Multifunction Phased Array Radar Symposium

Wide Bandgap Device Technology Overview

November 18, 2009

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Cree, Inc.

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Cree Overview

- **Founded in 1987 to Commercialize Wide Bandgap Materials and Devices**
  - Traded on NASDAQ (CREE)
- **Annualized Sales $567M (FY 2009)**
- **3200+ Employees**
- **3 U.S. Locations, applications offices and facilities in Europe and Asia**

Excellence in Manufacturing

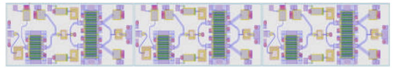
- World's Largest Fabricator of GaN-on-SiC
  - > 1000 wafers per day
  - Ship >15 million devices per day
- World's Largest Supplier of SiC substrates
  - Supply 95% of the world's supply of single crystal SiC
- Vertical Integration
  - Crystal Growth => Device Fabrication => Package/Test

Corporate Headquarters
Durham, NC

Cree WBG Technology Center of Excellence

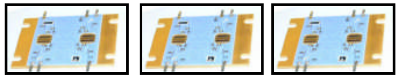
Economies of scale

Power Products



WBG MMICs

RF Transistors

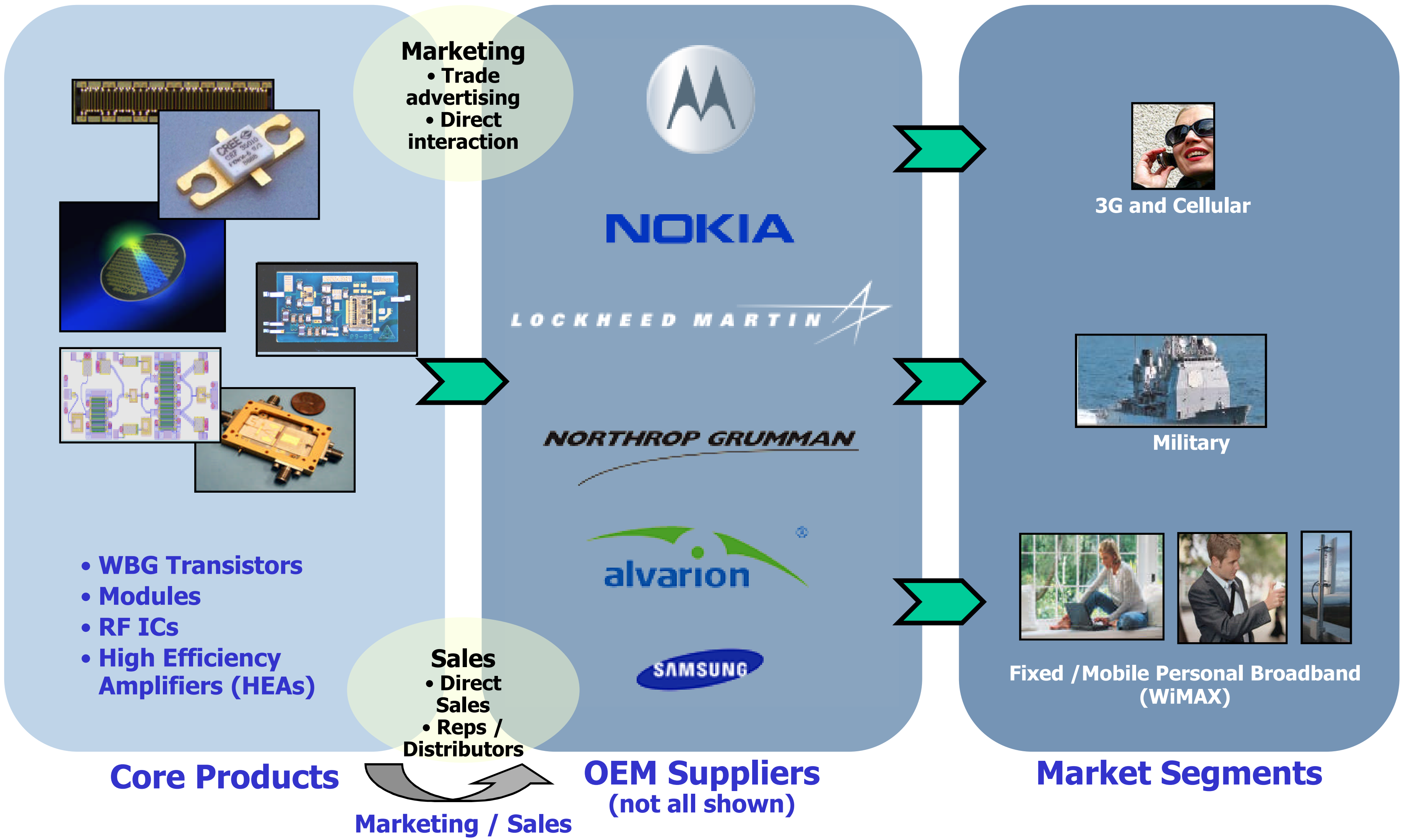


RF Modules

- Opened August 2006 to support large-scale commercial production and advanced research in SiC and GaN RF and Power products
- Located in Research Triangle Park (RTP), North Carolina
  - 2 miles from main campus
- Worlds largest dedicated WBG device production facility
  - 40,000 sq. ft.
  - RF MMIC On-wafer probe / dice
  - RF Production Package and Test
  - Microwave Reliability Labs

CREE

RF Business Segments



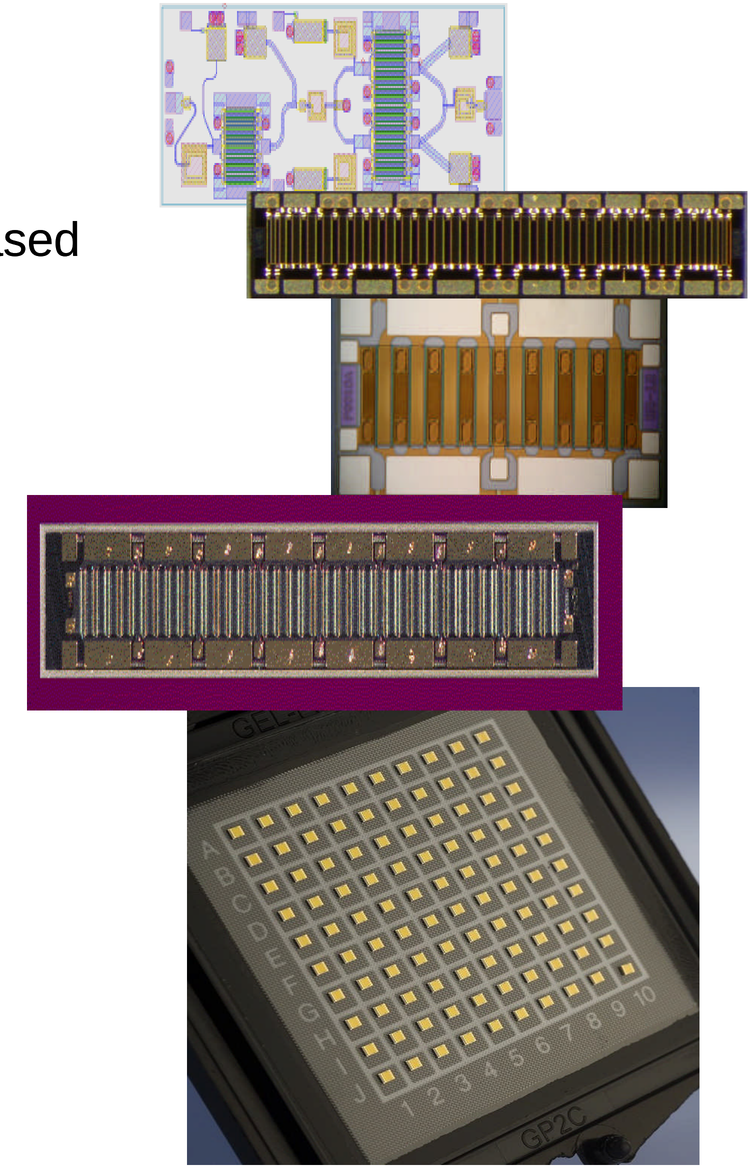
Cree Microwave Process Technologies

Silicon Carbide MESFET

- 20 years -- Pioneering the Technology
- 4 years in production
    - 2nd Generation process fully released
- Growing production volume
- UHF to 4GHz geometries
- Discrete + MMIC processes

Gallium Nitride HEMT

- >10 years advancing R&D
    - One of the technology Pioneers
- UHF to 40GHz geometries in R&D
- 1st Generation Commercial Process
    - V3 DC-8 GHz Process released
    - X-Band Process targeted 2010
    - Ku-Band Process targeted 2011
    - Discrete + MMIC processes



GaN Commercial Products

GaN HEMT for WiMax

Cree's GaN HEMT product line has been optimized for WiMax applications with tailored performance to obtain the best combination of bandwidth, efficiency, linearity and gain. Each device has been measured under 802.16-2004 compliant signals for offset mask compliance and EVM or RCE. The current voltage rail for Cree's GaN HEMT products is 28 volts.

Product Family[1]

RoHS COMPLIANT

Part Number	Frequency Band	Operating Voltage	Pave	Gain	802.16-2004 RCE[2]	Drain Efficiency	Package
CGH27015F	2.4 to 2.9 GHz	28 V	2 W	14 dB	34	24 %	440166
CGH27120F	2.4 to 2.9 GHz	28 V	12 W	13 dB	31	20 %	440193

Part Number	Frequency Band	Operating Voltage	Pave	Gain	802.16-2004 RCE[2]	Drain Efficiency	Package
CGH35015F	3.3 to 3.9 GHz	28 V	2 W	12 dB	-34 dB	24 %	440166
CGH35015S	3.3 to 3.9 GHz	28 V	2 W	12 dB	-34 dB	24 %	440178
CGH35030F	3.3 to 3.9 GHz	28 V	4 W	12 dB	-34 dB	23 %	440166
CGH35060F	3.3 to 3.9 GHz	28 V	8 W	12 dB	-33 dB	22 %	440193
CGH35120F	3.3 to 3.9 GHz	28 V	12 W	11 dB	-31 dB	20 %	440193

Note[1]: Performance features dependent on amplifer design approach.
Note[2]: -34dB RCE is equivalent to 2% rms EVM.

Package Types 440166, 440178, 440193, 440196

Package Type: 440166 Overall Size 0.330" x 0.555"

Package Type: 440178 Overall Size 0.205" x 0.320"

Package Type: 440193 Overall Size 0.805" x 0.730"

Package Type: 440196 Overall Size 0.205" x 0.325"

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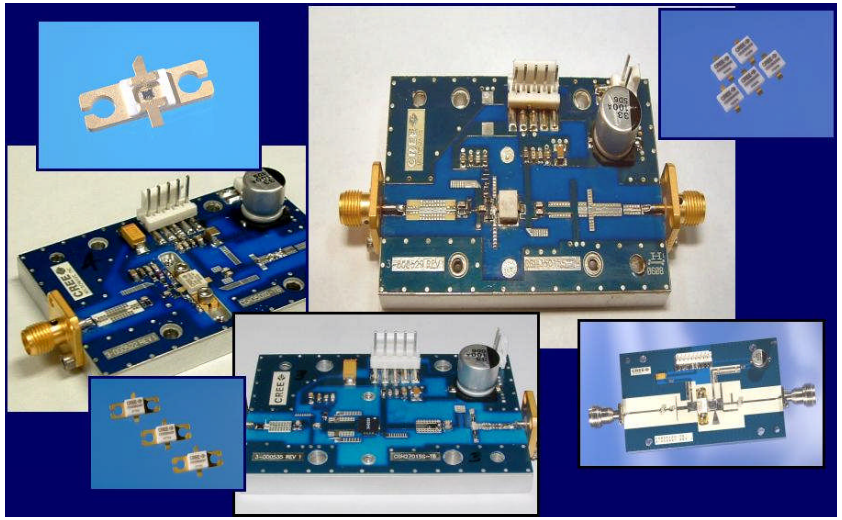
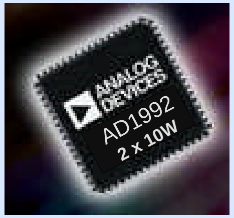
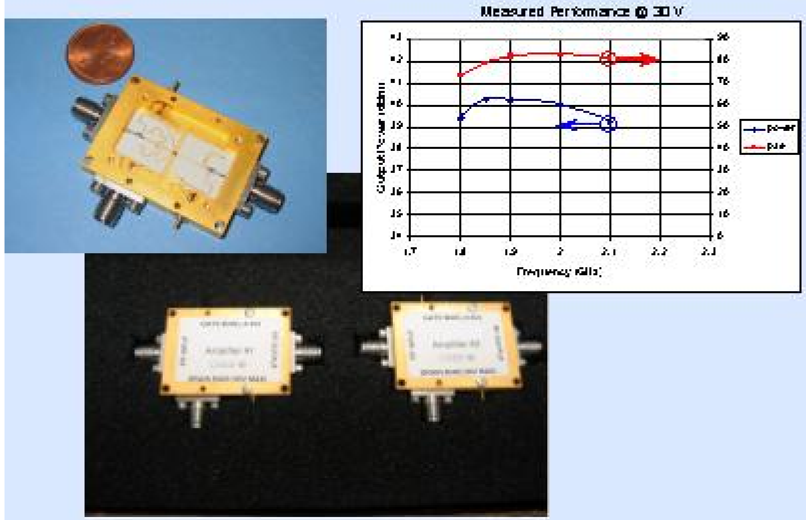


- GaN WiMAX Transistor Products
  - 2.4 - 2.9 GHz
  - 3.3 - 3.9 GHz
- General Purpose GaN Products
  - DC – 4 GHz (packaged)
  - DC – 6 GHz (bare die)
- Multiple die engines
  - 15, 30, 60, 120, 240 Watts

Digital Audio Meets Switch-mode GaN (the Future of MMIC PA technology)



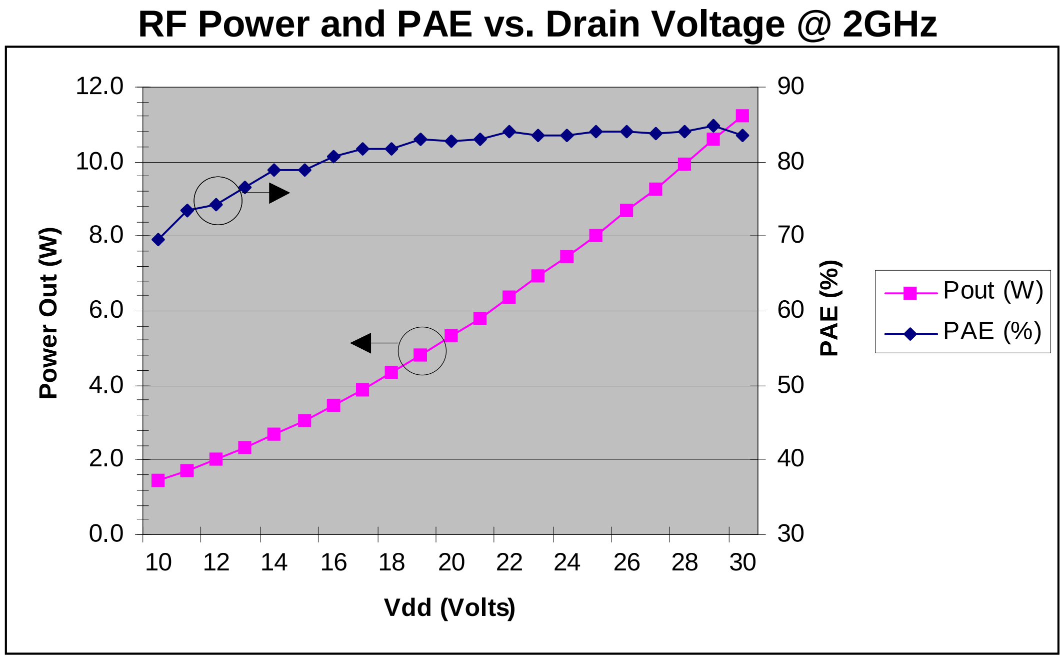
- Analog Devices: AD1992
- Class D analog amplifier (switch-mode)
- Vd = 5 volts
- Output Power = 10 W
- Efficiency = 84%



- Cree new product development
- Switch mode RF amplifier
- Vd = 30 volts
- RF Output Power = 10 W
- *Power Added Efficiency = 84%!*
- Frequency = 1.9-2.1 GHz

GaN is enabling ultra-high efficiency RF amplifiers with performance not thought possible 5 years ago

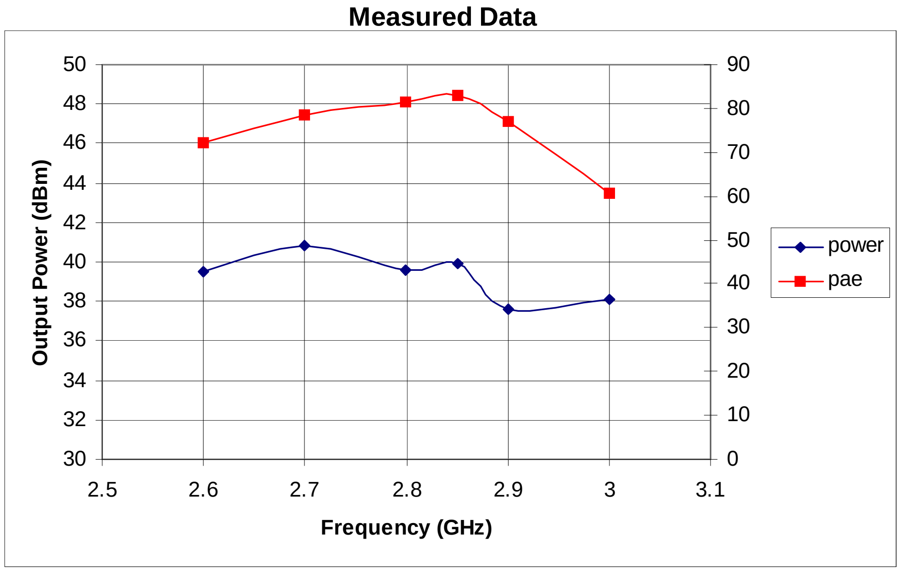
Switch-mode GaN
(High Efficiency with Variable Power!)

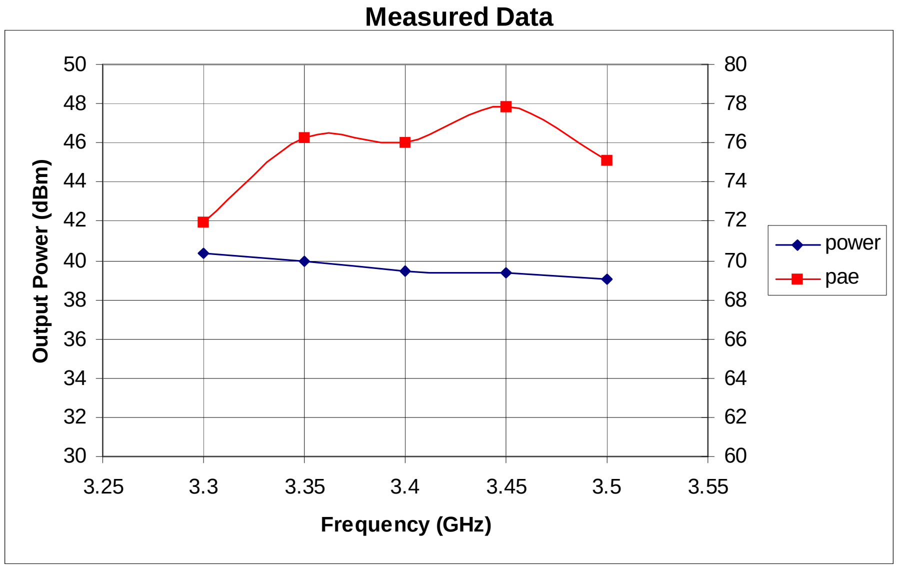


- PAE is maintained above 80% from 3.5 W to 11.2 W RF power out!
- A very effective high efficiency variable power amplifier

GaN can facilitate very high efficiency phased arrays with variable power *on-demand* for future growth or to counter immediate threats

Approach Validated at Higher Frequencies and Moderate Bandwidths





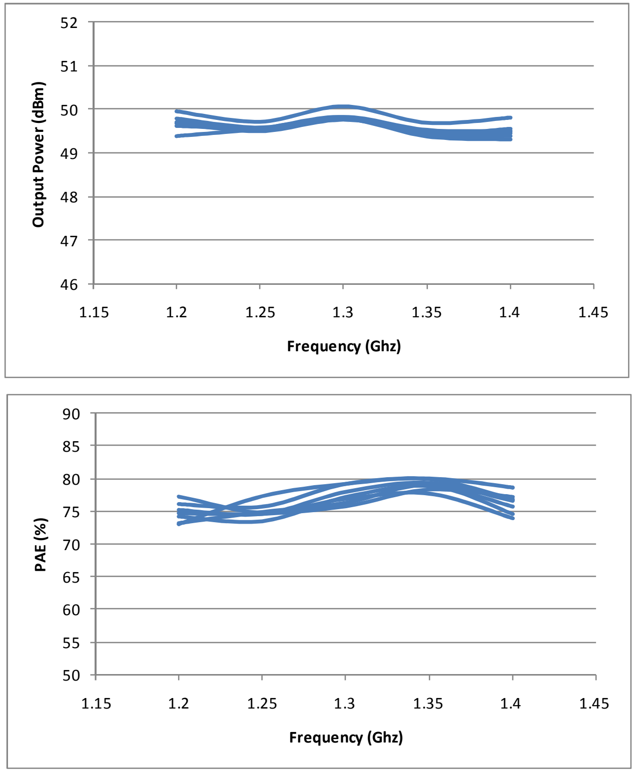
- ~10 Watts RF Out
- 12 dB Power Gain
- 76-82% PAE
- 2.7 – 2.9 GHz

- ~10 Watts RF Out
- 11 dB Power Gain
- 72-78% PAE
- 3.3 – 3.5 GHz

GaN can facilitate very high efficiency phased arrays
at the higher frequency bands

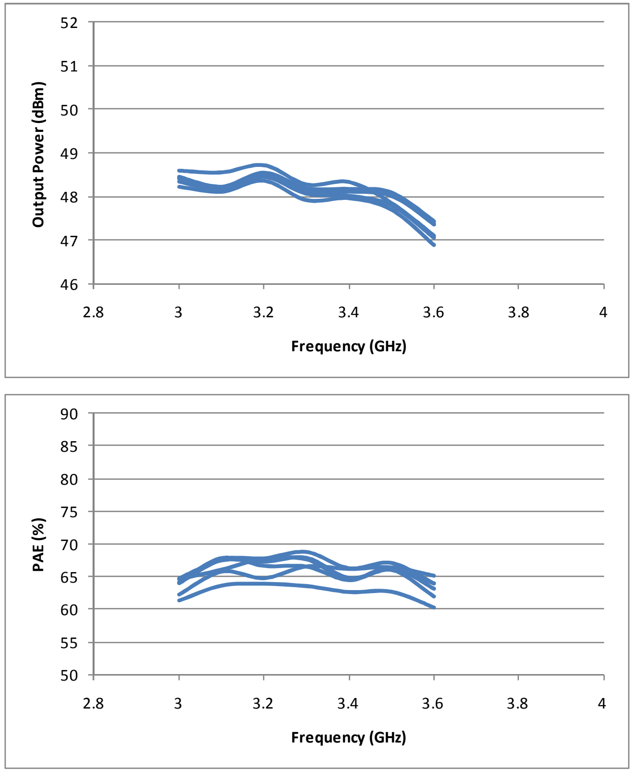
Approach Validated at Higher Power Levels

Measured Data



- >65 Watts RF Out
- >10 dB Power Gain
- 75-80% PAE
- 1.2 – 1.4 GHz

Measured Data

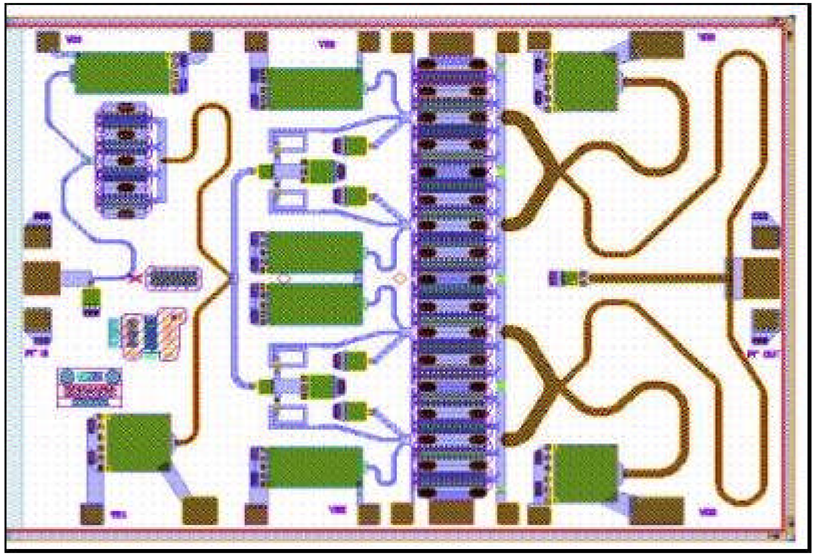


- ~ 50-60 Watts RF Out
- >10 dB Power Gain
- ~ 65% PAE
- 3.0 – 3.6 GHz

GaN can facilitate very high efficiency @ higher power levels

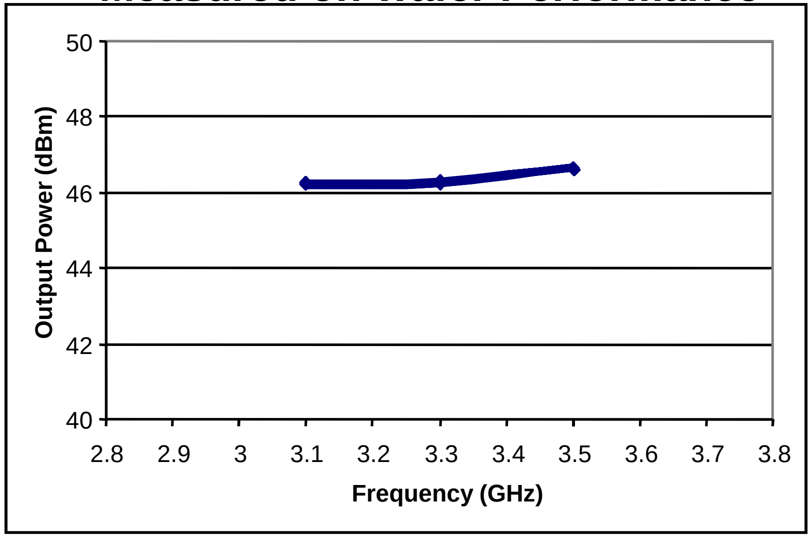
Sponsored by Dr. Mike Harris,
US Air Force, SWARM, FA8650-08-D-1302-0005

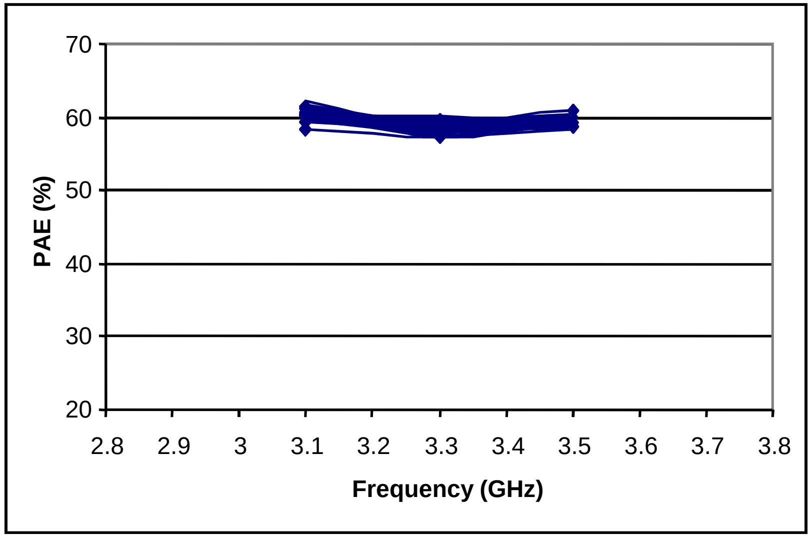
Two-Stage High Efficiency GaN S-Band HPA MMIC



- Bandwidth: 3.1-3.5 GHz
- 2-Stage (2mm driving 12mm)
- RF P_{OUT}: 40 watts min at 28V
- PAE: 60% (Typ)
- Associated Gain: 25dB (typical)
- Size: 4.0mm X 3.0mm

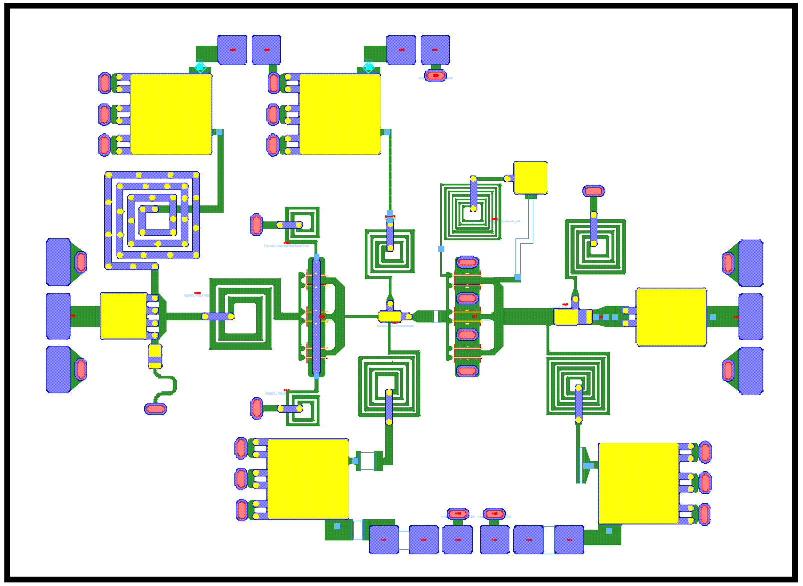
Measured on-wafer Performance





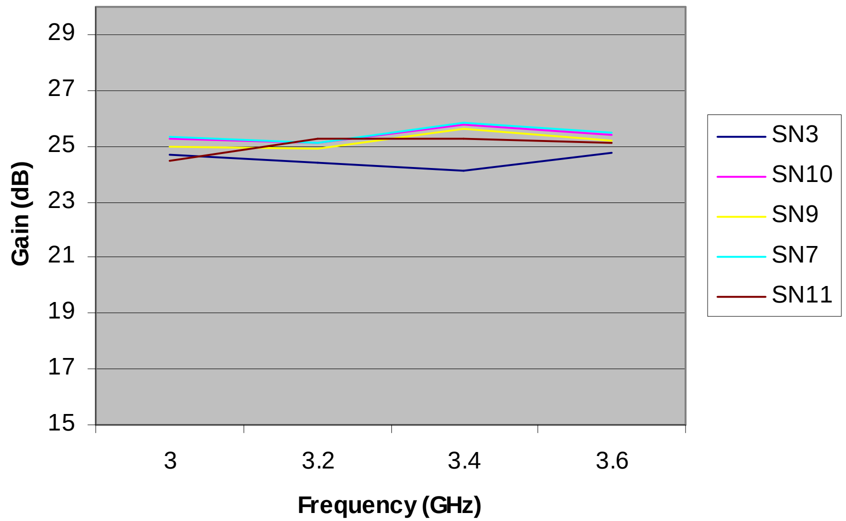
Sponsored by Dr. Barry Perlman,
US Army Research, Development and Engineering Command (RDECOM)
Communications-Electronics R&DE Center (CERDEC)

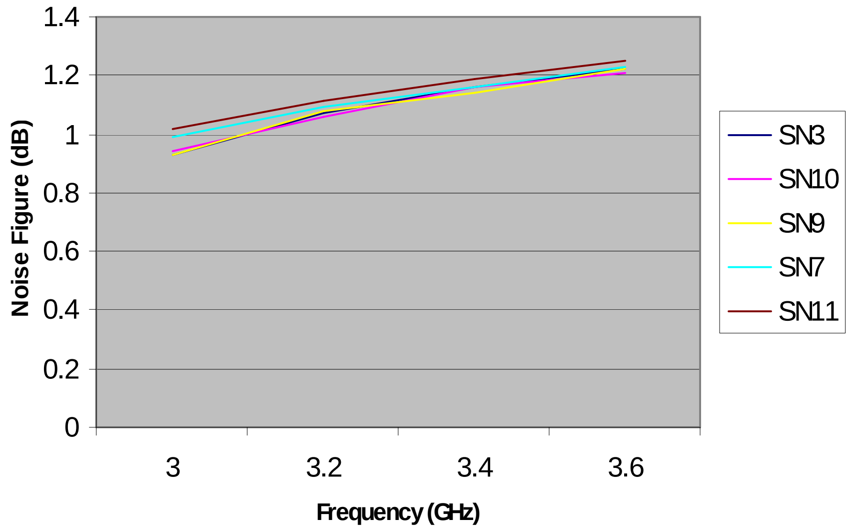
High Dynamic Range GaN LNA



- Bandwidth: 3.1-3.5 GHz
- Nominal gain: 25dB
- Noise Figure: 1.1 dB (Typ)
- Output TOI: 34.5 dBm
- Size: 3.2mm X 2.3mm

Measured Performance





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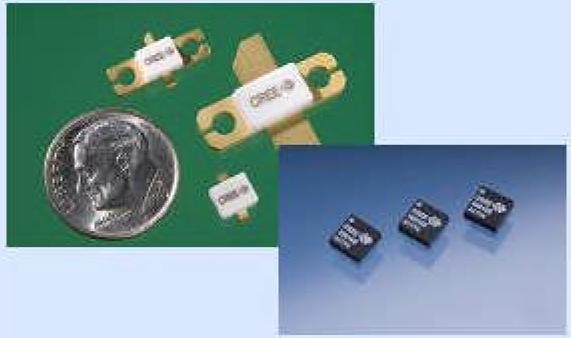
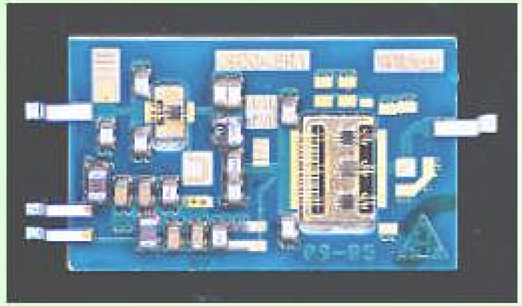
Cree S-Band COTS WiMAX Products

Components



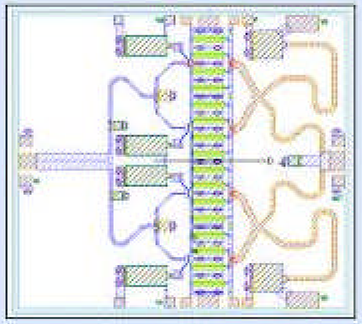
- Frequency: 2.0 to 4.0 GHz
- Gain: 13dB
- P3dB ~ 13W
- PAE: 60%
- Vdd: 28V
- Technology: GaN

Modules



- Frequency: 3.4 to 3.8 GHz
- Gain: 15dB
- P1dB ~ 30W
- PAE: 40%
- Vdd: 48V
- Technology SiC

RF ICs

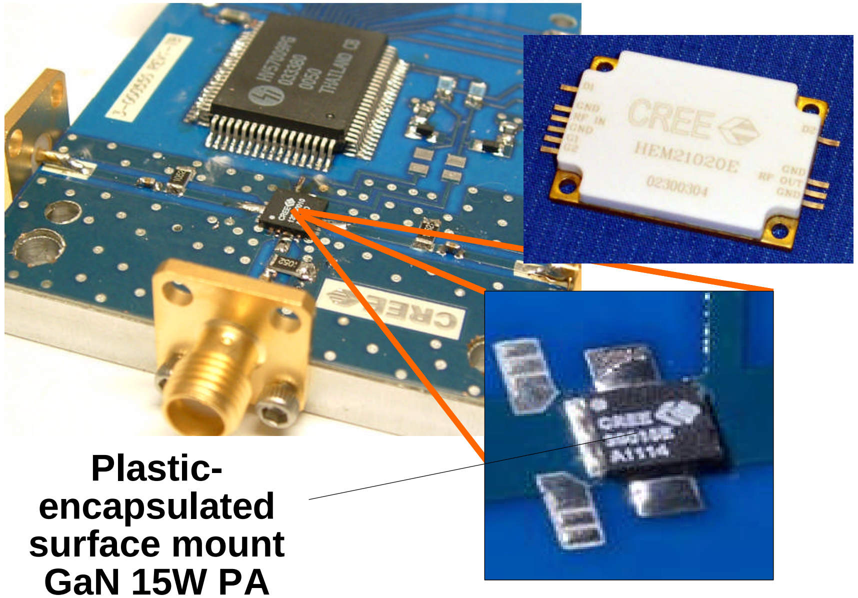


- Frequency: 3.3 to 3.9 GHz
- Gain: 15dB
- P1dB: 60W, P_{AVG}~7W$_{@2\% EVM}$
- PAE: 58-60% @ P_{SAT}
- Vdd: 28V
- Technology: GaN

Cree has developed low cost COTS components for numerous commercial applications

Commercial “COTS” T/R modules

Commercial Module Construction



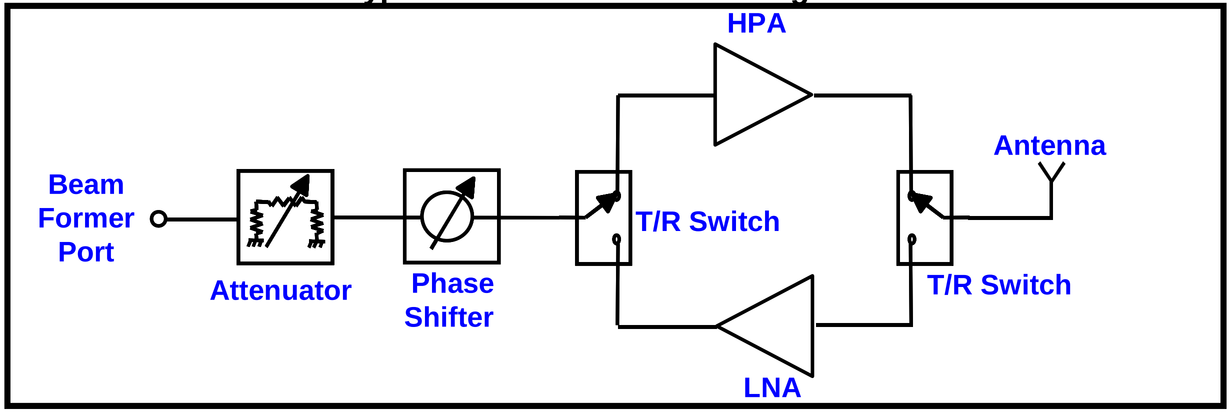
Plastic-encapsulated surface mount GaN 15W PA

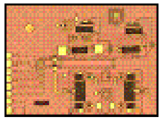
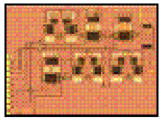
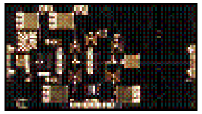
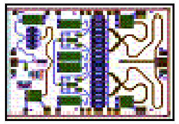
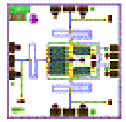
- PC “motherboard” construction
- Low cost, high volume assembly
- Low power dissipation surface-mount commercial components
- Non-hermetic assembly

Next generation WiMAX systems will utilize low cost COTS T/R Modules in commercial phased array antennas

Typical S-Band T/R Module
GaN MMIC Component Performance

Typical T/R Module Block Diagram



Component	6 bit Attenuator	6 bit Phase Shifter	LNA	2-stage Power Amp	T/R Switch
Frequency (GHz)	2.7 – 3.5	2.7 – 3.5	2.7 – 3.5	3.1 – 3.5	2.7 – 3.5
P_{OUT} or TOI	51 dBm	51 dBm	34.5 dBm OTOI	40 Watts	>20W @ $P_{.1dB}$
Gain / Loss	-4.9 dB	-5.6 dB	25 dB	25 dB	-0.75 dB
NF or PAE	---	---	1.2 dB NF	60% PAE	---
Size	2.5mm x 3mm	3mm x 3mm	3.2mm x 2.3mm	4.0mm x 3mm	2mm x 2mm

GaN MMICs for Next Generation T/R Modules are already being developed with excellent results

GaN Benefits for MPAR

- Next generation MPAR T/R modules must use COTS components and processes to achieve lowest cost
  - Similar to commercial PC motherboard construction
  - Use of surface-mount plastic encapsulated components
  - Leveraging commercial production lines and manufacturing infrastructure
- GaN technology can offer significant cost and performance benefits:
  - Ultra-high efficiency PAs
    - Low cost surface-mount assembly
    - Air cooling
    - Lower prime power consumption
    - Facilitates variable power out while maintaining high efficiency
  - High power density
    - Smaller, lower cost RF ICs
    - High dynamic range low noise amplifiers (LNAs)
  - Higher voltage operation (28V migrating to 48V)
    - Lower DC distribution losses / Improved system efficiency
- Will exploit commercial market leverage (COTS)
  - Future commercial base stations WILL use GaN based PAs and RF ICs
    - Many will be phased array antennas

GaN enables a wider trade-space for system optimization

What Additional R&D is Needed to Keep the Momentum Going?

- Further GaN switch-mode device and circuit optimization
  - Device improvements to further optimize switch-mode performance
  - Improved time-transient RF device circuit models
  - Switch-mode circuit topology optimization
    - Bandwidth enlargement using advanced circuit design techniques
- Device Power, Cost, and Thermal Optimization
  - Ultra-high efficiency PAs permit the use of smaller periphery die leading to lower cost
  - Optimal die size depends on total power and max channel temperature permissible
  - Trade space and optimization application dependent
- Device / Module Packaging and Interconnects
  - Further development required to support low cost, non-hermetic surface-mount devices, RF ICs, and modules
    - RF
    - Mechanical
    - Thermal
    - Environmental