



Freebird

semiconductor

Development Strategies of eGaN HEMTs for Space Applications

BY

Jim Larrauri

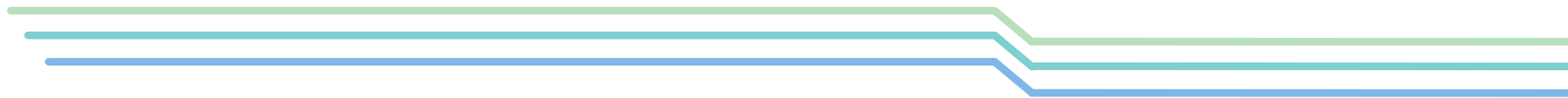
Co-Founder & Chief Strategy Officer

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 - FBS-GAM Series (**G**aN **A**daptor **M**odules)
 - FBS-GAM Series Applications



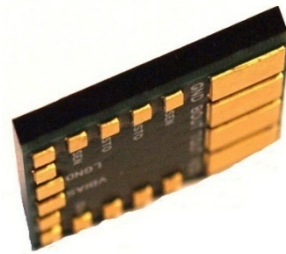
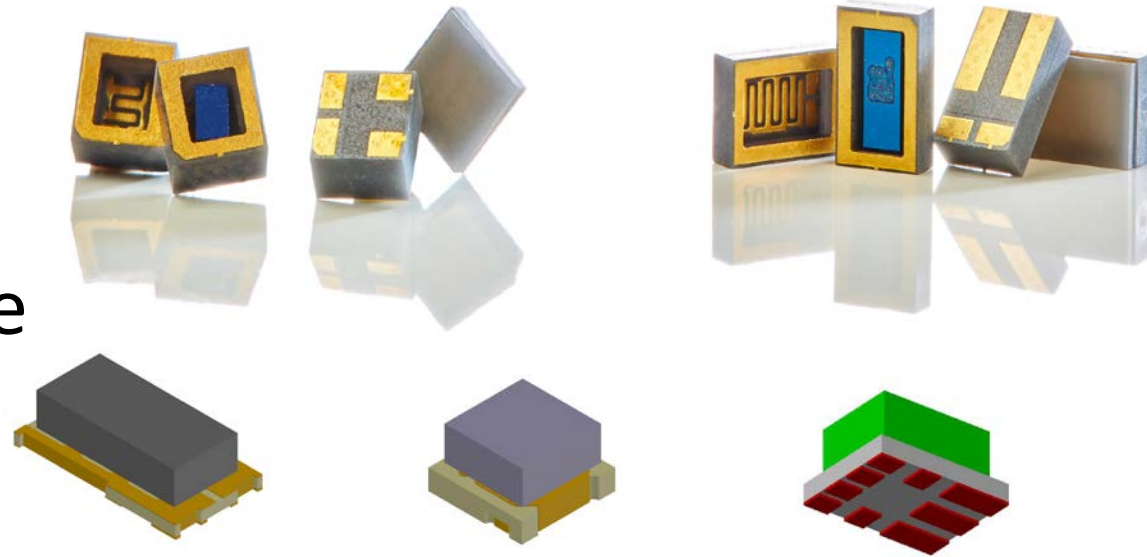
Introduction to Freebird Semiconductor

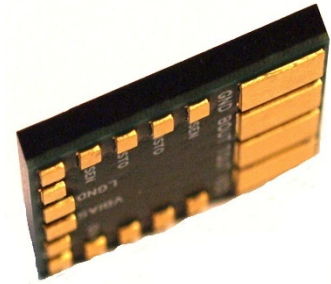


Freebird Semiconductor Corporation is a fabless manufacturing & design company dedicated to addressing High Reliability power management problems by using emerging semiconductor technologies.

We are focused on delivering Enhancement Mode Gallium Nitride Power Switching Transistors (eGaN HEMTs) and circuits with disruptive, (r)evolutionary advantages over silicon based solutions into the high reliability market.

- FBG Ceramic Hermetic Discrete
- FDA Die Adaptor products
- **GAM GaN Adaptor Modules** with Dual Driver & Integrated output power HEMTs (Patented Designs)

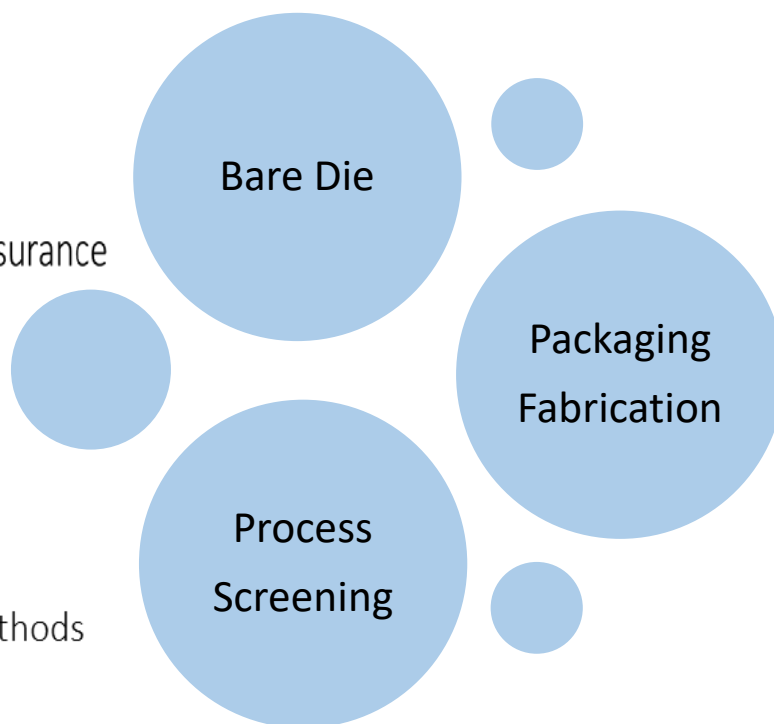




Development Strategies of eGaN HEMTs for use in Space

Eliminate Variability in Space Level eGaN Designs

- Control Mask Set
- Control Process Run Card
- Control Bump Run Card
- Control Probing and Screen Programming
- Prevent unauthorized process modifications
- Wafer lot acceptance with radiation hardness assurance
- Continuous die supply Assurance



- Pre & Post Test
- Incorporate Industry Acceptable Test Methods
- Perform 100% Testing

- Hermetic Packaging (Cavity Devices)
- No Grounding of Packaging (Excellent Di-electric Properties)
- Creepage & Clearance to Rated Voltage
- Low Conduction Losses
- High Thermal Conductivity with near CTE to Silicon
- Low parasitic Inductance Connectivity
- Low DC resistance
- Fabricate & Source Domestically (USA)

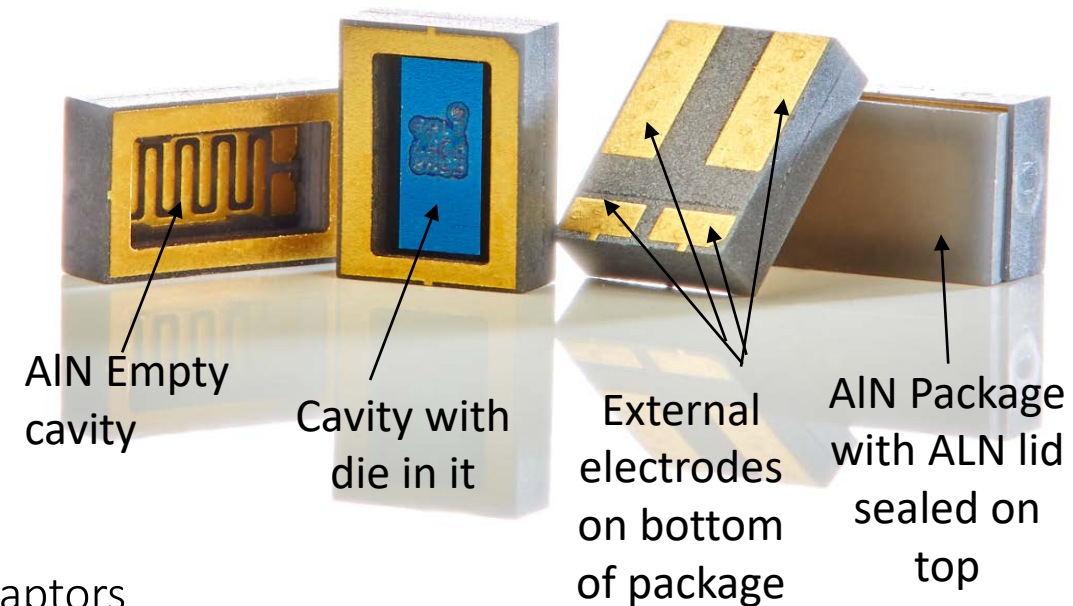
Implementing Core Controls

Freebird Semiconductor High Reliability eGaN[®] Chip Die

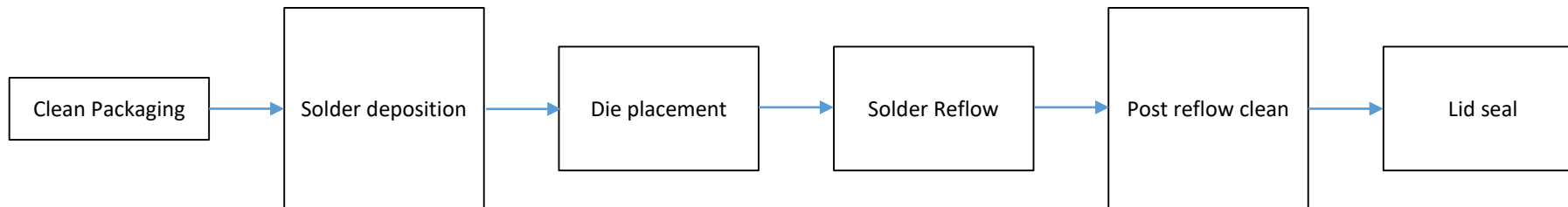
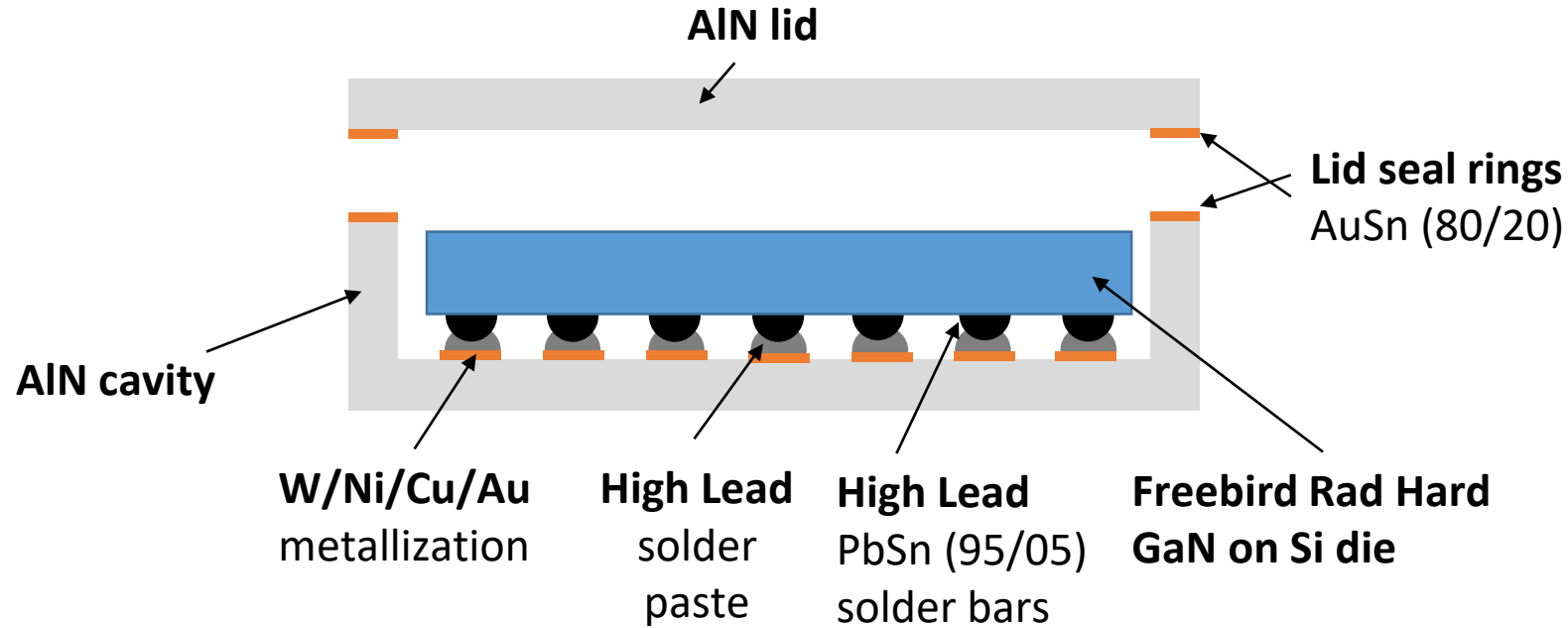
- Sourced under a proprietary source control die agreement with “Efficient Power Conversion” (EPC), our fab source who manages wafer production- under this agreement Freebird Semiconductor Controls SCD Die:
 - ✓ Mask Set
 - ✓ Process Run Card
 - ✓ Bump Run Card
 - ✓ Probe and Screen Programming
 - ✓ Modifications Require Approval
 - ✓ Freebird also maintains a proprietary long-term-supply sourcing agreement with (EPC)
 - ✓ Freebird processes all wafer/die lots are fully processed IAW our wafer lot acceptance RHA plans.

Semiconductor Ceramic Packaging

- Controlling advanced high reliability ceramic package developments are ideally achieved by domestically (USA) sourcing & fabricating- ***Freebird's proprietary package designs ARE!***
- Aluminum-Nitride (AlN) material**, produced as **ceramic cavity-base and lid combinations** offer a **superior** package solution to traditional Alumina (Aluminum Oxide Al_2O_3) and can be integrated as a chip-scale interposer base design for BGA die adaption-
- FREEBIRD* has developed this packaging:**
 - ✓ Excellent Hermetic Sealing (Cavity Devices)
 - ✓ Non-metallic lids (Excellent Di-electric Properties)
 - ✓ Proper Creepage & Clearance to Rated Voltage
 - ✓ Low Conduction Losses
 - ✓ High Thermal Conductivity with near CTE to Silicon
 - ✓ Low parasitic Inductance Connectivity
 - ✓ Low DC resistance $<1\text{m}\Omega$ interface for BGA die interface adaptors



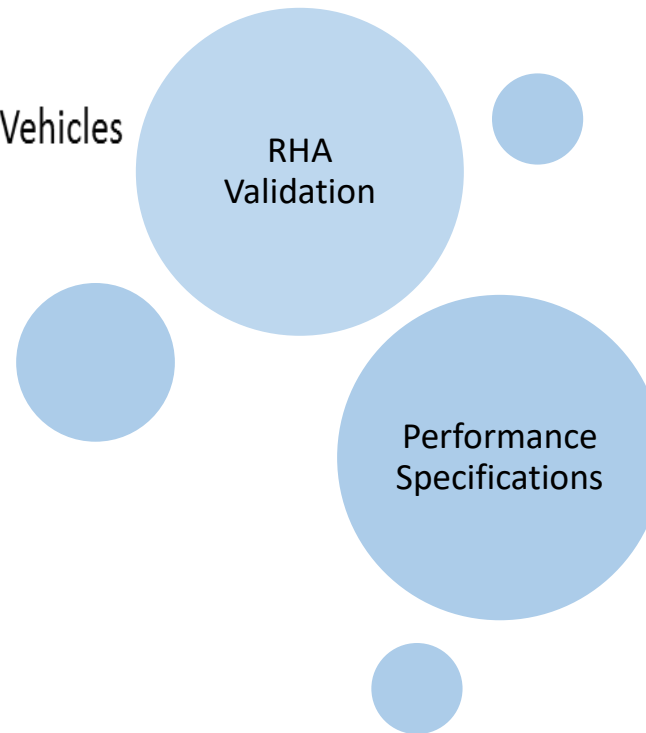
Basic Product Structure & Process Assembly



FREEBIRD SEMICONDUCTOR PROCESS SCREENING FLOW INCORPORATES ESTABLISHED SCREENING METHODOLOGIES

Operation	Test	Base Standard	Test Methods	FBG SERIES Sample Size	FDA SERIES Sample Size	COMMENTS
✓ Pre-Assembly	Probe Testing		Freebird Internal	100%	100%	
	Visual inspection	750		100%	100%	
✓ Post-Assembly	Die Shear	750		5	5	
	X-Ray	750		5	5	
✓ Process Screening	Pre Conditioning	Jedec	JESD22 A- 113	N.A	N.A	
	Electricals	750	3411,3413,3421,3404	100%	100%	
	Temp Cycling	750	TM1051	100%	100%	
	Constant Acceleration	750	TM2006	100%	N.A	
	PIND	750	TM2052	100%	N.A	
	Initial Electricals (Read and Record)	750	3411,3413,3421,3404	100%	100%	
	HTGB	750	TM1042 Condition B	100%	100%	
	Interim Electricals (Read and Record)	750	3411,3413,3421,3404	100%	100%	
	HTRB	750	TM1042 Condition A	100%	100%	
	Final Electricals (Read and Record)	750	3411,3413,3421,3404	100%	100%	
	Final Electricals (High and Low Temperatures)	750	3411,3413,3421,3404	100%	100%	
	X-RAY	750	TM2076	100%	100%	
	Hermetic Seal, Fine & Gross Leak	750	TM1071	100%	N.A	
	Final Electricals	750	3411,3413,3421,3404	100%	100%	

- Reproducible Wafer Lot Acceptance Procedures
- Radiation Test With Qualified Personnel Versed in RHA With Technology Of DUT
- Single Event Test With Suitable ION Species
- Total Ionizing Dose Test To Suitable Levels
- Correlate ELDRs Performance Of Technology To TID Test Vehicles
- Validation of Neutron DD Conformance

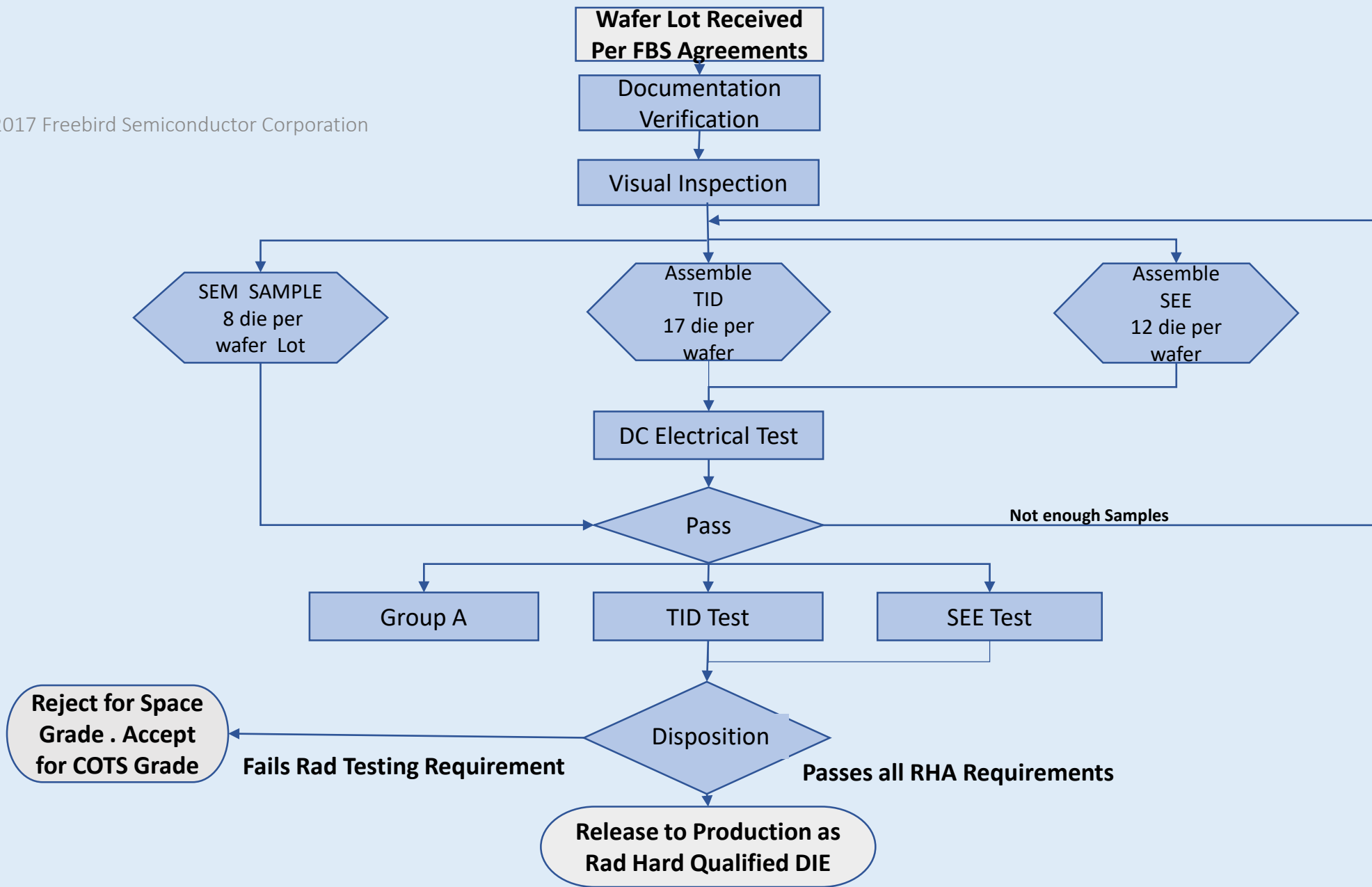


- Conformance Testing to Established Vehicles As Possible
- Qualification On All Die & Package Elements
- Incorporate Technology Specific Test Methodologies
- Embrace Aerospace Quality Management Systems

Key Strategies

Freebird Wafer Lot Acceptance Testing

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Radiation Conformance Qualification

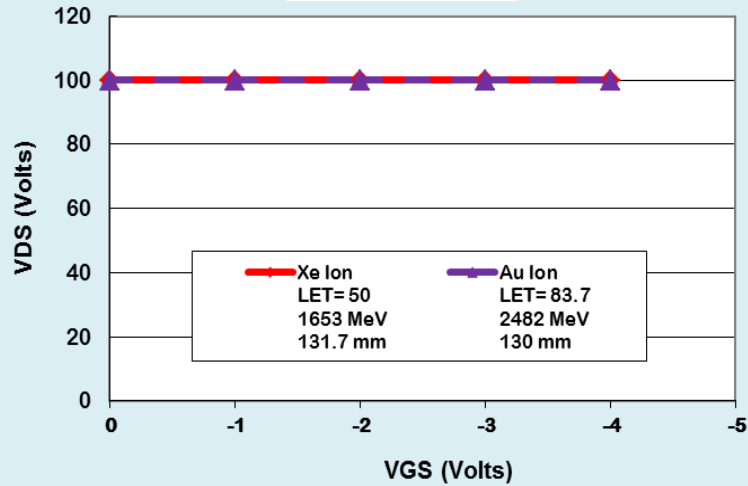
- ✓ **Radiation testing is conducted by Freebird Semiconductor Personnel**
 - ✓ SEE testing performed at “Texas A&M” (TAMU on our complete portfolio)
 - ✓ TID testing conducted at VPT Rad with standard testing up to 300kRads
 - ✓ ELDRs –portfolio sample tested, with no deviation from TID
 - ✓ Neutrons testing conducted on our technology completed & passed

Group D Summary OF FBG/FDA Product Portfolio

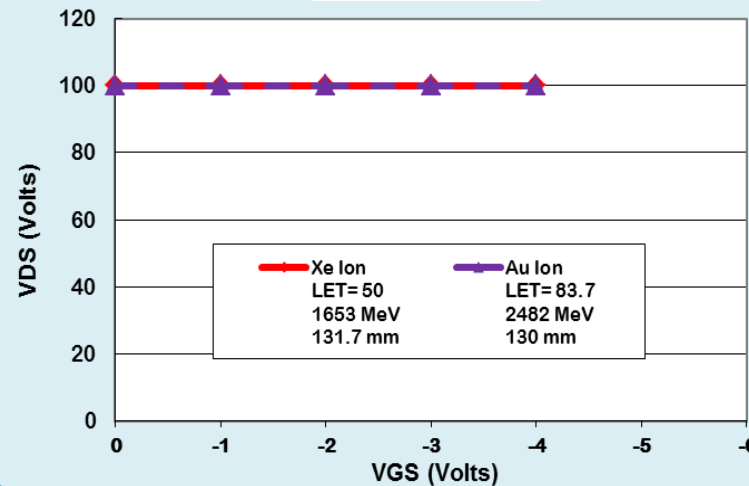
Operation Performed	Standard - Ref	Conditions	Reports Generated
Electricals Measurements	3411,3413,3421,3404	25°C	
Steady State Total Ionizing Dose	1019	5 die per wafer per Bias	TID report 100K/300K
Electricals Measurements	3411,3413,3421,3404	25°C	
Electricals Measurements	3411,3413,3421,3404	25°C	
SEE Irradiation	1080	3 die per wafer and ion exposure	SEE report both XE / AU Species Reported
Electricals Measurements	3411,3413,3421,3404	25°C	

100V FBG10NXX Device Single Event Effect Result Examples

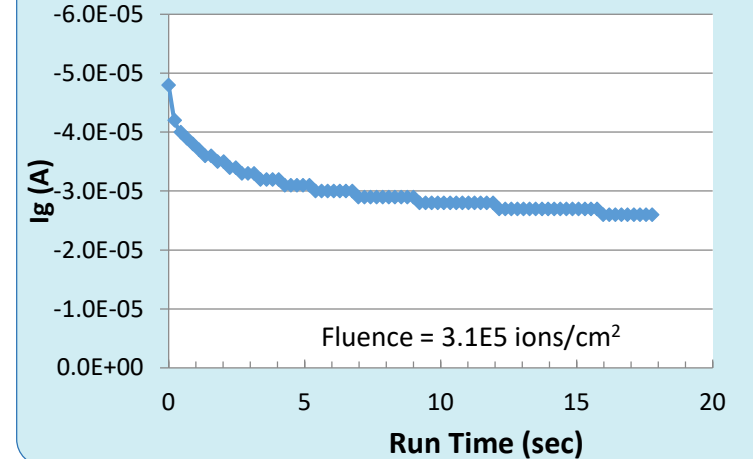
Small Size Die



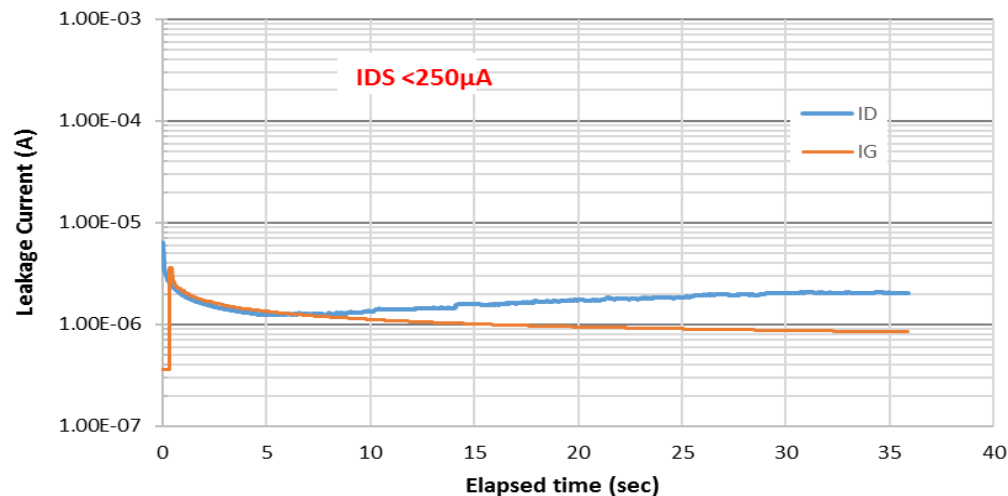
Larger Die Sie



Au ion Let=83.7 2482MeV 130um
VDS=100V VG=-4V

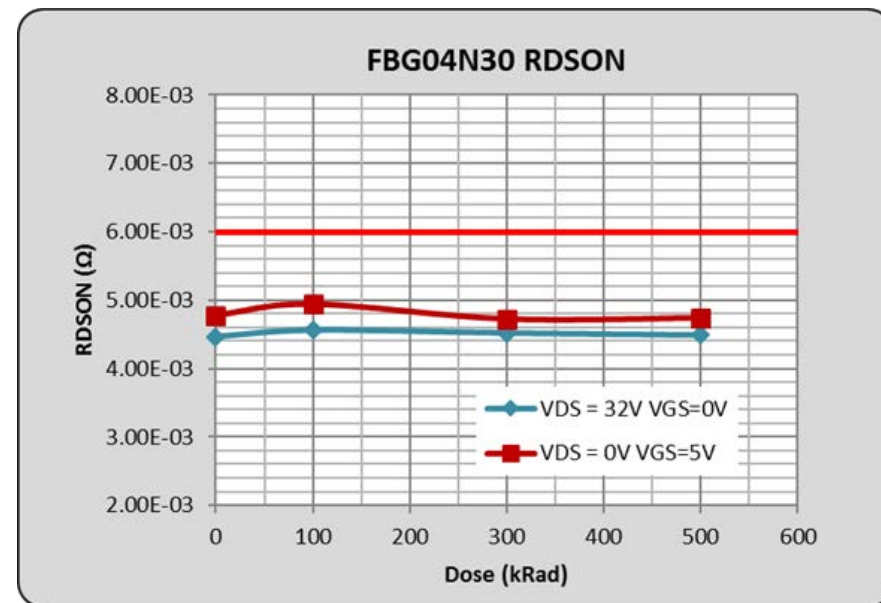
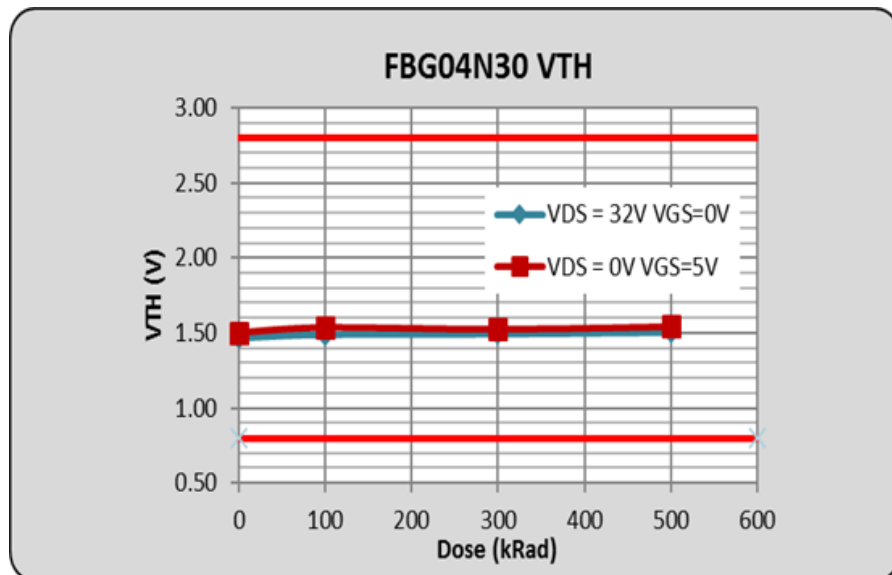
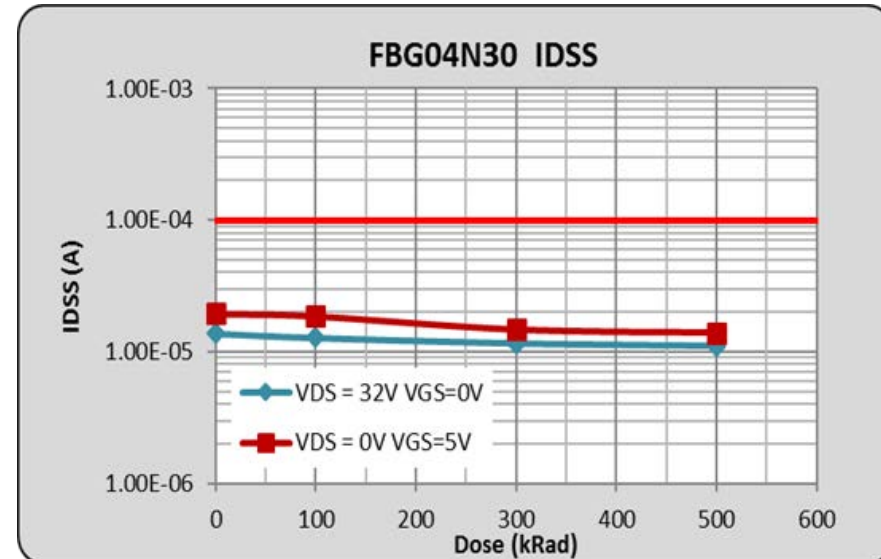
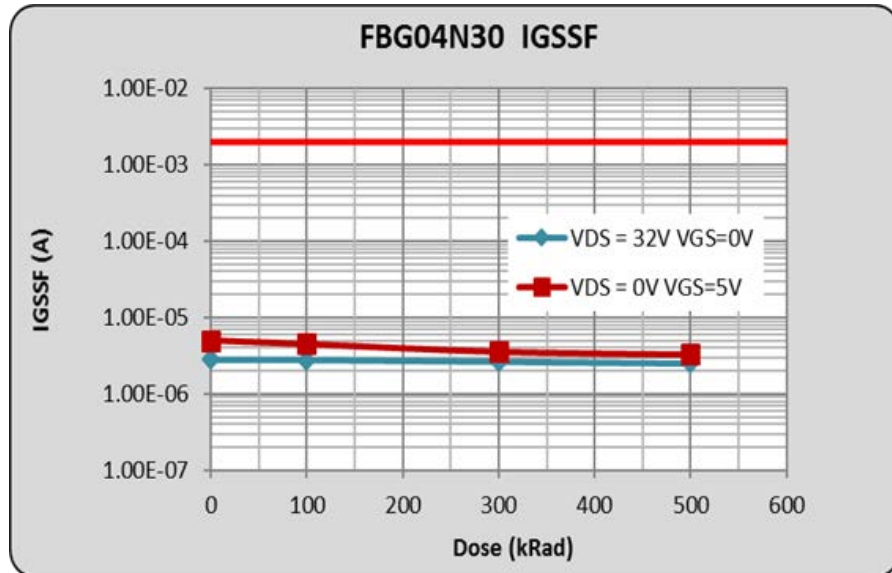


FBG10N30x Au ion V_{DS} = 100v V_{GS} = -4V



TEST	TYPICAL ENVIRONMENT			
SEE SOA	Ion	LET MeV/mg/c m ²	Range mm	Energy MeV
	Xe	50.8	125	1583
	Au	84.6	124	2365

40V FBG04N30X TID Response Example



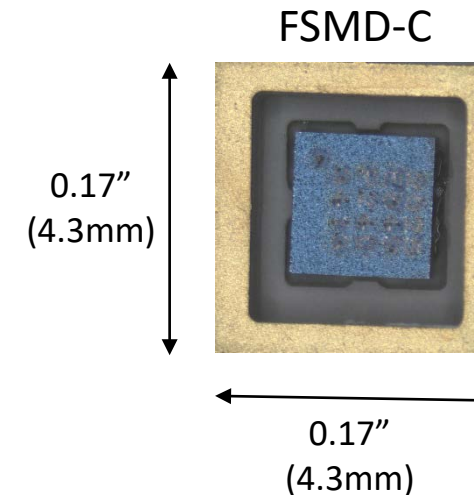
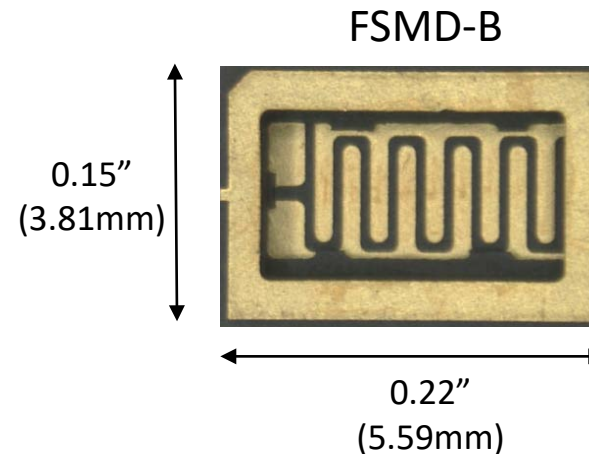
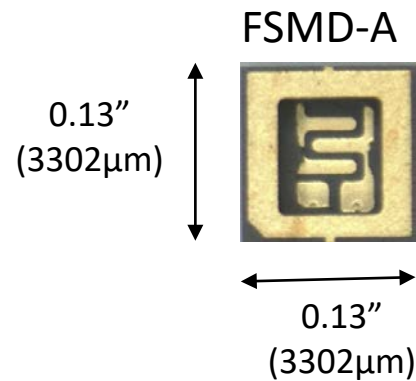
Conformance Qualifications (FBG) Hermetic & (FDA) Die Adaptor Series

- ✓ Freebird Semiconductor Manufacturing Assembly is conducted exclusively at our (USA) facilities located in Haverhill, Massachusetts (USA).
- ✓ Firebird Semiconductor screening conformance qualifications performed at a domestic (USA) DLA lab suitable MIL-PRF-19500 facility equipped to perform qualification inspection, conformance inspection & screening tests on devices to MIL-STD-750 Test Methods. Conformance qualifications are also performed in Freebird manufacturing facilities. Our qualification methods are performed consistent with an equivalent MIL-PRF-19500 guideline for semiconductor devices;

CONFORMANCE SCREENING FLOW PER FREEBIRD					
Operation	Test	Base Standard	Consistent Test Methods	Hermetic FBG Sample Size	Die Adaptor FDA Sample Size
✓ Group A Inspection (Conformance)	A-2 DC Static Tests at 25°C		3411,3413,3421,3404	116	116
	A-3 High & Low Temp DC Static Tests		3411,3413,3421,3404	116	116
	A-7 Gate Charges & Capacitance		TM3471 Condition B,TM3473	45	45
✓ Group B Inspection (Conformance)	B-1 Physical Dimensions	750		22	22
	B-2 Solderability	750	TM2026	15	15
	B-2 Resistance to Solvents	750	TM1032	N.A	N.A
	B-3 Pre-Electricals	750	3411,3413,3421,3404	22	2
	Temperature cycling	750	TM1051		N.A
	Hermetic Seal, Fine Leak	750	TM1071		22
	Electricals Measurements	750	3411,3413,3421,3404		N.A
	Bond strength	750	TM2037	N.A	N.A
	Die Shear	750	TM2017	22	22
	Cross section	750			5
	B-4 Pre-Electricals	750	3411,3413,3421,3404	22	22
	Intermittent Op Life, 2000 cycles	750	TM1036		N.A
	Hermetic Seal, Fine & gross Leak	750	TM1071		22
	Electricals Measurements	750	3411,3413,3421,3404		5
	Die Shear	750	TM2017	N.A	5
	Cross Section				
	B-5 Pre-Electricals	750	3411,3413,3421,3405	22	22
	Accelerated Steady State Gate-Stress	750	TM1042 Condition B		
	Electricals Measurements	750	3411,3413,3421,3404		
	Accelerated Steady State Reverse Bias	750	TM1042 Condition A		
	Electricals Measurements	750	3411,3413,3421,3404		
	Multiple Reflow	JESD22-A113	20 Sn/Pb reflow cycles	15	15
	Die Shear	750	2017		

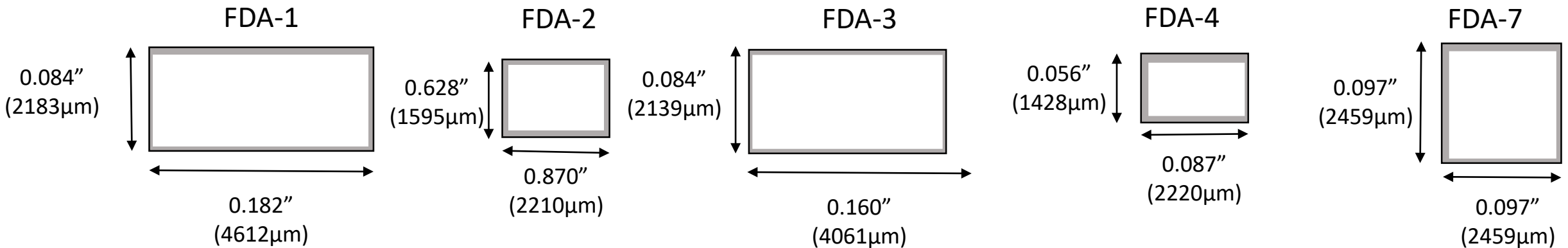
CONFORMANCE SCREENING FLOW PER FREEBIRD						
Operation	Test	Base Standard	Consistent Test Methods	FBG Sample Size	FDA Sample Size	COMMENTS
✓ Group C Inspection (Conformance)	C-2 Pre-Electricals	750	3411,3413,3421,3404	22	22	TO BE PERFORMED YEARLY ON PACKAGE TYPE DESIGN
	Temperature cycling	750	TM1051			
	Terminal Strength	750	TM2036	N.A		
	Hermetic Seal, Fine & gross Leak	750	TM1071		N.A	
	Moisture Resistance	750	TM1021	22		
	Electricals Measurements	750	3411,3413,3421,3404		22	
	C-3 Pre-Electricals	750	3411,3413,3421,3404	22		
	Shock	750	TM2016			
	Vibration, Variable Frequency	750	TM2056		22	
	Acceleration	750	TM2006			
	Electricals Measurements	750	3411,3413,3421,3404		5	
	Die Shear	750	TM2017	N.A	5	
	Cross section			N.A	5	
	C-4 Salt Atmosphere (Corrosion)	750	TM1041	15	15	
✓ Group D Inspection (Conformance)	C-5 Thermal Resistance	750	TM3161	3	3	
	C-6 Intermittent Op Life, 4000 cycles (Cont B4)	750	TM1036	22	22	
	Hermetic Seal, Fine & gross Leak	750	TM1071	22	N.A	
	Die Shear	750	TM2017	N.A	5	
✓ Group E Inspection (Qualification Inspection)	Cross Section			5	5	TO BE PERFORMED ONCE DURING QUALIFICATION OR WHEN A MAJOR PROCESS CHANGE OCCURS.
	C-7 Internal Water Vapor	750	TM2018	3	N.A	
	TID	750		5	5	
	SEE	750		3	3	
	Neutron	750		30	30	
	E-1 Pre-Electricals	750	3411,3413,3421,3404	45	45	
	Temperature cycling - 500 Cycles	750	TM1051			
✓ Group E Inspection (Qualification Inspection)	Electricals Measurements	750	3411,3413,3421,3404	N.A	5	TO BE PERFORMED ONCE DURING QUALIFICATION OR WHEN A MAJOR PROCESS CHANGE OCCURS.
	Die Shear	750	TM2017	N.A	5	
	Cross Section			N.A	5	
	E-2 Steady-State Life - 1000 hours	750	TM1042 Condition B	45	45	
	E-2 Steady-State Life - 1000 hours	750	TM1042 Condition A	45	45	
	Electricals Measurements	750	3411,3413,3421,3404	45	45	
	E-4 Thermal Resistance	750	TM3161	3	3	
	E-5 Barometric Pressure	750	TM1001	3	3	
	E-6 ESD	750	TM1020	11	11	
	E-7 Resistance to soldering heat	750	TM2031 for FDA Solder Wave Sn/Pb reflow	3	3	

FBS Part Number	V _{DS} (V)	I _D (A)	R _{DS(ON)} (mΩ)	Q _G (nC)	Package Style
FBG04N08AX	40	8	24	3	FSMD-A
FBG10N05AX	100	5	38	3	FSMD-A
FBG20N04AX	200	4	102	2	FSMD-A
FBG04N30BX	40	30	6	13	FSMD-B
FBG10N30BX	100	30	9	11	FSMD-B
FBG20N18BX	200	18	26	9.8	FSMD-B
FBG30N04CX	300	4	404	2.2	FSMD-C



Freebird Radiation Hardened Die Adaptor (FDA) Product

FBS Part Number	V _{DS} (V)	I _D (A)	R _{DS(ON)} (mΩ)	Q _G (nC)	Package Style
FDA04N08X	40	8	16	3	FDA-2
FDA10N05X	100	5	30	3	FDA-2
FDA20N04X	200	4	100	2	FDA-4
FDA04N30X	40	30	4	13	FDA-1
FDA10N30X	100	30	7	11	FDA-1
FDA20N18X	200	18	25	9.8	FDA-3
FDA30N04X	300	4	400	2.2	FDA-7



Certificate of Registration

Intertek

This is to certify that the quality management system of

Freebird Semiconductor Corporation

Main Site/Central Function: 17 Parkridge Road, Unit E, Haverhill, MA 01835 USA

has been assessed and registered by Intertek as conforming to the requirements of

AS9100C and ISO 9001:2008

The quality management system is applicable to

Design and manufacture of high-reliability semiconductors devices and circuits.*

Certificate Number: **0059164-00**
Initial Certification Date: 03 February 2017
Certificate Issue Date: 03 February 2017
Certificate Reissue Date:
Certification Expiry Date: 14 September 2018


Calin Moldoveanu – President, Business Assurance
Intertek Testing Services NA, Inc. dba Intertek –
4700 Broadmoor Avenue S.E., Kentwood, MI, (45912) USA


ANAB
ACCREDITED
ISO 9001:2008
MANAGEMENT SYSTEMS
CERTIFICATION BODY

The assessment was performed in accordance with the requirements of AS9104/1:2012-01. Intertek is accredited under the Aerospace Registrar Management Program and IAQG ICOP scheme.

In the issuance of this certificate, Intertek assumes no liability to any party other than to the Client, and then only in accordance with the agreed upon Certification Agreement. This certificate's validity is subject to the organization maintaining their system in accordance with Intertek's requirements for systems certification. Validity may be confirmed via email at certificate.validation@intertek.com or by scanning the code to the right with a smartphone.

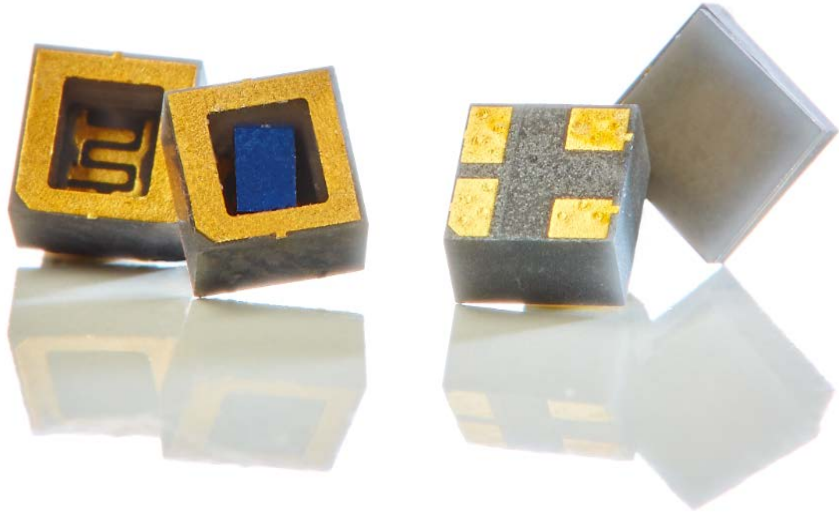
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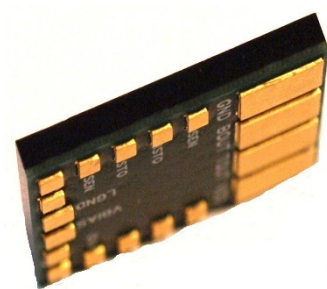
Conforming Space eGaN discrete products



- Freebird uses source controlled die from foundry
- Proprietary processes for die
- High lead content solder bumps
- Radiation tested die

- Domestic Hermetic Packaging and “Chip Scale” Die Adaptors developed in AlN ceramic material.
- Elimination of Wire-Bonds
- 40V to 300V Hermetic eGaN portfolio qualified & available!
- Short form abstract qualification reports are now available on our web-sites www.freebirdsemi.com



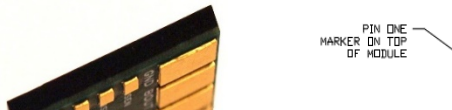


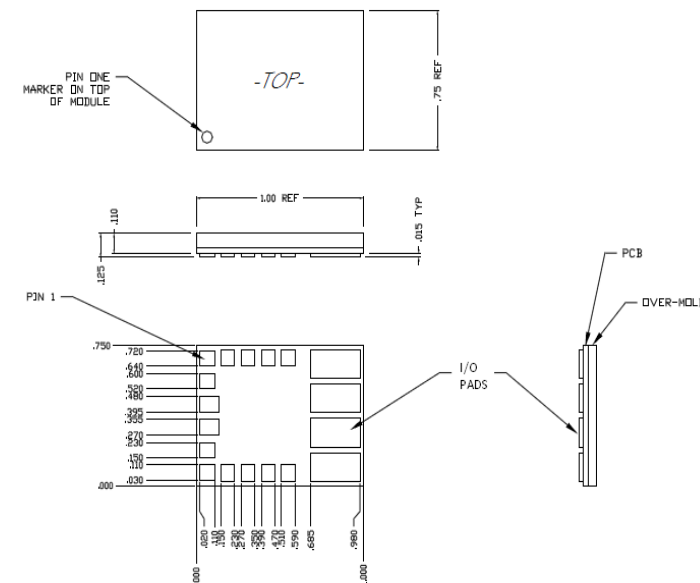
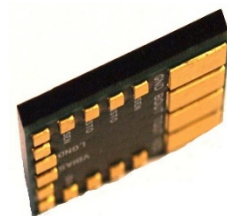
HOW TO DRIVE eGaN- in Space Borne Applications? Radiation Hardened GaN Adaptor Modules (Drivers with Logic)

Advanced Detail Release of Freebird Semiconductors Radiation Hardened GaN Driving GaN MULTI-FUNCTION

**½ Bridge Configuration or
Independent High & Low Side Driver
Logic Protection Circuitry
Integrated Output Power GaN HEMT's**

• **FBS-GAM02-P-C50**

- **50V Fully de-rated, 10A Half-Bridge Multi-function Module**
 - (100V FDA Chip Scale Series GaN Driving GaN Die Technologies internally utilized)
 - Two Independent Power Switches w/High Speed Gate Driver Circuits and “Catch” Diodes
 - Input UVLO, Input OVP Shut Down, Power Good Status Detection
 - Operation up to +1Mhz
 - High-Side Driver
 - Low-Side Driver
- 
- PIN ONE
MARKER ON TOP
OF MODULE

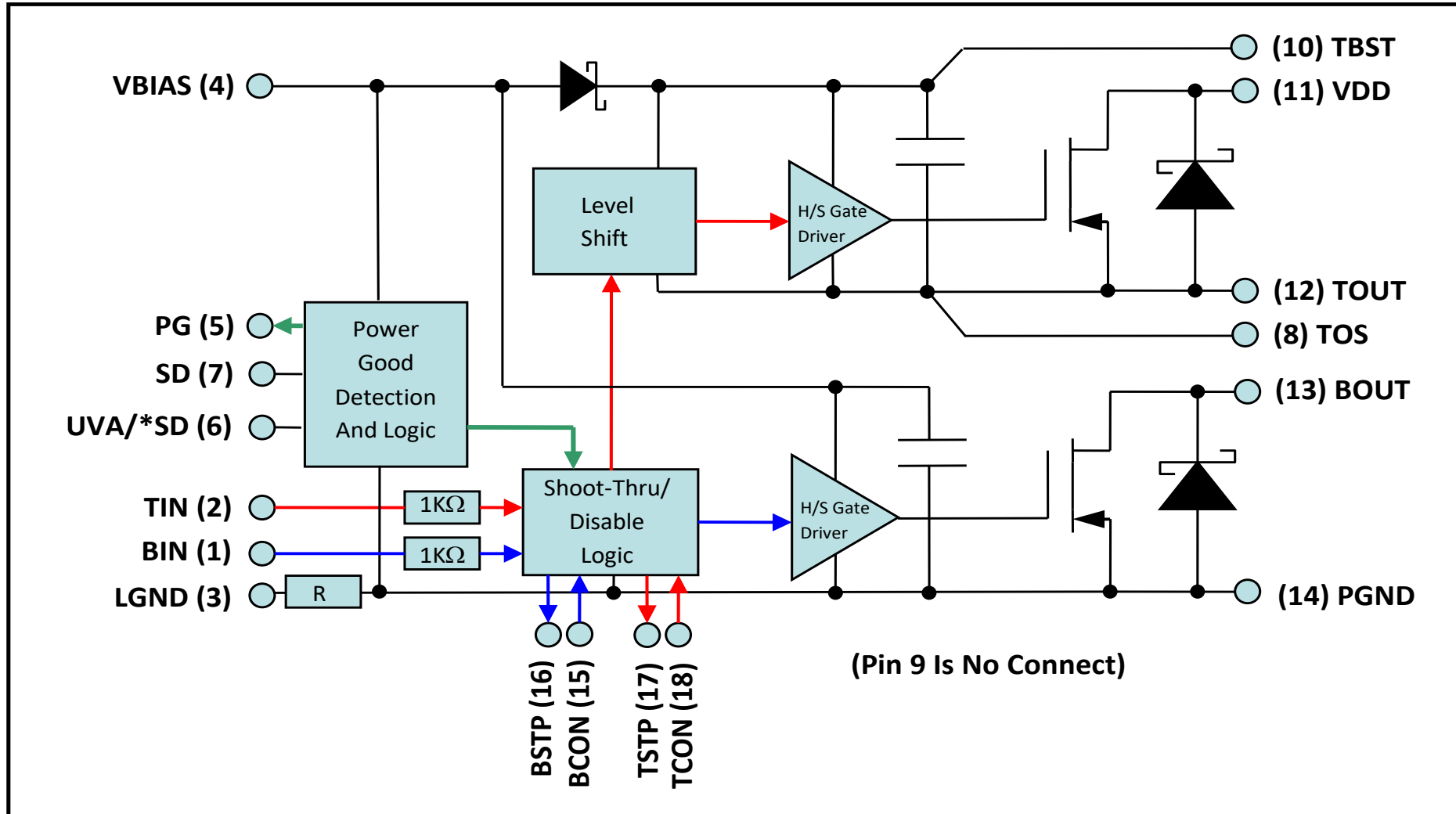


- **Multi-Function- Possible Connections**

- **Half-Bridge w/ Shoot -Through Protection**
- Single Low-Side Power Driver
- Single High-Side Power Drive
- Dual Independent Low- and High-Side Power Drivers

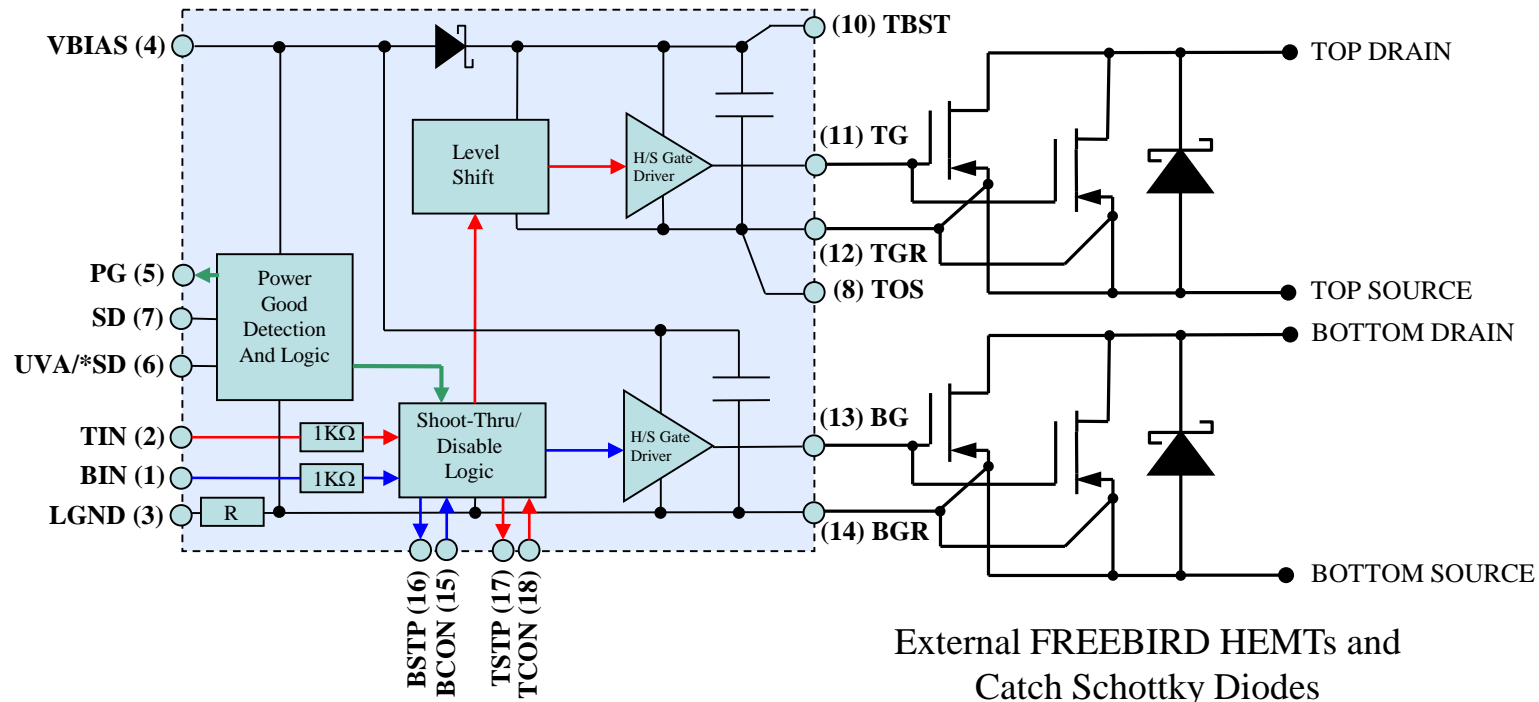
- FBS-GAM02-P-C50 Commercially Screened Development Vehicle
- FBS-GAM02-P-R50 (Radiation Hardness Assured Commercially Screened AEC-Q10X Plan)
- Designed under but not limited to Freebird patent filings: International Application No.: PCT/US2016/065952, U.S. Application No. 15/374,756 International Application No.: PCT/US2016/065946, U.S. Application No. 15/374,774

FBS-GAM02 Block Diagram



FBS-GAM02P-C-PSE (Power Switch External Varient)

- ❖ Allows (External) HEMTs of Different Ratings to be Used
- ❖ Allows (External) Paralleled HEMTs for Higher Current-Carrying Capability
- ❖ PSE Module provides both Independent Low- and High-Side Gate Drivers

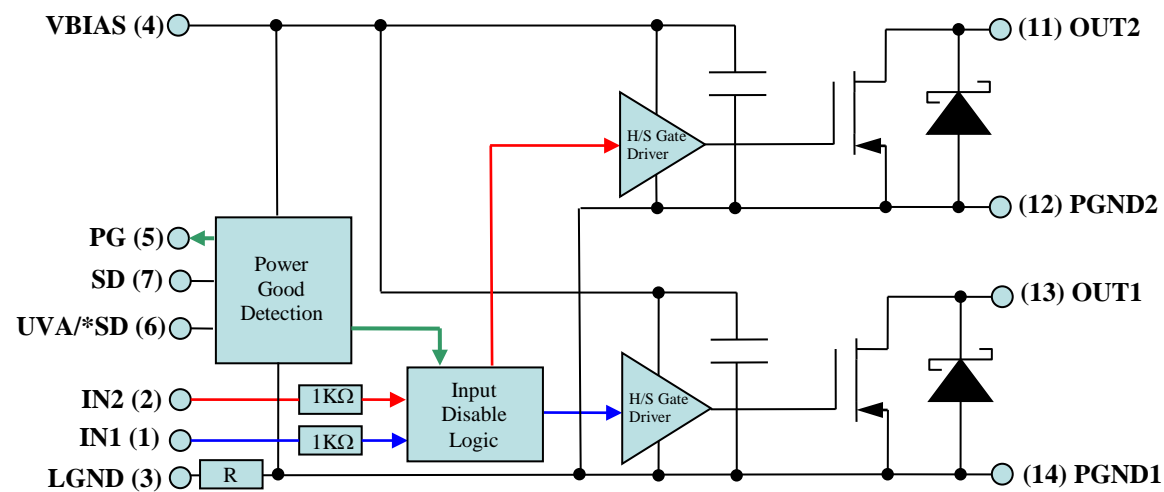
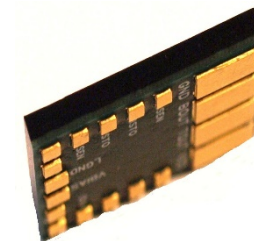


FBS-GAM02P-C-PSE

GaN Adaptor Module (GAM) Products

• FBS-GAM04-P-C50

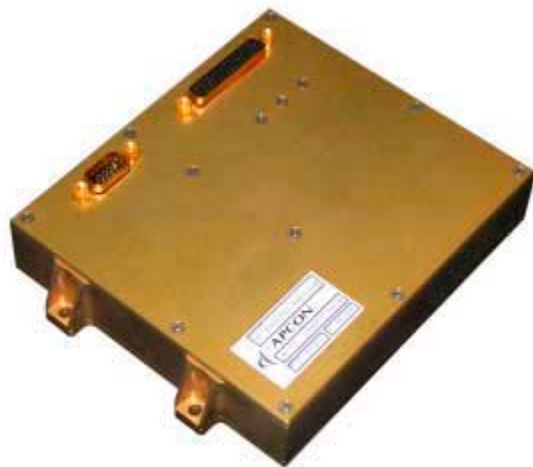
- 50V, (fully de-rated)10A Dual Low-Side Switch Module
 - (Internal FDA Series Chip Scale Series 100V rated GaN Driving GaN Die Technologies)
- Independent Power Switches
- DC to 1MHz+ Operation
- Possible Applications:
 - Synchronous Rectifiers w/Primary-Side Control in Isolated Forward/Flyback Converter
 - Primary Power Switches for Push-Pull Converter
 - Actuator PWM Controllers
 - FBS-GAM04-P-C50 Development Vehicle
 - FBS-GAM04-P-R50 (Radiation Hardness Assured)



(Pins 8,9,10,15,16,17 and 18 Are No Connect)



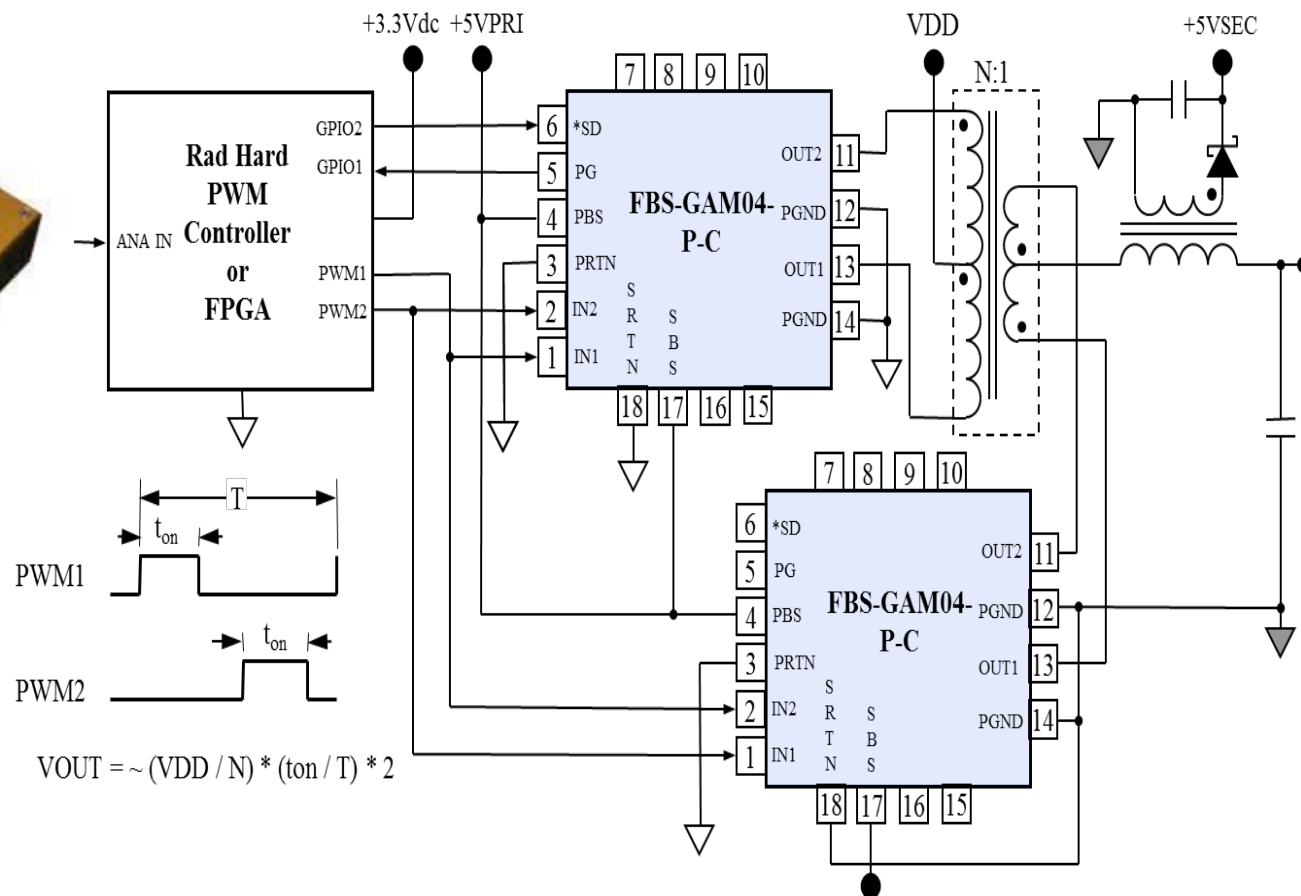
- FBS-GAM0X-P-C50 is the development vehicle to our form-fit function RHA versions:
 - FBS-GAM0X-P-R50 Commercial Space, Epoxy Over-molded, Extreme Copper units
 - FBS-GAM0X-C-R50 Hermetic AlN Ceramic form-fit function unit in process.
 - RHA versions incorporate FDA Series 100V Rated eGaN HEMT technologies designed, fabricated & tested according to Mil-Std-750 Method 1019 for total ionizing dose with total ionizing in-situ Gamma Bias for (i) $V_{GS} = 5.1V$, (ii) $V_{DS}=V_{GS}=0V$ and (iii) $V_{DS}=80\% B_{VDSS}$, devices are “guaranteed by design” to *no less* than 100 kRad (Si)
 - Single Event Immunity Heavy Ion: Au, $\sim LET = 83.7, 2482 \text{ MeV}$, Range = 130um
- *Freebird incorporating “Hard Switch Testing Techniques” of FBS-GAM0X design for robustness validation in-situ. Radiation Hardness Assured test-bed conducts full switching functionality on a ½ Bridge configuration in total ionizing environment*



• Power Supplies!

- Forward, Flyback, Boost, Full-Bridge,
- Buck, Weinberg, Cúk
- Non-Isolated, Isolated
 - Primary-Side, Secondary-Side

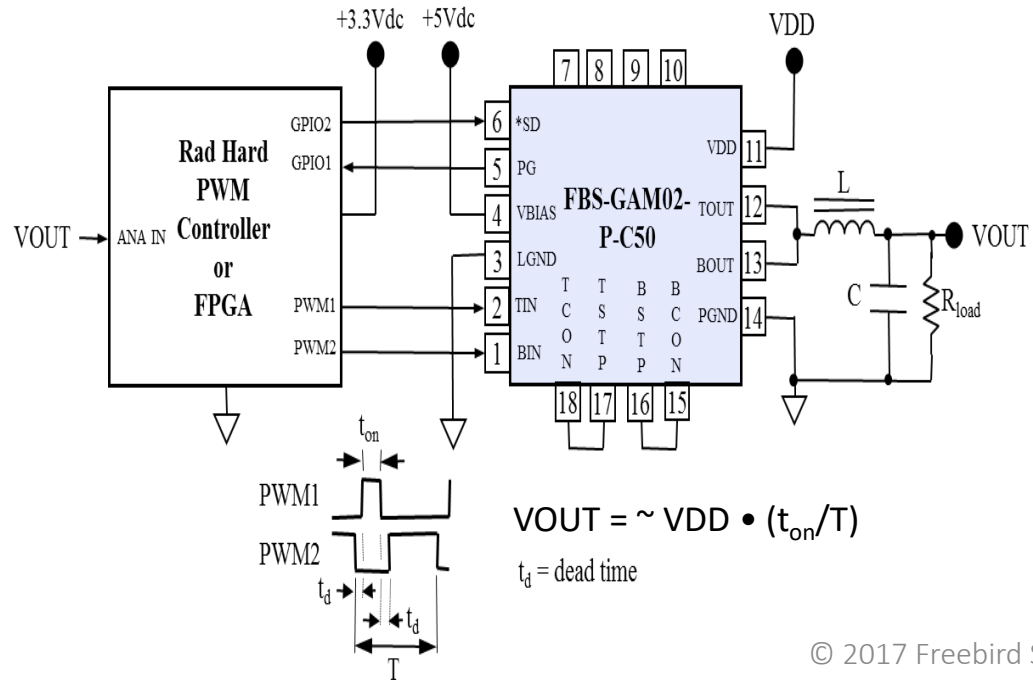
• Isolated Synchronously-Rectified Push-Pull Converter



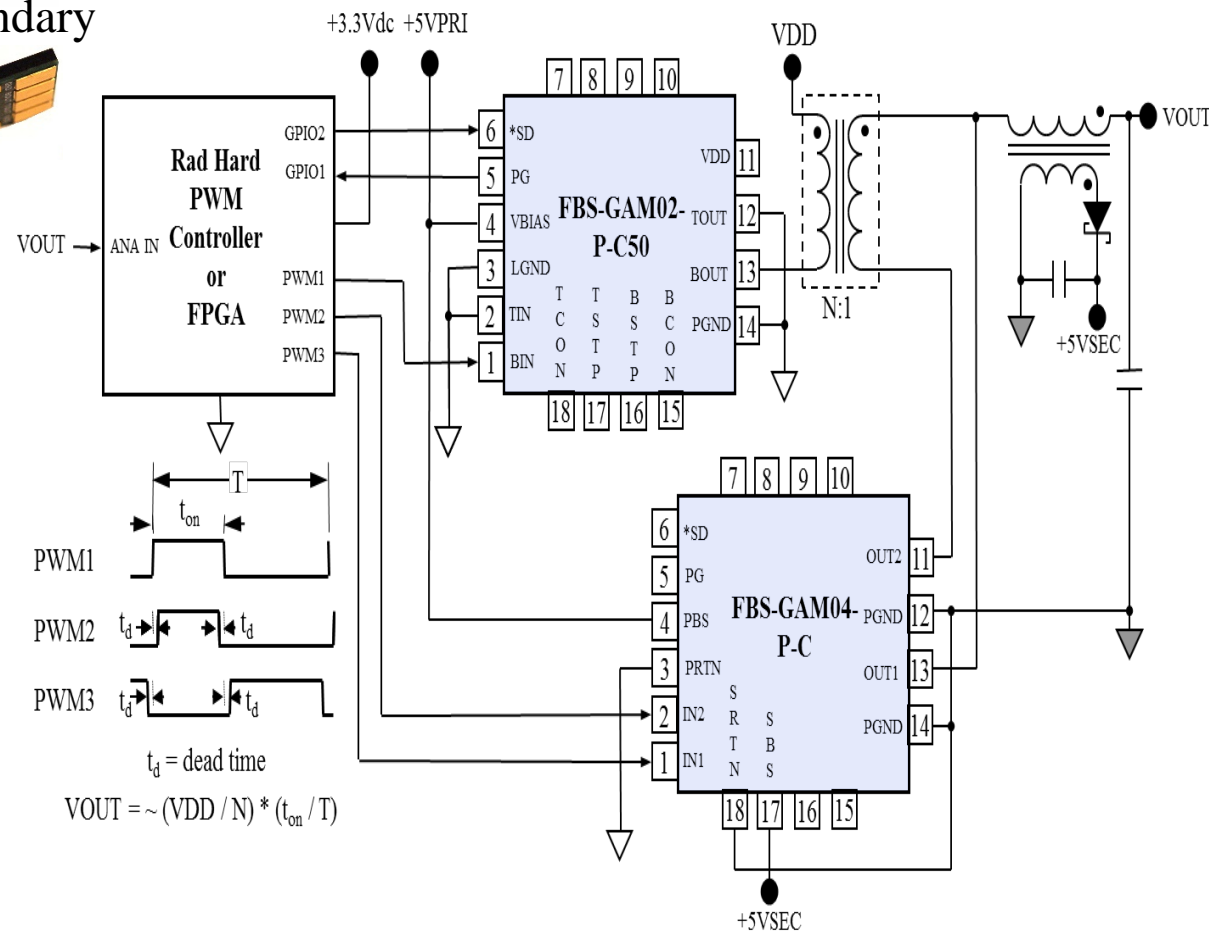
GAM Applications – Power Supplies



• Non-Isolated Synchronous Buck Converter (POL)



• Isolated Synchronously-Rectified Forward Converter



- **Motors! Single → Three Phase**

- Single Phase Motor: Pump (Tank to Load)
- Two Phase Motor: Bidirectional Actuator (L/R, U/D. In/Out)
- Three Phase Motor: Regulated Speed Control (Reaction Wheel)
- Motor Voltage Increases w/Power Requirements

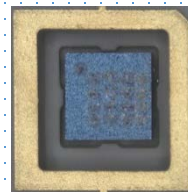
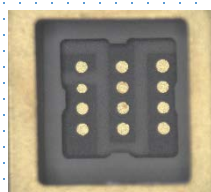
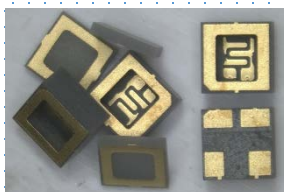
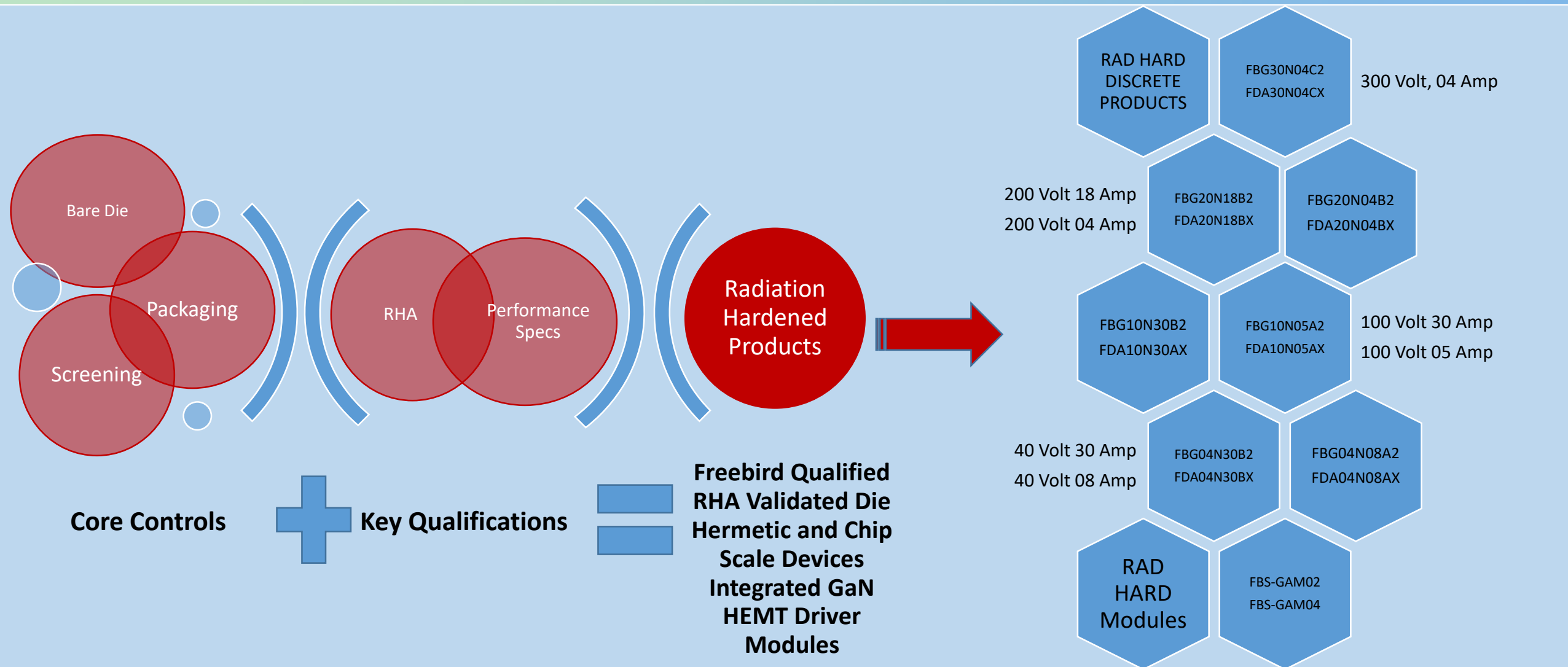
- **50V/0.5kW Motors**

- **FBS-GAM02-P-C50 // FBS-GAM02-P-R50**

- Single Phase Motor – 1x GAM02, Low Side Drive ONLY
 - High-Side Power Switch DC NOT Possible
- Two Phase Motor – 2 x GAM02, Half-Bridge One Per Phase
- Three Phase Motor – 3 x GAM02 Half-Bridge, One Per Phase



- Actuators\Power Switches\Squib Drivers
 - Low-Side/High-Side – FBS-GAM02
 - DC Operation Possible, Low Side
 - High-Side – FBS-GAM02
 - Low-Side – FBS-GAM02
 - DC Operation Possible
 - Dual Low Side – FBS-GAM04
- Load Dump Switches
 - Battery Discharge
 - Battery Conditioning
 - Fault Protection
 - Controlled Current Path





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THANKS



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