Advanced technologies providing RF capabilities for satellite systems

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Agenda

- Qorvo Space Business Approach
- “Typical” Space Flow Chart
- Qorvo GaN Process Qualification
- Product/Design Enhancements

What is Qorvo doing for Space Applications?

Innovative RF solutions for everything that connects our world

- We provide innovative RF solutions
- 25+ years of Space Qualification Heritage
- Committee participant in industry led GaN for Space consortium
- Space Qualification at the die level
- Tailor the qualification to the customer needs
- In house commercial grade packaging
- GaAs and GaN qualified processes.

DEFENSE & AEROSPACE

Advanced RF technology enabler; Drives Reliability;

Advances the State of the Art

WIRED & WIRELESS NETWORK INFRASTRUCTURE

Early adopter of RF technology for commercial markets

MOBILE RF

Provides large manufacturing scale

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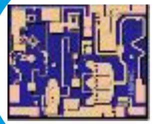
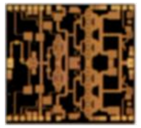
all around you

Qorvo's Space Strategy

Build on Qorvo's +25 year space qualified GaAs MMIC legacy



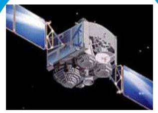
Push GaN space qualification capability



Offer space products and services that support our customers

Active participation in GaN space qualification roundtables

Continue to support legacy products and programs



Qorvo GaAs pHEMT processes, QGaN15 & QGaN25 are released processes for Space applications

A “Typical” Space Qualification Flow Chart

Wafer Fabrication

On-wafer Probe

Visual Inspect

QCI Sample Burn-In Evaluation

- Fixture samples
- Assembly screens
- Fixture tests
- 240-hour burn-in
- Fixture tests
- 1000-hour life test
- Fixture tests

Wafer Level LAT

- Bond-pull testing
- Backside metal adhesion testing
- Lot process monitor information

<u>Other Capabilities</u>

- Visual Inspection options
- Commercial Packaging
- In house Assembly
- Design Partnering
- 3rd Party sourcing for additional testing

Customizable for specific opportunity needs

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Qorvo 250nm and 150nm GaN Process Qualification

Stress Testing	Life Testing	Radiation Hardness
Accelerated Life Testing	DC Accelerated Life Testing	Total Ionizing Dose
Extended Reverse Bias Test	RF Operating Life Testing	Total Ionizing Dose Testing
Gain Stability	RFOLT QGaN25*	Proton Radiation Testing
Power Step Stress	Pulsed RFOLT QGaN25*	Heavy Ion Testing (SEE)
Early Life Failure Test		
ESD (HBM, CDM)		
Hydrogen Sensitivity Test		

- Completed testing by Qorvo or one of Qorvo's Partners
- In the absence of an industry wide standard, Qorvo has used these successful tests as the basis for space qualified process declaration.

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Performance Enhancements

Performance (SWaP-C)

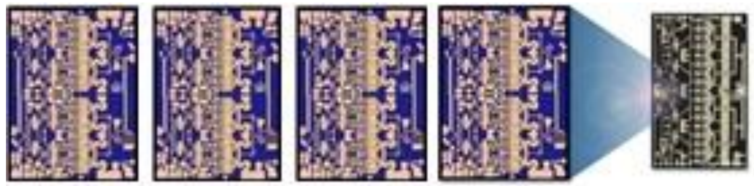
- Frequency
  - Product development for traditional and emerging satellite bands - Specific bands versus wideband
  - Reconfigurable MMICs Capability – Size & component count reduction; Performance boost over wideband
- Power Added Efficiency – Simplify Thermal Management; Extend Battery Life
  - Process enhancements – Loss reduction; Reducing power dissipation
  - Design for Max PAE - Load Targets, Doherty, Bias Class, Harmonic Trapping
  - New design techniques enabled by process enhancements
- Linearity – Reduce Distortion; Reduce data errors
  - Clear requirement definition at the component level not just the system level requirement
  - Design with linearity as a priority versus saturated power and bandwidth
  - FET model optimized for linearity
  - Data collection and application circuit optimization
- Thermal Dissipation
  - Accurate Finite Element Models for Channel Temperature that are validated with Micro Ramen measurements
  - In-house & high volume eutectic die attach for GaAs and GaN to a variety of heat spreader material types
  - FET layout with RF and thermal performance considerations

SWaP-C: Size, Weight and Power & Cost

Provides clear advantages

Size & weight

- Critical in Space applications
- GaN offers a 3-5X increase in power density versus GaAs
- Packaging for Commercial (LEO or Short Operating Life)



4 Ku-band pHEMT PAs = 1 GaN PA

Power

- LNA power consumption must be evaluated
- Higher power-added-efficiency (PAE) = less system prime power
- Higher operating voltage = less current and lower I^2R loss

Cost

- Lower system level operating cost
- Higher W/mm = smaller size = lower weight

Manufacturing Options for SWaP-C

High K materials for increased thermal dissipation (weight & power)

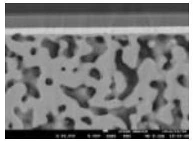
- Direct Cu attach vs. CuMoly or CuW composites for the highest K
- High K die attach materials

Packages (size, weight and power)

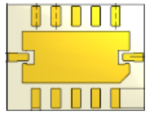
- Thermal Spreader Direct Attach
- Embedded heat sinks or Cu bases

Assembly for size and Weight reduction

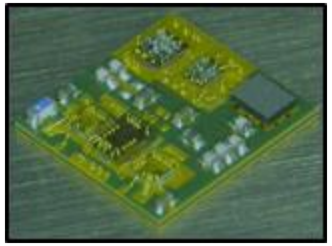
- Bump die or flip-chip
- Die to die bonding


Sinter Die Attach

CP Leadless Copper


EHS Package

QFN GaN Plastic

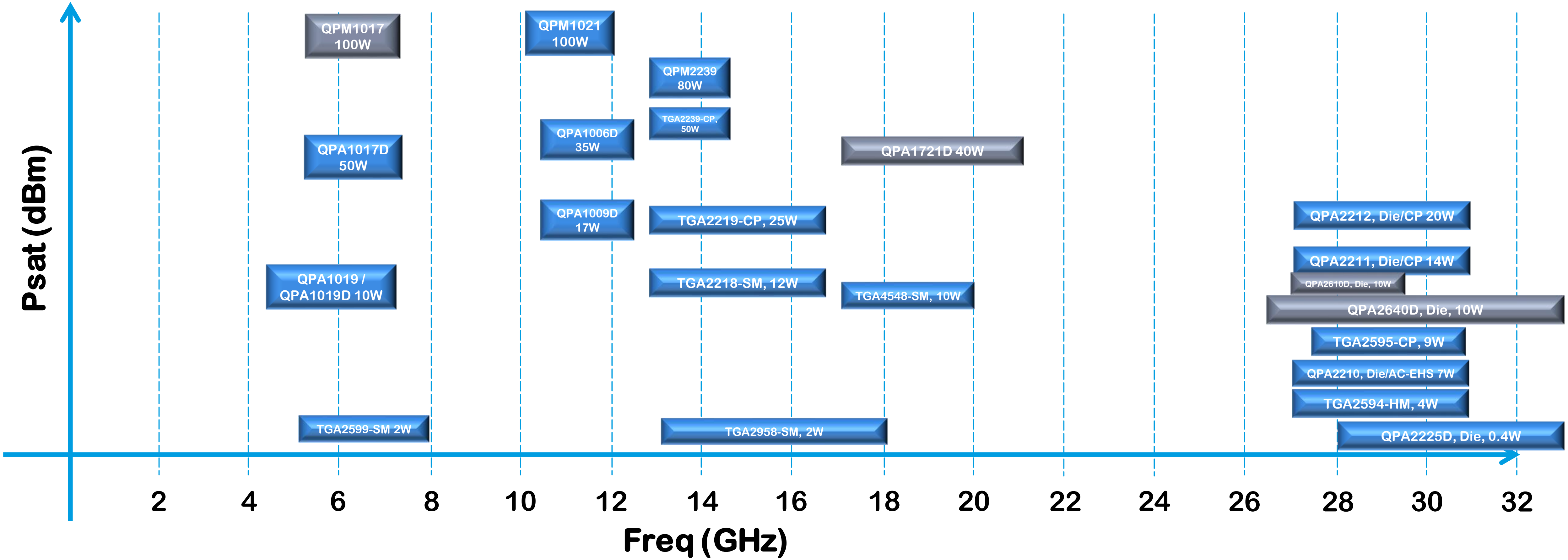

Mixed Assembly - Modules

EHS GaN Air Cavity


Eutectic Attach / Thermal Spreader

MCM Laminate Plastic

Frequency Coverage Highlights for GaN MMIC PAs



GaAs LNAs and RF control integrated circuits also available.

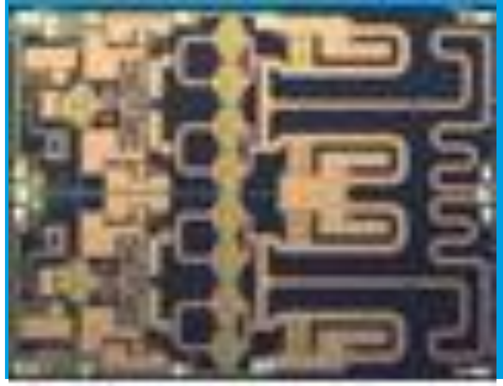
S/X band Reconfigurable 25W GaN HPA

Peak Performance in bands; Size & Weight reduction

Advantages over Broadband Amp?

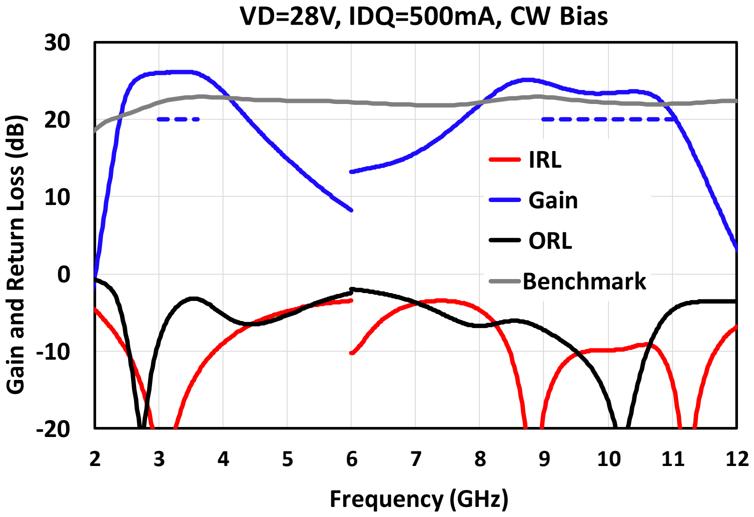
- 25% Less Die Area
- More S-band and X-band Gain
  - Power Up: 1.1-2.1 dB
  - PAE up 10-20 points
- X-Band Operation
  - Power Up: 0.7-2.1 dB
  - PAE Up: 8 to 15 point

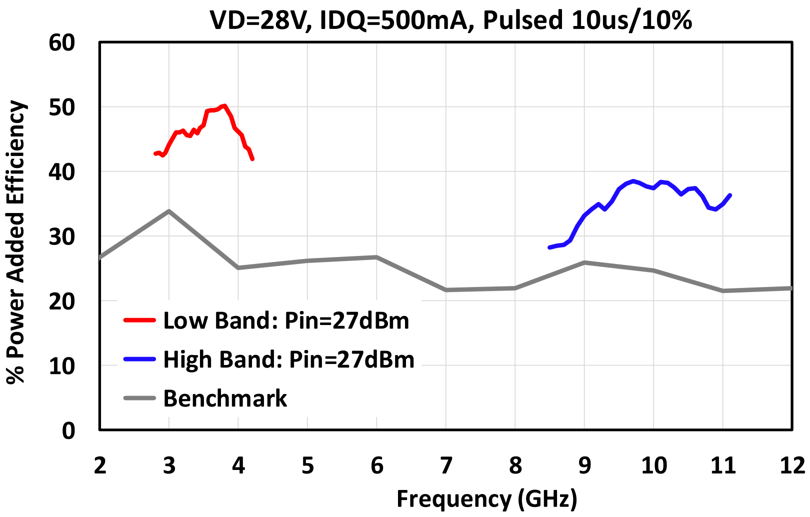
2-18 Ghz 20 W NDPA Die Size:
5.34 (X) x 5.00 (Y) = 26.7 mm^2

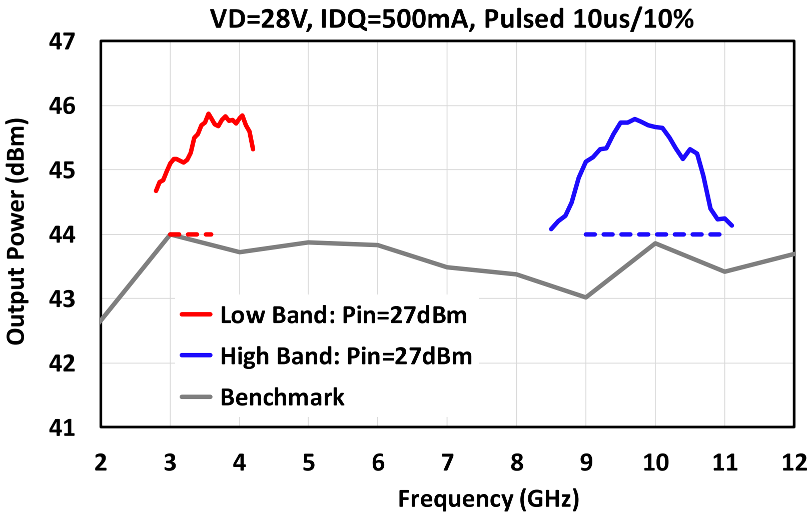


Performance

- S-band 3.0-3.5 GHz
  - Power: 32-38 W
  - PAE: 44-47 %
- X-Band 9-11 GHz
  - Power: 26-37 W
  - PAE: 33 38%
- Die Size: 5.1 x 3.92 = 20 mm^2







Power Amplifier Classes

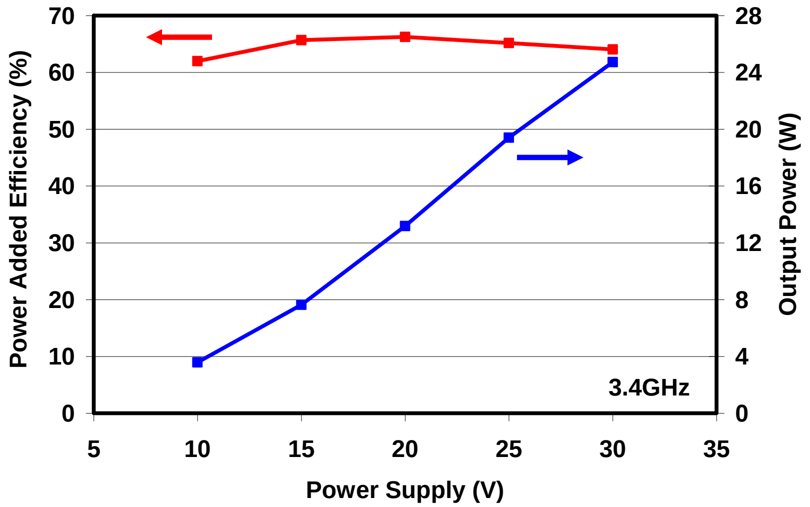
Power Amplifier Class	Max Theoretical Drain Efficiency	Conduction Angle	Advantages	Disadvantages
A	25%-50%	Θ = 360	Can be simpler than other classes, amplifying element is always conducting Device has no “turn-on” time, typically better higher frequency performance	Low efficiency, More heat dissipation, stresses power supply.
AB	50 - 78.5%	180< Θ <360	Higher efficiency than Class A, Better linearity than Class B, Higher ss gain; Higher RF Power	Lower Efficiency than Class-E/F
B	78.5%	Θ = 180	Better possible efficiency versus Class AB and A	Crossover distortion; degraded linearity
C	80%	Θ < 180	High efficiency	Degraded linearity
E	100%	Θ = 0	Higher efficiency	Degraded linearity; Very low ss gain; BW limited due to harmonics; Large voltage swing across the device; Requires higher voltage handling for the transistors and capacitors; Can be difficult to match
F	100%	Θ = 0	Higher efficiency	Degraded linearity; Very low ss gain; BW limited due to harmonics; Requires higher voltage handling for the transistor and capacitors; Output capacitance of device not naturally absorbed into network → need inductor to tune it out

Power Added Efficiency

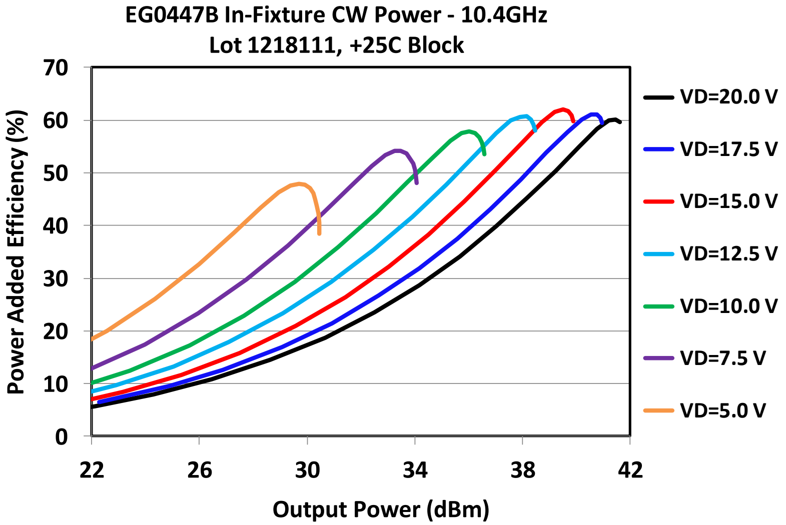
X-band & S-Band Examples; Applicable to Satellite bands; Linearity must be evaluated

- High efficiency switched mode of operation
- Bandwidth requirements are modest
- Theoretically maintains PAE at reduced power supply voltage
- Theoretically linear output power in Watts versus supply voltage
- Simple low loss output matching network (~ 0.4dB)

S-band; 20W (CW), 60% PAE, 33dB Gain



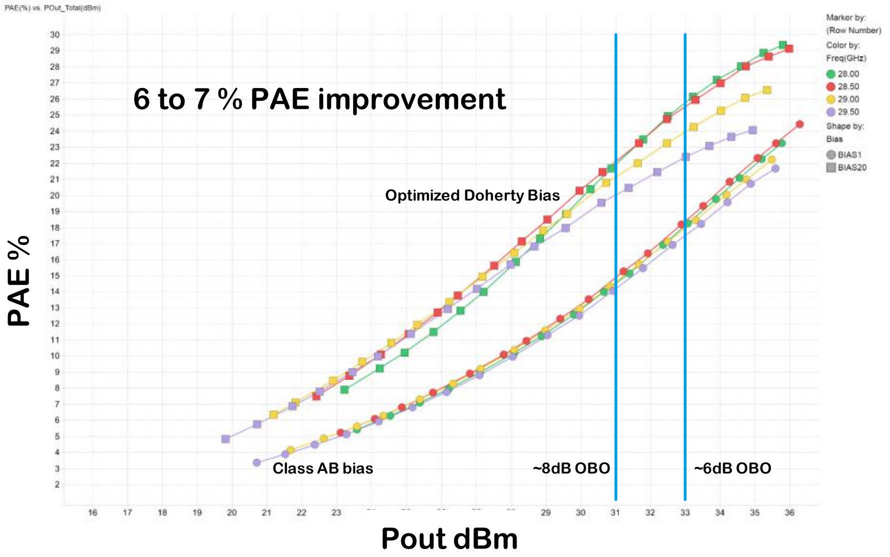
X-band Class-E: 13W (CW), 60% PAE, 20dB Gain

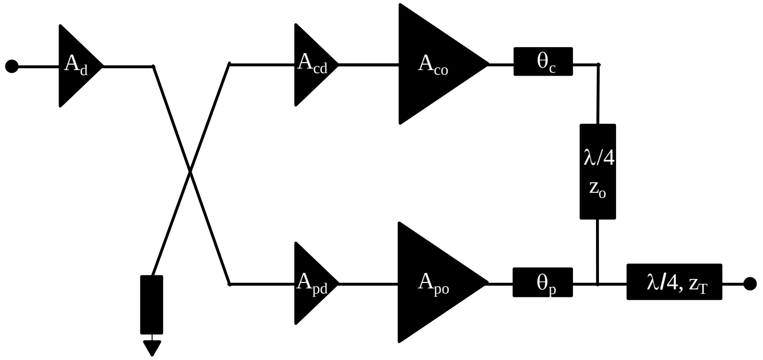


10W Psat Ka-band Doherty

QPA2810

Freq: 27 to 29.5 GHz
Psat: 40 dBm
<u>At 8 dB OBO:</u>
Power: 31.5 dBm
PAE: >20%
Gain: 26dB
Bias:
Technology: QGaN15
Package: die
Size: 4.22 x 2.30 x 0.1mm



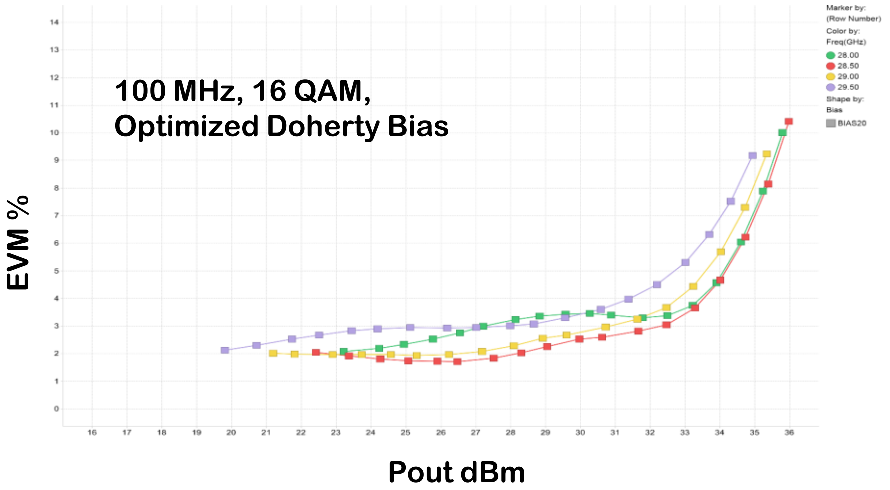


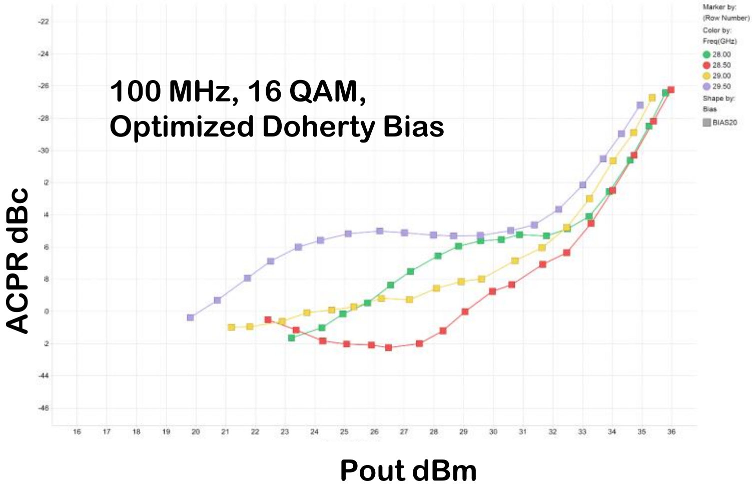
QPA2810D Block Diagram

Benefits

High PAE in back-off power conditions compared to Class AB bias

EVM and ACPR improvements compared to Class AB bias





X-band: 10.7-12.7GHz 35W & 17 W GaN PAs

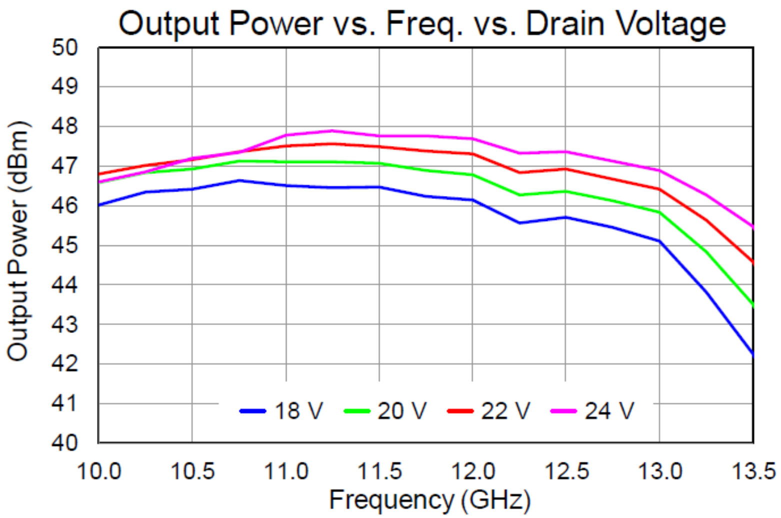
QPA1006D
Bias: 20V/1200mA
IM3: 26dBc, P0=38dBm/tone
Size: ~25.9mm²

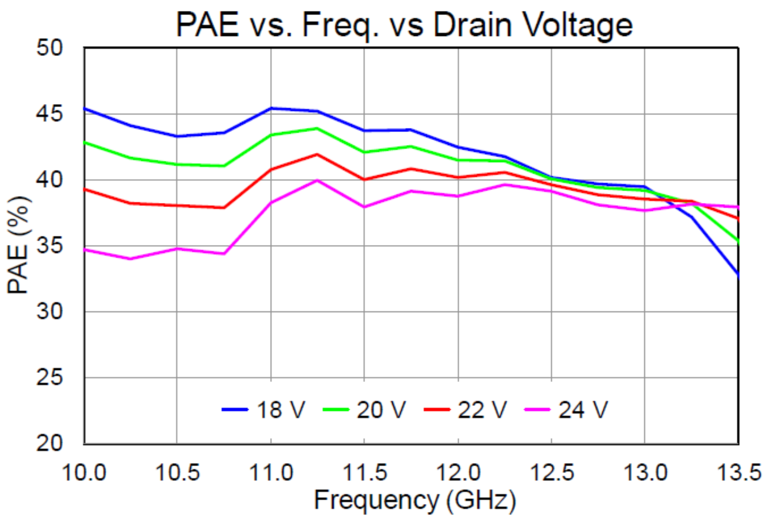
QPA1009D
Bias: 22V/380mA
IM3: 33dBc, P0=35dBm/tone
Size: ~13.5mm²

Power, Efficiency & Linearity for SATCOM.

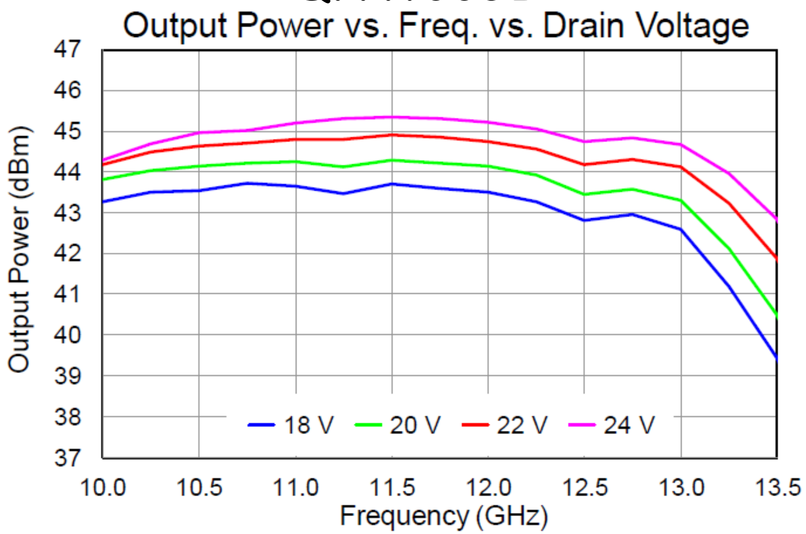
SWAP-C being applied at the IC design level.

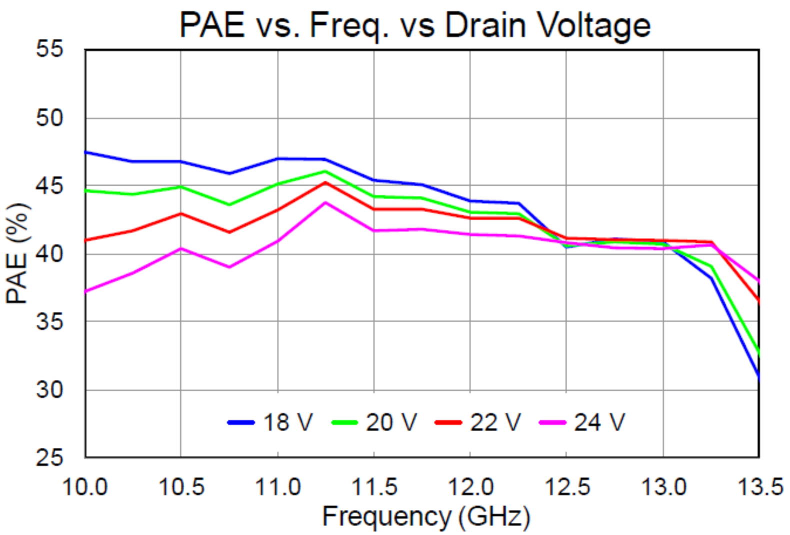
QPA1006D





QPA1009D





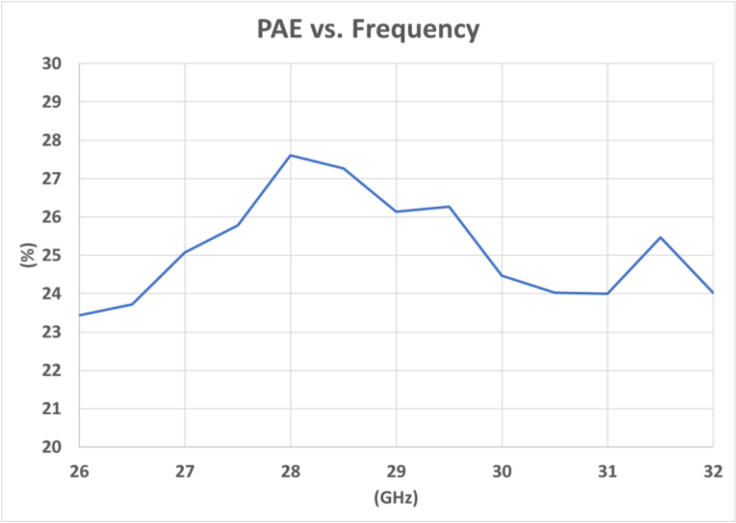
Ka-band: Linear Power and Efficiency for Satcom

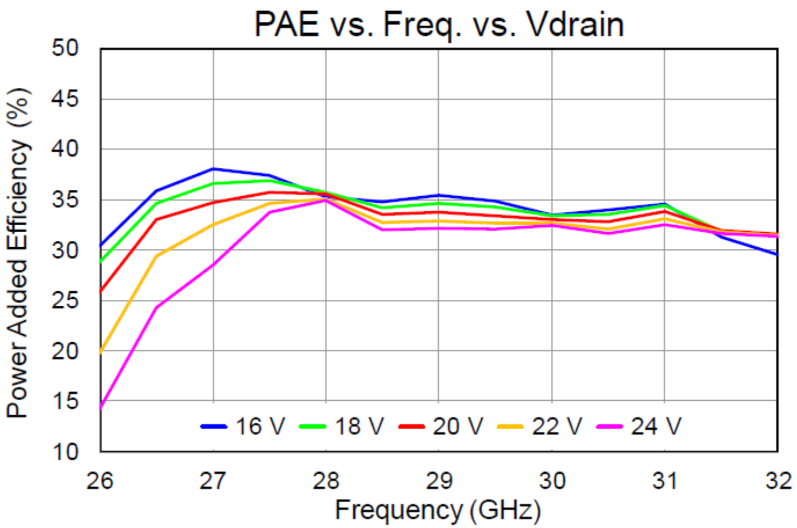
Model & Design for Linearity/PAE/Size - Directly Impacts the System SWAP

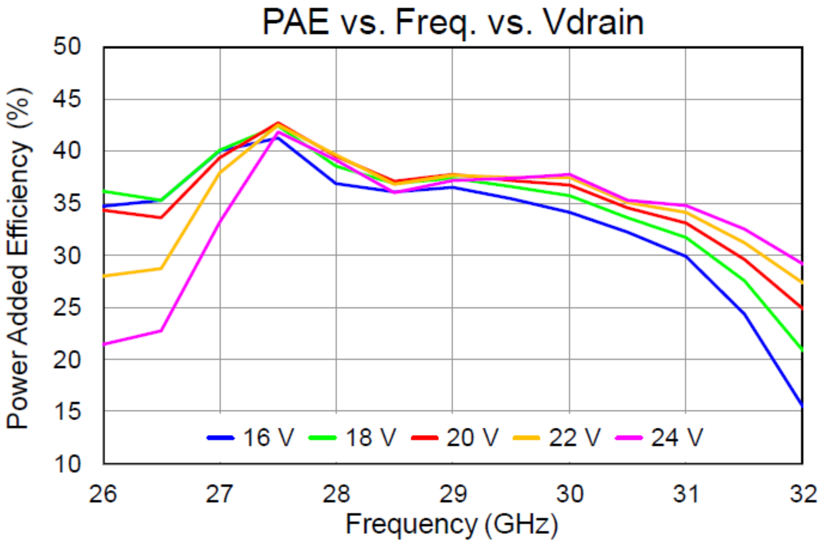
Psat: 20W
PAE: 26%
LSG: 18dB
IMD3: 5W/tone, 25dBc
SSG: 23dB
Bias: 20V/560mA
Technology: QGaN15ES

Psat: 7W
PAE: 32%
LSG: 16dB
IMD3: 1.25W/tone, 25dBc
SSG: 25dB
Bias: 20V/200mA
Technology: QGaN15ES

Psat: 14W
PAE: 34%
LSG: 17dB
IMD3: 2.5W/tone, 25dBc
SSG: 26dB
Bias: 22V/280mA
Technology: QGaN15ES





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