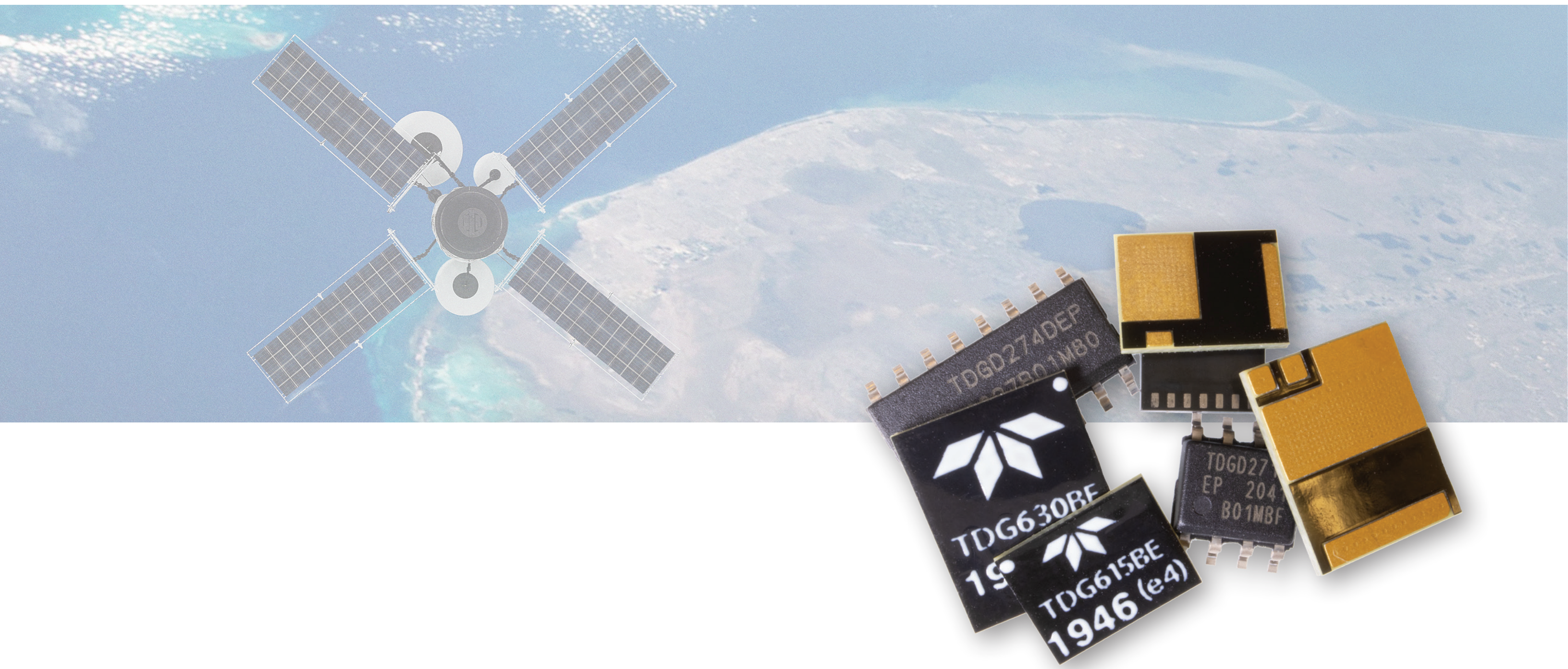
GaN Power Overview

High Efficiency Solutions for Avionics, Defense & Space



TELEDYNE e2V
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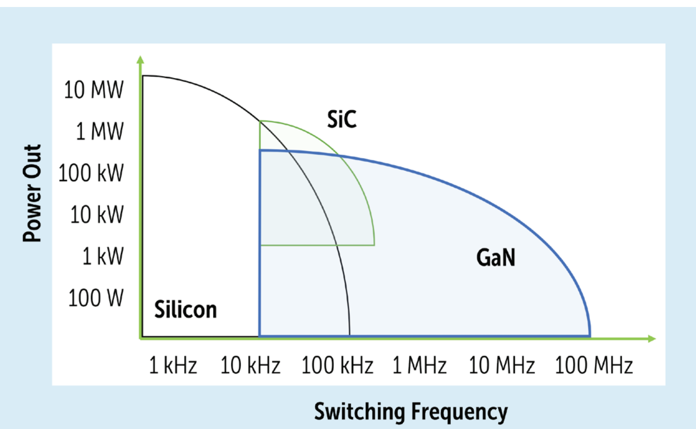
GaN Power for Defense and Space Applications - Are we there yet?

Claims for wide bandgap semiconductors, and Silicon Carbide (SiC) and Gallium Nitride (GaN) in particular, have been around for more than a decade. In that time, the reality has started to catch up with the hype. In this overview, we look at suitability of GaN devices for applications requiring high reliability performance such as Low Earth Orbit (LEO) space constellations and very high-altitude aircraft, and tour the Teledyne product range.

Why Use Wide Bandgap Semiconductors?

Typically, high voltage, high current power conversion circuits have employed silicon-based transistors such as IGBTs and Super-Junction (SJ) MOSFETs. These devices have well-proven track records and an ecosystem of supporting components. So why make the leap to less mature technologies?

The higher semiconductor bandgap and other material properties of SiC and GaN devices compared to the more traditional silicon-based devices creates a number of advantages, including smaller, faster, lower loss/ higher efficiency devices.



Many industries have their equivalent of the Moore's Law graph, an illustration that neatly encapsulates the hopes of a market and is published repeatedly. For this segment, it is shown above, and displays the approximate switching speed of available devices against the achievable power levels for different technologies.

There are evolving versions of this graphic, but the takeaways are that both SiC and GaN are capable of high switching speeds and high power levels. In reality, silicon devices are evolving too, but are believed to be near their theoretical limits at this point. At the time of writing, devices are available in silicon operating at over 3 kV, SiC at 1.7 kV, and GaN at 650 V.

Why GaN over SiC?

For many space and defense applications such as satellite power and point of load (POL) conversion, power levels are more likely to be medium than very high, but enormous value can be gained from smaller sized system components. The fact that GaN is capable of device switching speeds of over 10 MHz has benefits beyond the extra efficiencies that come with faster edge speeds. Higher frequencies allow supporting components such as inductors, transformers and capacitors to be shrunk, saving overall size and weight significantly. Using GaN, power systems can be a quarter the size, a quarter the weight, and four times the efficiency of silicon-based systems, gains that are ahead of SiC.

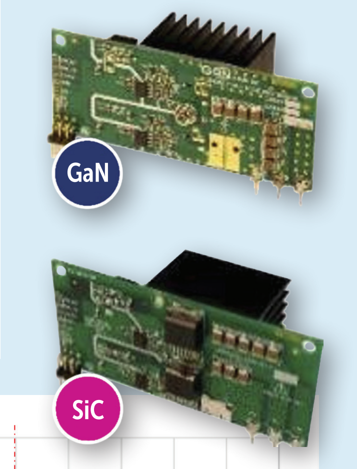
Comparing Technologies

Param.	Symbol	Units	650V Silicon MOSFET	600V Silicon IGBT	900V SiC	650V GaN
Switching Energy	E_{ON}/E_{OFF}	µJ	Not avail.	940/ 440	47/ 17	**29/ 8**
FOM	$QG*R_{DS(on)}$	nC*mΩ	4,480	10,725	1,976	**358**
Induct.	L_{SOURCE}	nH	2	12	5	**0.2**
Reverse Recovery	QRR	nC	10,000	320	135	**Zero**

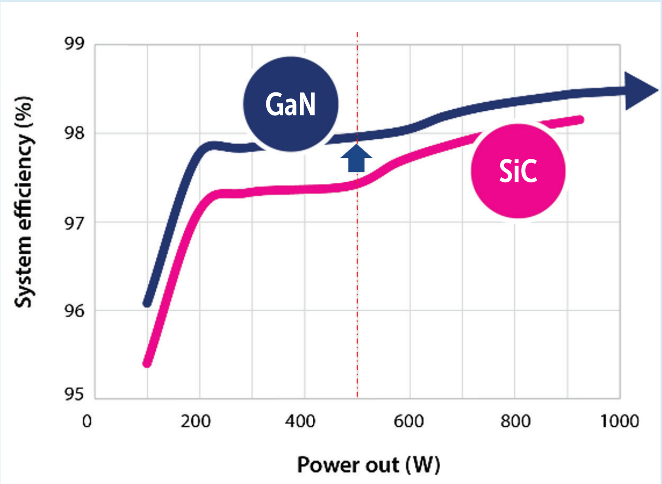
The table above shows a variety of parameters and how they compare between traditional silicon technologies, SiC and GaN, where in each case lower numbers are better. Overall, GaN is easy to drive, low inductance, easy to parallel, and on a cost reduction curve with the potential to be at parity with silicon.

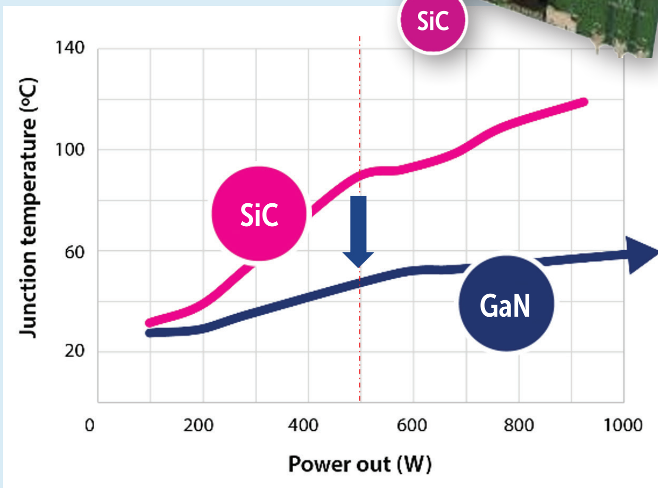
Example Comparing GaN & SiC

To further illustrate GaN's advantages in low to medium power applications, a comparison design was executed in both GaN and SiC. The circuit was a synchronous buck dc-dc 400-200 V converter system, 900 W, with a switching frequency of 200 kHz, and running at ambient 25 °C. The two layouts, shown to the right, used as close to identical layouts as possible, the same number of layers and thermal management.



The graph below left shows system efficiency for each, with GaN exhibiting 25% lower losses. This translates into higher density layouts. The graph lower right of junction temperature shows GaN running 60 °C cooler, which has a significant impact on reliability.





Why can GaN be Trusted?

Over the decades, silicon-based devices have become well understood, and a suitable set of standardized test methods and specifications have evolved. Some of these can be applied to GaN devices to prove reliability. However, GaN is a different material to silicon, and devices often have different geometries, leading to the fact that some failure mechanisms will be different; this can make some of the original tests irrelevant, and new ones required. In the early days of GaN power development, individual vendors had to evolve these on their own, making comparisons and auditing difficult. Since 2017, the independent semiconductor trade organization JEDEC has been active in this area, with JC-70 focusing on wide bandgap semiconductors, and JC-70.1 specifically on GaN.

Reliability stress tests quoted on datasheets for GaN typically borrow from JEDEC and automotive tests (for example AEC AQ101) designed for silicon devices, and add additional tests more tailored to GaN. For hi-rel applications such as avionics, defense and space, we've added qualification and screening that goes significantly beyond these, as detailed below.

GaN Qualification & Screening

	Qualification	Screening
Standard Test for Hi-Rel Applications	• Standard IC Qualification tests including HTRB, HTGB, Temp Cycle, HTSL, Solderability, and ESD. • Apply **Teledyne specific qualification tests** with Dynamic Burn-in of 15 k cycles, low pressure tests, step stress testing, sulfuric tests and operational life tests	• Standard 25 °C testing • Extended temperature -55 to 125 °C tests
Space	As above, plus: • Additional radiation qualifications • SCD options for full Teledyne space qualification	As above, plus: • Space screening including burn-in of 240 hours at 125 °C, and PDA.

Why Teledyne GaN?

GaN brings a number of inherent advantages, and we've taken reliability and ease-of-use many stages further.

Increased Power Density

GaN technology is superior to silicon (Si) in the creation of small power systems providing more efficient power conversion. Use of GaN impacts not only the power transistor, but also overall product design and in decreasing cost around other system components including: capacitor, cooling, heat sinks, and inductors.

With GaN technology, power systems are typically:

- 4 x smaller (1/4 the size)
- 4 x lighter (1/4 the weight)
- 4 x efficiency (1/4 the efficiency loss)

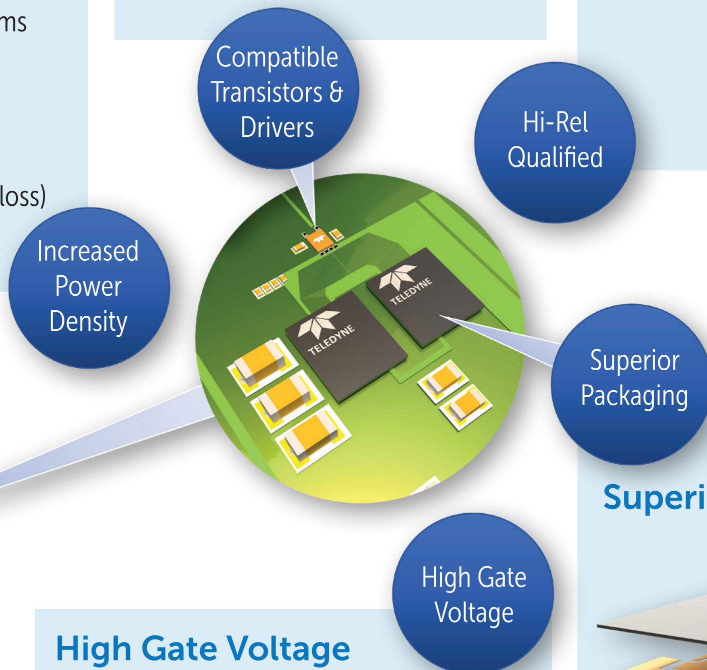
Compatible Transistors & Drivers

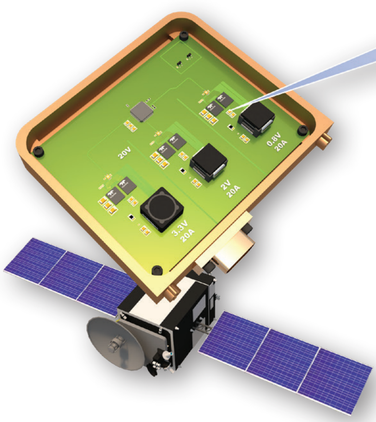
Whether 100 V or 650 V, Teledyne offers fast, efficient drivers that allow you to get the best out of our industry leading GaN HEMTs, as detailed later.

Hi-Rel Qualified

Qualification tailored to GaN:

- Diffusion lot traceability
- Full temp testing -55 to 125 °C
- Stress tested
- Sample radiation tested
- Screening for low jitter parts

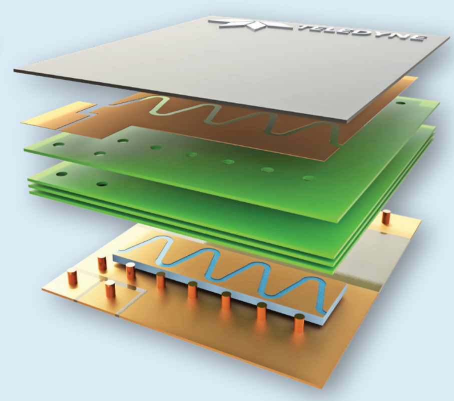




High Gate Voltage

GaN parts tend to be sensitive to voltage spikes on the gate, requiring careful driver design. This can be a particular issue in space applications. Our HEMTs have the widest tolerance to gate voltage in the market, with recommended drive from 0 to 6 V drive, tested up to 9 V.

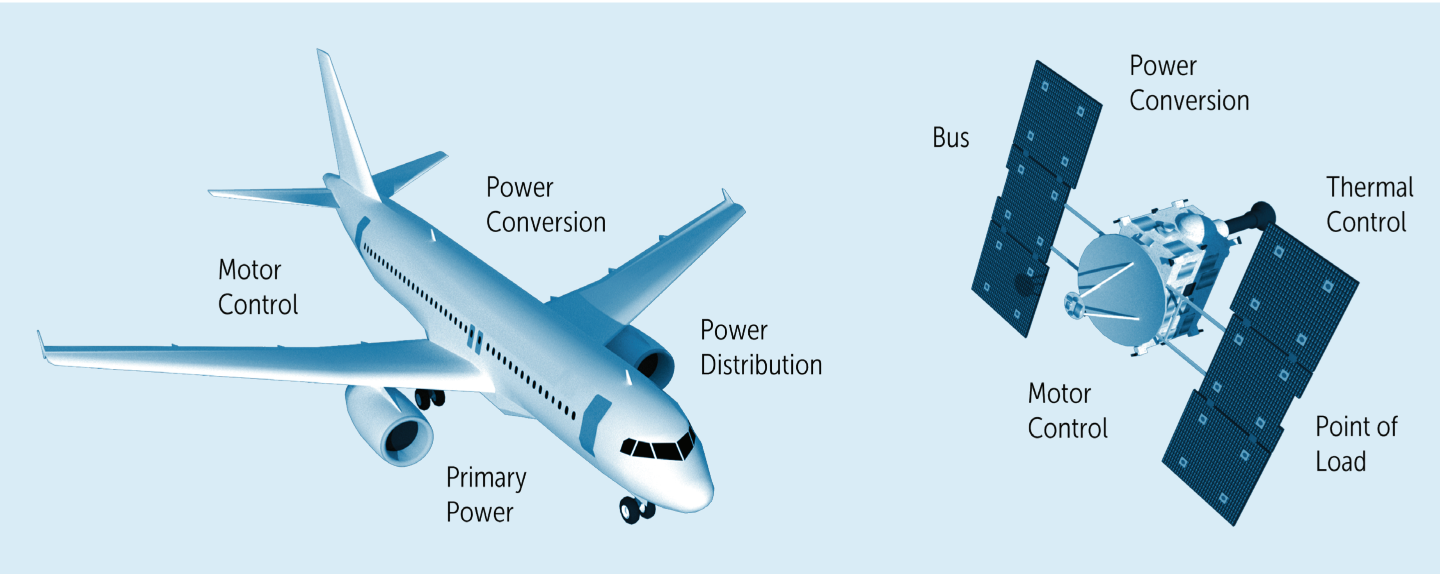
Superior Packaging



- Based on GaNPX® packaging which solves heat management headaches associated with die-based solutions.
- No wire bonds required externally, or employed inside the package, enabling ultra-low inductance and much higher manufacturing reliability.
- Bond wires have multiple failure modes, including bond cracking, bond wire lift-off, bond diffusion embrittlement, fusing, heel cracking
- Thick RDL & top copper providing extremely low RON
- Embedded package using high-TG material
- Overall design achieves optimized thermals

Applications

GaN is increasingly used in avionic, defense and space applications. With new FPGAs and 60 nm ASICs requiring 0.8 V supplies, GaN enables Step Down POLs in one stage from 20 V to 0.8 V. Similarly in Avionics, the need for smaller modules to drive three-phase brushless motors is well served by GaN, where their small form-factor and low output capacitance make driving inductive loads easier. Other examples are shown below.



Why Not Use COTS GaN?

Buying from Teledyne provides extensive benefits, including:

- Traceabiliy to a single diffusion lot
- A controlled baseline – one wafer fabrication site, one assembly site and one test/screen site
- Wafer keep-out areas
- European and US-suitable versions of many products
- Obsolescence support
- 100% electrical test from -55 to +125 °C for parameters such as $R_{DS(on)}$, Dynamic $R_{DS(on)}$, $V_{gs(th)}$, I_{DSX}, I_{GSS}
- Support for additional or reduced screening

Practicalities of Using GaN

Designing with GaN is straightforward, but some differences between traditional lower efficiency technologies such as silicon need to be taken into account. These include board layouts that accommodate faster edge speeds, and the avoidance of current loops. More detailed application information can be found on these topics:

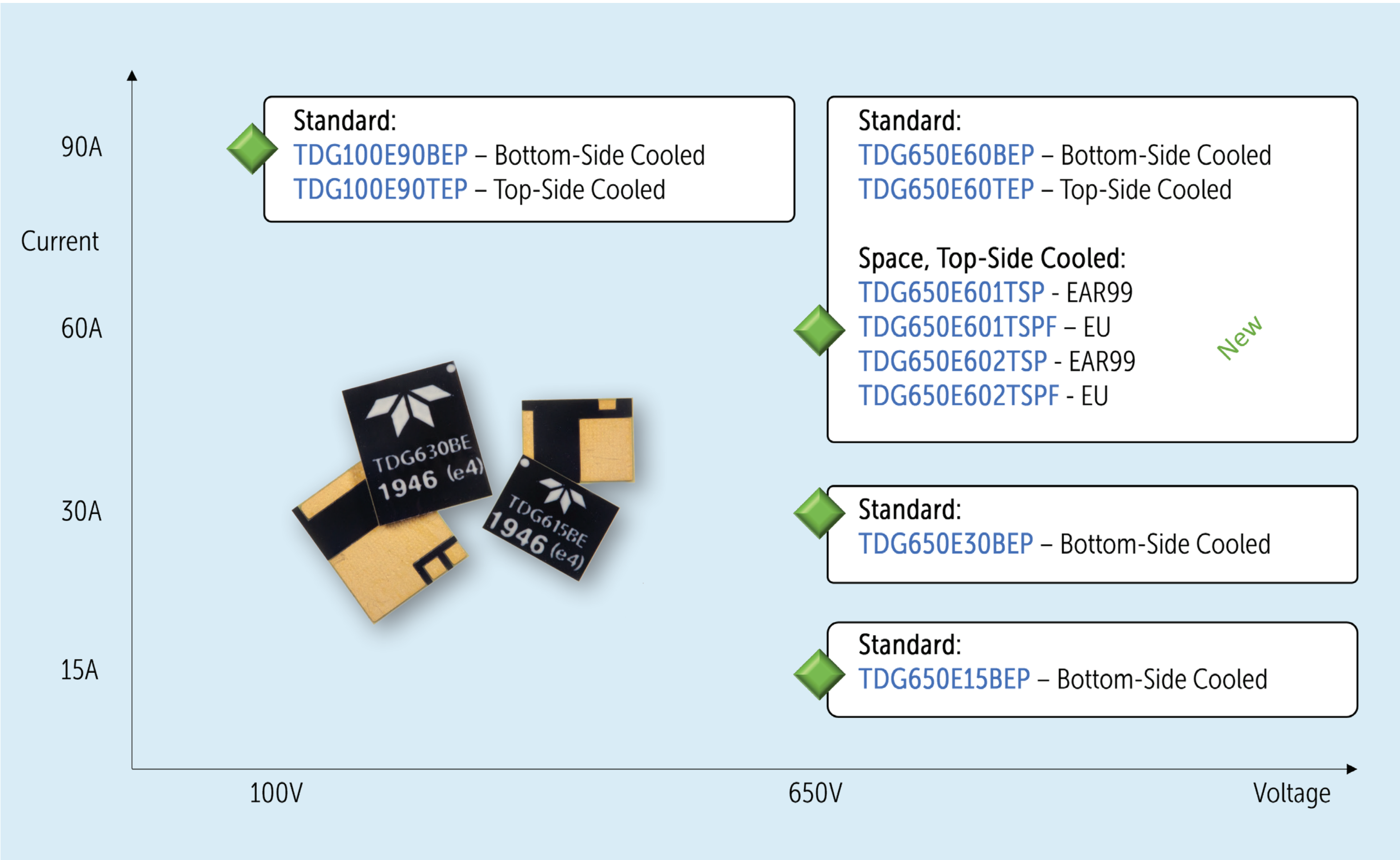
- PCB Layout Considerations with GaN E-HEMTs
- EZ-Drive Solution for GaN Transistors
- Soldering Recommendations
- Gate Driver Design for GaN E-HEMTs
- GaN Switching Loss Simulation LT Spice

Teledyne GaN Portfolio

Teledyne has carefully selected transistors and drivers that are compatible with each other, and give the best possible system performance.

Hi-Rel GaN HEMTs

We offer 100 V products that give plenty of headroom for POL systems, and 650 V for system power conversion and other applications such as motor control. Our product range, as of February 2022, is shown below.



The properties of GaN allow for high current, high voltage breakdown and high switching frequency. Our parts are based on GaN Systems innovations with industry leading advancements such as patented Island Technology® and GaNPX® packaging. GaNPX® packaging enables low inductance & low thermal resistance in a small package.

Some classes of product are offered in both top-side and bottom-side cooled versions:

- Top-side cooled - very low junction-to-case thermal resistance for demanding high power applications. Enable very high efficiency power switching.
- Bottom-side cooled - compact solution for lower power designs

Standard products have been through Teledyne HiRel's screening process, which balances qualification rigor with cost. We can support custom SCDs for either lower or higher levels of screening depending upon end application and budget.

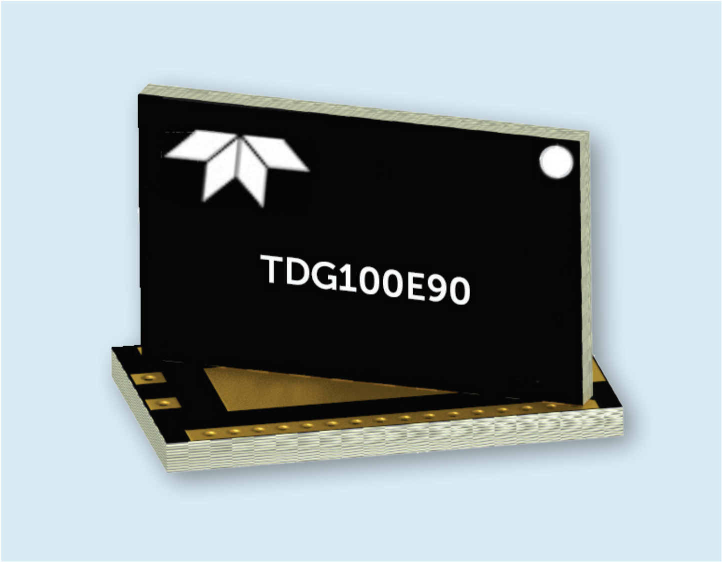
Our new space-level 650 V 60 A parts offer catalog convenience for LEO/MEO constellations and similar space applications.

100 V HEMTs

Part Number	Voltage	Current	$R_{DS(ON)}$	Dimensions (mm)	Description
TDG100E90BEP	100 V	90 A	7 mOhm (typ)	7.6 x 4.6 x 0.5	Ruggedized Plastic Bottom-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 100 V, 90 A
TDG100E90TEP				7.0 x 4.0 x 0.54	Ruggedized Plastic Top-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 100 V, 90 A

Features

- 100 V enhancement mode GaN power switches
- $R_{DS(on)} = 7\ m\Omega$
- $I_{DS(max)} = 90$ A
- Ultra-low FOM Island Technology® die
- Low inductance GaNPX® package
- Easy gate drive requirements (0 V to 6 V)
- Transient tolerant gate drive (-20 V / +10 V)
- Very high switching frequency (> 100 MHz)
- Reverse current capability
- Zero reverse recovery loss
- Small 7.6 x 4.6 mm^2 PCB footprint
- Source Sense (SS) pin for optimized gate drive
- Single diffusion lot available
- RoHS compliant
- Enhanced wafer level reliability
- HiRel qualification flow
- Obsolescence support



Applications

- High efficiency power conversion
- High density power conversion
- ac-dc Converters
- Bridgeless Totem Pole PFC
- ZVS Phase Shifted Full Bridge
- Half & Full Bridge topologies
- Synchronous Buck or Boost
- Uninterruptable Power Supplies
- Motor Drives
- Single and 3-phase inverter legs
- Fast Battery Charging
- dc-dc Converters
- On Board Battery Chargers
- E-Switch

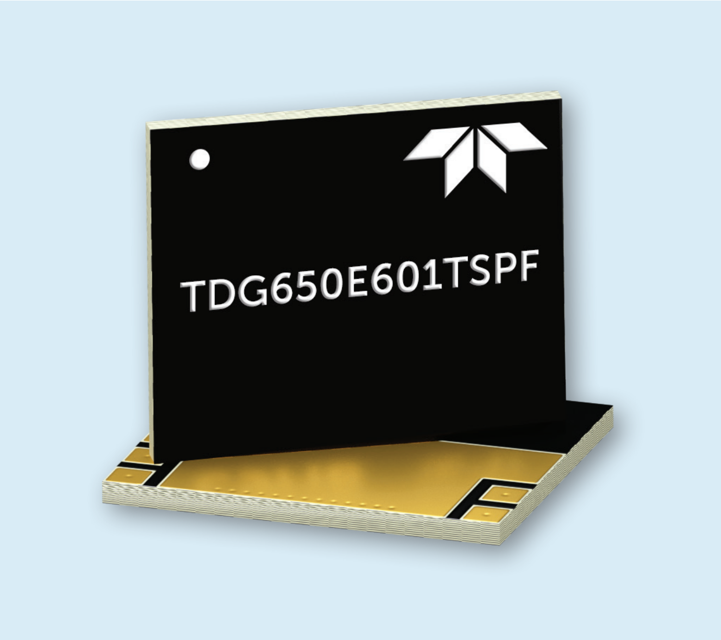
650 V HEMTs

Part Number	Voltage	Current	Rds (ON)	Dimensions (mm)	Description
TDG650E60BEP	650 V	60 A	25 mOhm (typ)	11.0 x 9.0 x 0.54	Ruggedized Plastic Bottom-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 650 V, 60 A
TDG650E60TEP				9.0 x 7.6 x 0.54	Ruggedized Plastic Top-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 650 V, 60 A
TDG650E601TSP					EAR-99, Space
TDG650E601TSPF					EU, Space
TDG650E602TSP					EAR-99, Space
TDG650E602TSPF					EU, Space
TDG650E30BEP		30 A	50 mOhm (typ)	7.1 x 8.5 x 0.56	Ruggedized Plastic Bottom-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 650 V, 30 A
TDG650E15BEP		15 A	100 mOhm (typ)	5.0 x 6.6 x 0.51	Ruggedized Plastic Bottom-Side Cooled Enhancement Mode GaN FET in GaNPX® Packaging, 650 V, 15 A

New Space Screened 60 A Catalog Parts

Two variants of space-screened 60 A products are offered:

- 601TSP offers the best transient drain-to-source voltage of the two, at 900 V vs. 750 V
- 602TSP offers the best drain-to-source on-resistance shift (30% max vs. 50% max)



In both cases, they offer:

- Space Production Screening
- Lot Acceptance Test options available
- 650 V enhancement mode power transistor
- Top-cooled, low inductance GaNPX® package
- $R_{DS(on)} = 25\ m\Omega$
- $I_{DS(max)} = 60\ A$
- Ultra-low FOM
- Simple gate drive requirements (0 V to 6 V)
- Transient tolerant gate drive (-20 V / +10 V)
- Very high switching frequency (> 10 MHz)
- Fast and controllable fall and rise times
- Reverse conduction capability
- Zero reverse recovery loss
- Small 9 x 7.6 mm^2 PCB footprint
- Dual gate pads for optimal board layout

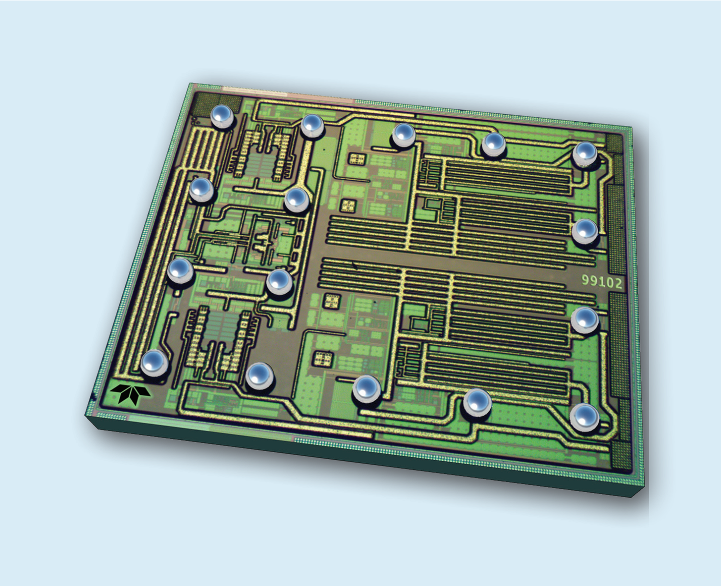
Hi-Rel GaN Drivers

High Speed Flip-Chip 100 V Driver - NEW

Part Number	Inputs	Max Voltage (V)	Driver Configuration	Output Under Voltage Lock Out (V)	Dead-Time Adjustable Range (ns)	Speed (MHz)	Package Type	Isolation (kV RMS)
TD99102	PWM	100	HS/ LS	3.6	1.8 - 23.5	20	Die	Non-Isolated

Features

- TID = 100 krad(Si)
- SEL Immune
- High- and Low-side FET drivers
- Dead-time control
- Fast propagation delay, 9 ns
- Tri-state enable mode
- Sub-nanosecond rise and fall time
- 2 A / 4 A peak source/sink current
- Bumped flip chip die



Applications

- dc–dc conversions
- ac–dc conversions
- Orbital Point of Load (POL) module power distribution
- Motor driver

The TD99102 is an integrated high-speed driver designed to control the gates of external power devices such as enhancement mode gallium nitride (GaN) High Electron Mobility Transistor (HEMT) and power MOSFETs. The outputs of the TD99102 are capable of providing switching transition speeds in the sub-nanosecond range for switching applications up to 20 MHz. The TD99102 is optimized for matched dead time and offers best-in-class propagation delay to improve system bandwidth. High switching speeds result in smaller peripheral components and enable innovative designs for high reliability orbital motor driver and POL applications. The TD99102 is available as a bumped flip chip die to enable minimum design footprint required for high speed switching power applications.

The TD99102 is manufactured on Peregrine's UltraCMOS® process, a patented advanced form of silicon-on- insulator (SOI) technology, offering the performance of GaAs with the economy and integration of conventional CMOS.

650 V Drivers

Part Number	Inputs	Max Voltage (V)	Driver Configuration	Output Under Voltage Lock Out (V)	Dead-Time Adjustable Range (ns)	Speed (MHz)	Package Type	Isolation (kV RMS)
TDGD271	VI	650	Single	3	N/A	1	SOIC-8 NB	2.5
TDGD274	PWM	650	HS/ LS	3	10-200	1	SOIC-16 NB	2.5

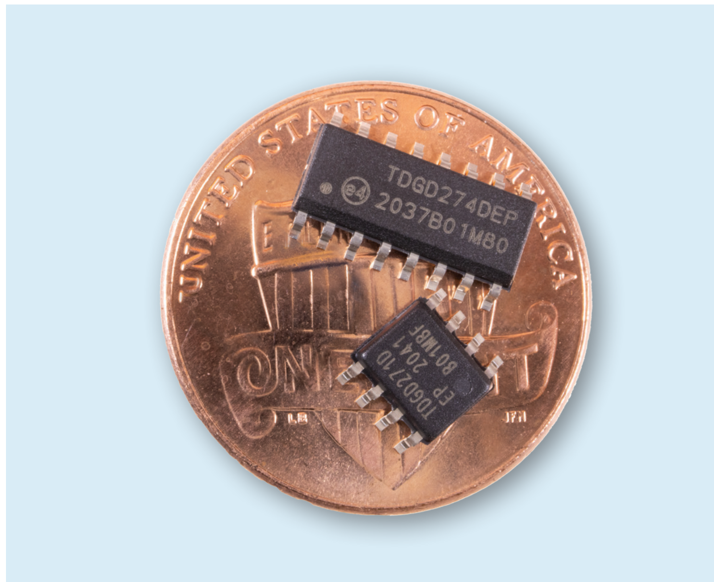
Single/Dual 4-Amp Isolated Gate Driver with High Transient (dV/dt) Immunity

Features

- Single, dual, or high-side/low-side drivers
- Single PWM or dual digital inputs
- High dV/dt immunity:
  - 200 kV/µs CMTI
  - 400 kV/µs Latch-up
- Separate pull-up/down outputs for slew rate control
- Wide supply range:
  - Input supply: 2.5–5.5 V
  - Driver supply: 4.2–30 V
- Very low jitter of 200 ps p-p
- 60 ns propagation delay (max)
- Dedicated enable pin
- High performance isolation technology:
  - Industry leading noise immunity
  - High speed, low latency and skew
  - Best reliability available
- Compact packages:
  - 8-pin SOIC
  - 16-pin SOIC
- Wide temperature range:
  - −55 to 125 °C
- One Diffusion Lot
- Teledyne 100% screening
- Obsolescence Support

Applications

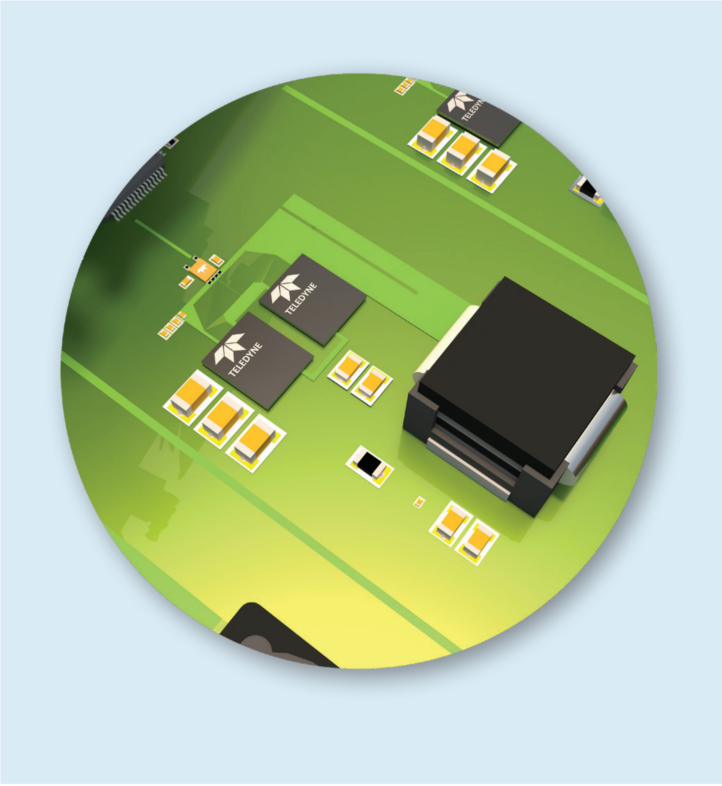
- dc/dc Converters
- Battery Management Systems
- Power Supplies
- Motor Control Systems



The TDGD27x isolators are ideal for driving power switches used in a wide variety of power supply, inverter, and motor control applications. The TDGD27x isolated gate drivers utilize a proprietary silicon isolation technology, supporting up to 2.5 kVRMS withstand voltage and fast 60 ns propagation times. This technology enables industry leading, common-mode transient immunity (CMTI), tight timing specifications, reduced variation with temperature and age, better part-to-part matching, and extremely high reliability. It also offers unique features such as separate pull-up/down outputs, driver shutdown on UVLO (Undervoltage Lockout) fault, and precise dead-time programmability. The TDGD27x series offers longer service life and dramatically higher reliability compared to opto-coupled gate drivers.

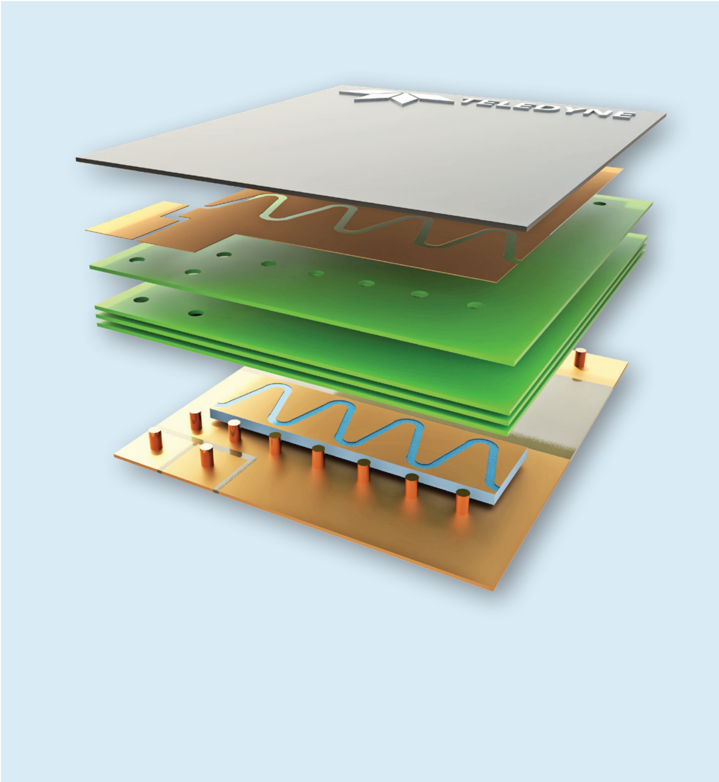
Driver outputs can be grounded to the same or separate grounds or connected to a positive or negative voltage. TTL-level compatible inputs with >400 mV hysteresis is available in individual control input (TDGD271) or PWM input (TDGD274) configurations. High integration, low propagation delay, small installed size, flexibility, and cost effectiveness make the TDGD27x family ideal for a wide range of isolated MOSFET/IGBT and SiC or GaN HEMT gate drive applications.

Ideally suited for driving Teledyne HiRel's TDG family of GaN HEMTs.



Global Sales Office

Teledyne e2v HiRel Electronics
765 Sycamore Drive
Milpitas, CA 95035 USA
Tel: +1 (408) 737 0992
Fax: +1 (408) 736 8708
tdemarketing@teledyne.com



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