INTEGRA

HV GaN for Scientific Applications

September 2024

Presentation Agenda

- ✓ SSPA market trends driving solid-state technology
- ✓ Overview of Integra's 100-150V HV GaN/SiC Technology
- ✓ Overcoming the barriers to practical solid-state power amplifier replacement of VED
- ✓ Examples of Integra's multi-kW transistors and amplifier pallets
- ✓ Novel SSPA architecture for megawatt level SSPA replacement of TWT/Klystrons
- ✓ Case Studies

Markets Trends Driving Solid-State SSPA Technology

- ✓ **Accelerating pull for higher single power transistors – multi kW**
- ✓ **Integra has reached system power levels in a component form factor. This is redefining SSPA system architectures over aerospace/defense, scientific, radar, and high power microwave applications**
- ✓ **VEDs for a number of end markets continue to decline, solid state replacement is accelerating as single transistor and pallet power levels continue to rise. Particle accelerator strong demand for 1-2MW SSPAs**
- ✓ **Integra's individual pallet powers continue to change the SSPA landscapes. With leap ahead SWaPC² we are seeing primes who previously bought system, begin to design their own system as Integra's HV GaN substantially reduces system complexity**
- ✓ **Pull accelerating for larger power transistor levels at C and X bands.**

Overview of Integra's 100-150V HV GaN/SiC

HV GaN/SiC Power Density

- ✓ Integra has invented a new patent pending transistor structure
- ✓ The structure enables significantly higher power density and 10% better efficiency
- ✓ Net result is we can produce the largest power transistor at significantly higher efficiency than competing processes.
- ✓ We have identified additional loss mechanisms which are being investigated in conjunction with the US Navy Directed Energy / High Power Microwave Work

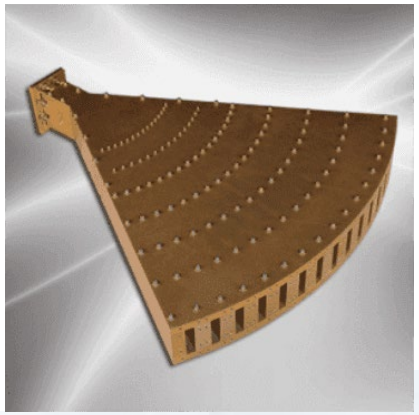
GaN/SiC Generation	Power Density	Power
Gen2 (50V)	8W/mm	1kW
Gen3 (100V)	12W/mm	3.6kW
Gen4 (100V)	22W/mm	6kW
Gen5* (150V)	29W/mm	10kW

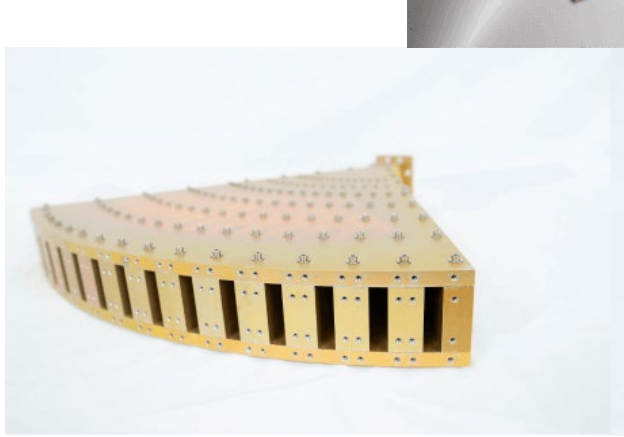
Overcoming Barriers to Practical Solid-State Replacement of TWTs/VEDs

- ✓ Previously the 50V GaN/SiC technology was limited to ~1kW per transistor
- ✓ The translated to practical solid-stage replacement of TWTs/VEDs to 10kW max
- ✓ Integra, in collaboration with Werlatone have redefined what is possible for practical SSPA replacement of TWTs/VEDs
- ✓ With the advent of single transistor powers up to 8kW and Werlatone's E-Plane power combining technology, the practical solid-state replacement of TWTs/VEDs has been increased to megawatt levels.
- ✓ Presently, Integra and Werlatone have collaborated on a scalable SSPA solution for megawatt level replacement of TWTs/VEDs and are actively working 4 system re-architectures utilizing Integra's HV GaN and Werlatone's E-Plane Technologies

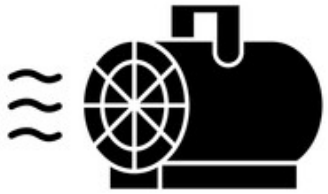
Werlatone Collaboration

- ✓ **Integra has been collaborating with Werlatone on an increasing number of SSPA 100kW and MW level SSPAs**
- ✓ **Werlatone has a unique high power, low loss combiner – the E-Plane Series**
- ✓ **E-Plane combiners have 18x the power handling of a standard radial combiner at lower loss factors**
- ✓ **Werlatone has a microstrip to waveguide launch standard product to go from Integra's HV GaN System Pallets directly to waveguide**
- ✓ **Currently working 1.2MW P Band SSPA, 1.3GHz 1.6MW L Band SSPA, 200kW 3GHz S Band SSPA with Werlatone**





HV GaN Enabling System Re-architecture Across Markets



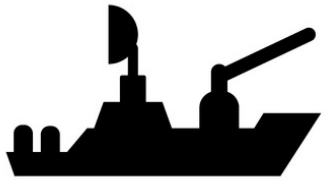
Industrial Drying

Agriculture

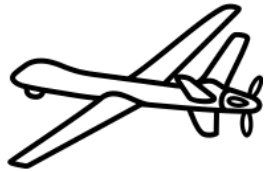
Directed Energy

High Power Microwave

Medical



Naval Radar TWT Replacement



Broadband Jamming

Avionics

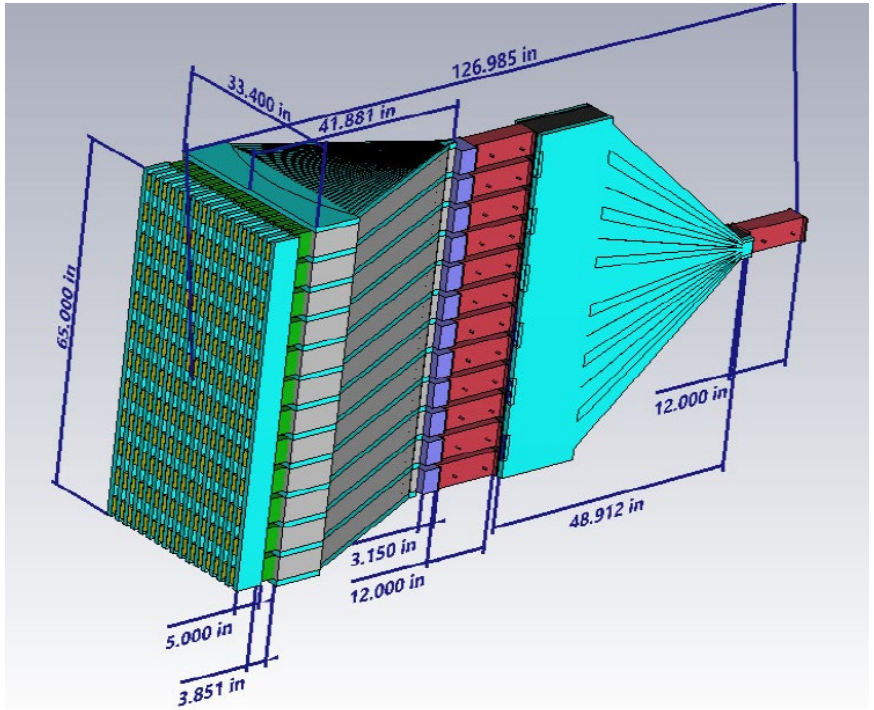
Particle Accelerators

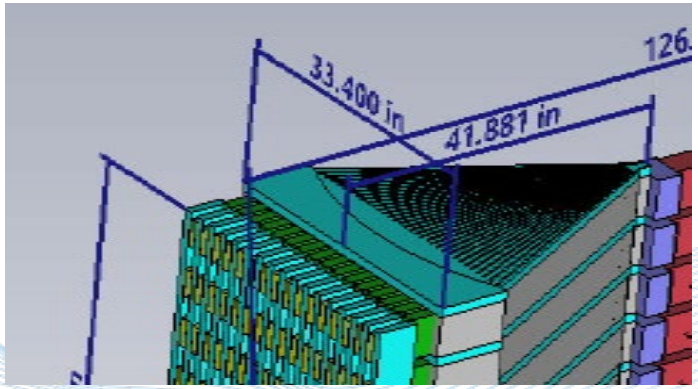
Early Warning Radar

Weather Radar

Werlatone Collaboration Case Study

- ✓ **MW level SSPA Core System**
- ✓ **1MW Upper L-Band to Lower S-Band water cooled system**
- ✓ **Utilizes 192 Integra 6kW System Pallets with integrated circulators, Werlatone microstrip to waveguide launches, 12 E Plane combiners, and 12 way E plane Combiner**
- ✓ **Integrated water cooling and shielding for the Integra System Pallets**
- ✓ **Integra and Werlatone will produce a system demonstrator for 50kW-100kW Compact SSPAs core based on 18 Integra System Pallets and 1 Werlatone E Plane in the space of 33” x 50” x 14”**





Case Study – Re-architecting a 150kW SSPA

- ✓ **Integra and Werlatone working with a European company have re-architected an SSPA system design with unparalleled SWaPC²**

- ✓ **The system concept utilized a total of 64 system pallets (4kW/ pallet) and a total of 4 E-Plane combiners, 1 4 way magic T along with cooling and a power supply. Each pallet was outfitted with an integrated circulator.**

- ✓ **Starting with 4kW / pallet, we dramatically reduce the number of power combinations eliminating power combiners, splitter, cables, and of course all the extra cooling to remove the 0.2dB heat loss per power combination.**

Case Study – Re-architecting a 150kW SSPA

Commercial RF System

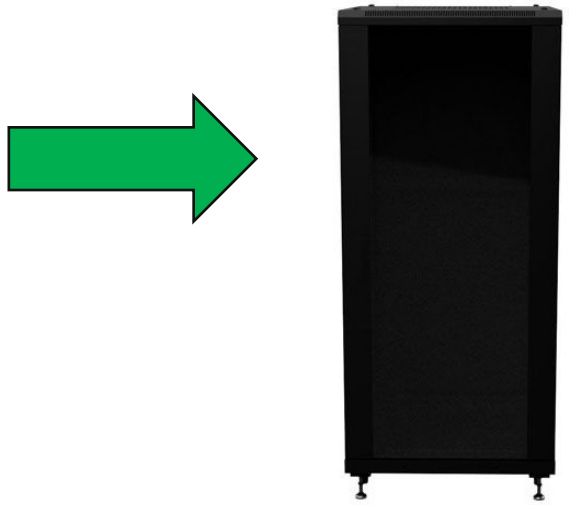
- ✓ Power
  150kW
- ✓ Volume
  52 cubic ft
- ✓ System Power Density
  2.88kW/ cubic ft

Integra Werlatone System

- ✓ Power
  200kW
- ✓ Volume
  17.4 cubic ft
- ✓ System Power Density
  11.49kW/ cubic ft

Commercial RF
50V, 150kW, S Band System
(2 x 6ft x 1.5ft racks)

Werlatone-Integra
100V, 200kW, S Band System
(1 x 4ft x 1.5ft rack)



Integra Werlatone has 400% higher system power density
Integra Werlatone can produce 50kW more power in 33% of the volume

Integra's HV GaN/SiC Accelerator SSPA Designs

UHF, L Band, S Band SSPA for Particle Accelerators

- ✓ **A Particle accelerator SSPA was one of the first HV Pallets that went to production using HV GaN in 2022**
- ✓ **Using a 4kW single transistor, the European company was able to reduce the size of their 1.6MW SSPA by 70%.**
- ✓ **Integra is presently working with Los Alamos to replace the Klystron's on the Proton Accelerator with HV GaN SSPA in conjunction with Werlatone.**

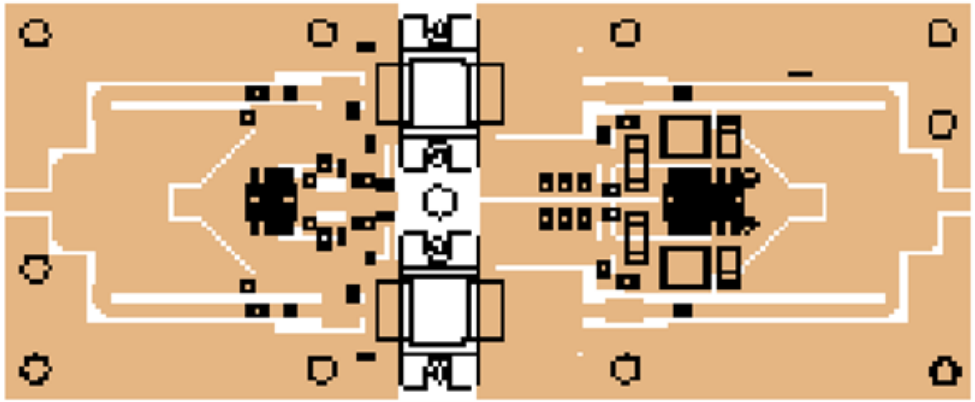
Accelerator Frequency	SSPA Pallet Power	Part Number	System SSPA
P Band	3.5kW	IGNP815	1.2MW
P Band	5kW	IGNP816	1.2MW
L Band	4kW	IGNP1304	1.6MW
S Band	5kW	IGNP3014	1.5MW

IGNP3030S5000 - 5kW 100V RF GaN/SiC Amplifier System Pallet

S-Band Particle Accelerator Applications

Key Features

- ✓ Industry leading power – 5kW amplifier pallet
- ✓ Optimized for S band particle accelerator VED replacement
- ✓ 2.0" x 4.9" pallet size



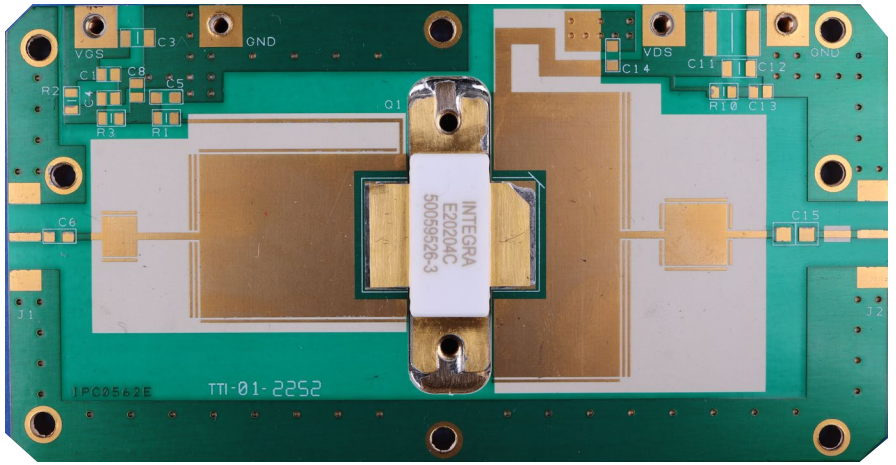
PARAMETER	VALUE	UNITS
Frequency	3.0	GHz
Output Power	5000	W
Pulse Width	10	uS
Duty Cycle	1	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V

IGNP1300S3600 – 4kW 100V HV GaN/SiC System Transistor

Particle Accelerator Applications

Key Features

- ✓ Industry leading power – 4kW single transistor
- ✓ Optimized for L Band Scientific Applications
- ✓ Unparalleled SWaPC²
- ✓ Enables re-architecting of high power systems



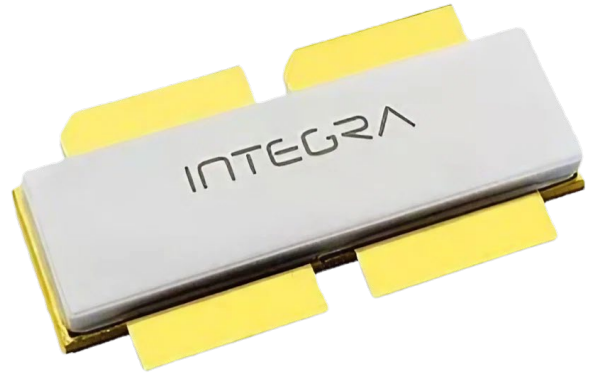
PARAMETER	VALUE	UNITS
Frequency	1300	MHz
Output Power	4000	W
Pulse Width	10	uS
Duty Cycle	4%	%
Efficiency	70	%
Gain	18	dB
Bias Voltage	100	V

IGN0450S6000 – 6kW 100V GaN/SiC System Transistor

UHF Radar Applications

Key Features

- ✓ Industry leading power – 6kW single transistor package
- ✓ Optimized for UHF Radar
- ✓ High Efficiency for Airborne UHF Radar
- ✓ System power in a component form factor



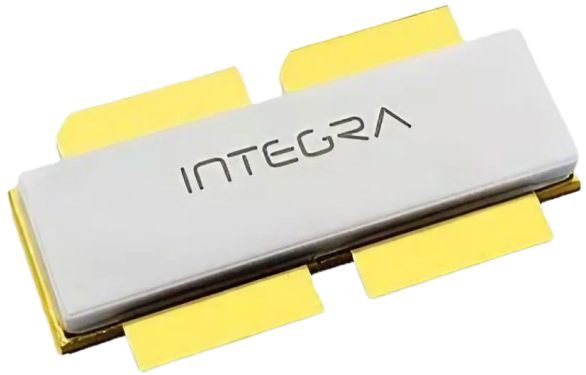
PARAMETER	VALUE	UNITS
Frequency	430 - 450	MHz
Output Power	6000	W
Pulse Width	100	uS
Duty Cycle	10	%
Efficiency	80	%
Gain	24	dB
Bias Voltage	100	V

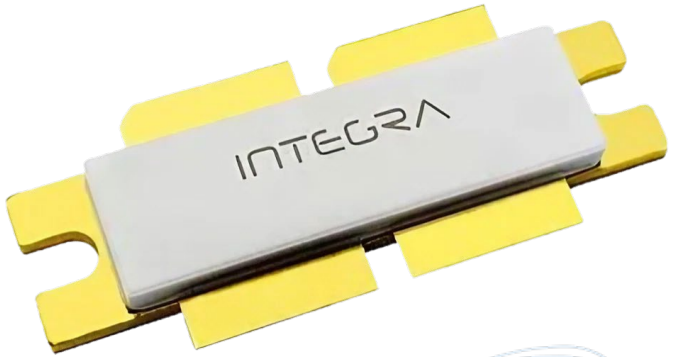
IGN0912S5000 – 5kW 125V HV GaN/SiC System Transistor

L-Band Avionics Applications

Key Features

- ✓ Industry leading power 5kW and Efficiency
- ✓ Optimized for L Band Avionics
- ✓ Unparalleled SWaPC²
- ✓ Enables re-architecting of TACAN and IFF Systems





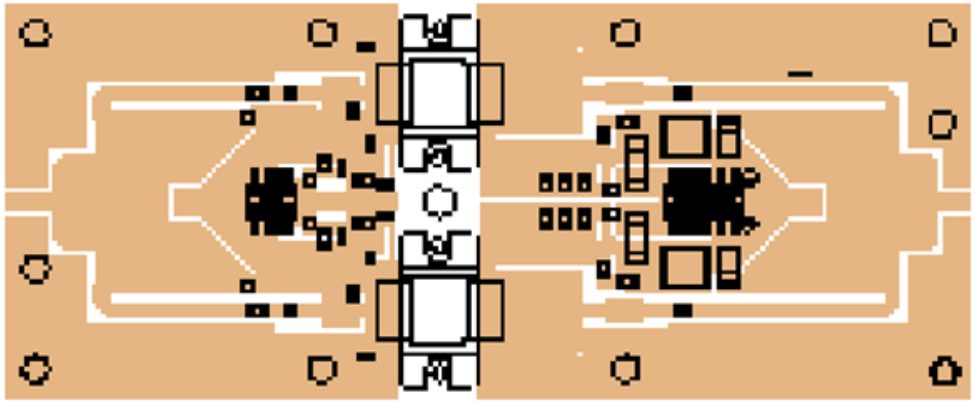
PARAMETER	VALUE	UNITS
Frequency	960 - 1250	MHz
Output Power	5000	W
Pulse Width	32	uS
Duty Cycle	4	%
Efficiency	75	%
Gain	20	dB
Bias Voltage	125	V

IGNP2931S4000 – 4kW 100V RF GaN/SiC Amplifier System Pallet

S-Band Early Warning Radar Applications

Key Features

- ✓ Unparalleled system power density
- ✓ Industry leading power – 4kW amplifier pallet
- ✓ Optimized for S band radar applications
- ✓ 2.0” x 4.9” pallet size



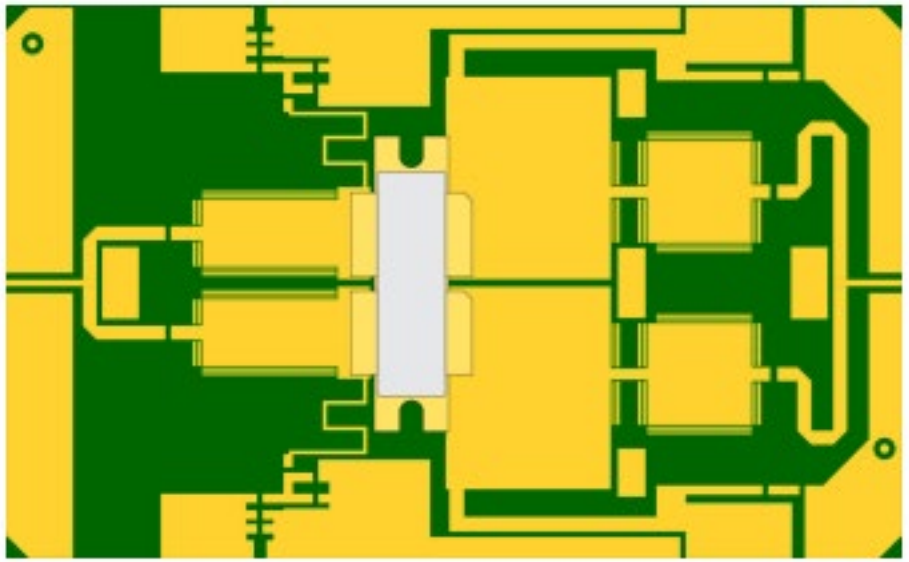
PARAMETER	VALUE	UNITS
Frequency	2.9 – 3.1	GHz
Output Power	4000	W
Pulse Width	100	uS
Duty Cycle	10	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V

IGNP0912S5000 – 5kW 125V HV GaN/SiC System Pallet

L-Band Avionics Applications

Key Features

- ✓ **Industry leading power – 5kW single transistor amplifier pallet**
- ✓ **Optimized for L Band Avionics**
- ✓ **Unparalleled SWaPC²**
- ✓ **Enables re-architecting of high power systems**



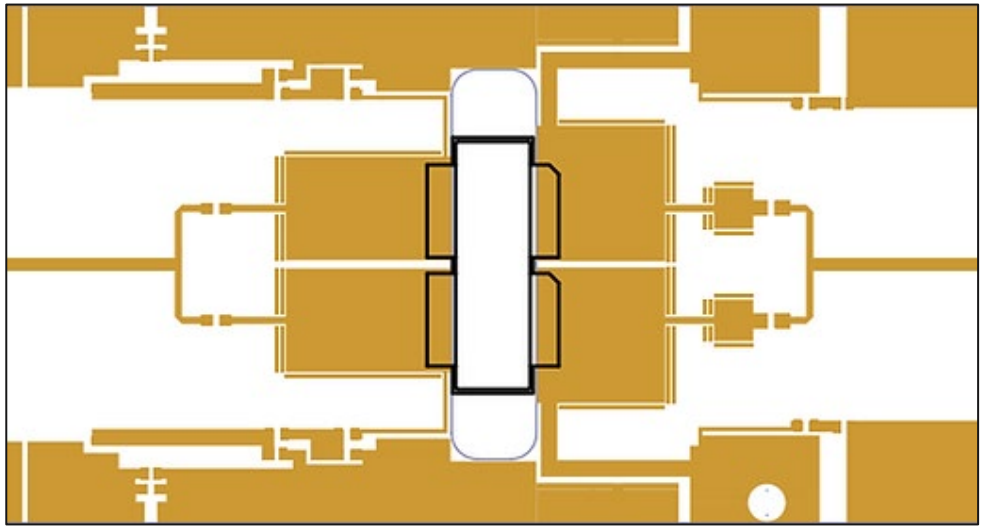
PARAMETER	VALUE	UNITS
Frequency	960 - 1250	MHz
Output Power	5000	W
Pulse Width	32	uS
Duty Cycle	4	%
Efficiency	75	%
Gain	20	dB
Bias Voltage	125	V

IGNP1214M3200 – 3.2kW 100V HV GaN/SiC System Pallet

L-Band Avionics Radar Applications

Key Features

- ✓ Industry leading power – 3.2kW single transistor
- ✓ Optimized for L Band Radar
- ✓ Unparalleled SWaPC²
- ✓ Enables re-architecting of high power systems



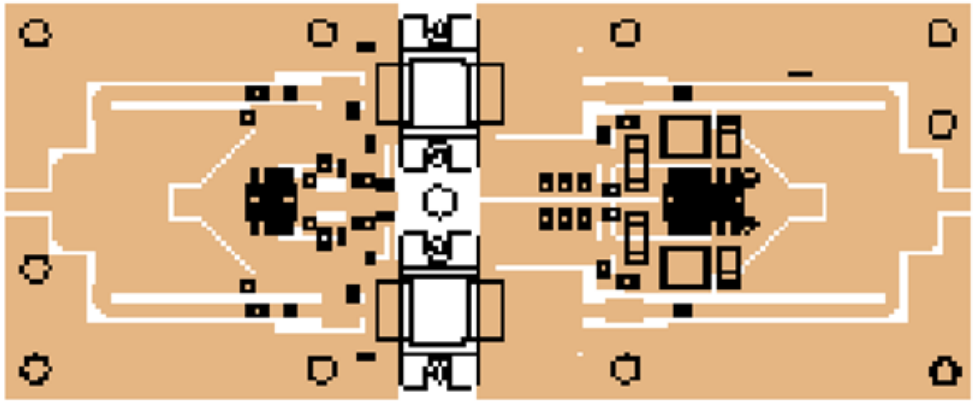
PARAMETER	VALUE	UNITS
Frequency	1.2 - 1.4	GHz
Output Power	3200	W
Pulse Width	100	uS
Duty Cycle	4	%
Efficiency	75	%
Gain	18	dB
Bias Voltage	100	V

IGNP2531S3000 –3kW 100V RF GaN/SiC Amplifier System Pallet

S-Band Directed Energy Applications

Key Features

- ✓ Industry leading power – 3kW amplifier pallet
- ✓ Optimized for S band directed energy applications
- ✓ 2.0” x 4.9” pallet size



PARAMETER	VALUE	UNITS
Frequency	2.5 – 3.1	GHz
Output Power	3000	W
Pulse Width	100	uS
Duty Cycle	1	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V

IGNP2731S3200 –3.2kW 100V RF GaN/SiC Amplifier System Pallet

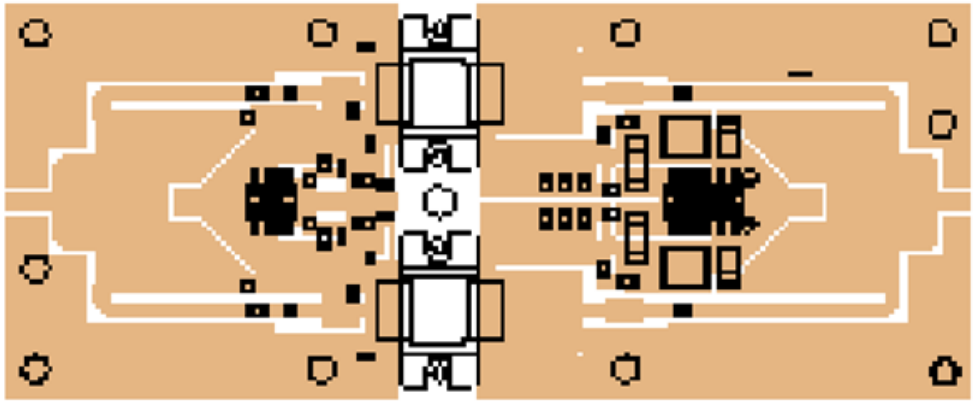
S-Band Radar Applications

Key Features

Industry leading power – 3.2kW amplifier pallet

Optimized for S-Band Radar applications

2.0” x 4.9” pallet size



PARAMETER	VALUE	UNITS
Frequency	2.7 – 3.1	GHz
Output Power	3200	W
Pulse Width	100	uS
Duty Cycle	1	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V

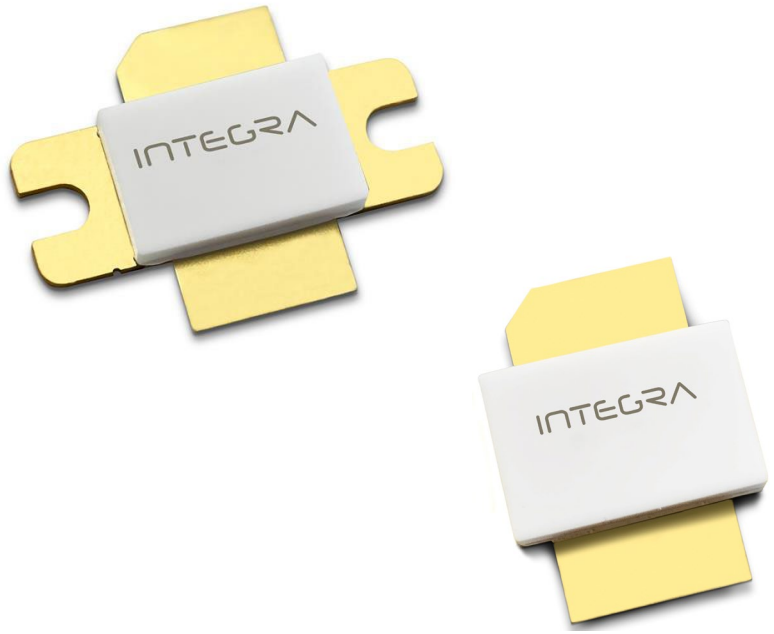
IGN2931S2500 – 2.5kW 100V GaN/SiC System Transistor

S-Band Radar Applications

Key Features

- ✓ Industry leading power – 2.5kW single transistor
- ✓ Optimized for S Band Radar
- ✓ Enables practical TWT replacement
- ✓ 300% more power than 50V GaN/SiC

PARAMETER	VALUE	UNITS
Frequency	2.9 - 3.1	GHz
Output Power	2500	W
Pulse Width	100	uS
Duty Cycle	10	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V



IGN2531S1600 – 1.6kW 100V GaN/SiC Transistor

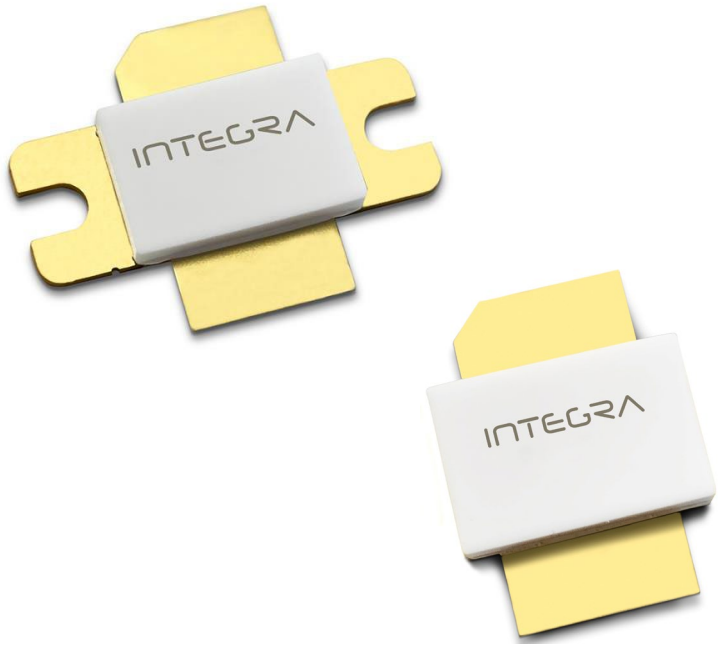
S-Band Directed Energy Applications

Key Features

- ✓ **Industry leading power – 1.6kW single transistor**

  Optimized for S Band Directed Energy Applications

- ✓ **Enables practical TWT replacement**
- ✓ **400% more power than 50V GaN/SiC**



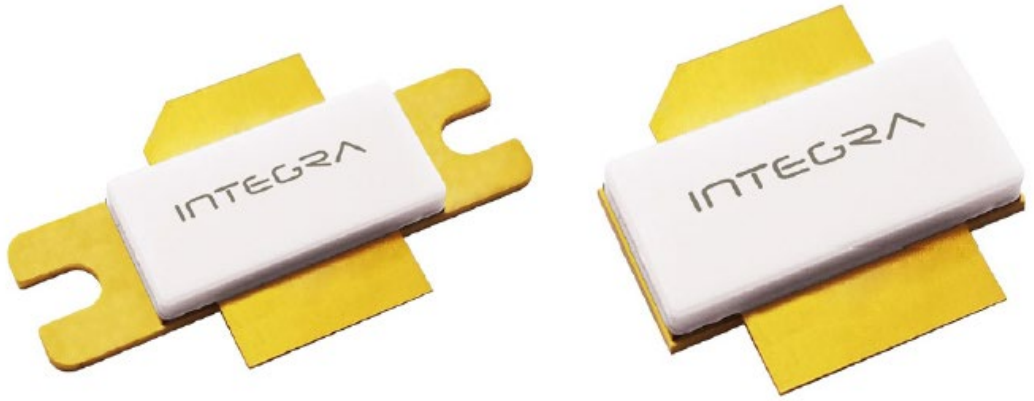
PARAMETER	VALUE	UNITS
Frequency	2.7 - 3.1	GHz
Output Power	1600	W
Pulse Width	100	uS
Duty Cycle	10	%
Efficiency	62	%
Gain	15	dB
Bias Voltage	100	V

IGN0450S3000 – 3kW 100V GaN/SiC System Transistor

UHF Radar Applications

Key Features

- ✓ Industry leading power – 3kW transistor
- ✓ Optimized for UHF Radar
- ✓ Single ended design



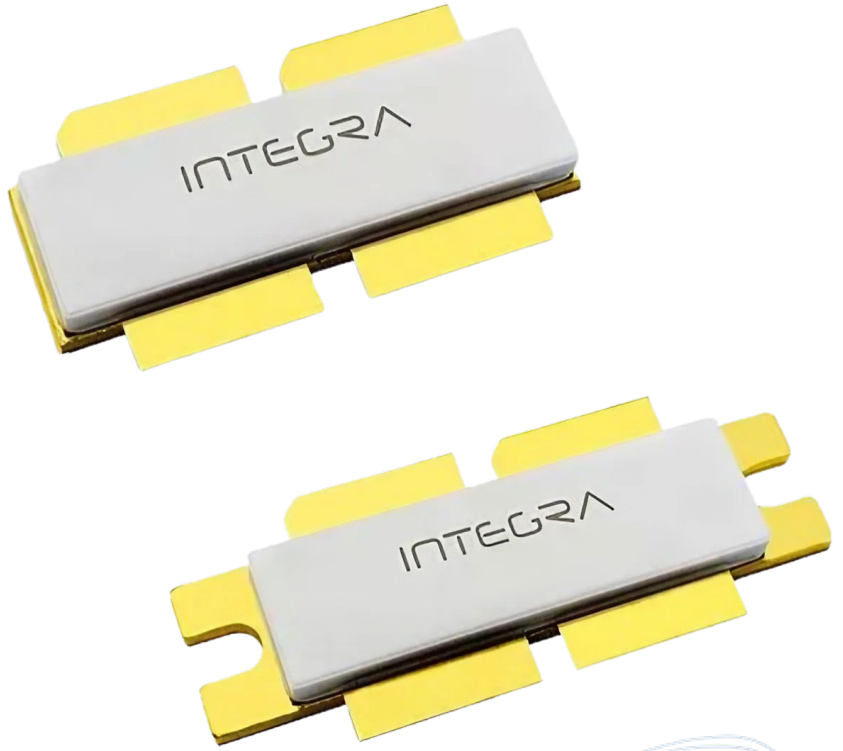
PARAMETER	VALUE	UNITS
Frequency	405 - 460	MHz
Output Power	3000	W
Pulse Width	100	uS
Duty Cycle	10	%
Efficiency	80	%
Gain	23	dB
Bias Voltage	100	V

IGN1012S2500 – 2.5kW 125V GaN/SiC System Transistor

L-Band Directed Energy Applications

Key Features

- ✓ Industry's first 125V RF GaN/SiC for Avionics Applications
- ✓ Industry leading power – 2.5kW single transistor package
- ✓ Optimized for L Band Directed Energy Applications
- ✓ Patented Thermally Enhanced GaN/SiC Technology



PARAMETER	VALUE	UNITS
Frequency	1.0 - 1.2	GHz
Output Power	2500	W
Pulse Width	10	uS
Duty Cycle	4	%
Efficiency	75	%
Gain	17	dB
Bias Voltage	125	V

IGN1214M3200– 3.2kW 100V GaN/SiC System Transistor

L-Band Radar Applications

Key Features

- ✓ Industry leading power – 3.2kW single transistor amplifier
- ✓ Optimized for L Band Radar
- ✓ Unparalleled SWaPC²
- ✓ Enables re-architecting of high power systems

PARAMETER	VALUE	UNITS
Frequency	1.2 - 1.4	GHz
Output Power	3200	W
Pulse Width	100	uS
Duty Cycle	4	%
Efficiency	75	%
Gain	18	dB
Bias Voltage	100	V