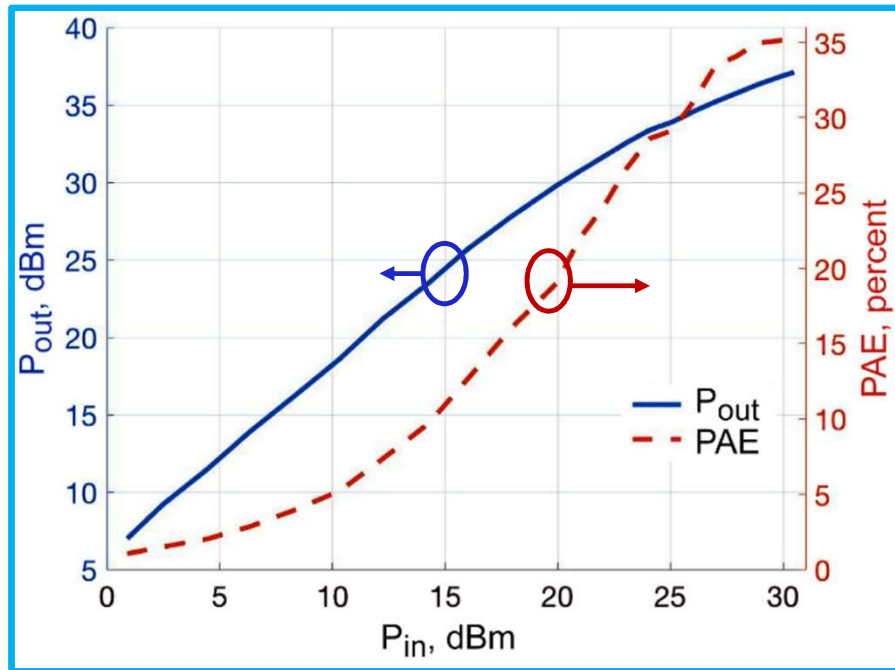
Schematic of the inverse Class-F amplifier design.



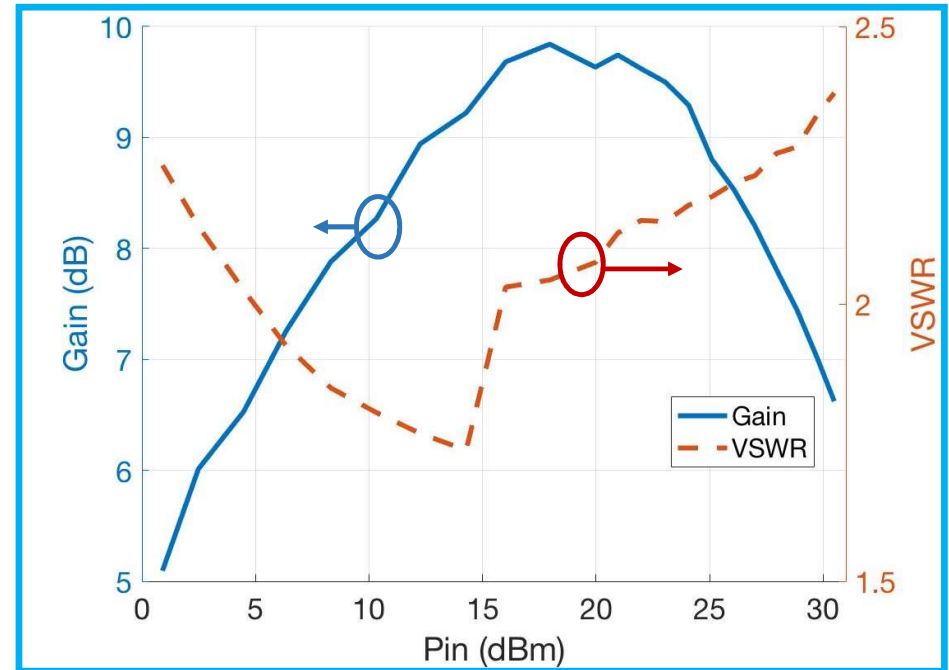
Measured —•— 8.4 GHz * 16.8 GHz
Simulated — 8.4 GHz * 16.8 GHz

Simulated and Measured ($\Gamma_{opt-out}$) 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.

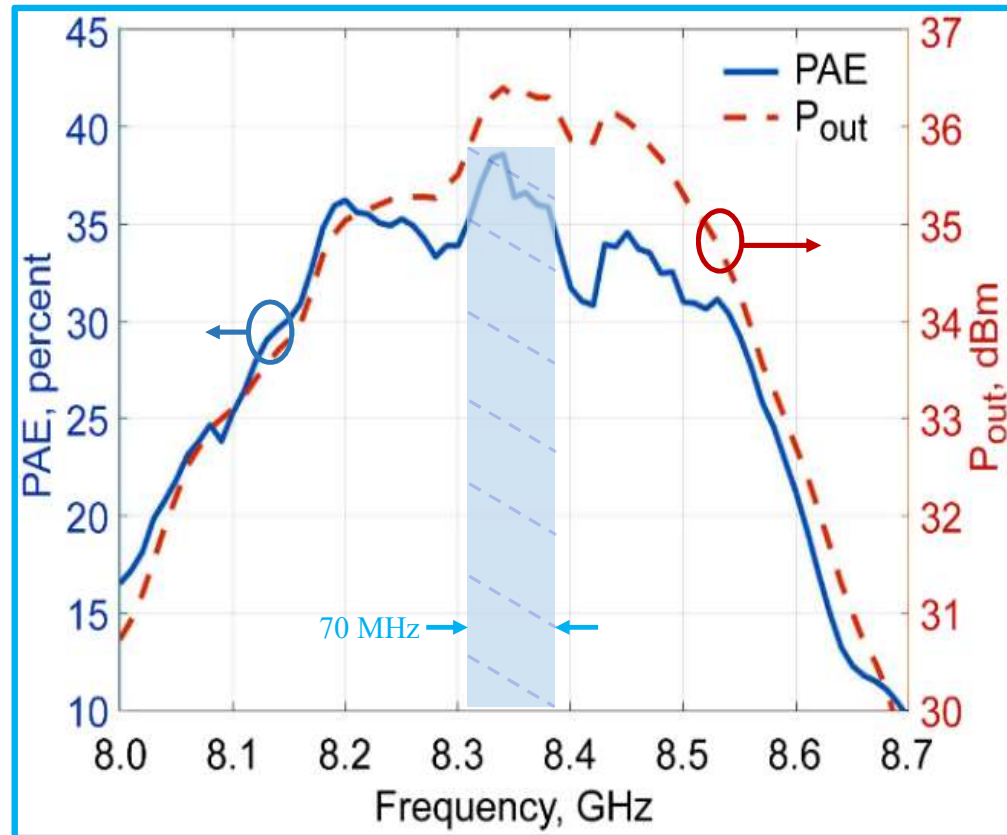


Measured gain and VSWR vs. P_{in} ; $V_{DS} = 40$ V, $V_{GS} = -3.2$ V, and frequency = 8.45 GHz

**Maximum $P_{out} = 5.14$ -W, PAE = 38.6%
with DE = 48.9%**

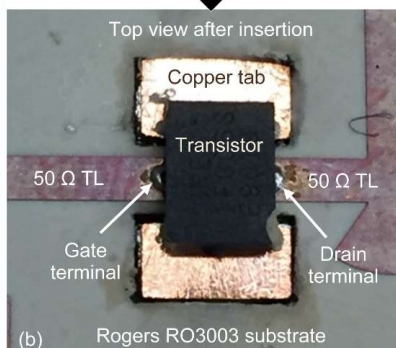
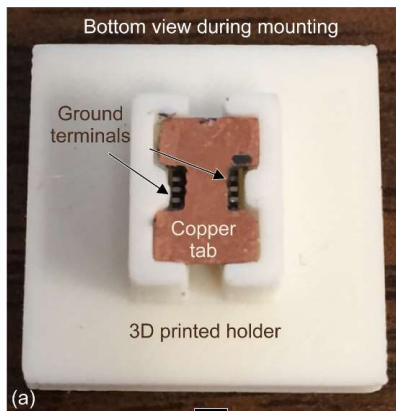
Inverse Class-F Bandwidth

70 MHz bandwidth
where $P_{out} > 36$ dBm
and $PAE > 35\%$
8.315 - 8.385 GHz



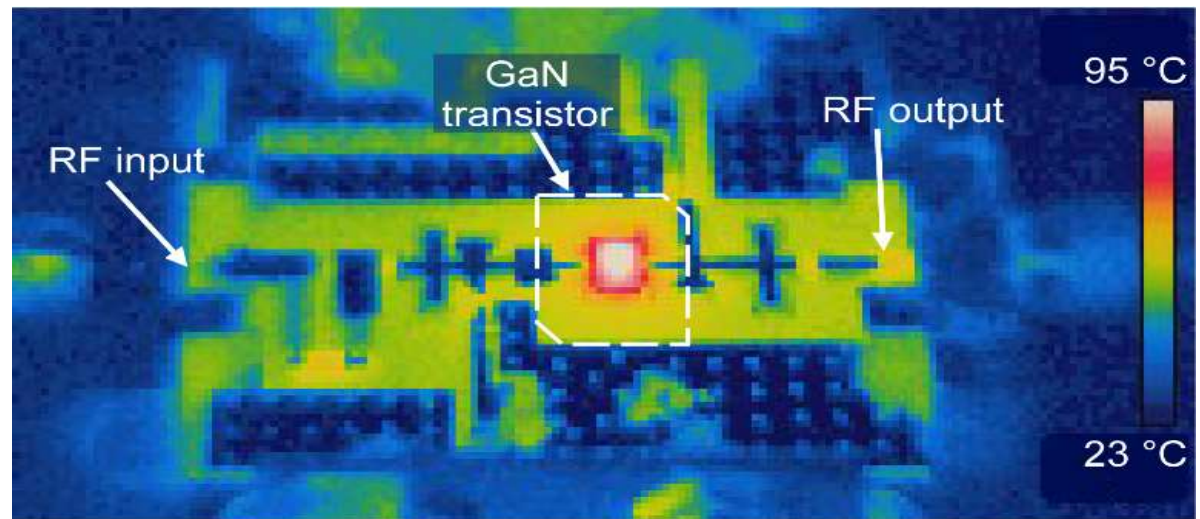
PAE and P_{out} vs. Frequency $V_{DS} = 40$ V, $V_{GS} = -3.2$ V; P_{in} ranges 21.5-30.35 dBm, VSWR ranges 2.4 -33

Thermal Management



CW operation required direct contact between transistor belly and heat sink

Freq. (GHz)	P_{in} (dBm)	V_{DS} (V)	Gain (dB)	PAE (%)	Temp ($^{\circ}$ C)	P_{out} (W)
8.36	29.9	32	6.3	37.3	95	4.2



Operating conditions observed through thermal imaging

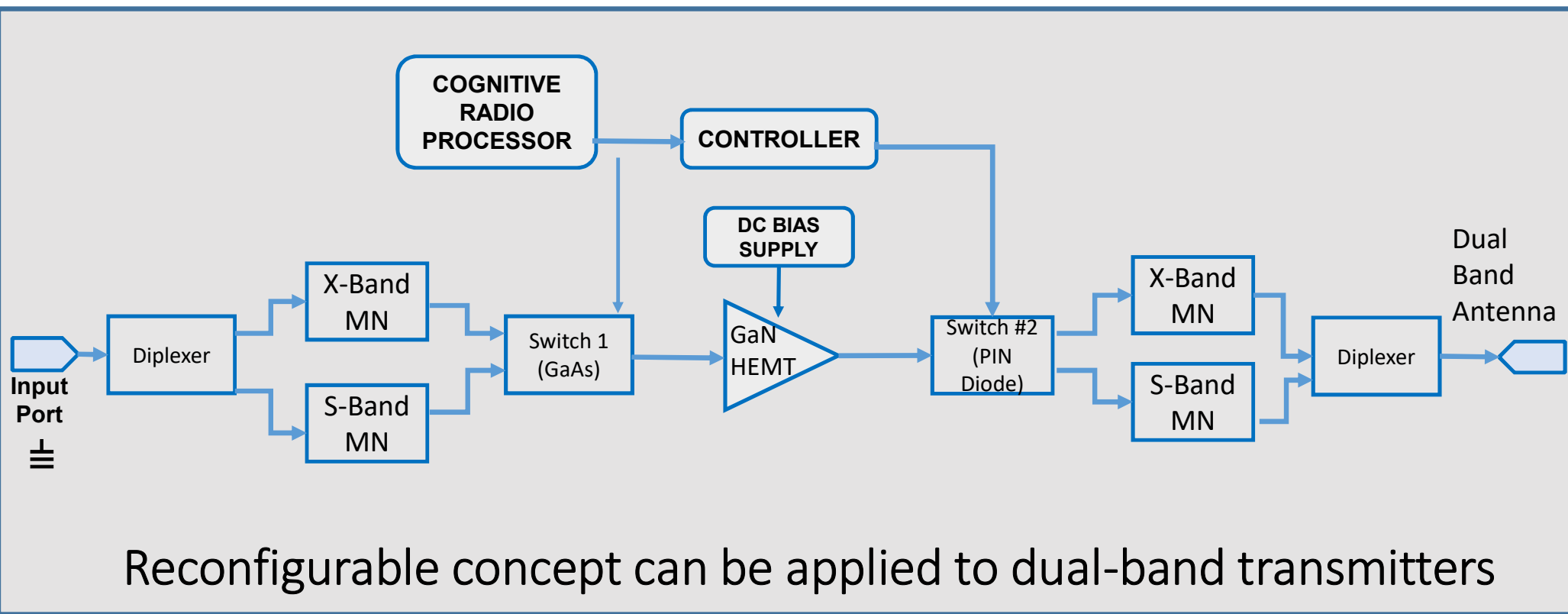
Operating conditions of measured package temp = 95 $^{\circ}$ C :

DC Power Dissipation \approx 7 W

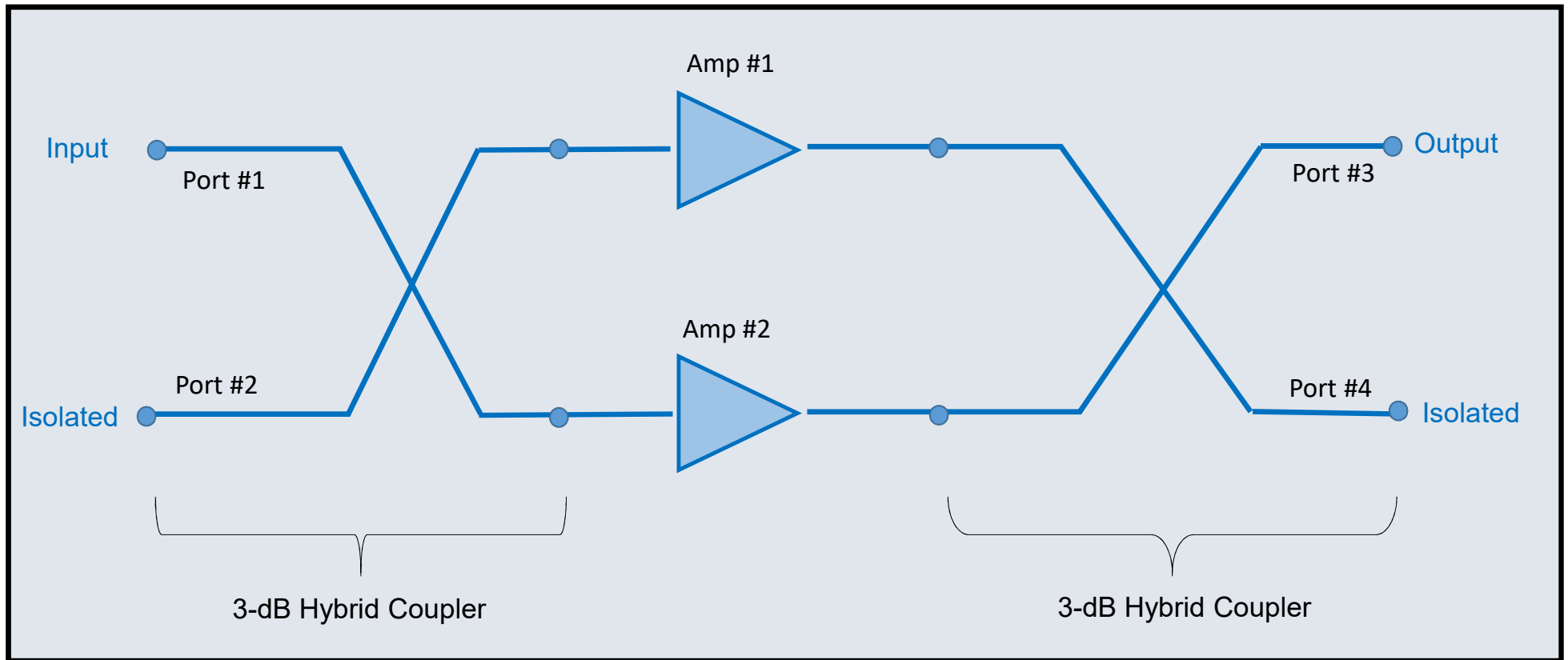
- Data sheet indicates for package temperature of 95 $^{\circ}$ C, the max allowed power dissipation is \approx 9 W.

Hence, achieved thermal safety margin of \approx 22%.

Dual Band Multi-Network Design

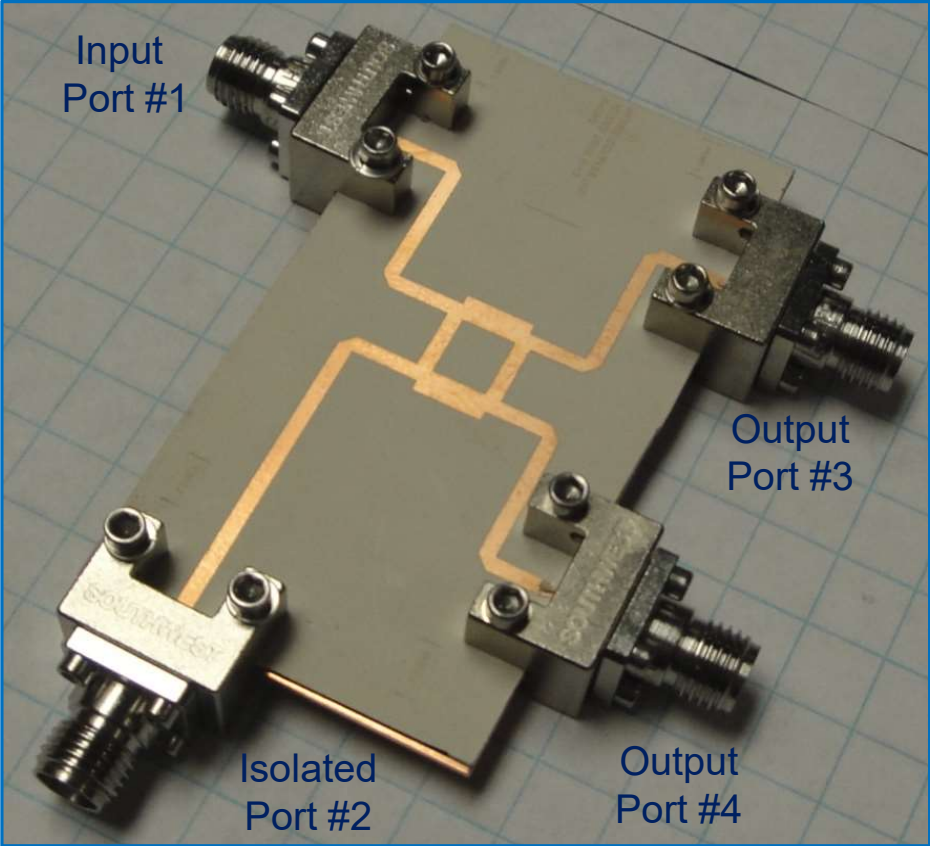


Power Variability - Balanced Amplifier



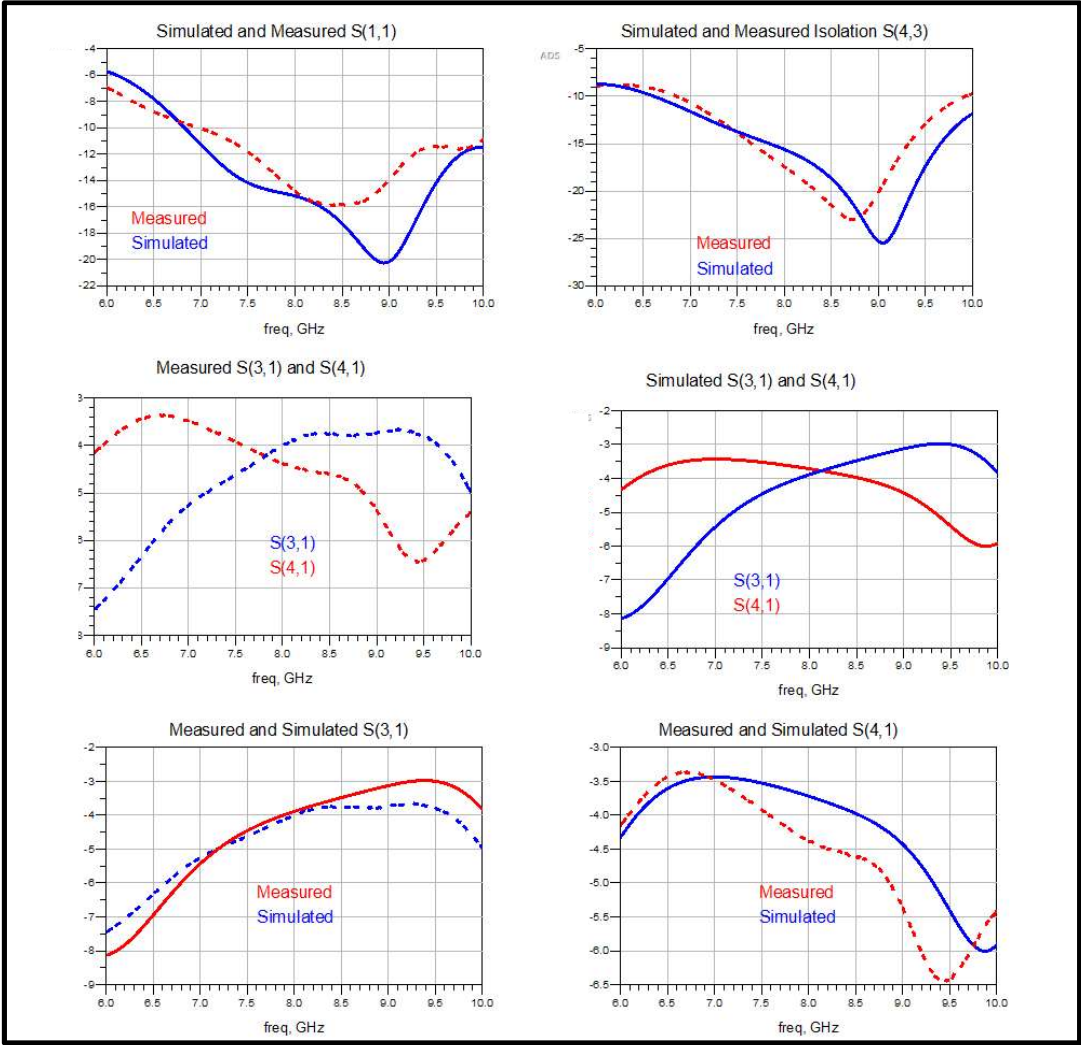
Balanced Amplifier Circuit Topology

Microstrip Branch Line 3-dB Hybrid Coupler

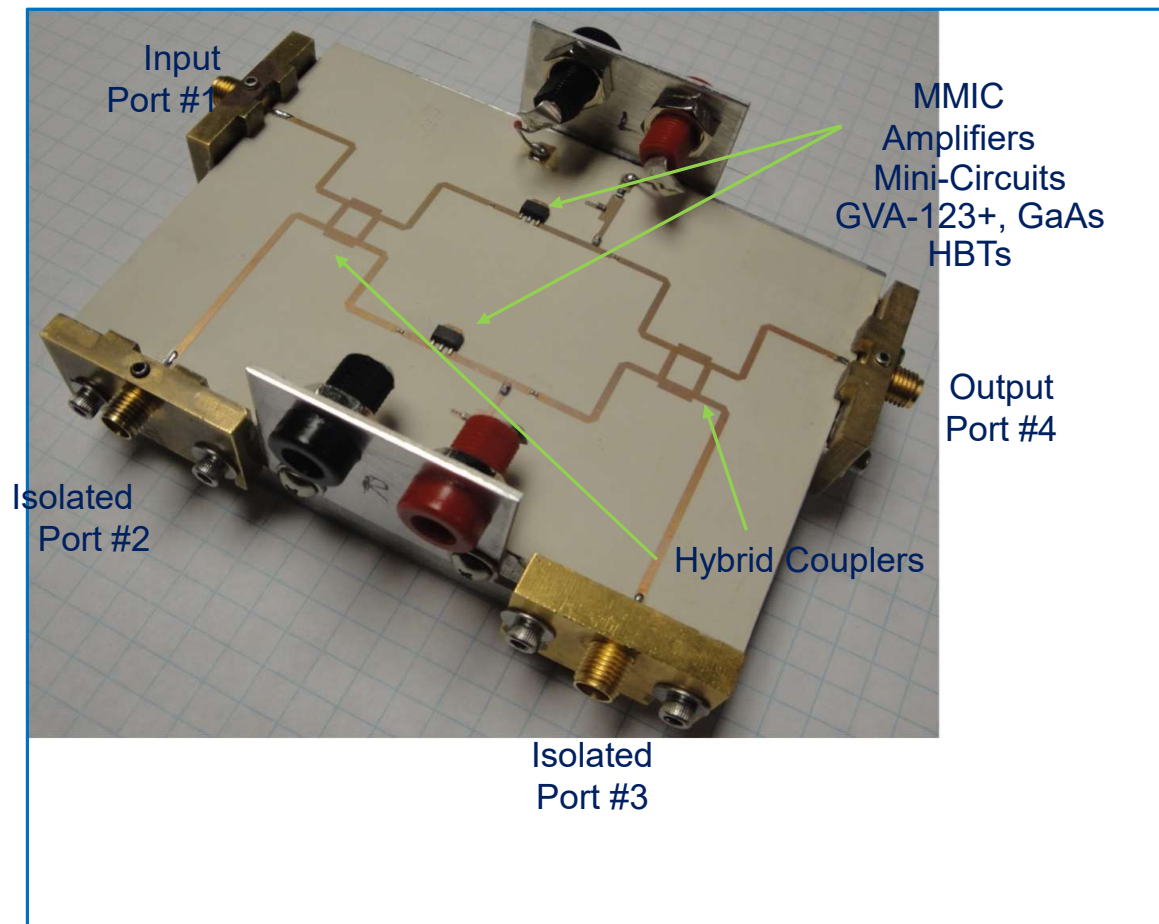


Substrate height, $h = 0.02$ inch & $\epsilon_r = 3.0$

Measured vs Simulated Results



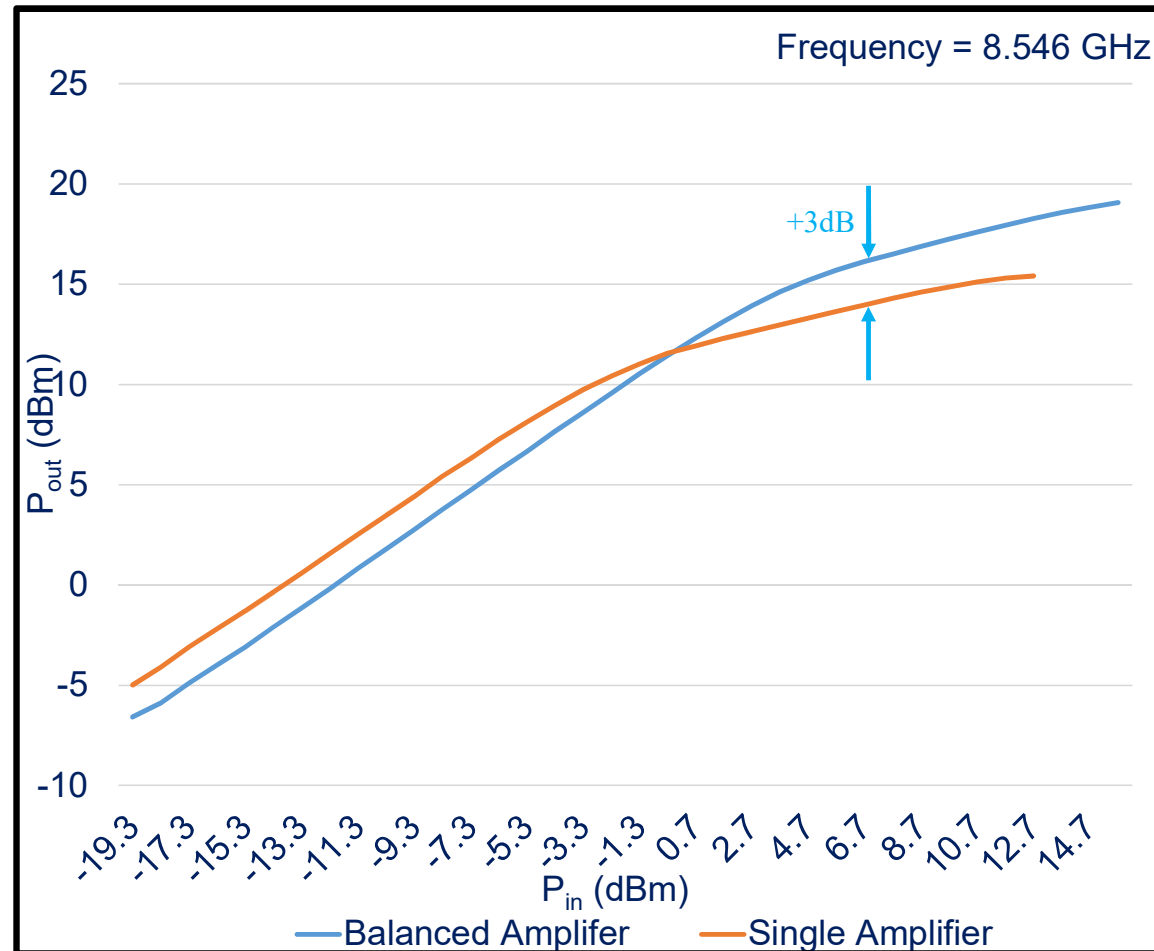
Fabricated Balanced Amplifier



Substrate height, $h = 0.02$ inch & $\epsilon_r = 3.0$

P_{in} vs. P_{out} for Single & Balanced MMIC Amplifiers

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 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 $P_{out} > 36$ 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.