BREAKTHROUGH SIMPLICITY

A Quad-Band InGaP HBT Power Amplifier Module with 60% EGSM Power Added Efficiency and 35:1 Open Loop Ruggedness

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Co-authors and Acknowledgements

- Co-authors
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- There is no such thing as an individual effort.

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Outline

- Power Amplifier Module Requirements
- Power Amplifier Ruggedness
    - Thermal Issues
    - Dynamic Current-Voltage Issues
- Fourth Generation HBT Process
- Power Amplifier Module Data
- Conclusions

Competing Power Amplifier Module Requirements

- Frequency Bands
- Output Power
- Power Added Efficiency
- Ruggedness (Ability to withstand load mismatch)
- Harmonics in Output
- Stability (No spurious emissions)
- Control Slope (ΔPout / ΔVcontrol)
- Switching Speed (Time delay from change in Vcontrol to settled Pout)
- Input Match
- Receive Band Noise (Spillover of transmit power to receive frequencies)

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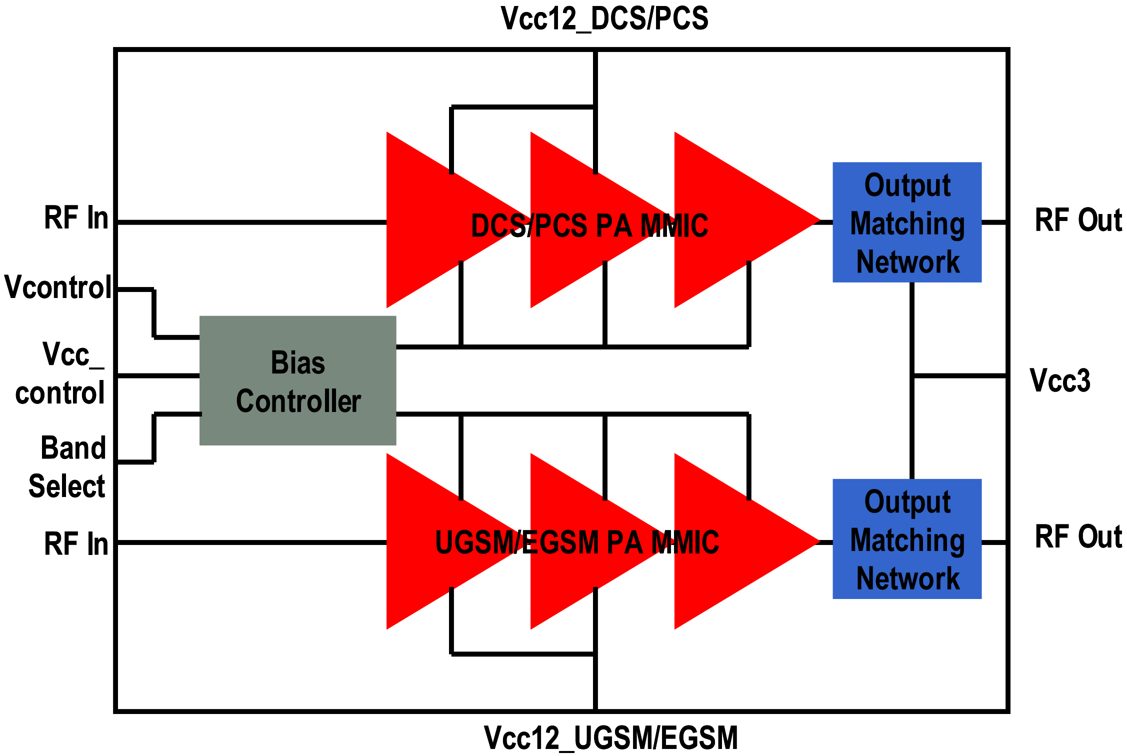
Generic Quad-Band Module Requirements

- Quad-Band
  - UGSM: 824-849 MHz
  - EGSM: 880-915 MHz
  - DCS: 1710-1785 MHz
  - PCS: 1850-1910 MHz
- Maximum Output Power
  - UGSM/EGSM: ≥35 dBm
  - DCS/PCS: ≥33.5 dBm
- Peak Power Added Efficiency
  - UGSM/EGSM: ≥55%
  - DCS/PCS: ≥50%
- Ruggedness
  - Withstand load VSWR > 10:1 at maximum rated inputs (Vcc = 5 V, Vcontrol = 2 V, Pin = 10 dBm) over temperature (-40 C to +85 C)



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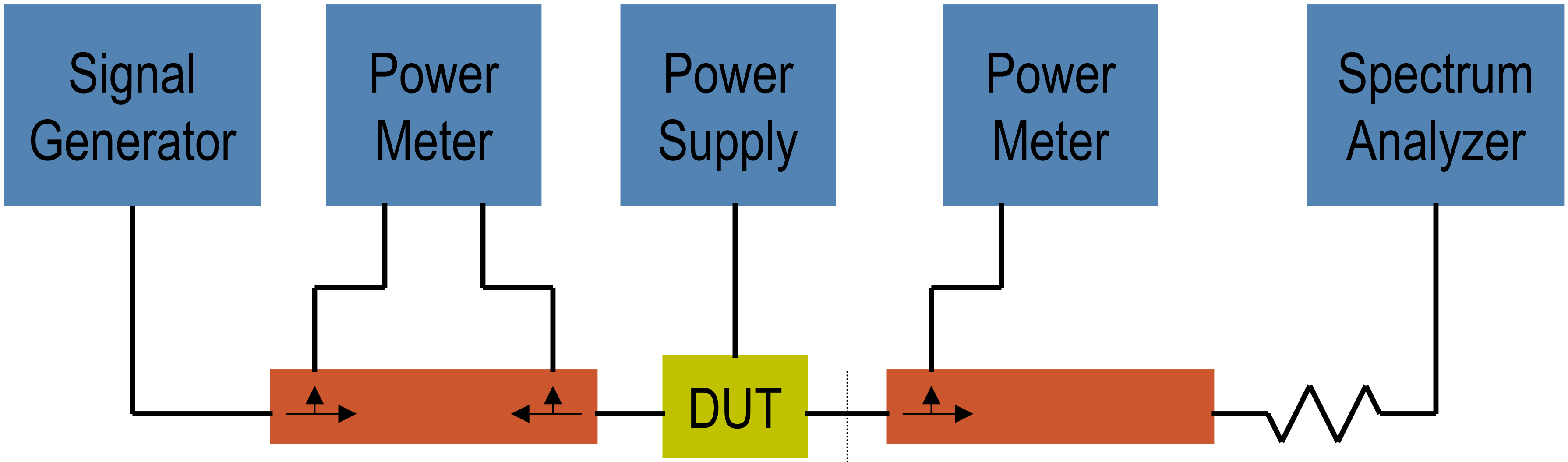
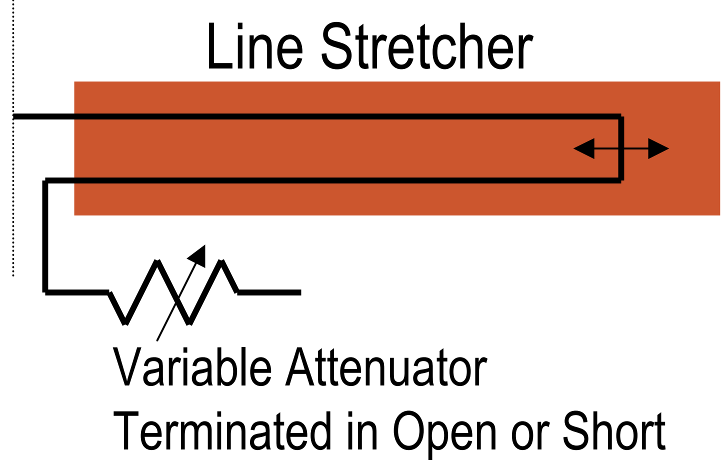
Power / Ruggedness Test Bench



- Perform 50 Ω Power Sweep
- Replace Output Coupler / Power Meter / Spectrum Analyzer with Line Stretcher / Variable Attenuator
  - Set attenuator for VSWR
  - Vary line stretcher for all phase angles
  - Monitor DUT current



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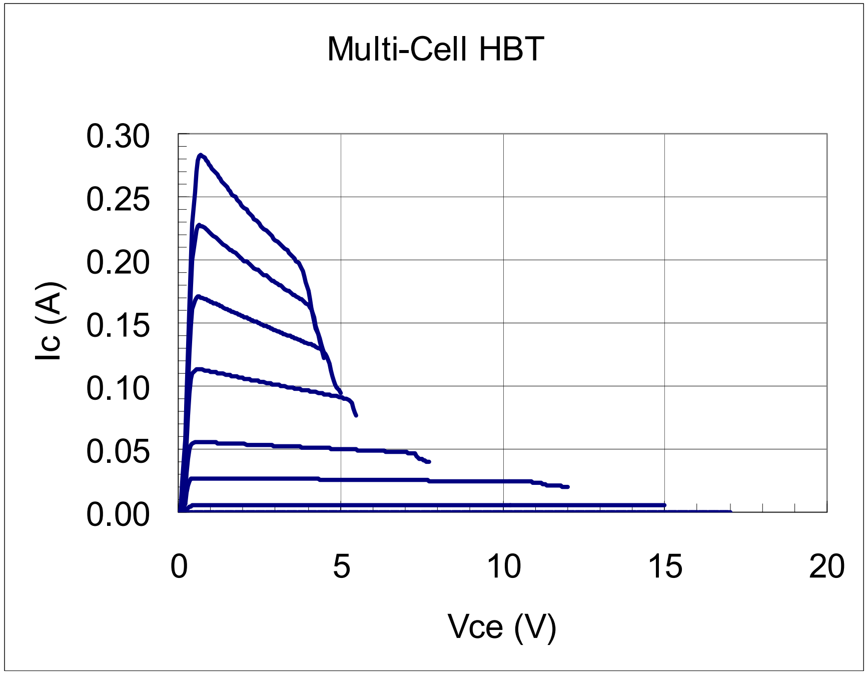
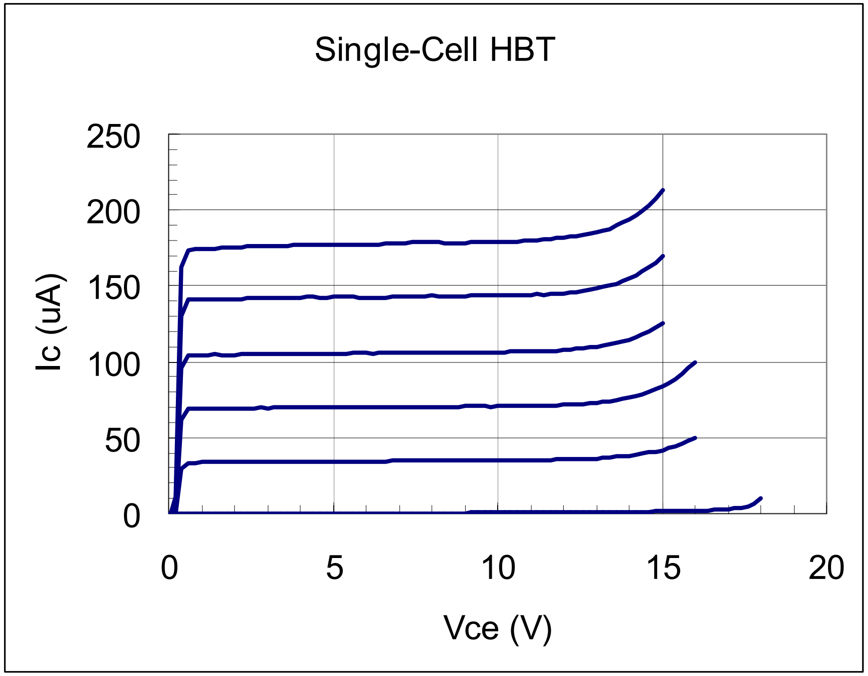
Causes for Ruggedness Failures in HBT Power Amplifier Modules

Thermal Runaway



Breakdown



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Electro-Thermal Simulation Used to Study Thermal Imbalance of Third Stage

- Each cell in third stage, multi-cell array is modeled with an enhanced Gummel-Poon model with an independent temperature node.
- The thermal sub-circuit is a thermal resistance/capacitance matrix coupling each cell to the heat sink and to other cells.
- Thermal resistance for an individual cell is measured with Dawson's technique.
- The thermal matrix is solved with an EM simulator using the similarity between the heat-transfer equations and the electro-static potential.
- Hierarchy is used to speed calculations.
  - Near cells are grouped and evaluated with cell-to-cell thermal coupling.
  - Groups are evaluated with group-to-group coupling.
- The simulation agrees with thermal imaging.

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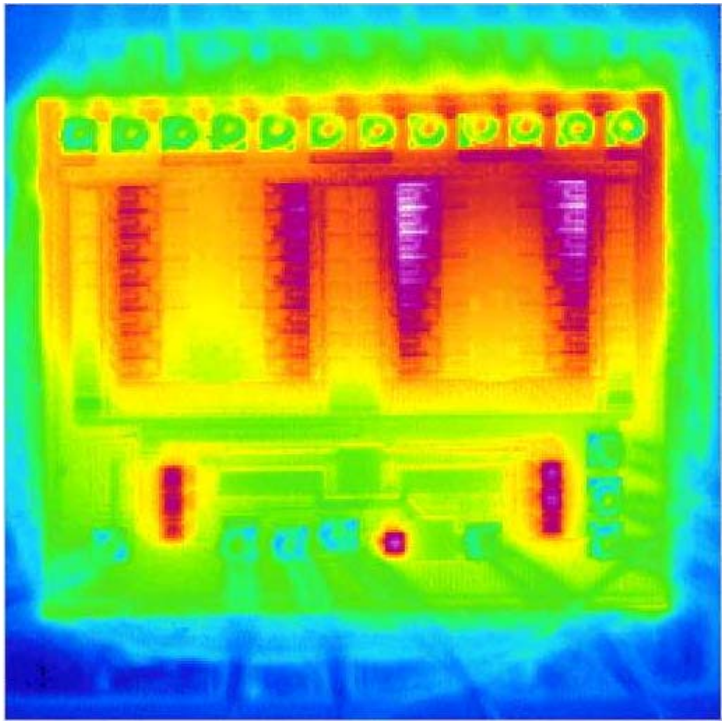
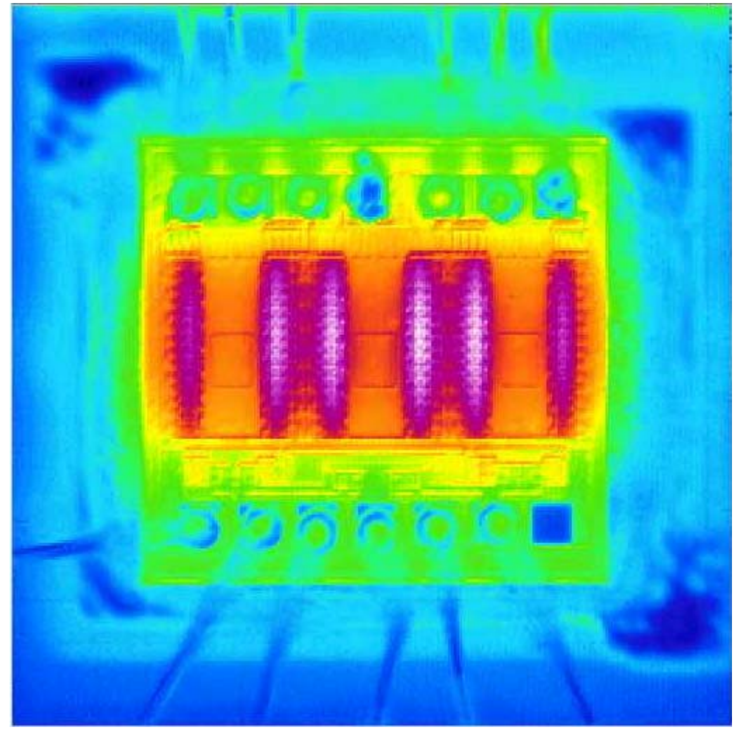
Infrared Imaging of PA Die Demonstrate Thermal Design Improvement

Old Design



New Design



- Thermal Design Improvements
  - RF Feed Symmetry Addressed
  - DC Ballasting Optimized
- IR Images of PA Under Ruggedness Test Conditions

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Waveform Measurements Are a Key Tool for Understanding Current-Voltage Dynamics

- The voltage waveform at PA die output is measured through a high impedance probe with a microwave transition analyzer (MTA) while the PA module is undergoing ruggedness testing.
- The impedance presented to the PA die by the module with the appropriate termination is measured separately.
- The current waveform is calculated from the voltage waveform and impedance data in real time during the measurement.
- The measured current-voltage waveforms have been corroborated by simulation.

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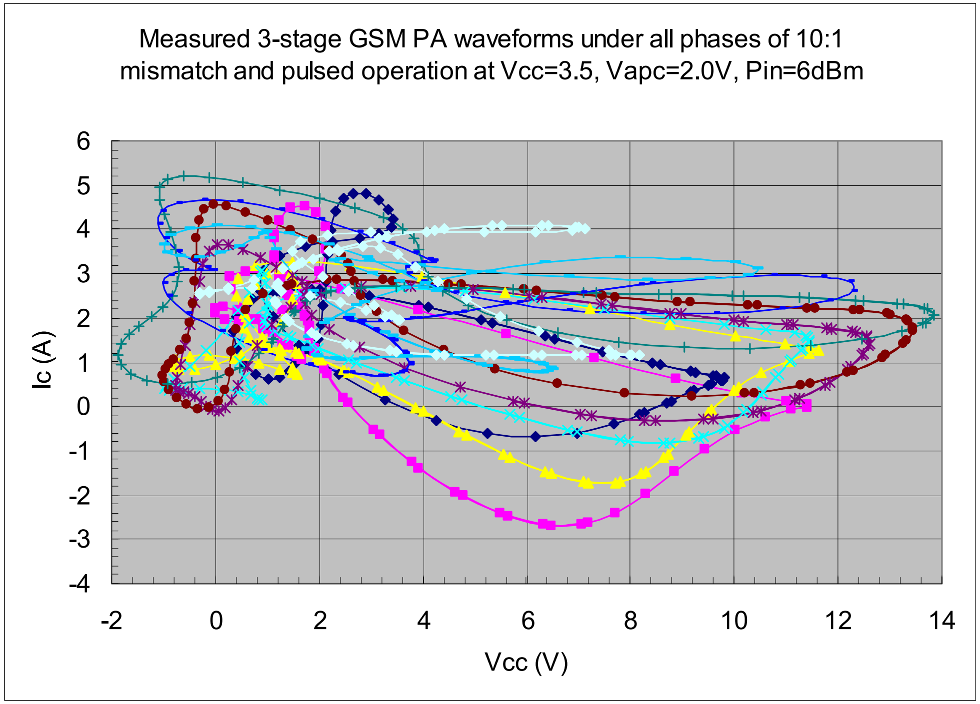
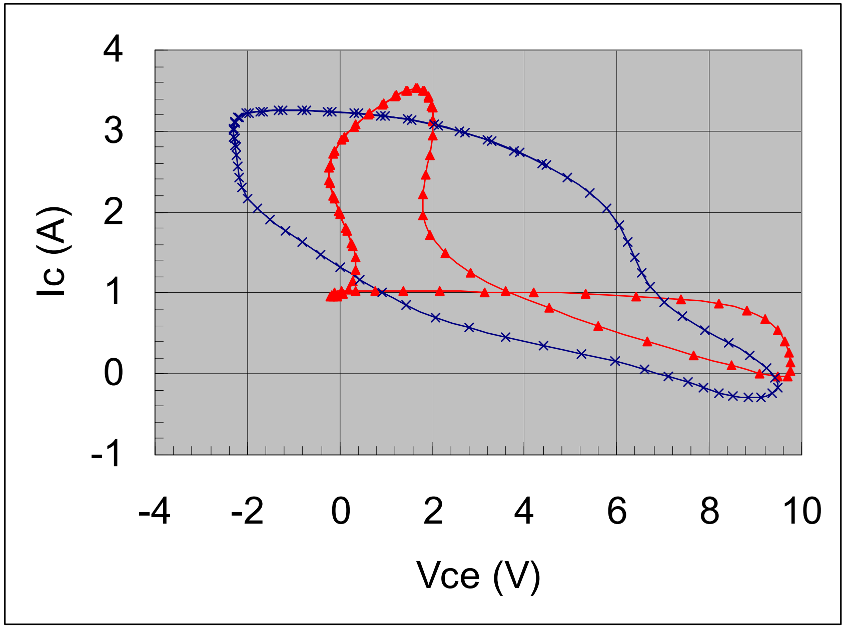
Waveform Measurements Highlight Breakdown Voltage Limitation



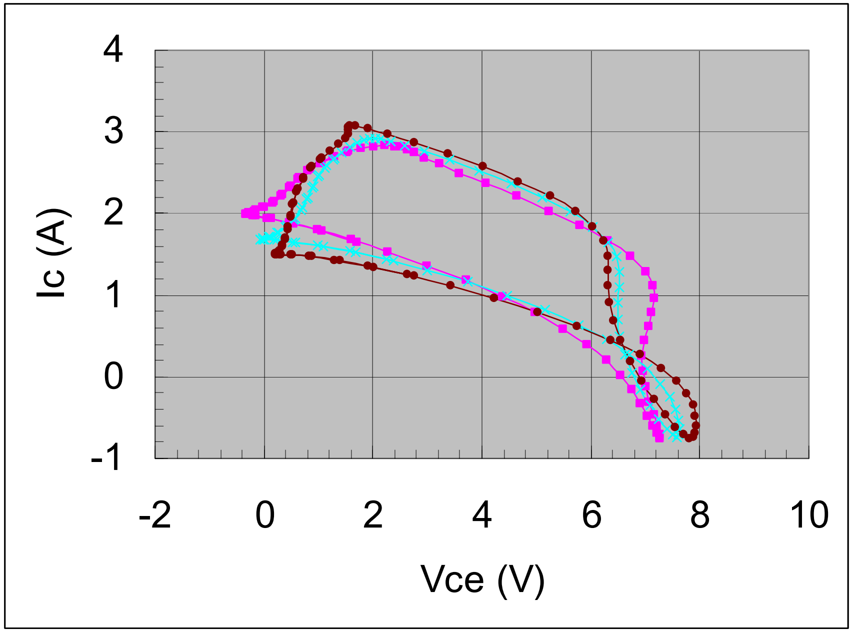
- Probe point is on PA module substrate at PA die output.
- Failure mechanism is understood by correlating failure point to instantaneous current-voltage swing.
- Typical failure condition points to breakdown voltage limitation.

Waveform Measurements Confirm that Thermal Imbalance Is Coupled to RF Imbalance

Old Design



New Design



- Waveform probed at multiple points on PA die output.

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Fourth Generation HBT Process

- Optimized Epitaxial Material
  - InGaP Emitter
  - Material Attributes To Improve Breakdown Voltage
- Optimized HBT Cells
  - Unit Cell Emitter Areas: 10 – 400 μm^2
  - Minimal Parasitics
  - Thermal Shunts
- Passive Elements
  - 0.93 $fF/\mu m^2$ MIM Capacitor
  - 50 Ω/square TFR
- Two Layers of Interconnect Metal
- Slot Through-Wafer Vias

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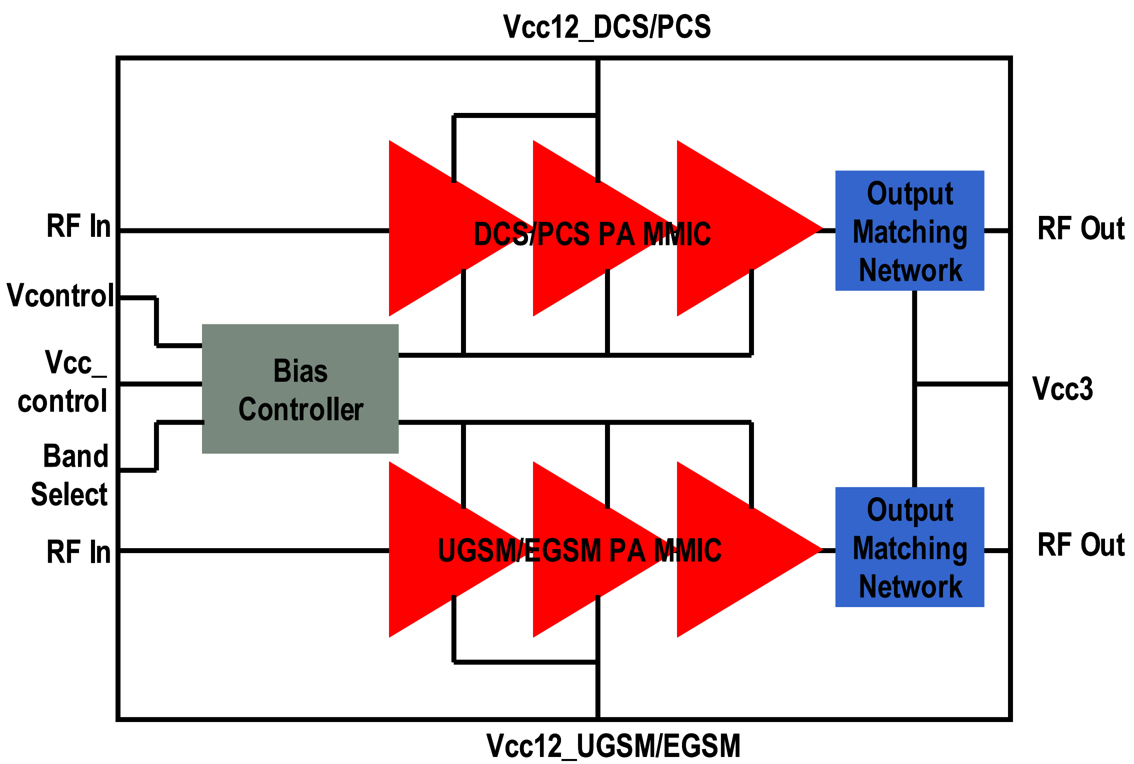
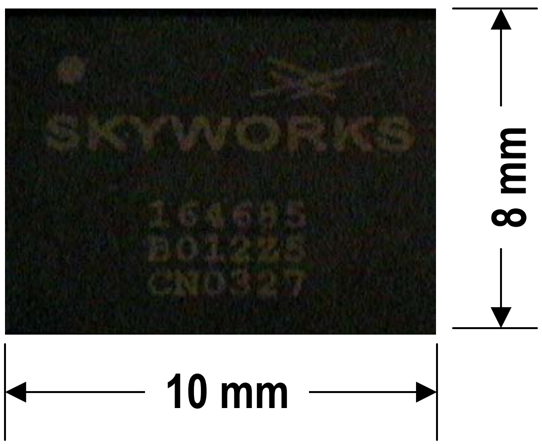
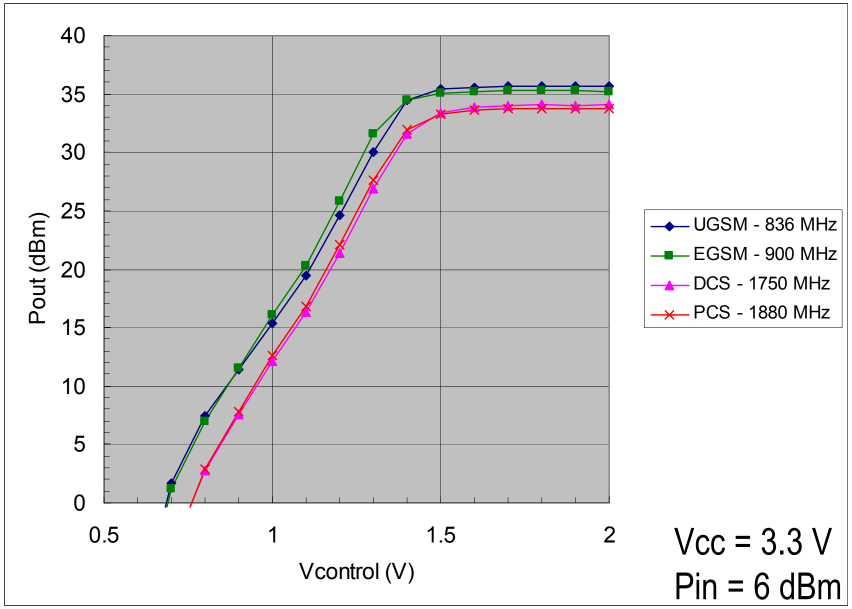
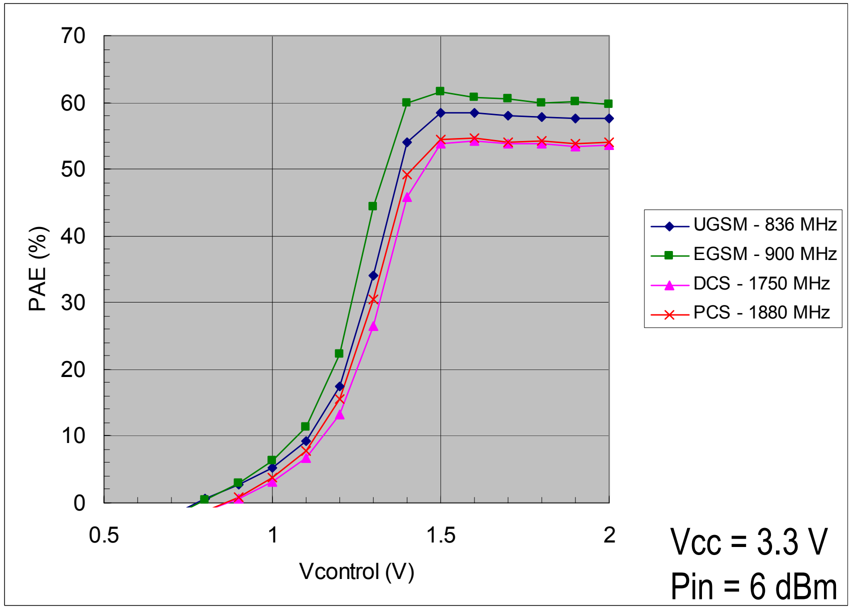
Quad-Band Power Amplifier Module





Output Power and Power Added Efficiency vs. Control Voltage





	Max Pout			Max PAE		
f (MHz)	Vapc (V)	Pout (dBm)	PAE (%)	Vapc (V)	Pout (dBm)	PAE (%)
836	2.0	35.65	57.68	1.6	35.58	58.41
900	1.8	35.28	59.95	1.5	35.07	61.52
1750	2.0	34.08	53.60	1.6	33.90	54.25
1880	2.0	33.79	54.03	1.6	33.63	54.62

Module meets power and efficiency goals.

Control Slope = 40 – 60 dB/V

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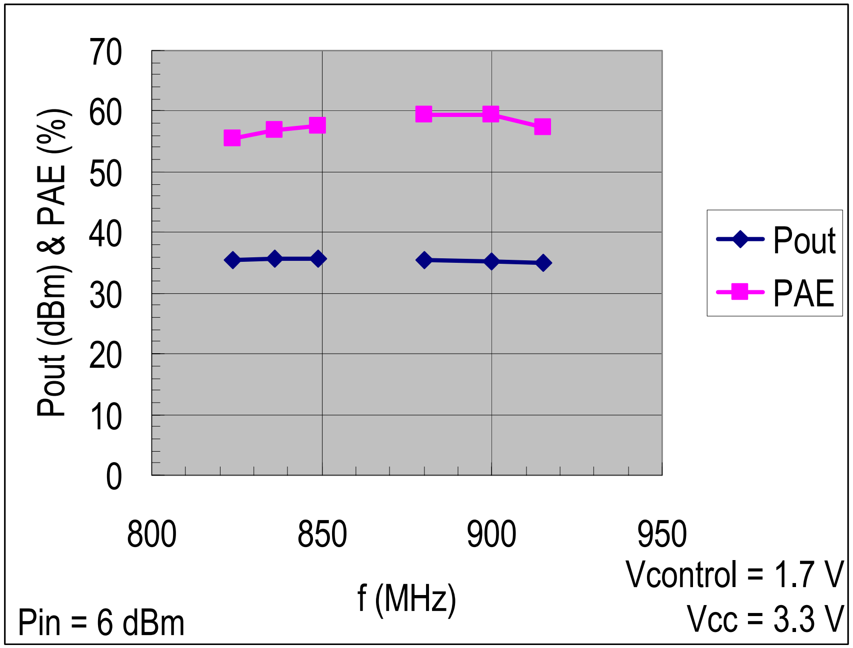
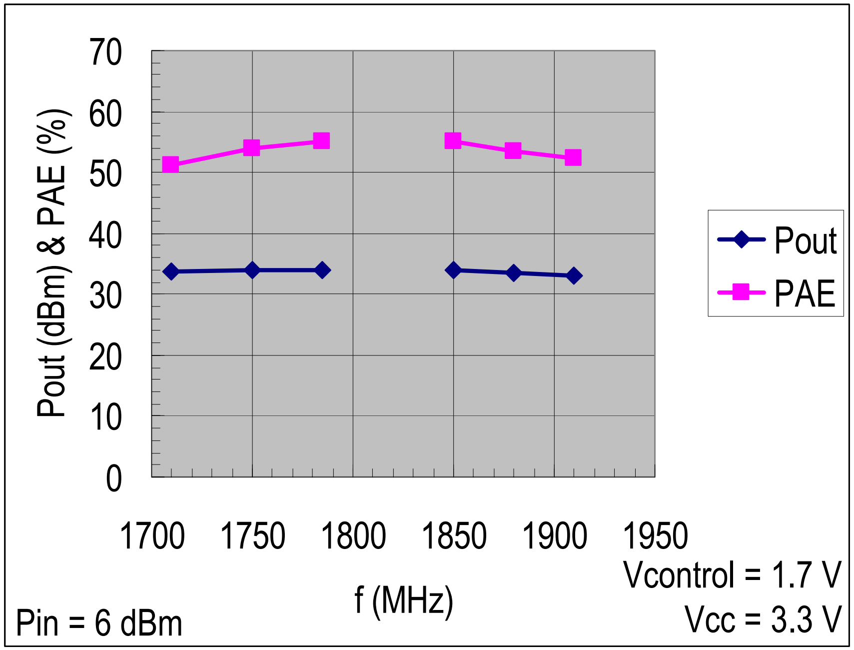
Output Power and Power Added Efficiency vs. Frequency

UGSM/EGSM



DCS/PCS



Output power is flat across band.

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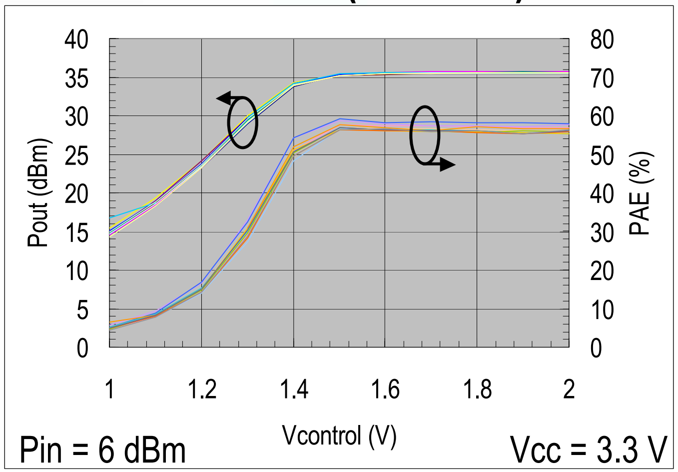
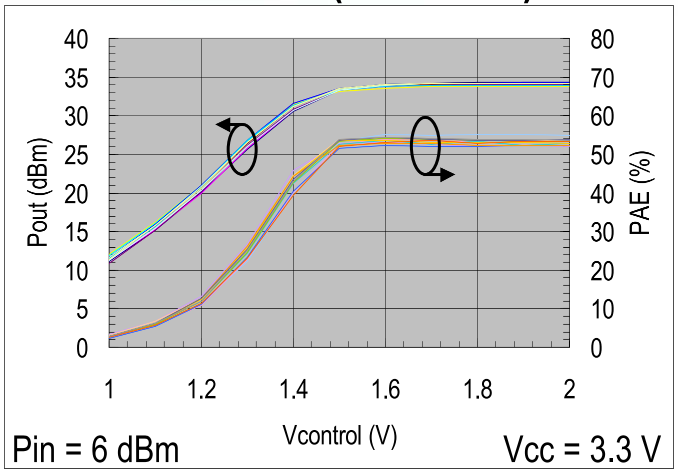
Output Power and Power Added Efficiency over 12 Modules

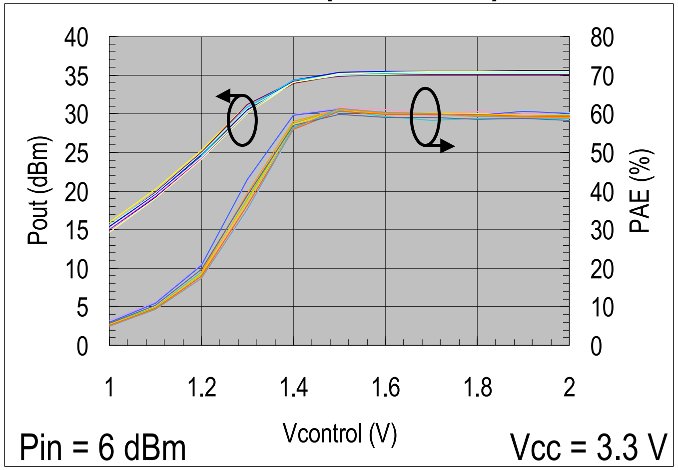
UGSM (836 MHz)



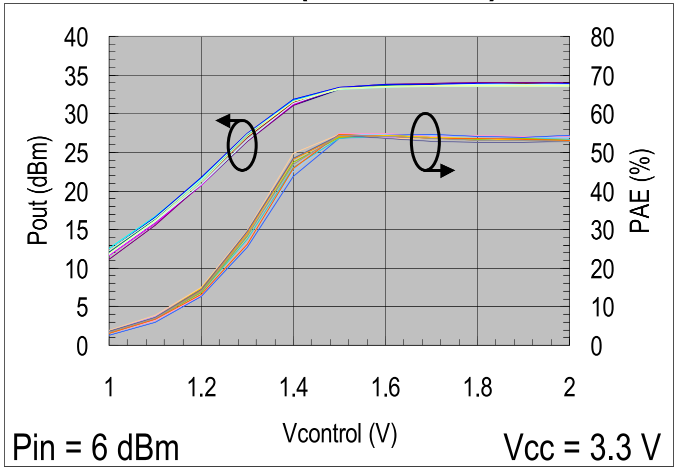
DCS (1750 MHz)



EGSM (900 MHz)



PCS (1880 MHz)



Power and efficiency are consistent between parts.

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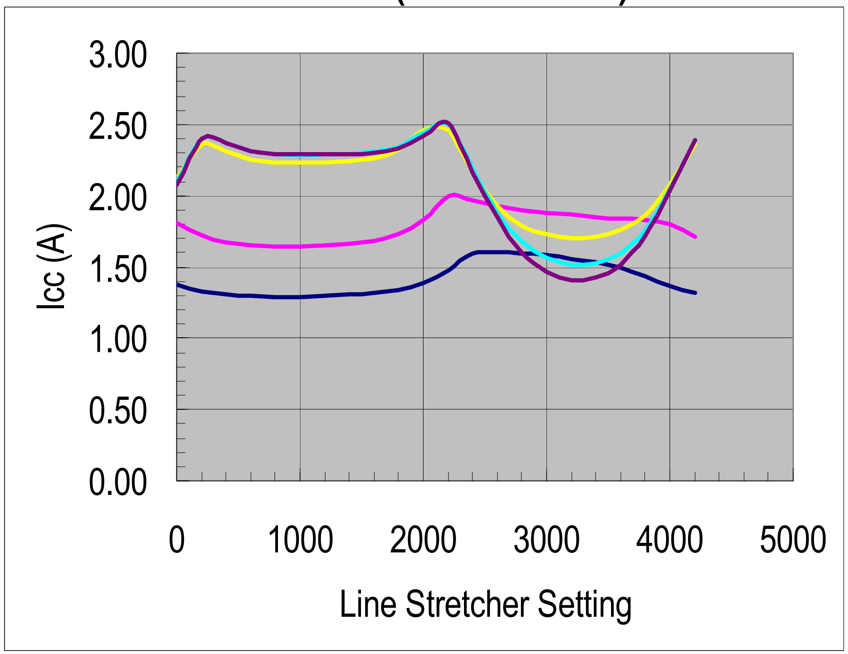
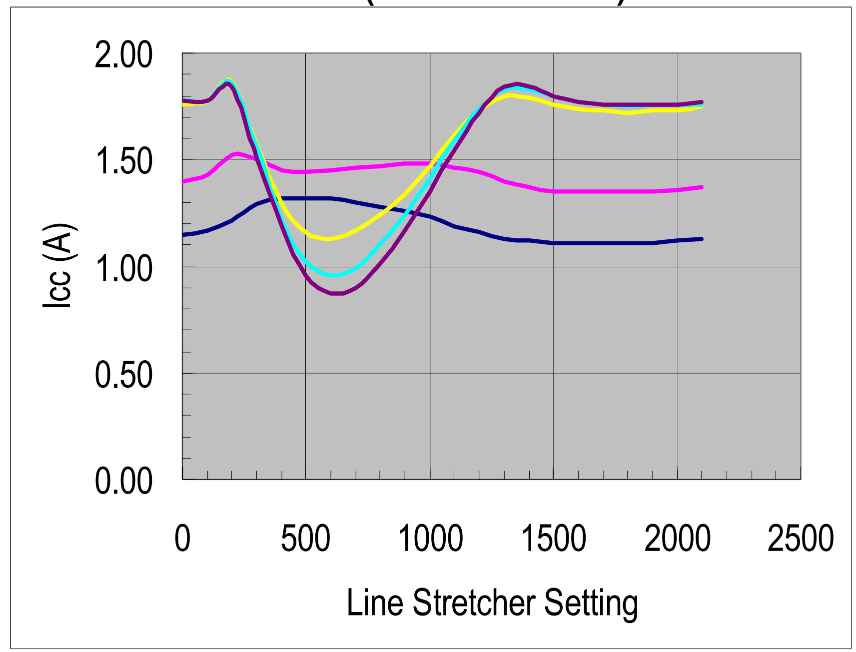
Ruggedness Test Results

EGSM (900 MHz)



DCS (1750 MHz)



Vcc = 5 V
Vcontrol = 2 V

Pin = 10 dBm
VSWR > 35:1 (900 MHz)
> 20:1 (1750 MHz)

Temperature / Duty Cycle

+90C/100% +85C/50% +25C/12.5%
-20C/12.5% -40C/12.5%

Power amplifier module surpasses ruggedness goal.

Conclusions

- Presented a Quad-Band Power Amplifier Module with High PAE and High Ruggedness
- Utilized Tools to Investigate Power Amplifier Module Behavior Under Ruggedness Test Conditions
  - Electro-Thermal Simulation
  - Infra-Red, Thermal Imaging
  - Waveform Probing
- Addressed Causes of Ruggedness Limitations
  - Thermal Imbalance
  - Breakdown Voltage

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