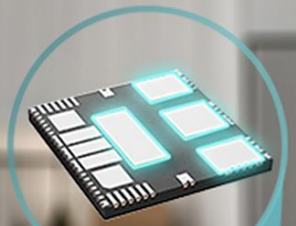
Webinar

The benefits of GaN in motor drives



Manu Balakrishnan

Systems and Applications Manager, Motor Drives

Charlie Munoz

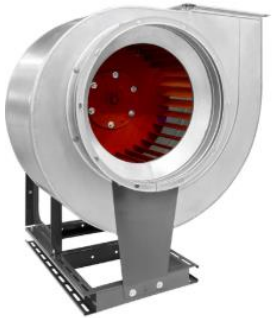
Product Marketing Manager, Motor Drives

Agenda

- Introduction
- TI introduces industry’s first GaN IPM (DRV7308)
- Why GaN in motor drives?
- How GaN increases inverter efficiency and eliminate heat sink
- Impact on motor cost, system efficiency, audible noise and solution size
- Design considerations when using GaN in motor drives and EMI
- Protected and reliable system designs
- Getting started

Introduction

- Today's market for appliances, heating, ventilation and air-conditioning (HVAC) systems and industrial drives strive for better efficiency.
- Consumers expect end equipment to have high levels of power efficiency and product reliability.
- Variable frequency drives (VFDs) improve system efficiency, especially if they have accurate and wide speed control.
- VFDs use an inverter to control motor speeds, along with high-frequency pulse-width modulation (PWM) switching to obtain true variable speed control.



Introducing industry's first integrated GaN IPM – DRV7308

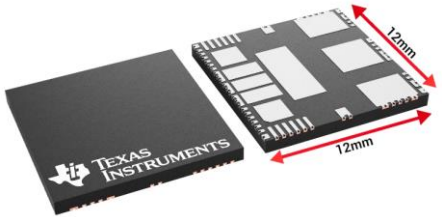
Features

Basic Specs: Triple ½ - half bridge with integrated GaN FETs

- Supply voltage: **450V (operating), 650V (absolute max voltage)**
- $RDS_{(ON)}$: **205 mΩ (per GaN FET) at 25°C**
- Peak current: **5A**
- Output voltage slew rate: **5, 10, 20, 40 V/ns (adjustable)**

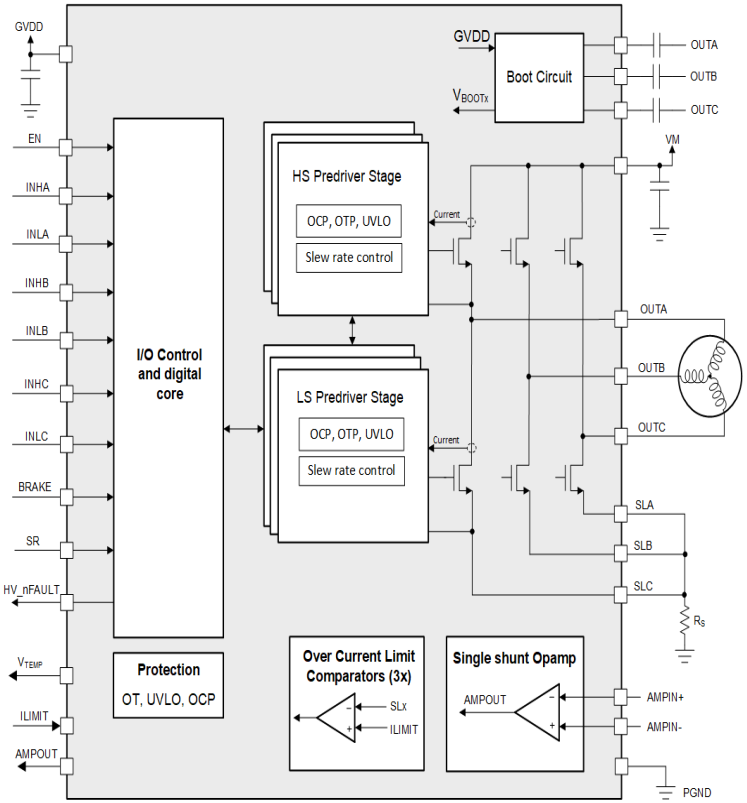
Key Features:

- Low switching loss: zero QRR, low C_{OSS}, slew rate control
- Low distortion: ultra low prop delay & dead time (< 200ns)
- Low side open source pins for 1 / 2 / 3-shunt current sense
- 12MHz, 15V/µs opamp for 1-shunt current sense
- Fast & efficient boot rectifier using GaN FET
- Up to 60kHz hard switching
- Integrated temperature sensor



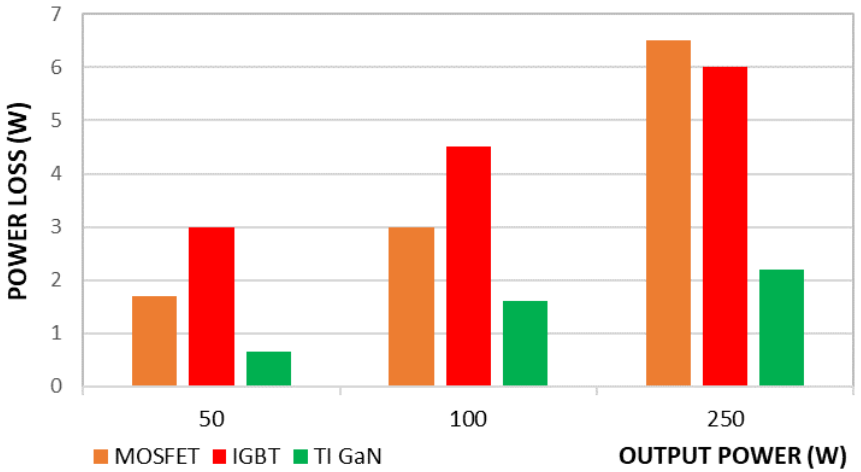
Protection:

- GVDD & bootstrap UVLO, over temperature protection
- Overcurrent protection for each GaN FET with < 400ns response
- Integrated 3x current limit comparators with adj. reference



Why use GaN in motor drives?

Highest efficiency: > 50% reduction in power loss



DRV7308 GaN IPM helps

- Increase efficiency: > 50% reduction in power loss
- Eliminate heat sink: Highest power density!
- Smaller package: 60% reduction in size: 12mm x 12mm
- Ultra-quiet: Less dead time and harmonics
- Eases EMI design: Clean switching with small loop area

DRV7308 GaN IPM enables 50% reduction in power loss

- Zero reverse recovery
- Lowest output capacitance (C_{OSS})
- No turnoff tail current
- Optimized slew rate
- Low $RDS_{(ON)}$

How GaN increases inverter efficiency

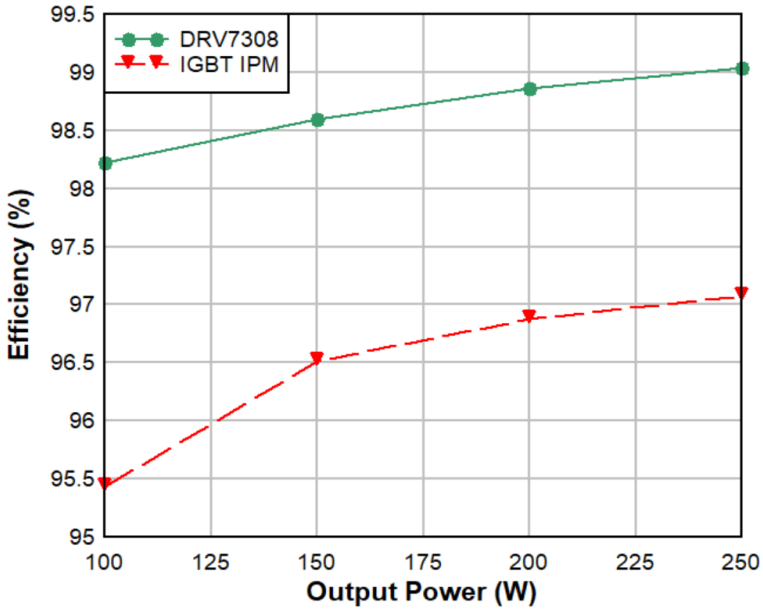
Conduction loss:

- GaN FETs: Proportional to $RDS_{(ON)}$
- MOSFET: Proportional to $RDS_{(ON)}$
- IGBT: Depends on knee voltage and dynamic on-state resistance, which causes higher losses

Switching loss: GaN minimizes loss compared to MOSFET / IGBT

- **GaN offers zero reverse recovery**
  - MOSFET: Body diode QRR limits di/dt & dv/dt and may cause phase-node voltage ringing
  - IGBT: Added antiparallel diode have QRR
- **Reduced V-I overlap loss:** Controlled and faster di/dt and dv/dt
- **No turnoff tail current in GaN**: IGBTs suffer from minority carrier recombination current (tail current), increasing turnoff loss
- **GaN offers lower capacitance** compared to IGBT and MOSFET

Efficiency comparison of DRV7308 and a 5A IGBT IPM in a 250W application

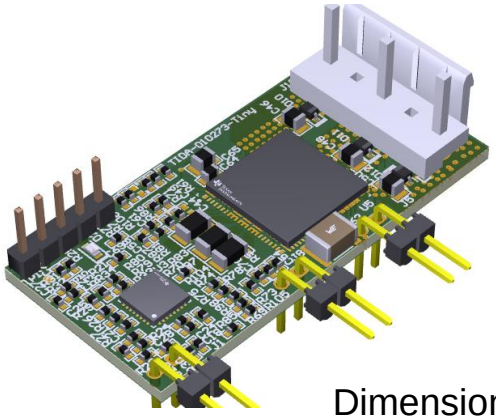


Heat sink elimination for 250W motor drive with DRV7308

TIDA-010273: 250W motor inverter with DRV7308

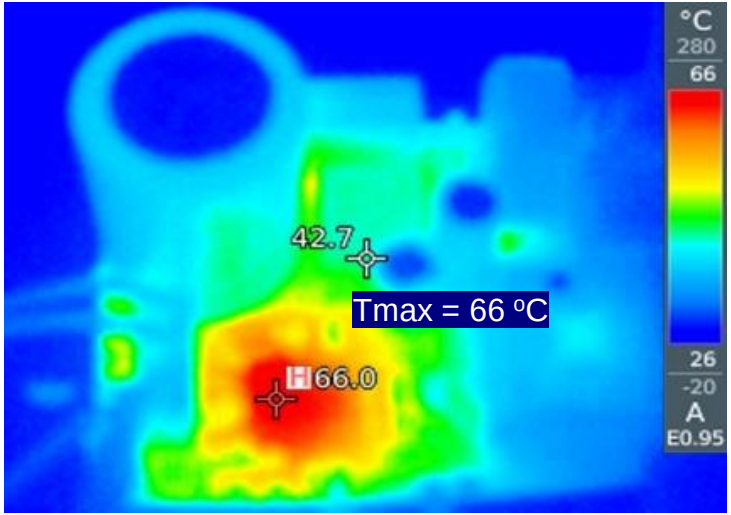
- 230VAC sensorless FOC
- 250W without heatsink
- Dead time < 200ns
- Prop delay < 200ns
- Standby power <0.1W

Dimensions: 80mm by 55mm



Dimensions: 48mm by 23mm

99% inverter efficiency with GAN IPM eliminating heat sink



Tested at 300VDC, 250W, 0.85ARMS, TA = 25 °C, Slew rate = 5V/ns

Higher GaN IPM efficiency enables lower motor cost

Lower motor losses

- High speed or low inductance motors need a high PWM frequency to reduce current ripple
- Higher current ripple: unwanted torque ripple, higher copper & core loss, inaccuracies in current sense
- MOSFET / IGBT-based IPMs normally used at 6kHz to 16kHz, DRV7308 allows high switching frequency

Better motor drive system cost for better system efficiency

- 2023 seasonal energy-efficient rating (SEER) of 14 for HVAC need more system efficiency
- >99% efficiency with DRV7308 helps to meet a motor drive efficiency of 85% with lower motor cost

	Motor output power (W)	Motor Efficiency (%)	IPM Efficiency (%)	System Efficiency* (%)	Comments
IGBT	250	85.0%	97.0%	80.8%	Existing solution for SEER of 13 (Current)
IGBT	250	89.4%	97.0%	85.0%	IGBT Solution with SEER of 14 (2023 onwards)
DRV7308	250	87.6%	99.0%	85.0%	GaN based solution with SEER of 14 (2023 onwards)

**Assumed 98% efficiency for other components in system*

DRV7308 can help meet SEER of 14 with a less efficient motor

Estimated material cost difference b/w a 89.4% and 87.6% motor = $0.63 (from motor copper saving)

Reference: https://www.eia.gov/todayinenergy/detail.php?id=40232

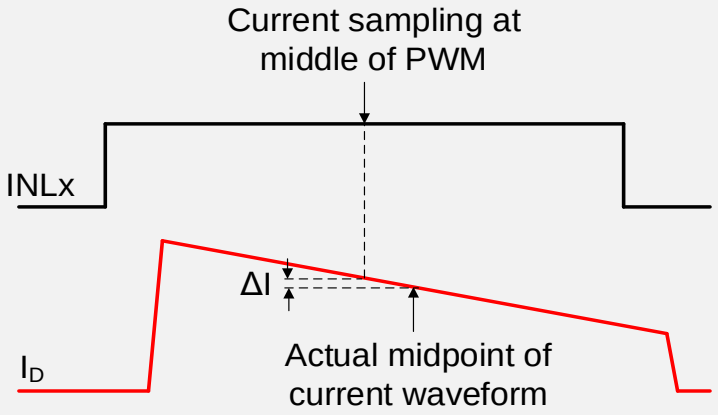
Impact on system efficiency

- VFD wide speed control helps achieve the highest compressor and heating system efficiency
  - In air-conditioning systems, the highest speed at startup helps to cool or heat faster.
  - A finer low speed control helps to maintain temperature.
- IGBT/MOSFET with >1µs DT and >500ns prop. delay limit min & max duty cycle and reduces speed range
- A higher dead time reduces voltage to motor and increases motor current for same power delivery

DRV7308 to realize an efficient VFD

- DRV7308 with dead time & prop delay < 200ns, enhances PWM duty-cycle range, speed range and motor voltage
- With low prop delay and mismatch, improves accuracy of current sensing and motor control efficiency

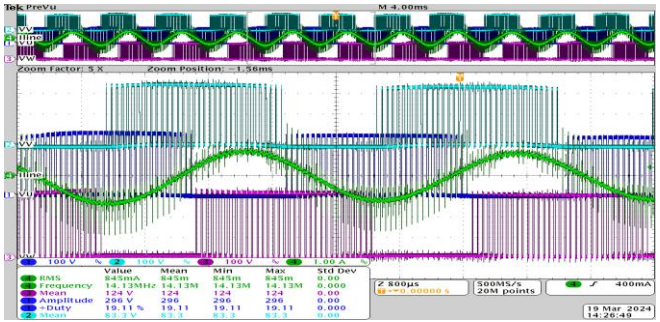
Impact of prop delay in current sense



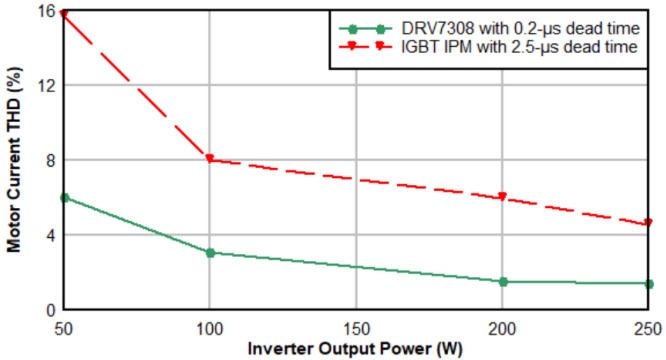
Impact on audible noise

- In motor-drive systems, one of the main sources of audible noise is torque ripple due to current distortion.
- Current distortion depends on PWM frequency, dead time, current-sensing accuracy and more.
- High PWM frequency reduces current & torque ripple, beyond audible range of frequency.
- In IGBT / MOSFET-based systems, dead time is 1µs to 2µs or more, resulting in motor current distortion.
- Dead-time distortion results in 6th harmonic on current, which typically falls in the audible frequency range.
- DRV7308's adaptive dead-time logic enables < 200ns of dead time, resulting in minimal current distortion.

DT < 200ns, low current distortion

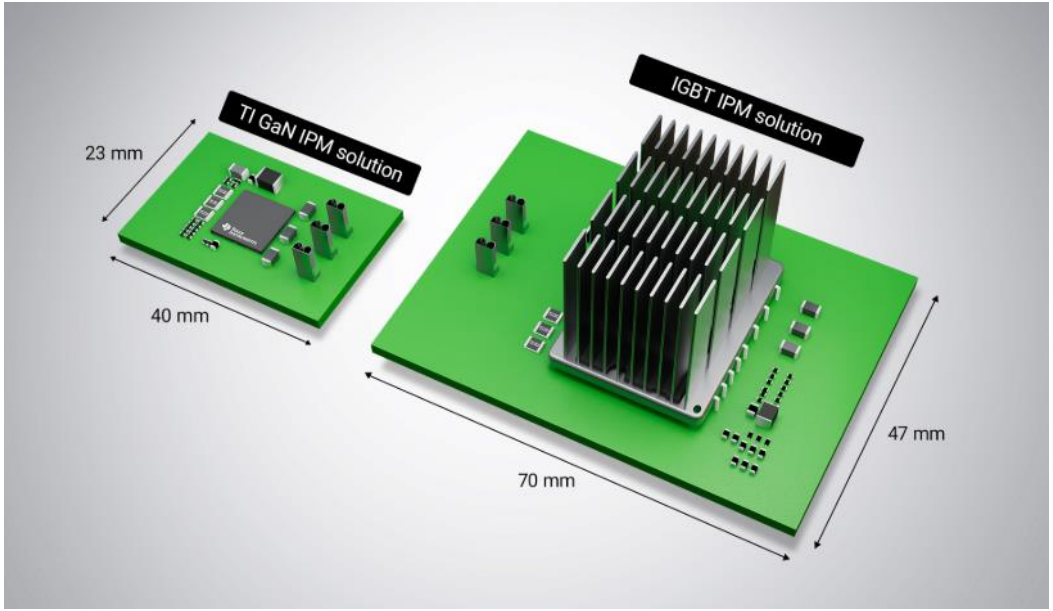


Motor current THD comparison



Impact on solution size

- DRV7308 comes in a 12mm-by-12mm package, which is **55% smaller** than competing 250W IPMs.
- High-level integration including single shunt current sense amplifier, three comparators for current limit, a temperature sensor and a suite of protective features **reduces solution size.**



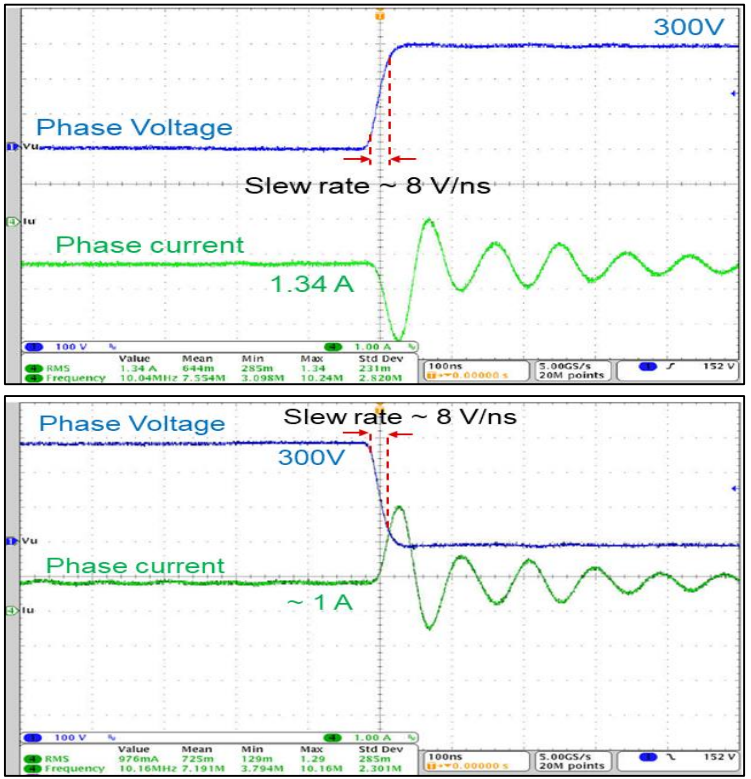
- Size reduction with heat sink elimination enables integration of inverter close to motor, and eliminates cabling from inverter to motor.
- Elimination of cable reduces switching capacitance, and minimizes switching loss and EMI concerns.

Design considerations when using GaN in motor drives

- DRV7308 integrates pre-driver slew rate (dv/dt) control
- Options of slew rate settings: 5, 10, 20 and 40 V/ns.
- Select slew rate as a tradeoff between motor winding insulation and switching loss optimization
- Lower slew rate options of DRV7308 cover the ranges offered by existing IGBTs and provides 99% efficiency
- Zero reverse recovery of GaN FET with lower parasitic and slew-rate control enables a clean voltage switching

Tested at 300V, 1A, 10V/ns with 2m cable & fan motor

Phase node voltage slew rate



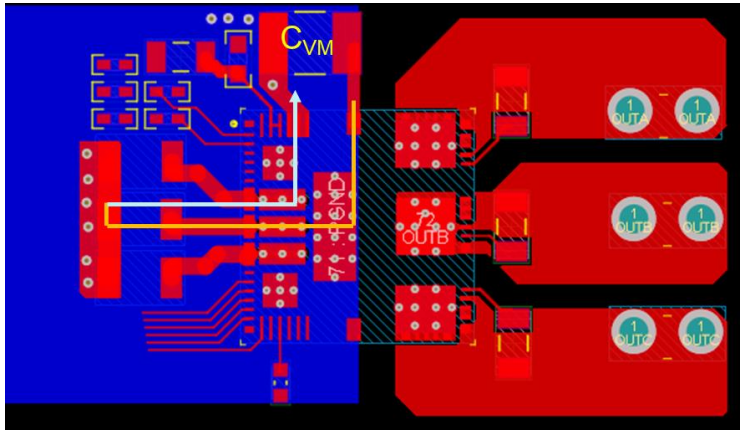
Conducted and radiated emission considerations

Conducted and radiated emissions depend on the switching frequency, dv/dt, di/dt, switching voltage oscillations and reflections and the switching current loop area

DRV7308 incorporates multiple design techniques & PCB layout options to address EMI & EMC concerns:

- **PWM switching frequency:** High frequency reduces current ripple & capacitor need. DRV7308 offers up to 60kHz switching, enabling wide options for designer
- **dv/dt:** Control phase-node switching slew rate
- **di/dt:** With zero QRR & low parasitic, GaN offer better switching without voltage overshoot & oscillation
- **Small switching current loop area:** Minimal loop area to DC bus decoupling capacitor (C_{VM}) is very minimal

Typical layout reference for DRV7308, illustrating small current loop area



Protected and reliable system designs

DRV7308 integrated protection features

- Over-current protection for each GaN FET
  - GaN needs faster and reliable overcurrent shutdown to protect from saturation.
  - Integrated OCP in each GaN FET eliminates the effect of parasitic and provides a faster response, in the order of a few hundreds of nanoseconds.
- GVDD and bootstrap under voltage lockout
- Over-temperature protection
- PWM input dead time
- Current limit protection using integrated comparators for all three phases
  - Protect against motor over load condition
- Fault condition indication pin (HV_nFAULT)

Getting started

You can start evaluating this device leveraging the following:

Content type	Content title	Link to content or more details
Product folder	650V, 205mΩ 3-phase integrated GaN intelligent power module (IPM) with protection and current sense	https://www.ti.com/product/DRV7308
Reference design	250W motor inverter reference design	https://www.ti.com/tool/TIDA-010273
White paper	How three-phase integrated GaN technology maximizes motor-drive performance	https://www.ti.com/lit/wp/slyy235/slyy235.pdf
Technical article	Achieving household energy efficiency and cost savings	https://www.ti.com/lit/ta/ssztd41/ssztd41.pdf
Development tool or evaluation kit	DRV7308 Evaluation Module	https://www.ti.com/tool/DRV7308EVM

Learn more at TI.com/GaNIPM

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265