Welcome!
Texas Instruments New Product Update

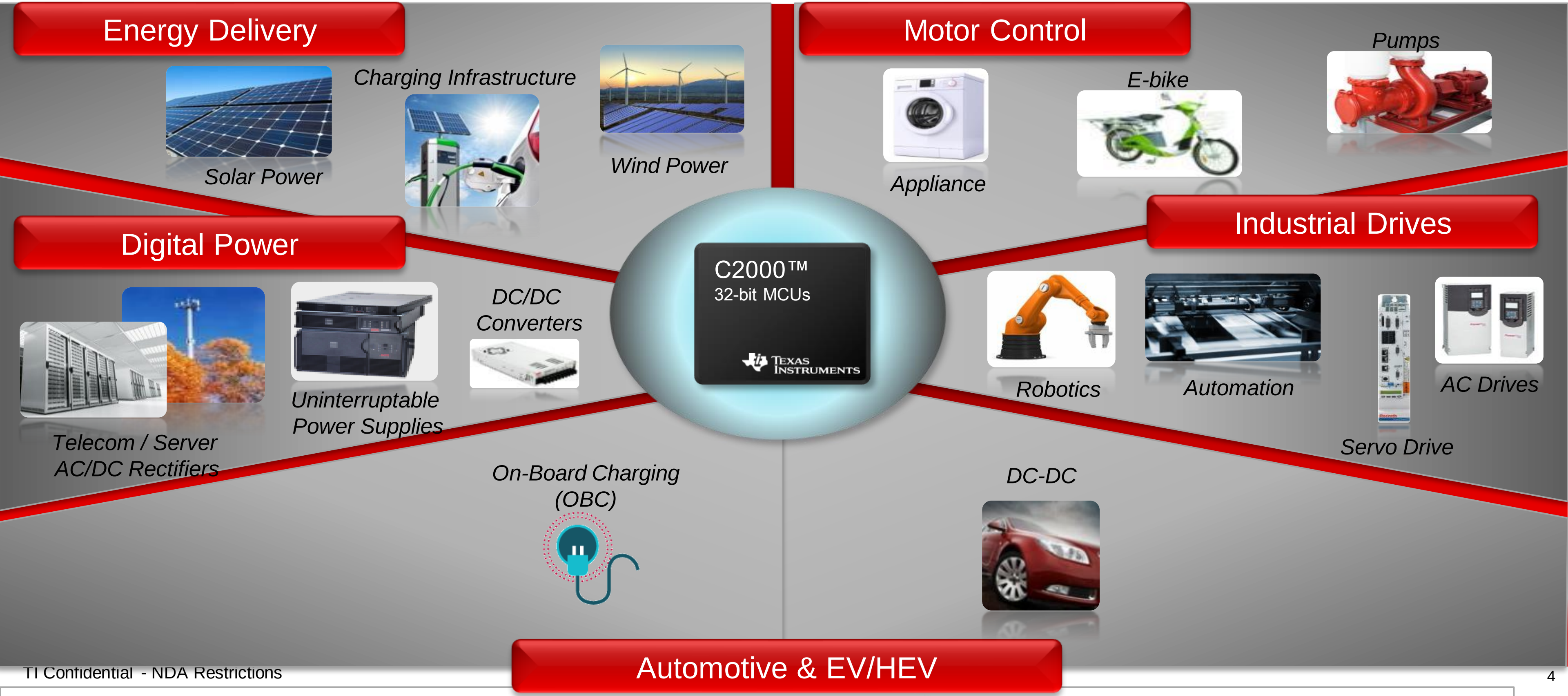
- This webinar will be recorded and available at www.ti.com/npu
- Phone lines will be muted
- Please post questions in the chat or contact your sales person or field applications engineer

TI's new C2000™ real-time controller series: TMS320F28002x

Agenda

- C2000™ real-time MCU introduction + identity
- C2000™ TMS320F28002x overview
- C2000™ Generation 3 enhancements overview
- C2000™ F28002x-based solutions + how to get started
- C2000™ + TI GaN overview: Maximizing efficiency, density, and reliability

Where are C2000™ real-time microcontrollers?



C2000™ controllers overview

C2000™ Real-Time Control Microcontrollers Texas Instruments

Scalable, **ultra-low latency**, **real-time controller** platform designed for efficiency in power electronics, such as high power density, high switching frequencies, GaN and SiC technologies

C2000 controllers

Sense

Highly accurate sensing
- 12-/16-bit ADCs, up to 24 channels
- ADC post processing, and externally accessible DACs

Process

High performance processing
Floating-point DSP C28x™ core + parallel multi-core architecture + instructions set optimized for control math, up to 925 MIPS

Control

Highly flexible, High-resolution PWMs:
- Up to 32 outputs
- Integrated comparators, eCAP, eQEP,
- Position Manager, Sigma-Delta Filter Module, trip zones

Interface

CAN, CAN-FD, LIN, UART, SPI, I2C, PMBus, USB, 10/100 Ethernet MAC, EtherCAT®, XEMIF

Expertise and support:
Software libraries, reference designs, and functional safety-compliant devices.

25 years expertise in real-time control systems

Leading innovation:
Config. Logic Block for peripheral customization, Fast Serial Interface for high-speed communication, ERAD for enhanced diagnostics and profiling

1.2-V core, 3.3-V I/O design	Up to 1.5 MB Flash, 256 kB RAM (ECC protected)	QFN, QFP, BGA packages	-40 to 125C temperature range	Q100 automotive qualified options

Over 750 million units shipped for industrial and automotive applications with compatible software

C2000 Platform: Built for Real-Time Signal Chain Performance

Power Electronics Applications

- Efficiency
- Integration
- Performance

Requirements

- Power efficiency
Higher density
- Lower-cost BOM
Modular Options
- Efficient/Faster Motor RPM
Higher Power Levels
Bi-dir Energy Flow

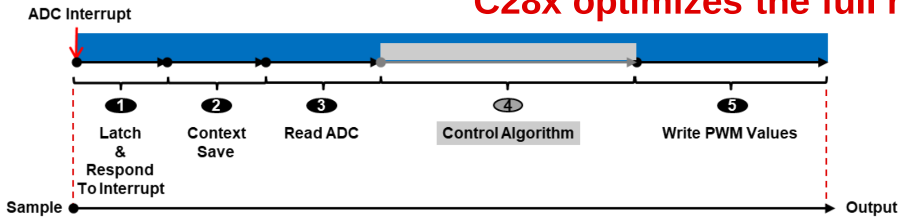
Design Challenge

- Low latency ADC-CPU-PWM update
- Faster PWM Switching
- Complex Power Control Topologies (HW/ SW)
- Device Platform
- More MIPS

TI C2000™ Real-Time Controllers

- Optimized architecture delivering 2x real-time performance versus ARM
- Fast, Flexible, 150ps resolution PWM delivering 98% efficiency for 2 MHz DC/DC switching
- F2838x = 24 ADC and 32 PWM channels
- Multi-core DSP architecture
- Scalable portfolio: $1 - $10, 32 kB - 1.5 MB flash
- Up to 925 MIPS, roadmap with next-gen CPU (C29x) to 3x more MIPS

C28x optimizes the full real-time signal chain



CPU	Control Algorithm (4)	Full Signal Chain (1-2-3-4-5)	Cycle Efficiency
C28 @200MHz	0.880 (49% of total time)	1.795 uS	100%
RF5 @400MHz	0.873 (48% of total time)	1.820 uS	49%

ARM based architecture needs to run 2x faster to be as real-time efficient as C28x based architecture

F28002x real-time controllers:
Real-time control meets system cost optimization and performance scalability

Single-axis servo

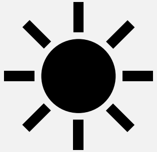
variable frequency drives

Appliances

Server + telecom power

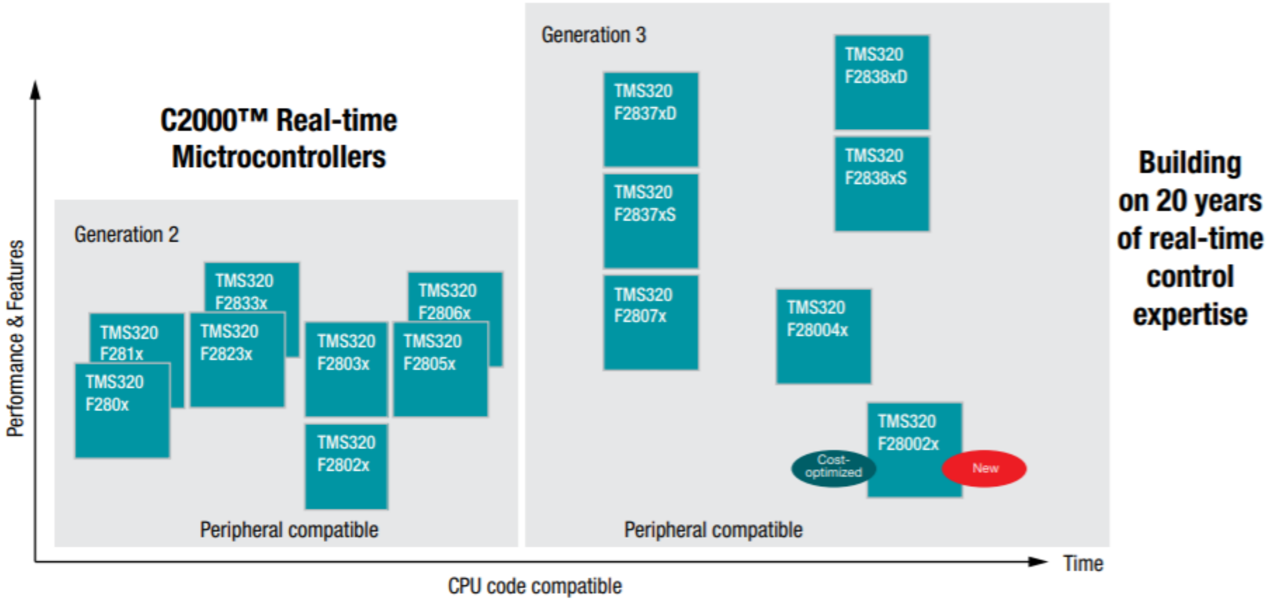
EV/HEV on-board charging and DC/DC converters

Solar inverters



The latest in extensive real-time control portfolio

- The F28002x series builds on **the third generation** improvements introduced in the F2838x, F2837x and F28004x series.
- The F28002x series allows to scale from high-end to mid-end to **low-end** while maintains differentiation and performance.
- The C2000 portfolio provides **pin-to-pin** and code compatibility, alleviating effort to scale products performance.
- It’s **easy to migrate** and build a range of products on similar technology, enabling a sustainable platform solution.



C2000™ F28002x

Now released to market!

Differentiation

Optimized for Low-Cost, High-Performance Power Control Applications

Streamlined performance

- 100MHz / 128 kB flash / 28 kB SRAM
- 100 MIPS DSP Processing Power
- Floating Point, Trigonometric Math Unit, NLPID & Division acceleration

Advanced actuation and design flexibility

- 4th gen ePWM enables implementation of the most advanced switching techniques for increased efficiency and power density
- Enhanced crossbars provide flexibility in combining inputs, outputs and internal resources for advanced control and protection mechanisms

Premium analog

- 2 12-bit 3.45MSPS ADC with post processing and threshold actions
- 4 Windowed Comparator Sub-system

Rich digital options

- CAN, QEP, Position Manager, UART, SPI, LIN, I2C, PMBus, FSI, etc.

Perfect portfolio

- Architecture compatible with F28004x, F2807x, and F2837x
- Pin-pin compatible with 64-pin F28004x
- Upgrade for popular Piccolo F2803x and F2802x

F28002x

Temperatures | 125C | Q100

Sensing
- ADC1: 12-bit, 3.45 MSPS, 8ch
- ADC2: 12-bit, 3.45 MSPS, 8ch
- 4x CMPSS : 12-bit DAC 8 COMP, 8 digital filters
- Temperature Sensor
- 2x eQEP
- 3x eCAP , 1x HRCAP

C28x™ DSP core 100 MHz
- FPU, FastDIV
- TMU w/ NLPID
- 6ch DMA
- CRC & HWBIST

Actuation
- 7x ePWM Modules 14x Outputs (8x High-Res)
- Fault Trip Zones

Connectivity
- 1x UART, 2x LIN/UART
- 1x I2C, 1x PMBus
- 2x SPI, 1x FSI
- 1x CAN 2.0B

Configurable Logic Block
- 2 Tiles

Memory
- 128 kB FLASH (1 bank) +ECC
- 24 kB SRAM +ECC
- ROM
- 128-bit Dual Security Zones
- Host Interface Controller (HIC)

Power & Clocking
- 2x 10 MHz OSC
- 1.2V VREG
- POR/BOR Protection

System Modules
- 3x 32-bit CPU Timers
- NMI Watchdog Timer
- 192 Interrupt PIE

Debug
- cJTAG / Real-time JTAG
- ERAD

Tools

Experimenter's Kit

Part Number: TMDSCNCD280025C '20Q2

LaunchPad

Part Number: LAUNCHXL-F280025C '21Q2

Software

C2000Ware™ Software Package

Application SDKs

Packages

Package	Footprint Dimensions	Temp
48-pin LQFP	9 x 9 mm	S, Q
64-pin LQFP	12 x 12 mm	S, Q
80-pin LQFP	14 x 14 mm	S, Q

Texas Instruments

C2000™ generation 3 enhancements

F2838x, F2837x, F2807x, F28004x, **F28002x**

F28002x comparison table

F28002x Highlights

- F28002x is a new and improved migration device for the popular F2802x/03x devices at an even lower cost
- FPU (floating point) + FastDIV functionality
- Accelerators (TMU, DMA)
  - NonLinear PID to boost efficiency for applications that demand especially fast transient response
- 2 ADCs with individual sample and hold, post processing and more flexible triggering
- NEW Host Interface Controller
- Feature rich comparator sub-system
- Variety of serial channels: FSI, PMBus, LIN, I2C, SPI, CAN, QEP, more

Comparison of F28002x series with Gen 2 and Gen 3 series

	GEN 3		GEN 2	
	F280025	F280049	F28027	F28035
Total MIPS	100	200	60	120
CPU	100	100	60	60
FPU	YES + FastDIV	YES	NO	NO
TMU	YES + NLPID	YES	NO	NO
DMA	YES	YES	NO	NO
CLA	NO	Type-2	NO	Type-1
Flash (KB)	128	256	64	128
RAM (KB)	24	100	20	20
ADC	2x12-bit	3x 12 bit	1X 12-bit	1x 12-bit
Sample & Hold	2	3	2	2
ADC Channels	16	21	16	16
ADC Post Processing	YES	YES	NO	NO
Comparators	4	7	2	3
CMPSS	CMPSS	CMPSS	NO	NO
Sigma-Delta Filter	0	4	0	0
ePWM Technology	Type-4	Type-4	Type-2	Type-2
PWM Channels	14	16	14	14
HRPWM Channels	8	16	7	7
CLB	YES	YES	NO	NO
HIC	YES	NO	NO	NO
QEP	2	2	0	1
CAN	1	2	0	1
UART	3	2	1	1
LIN	2	1	0	0
I2C	2	1	1	1
SPI	2	2	1	2
FSI	1	1	0	0
PMBus	1	1	0	0
Packages	48, 64, 80	56,64,100	38,48	56, 64, 80
1ku price	$1.52 - $3.30	$4.85 - $7.95	$2.20 - $4.08	$3.05 - $5.80

C2000™ Generation 3 Enhancements

New process technology allows for more features: accelerators (TMU), memory, peripherals, lower power consumption.

Modules	Enhancement
ePWM	flexible load capability, DB generation, advance trip-zone functionality, more high resolution PWMs
X-BAR	flexible crossbars for premium advanced control and protection mechanisms
ADC	Improvements to sensing capability through additional ADCs, and ADC post-processing hardware
CMPSS	new Comparator Subsystem (CMPSS) with windowed comparators
FSI	latest peripherals like high-speed Fast Serial Interface (FSI) at up to 200 Mbps
CLB	new Configurable Logic Block (CLB) provides further system integration and customization
Memory	enhancements with addition of ECC, parity, dual-zone security memory and DMA

C2000™ F28002x solutions & get started

Getting Started with F28002x

F28002x real-time control MCU	Description
Getting Started	Datasheet
	Technical Reference Manual (TRM)
	F28002x controlCARD and experimenter's kit bundle
	C2000Ware software
	Digital Power software development kit
	Motor Control software development kit

- Datasheet
- Technical Reference Manual (TRM)
- F28002x controlCARD and experimenter's kit bundle
- C2000Ware software
- Digital Power software development kit
- Motor Control software development kit

Two phase, interleaved LLC DC-DC Converter for EV/HEV Applications: TIDM-1001

Design Status: F28002x support DPSDK, legacy F2837xD support in ControlSUITE

Features

- Two-phase interleaved LLC resonant DC-DC solution showcasing type-4 PWM, ADC and CMPSS features on C2000 real-time controller
- V_{in}: 370V – 410VDC, V_{out}: 12VDC, I_{out}: 42.5A, P_{out}: 500W
- Peak efficiency: 94.5%, Efficiency > 90% (loads >10%)
- Switching frequency: 200-350 kHz (Resonant 250 kHz)
- Software based current sharing
- Configurable phase shedding, soft-start, and SR limits
- Fault protection: primary current, output voltage and current
- PMBUS library can be added

Applications

- EV 400V to 12V DC-DC
- Server power supplies
- Telecom power supplies

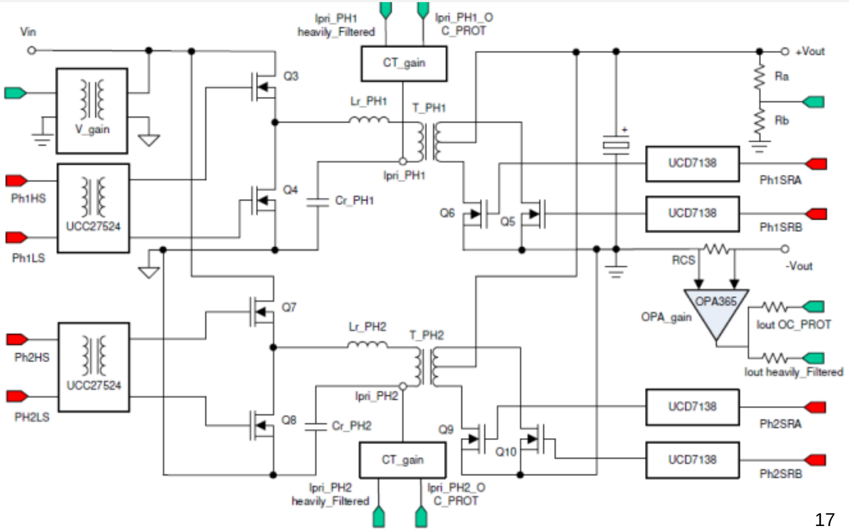
Tools & Resources

- TIDM-1001
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.

- **Device Datasheets:**
  - TMS320F280025C
  - UCD7138
  - UCC27524

Benefits

- Cost effective F28002x device
- Type-4 PWM enables control of multi-phase resonant converters without SW overhead and constraints
- Current balancing with no additional hardware achieves << 5% phase mismatch
- PowerSUITE GUI and SDK support enables easy evaluation and development



Encoder based Servo Drive

Features

- Low-cost, single-chip high-voltage servo drive
- Fast Current Loop FOC
  - PWM latency and FOC execution time signally improve by using Floating Point Unit (FPU), Trigonometric Math Unit (TMU) and Fast Integer Division Unit (FINTDIV)
  - < 2.0us current loop (PWM update), > 96% modulation index to achieve higher speeds
- Dynamic analysis using SFRA
  - Noise is injected into the current loop and output response is measured/ analyzed

Applications

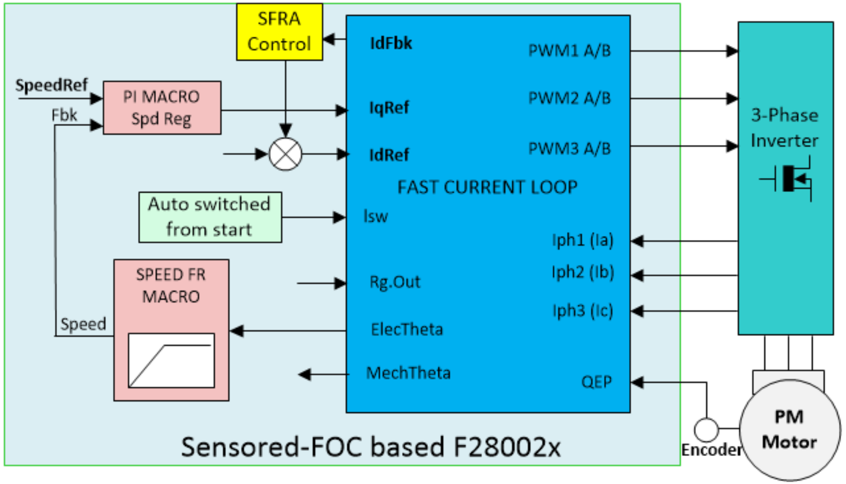
- Industrial servo drives
- Factory automation and control
- Robotics

Tools & Resources

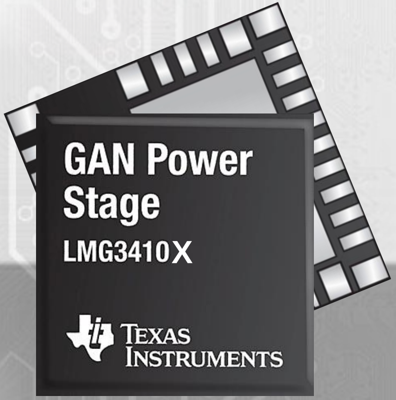
- MotorControl SDK
- **Key TI Device:** TMS320F280025C
- **Development Board:**
  - TMDXCNCD28025C
  - TMDXIDDK379D

Benefits

- Cost effective F28002x real-time controller
- Improve current loop stability at higher speeds
- Reduce inverter power dissipation
- Easily measure performance in terms of stability and closed loop bandwidth



Maximize Efficiency and Power Density, with TI-GaN and C2000



GaN + C2000: World's most efficient power / control

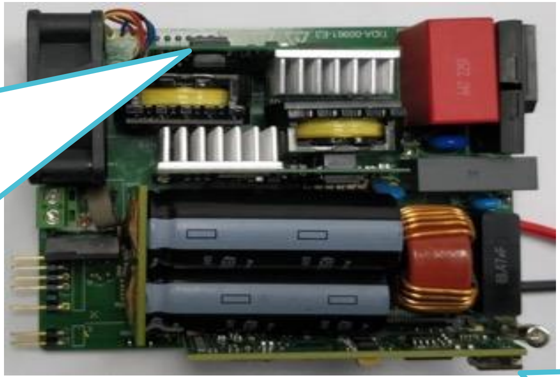
- Both LMG341x GaN & C2000 enable high frequency switching for high power density
  - GaN FETs have inherently lower switching and conduction losses, to switch at high frequencies and increase power density
  - C2000 offers precision sensing, powerful processing and premium actuation capabilities engineered specifically for high frequency power conversion and control applications
- TI GaN with integrated gate drive and protection. Enables fastest GaN switching in the market, for high efficiency and reliability .
- C2000™ is a platform of scalable, ultra-low latency, real-time controllers designed for power supplies that demand high power density and high efficiency, perfectly paired with GaN and SiC technologies

TI-GaN + C2000: Delivering World's most efficient power solution

1MHz CrM PFC
with 99% Efficiency

TI-GAN

- Integrated driver delivers 2X switching speed and half the losses of discrete GaN
- Built-in protection designed for operation under extreme conditions
- Simple interface signal for closed loop connection with C2000



Power Density: 250 W/in^3 (15.2 W/cm^3)
Versus
Silicon: 55 W/in^3 (3.4 W/cm^3)

C2000

- 12-/16-bit ADCs with up to 3.5MSPS for high speed and accurate voltage and current sensing
- Powerful 32-bit Floating point DSP enabling multi-phase and multi-level control topologies
- Highly flexible, High resolution 150ps PWM enables high frequency converter design

C2000™ MCU | Ideal for GaN control

Processing
Floating-point CLA Real-Time Co-Processor, TMU, NLPID for offloading control loop functions from the main core

Design challenge
Enables fast control loop for higher bandwidth and improved static and dynamic performance.
Allows single MCU multiple control loops

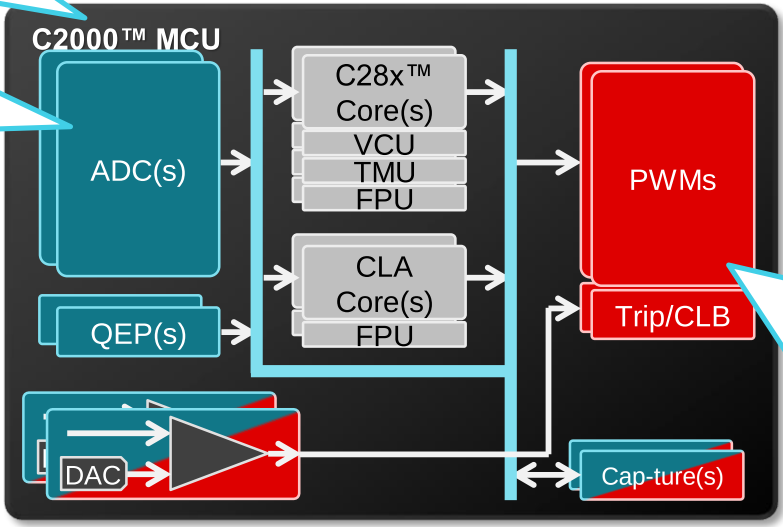
Color Key
Sensing
Processing
Actuation

Sensing
12-/16-bit ADCs with up to 3.5MSPS

Tightly coupled ADCs / PWMs

Externally accessible DACs

Design challenge
Enables fast and accurate current/voltage sensing schemes.



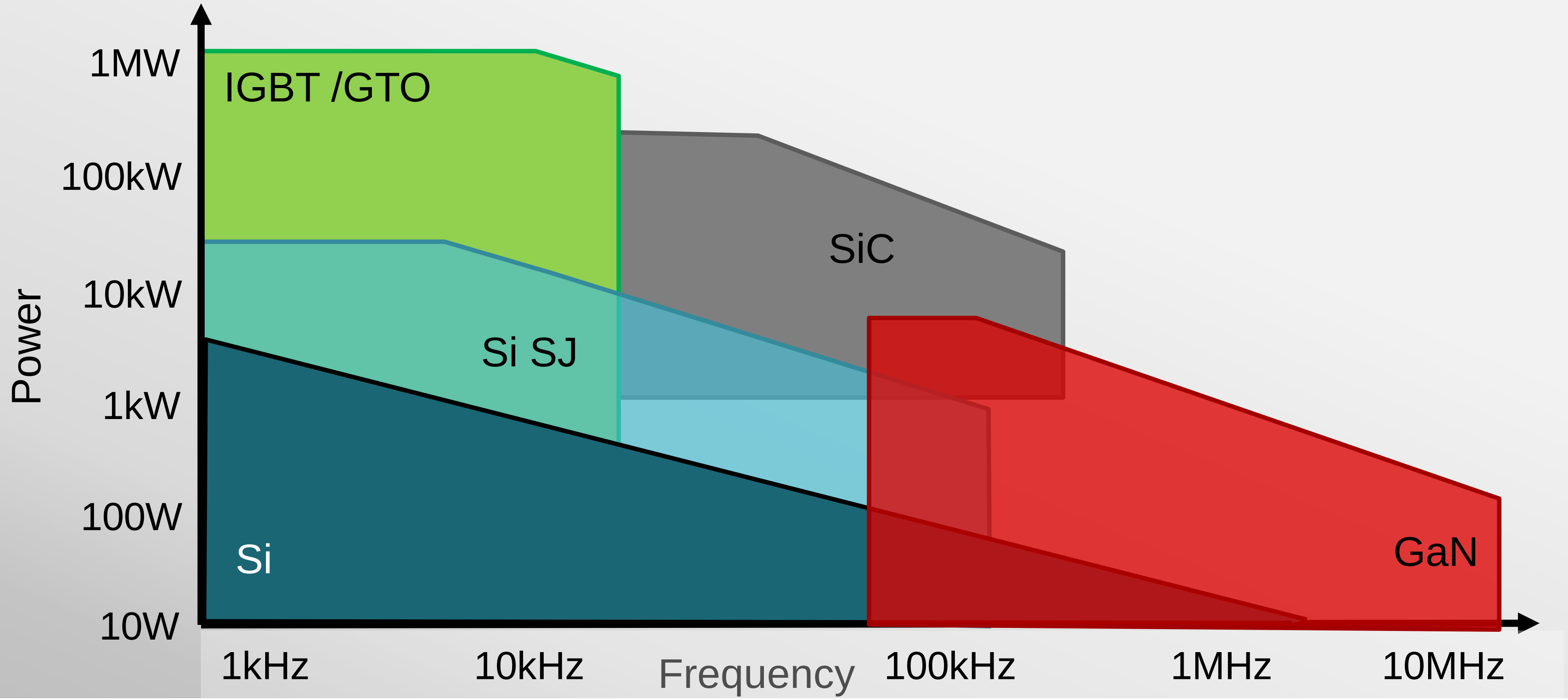
Actuation
High-resolution PWMs (150 ps)

Trip zones for accurate PWM shape definition

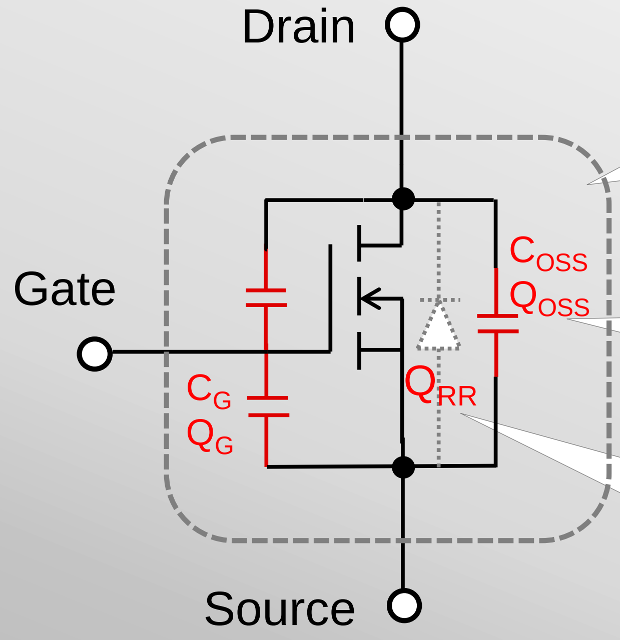
Integrated comparators for peak current mode control

Design challenge
Efficient multi-phase & multi-level control topologies
Protect shoot-through/short circuit, PWM interlocks

Power Devices: Mapping Power and Frequency



GaN: Key Advantages Over Silicon FET



Low C_G,Q_G gate capacitance/charge (1 nC-Ω vs Si 4 nC-Ω)
- ✓ faster turn-on and turn-off, higher switching speed
- ✓ reduced gate drive losses

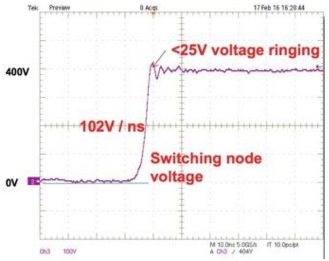
Low C_{OSS},Q_{OSS} output capacitance/charge (5 nC-Ω vs Si 25 nC-Ω)
- ✓ faster switching, high switching frequencies
- ✓ reduced switching losses

Low R_{DSON} (5 mΩ-cm^2 vs Si >10 mΩ-cm^2)
- ✓ lower conduction losses

Zero Q_{RR} No 'body diode'
- ✓ No reverse recovery losses
- ✓ Reduces ringing on switch node and EMI

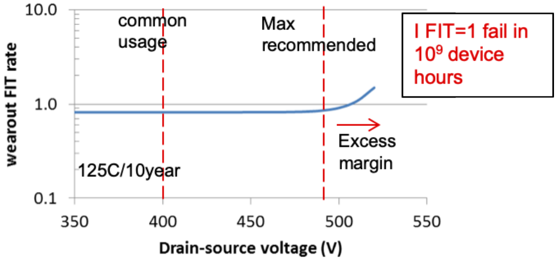
TI-GaN: Most Efficient and Reliable GaN

Twice the Speed, Half the Losses



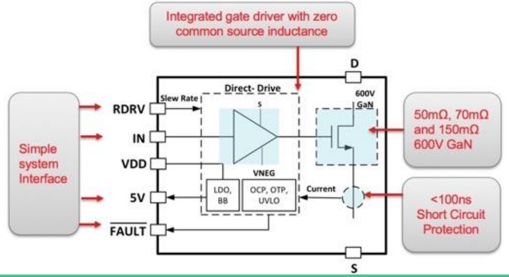
Highest switching speed in the industry enabling 50% lower losses in 65W to >10kW applications

Lifetime Reliability



Robust self-protected solutions with >30M device reliability hours and >3GWHr of power conversion to date

Low Cost and Integrated



TI Owned process and manufacturing of GaN FET with integrated driver and protection in a low inductance package

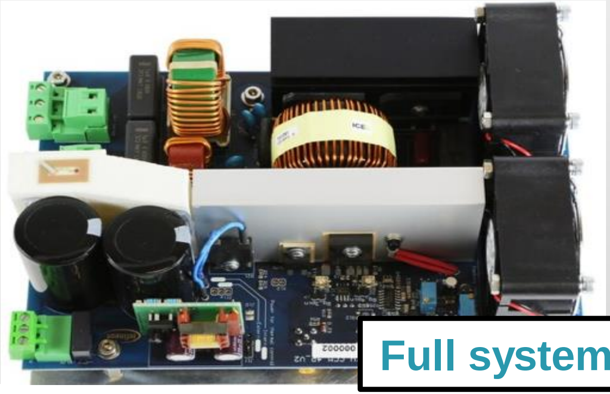
LMG3410x GaN + C2000: Maximize Power Density

TI GaN:
- 10x higher switching frequency
- 5x reduction in magnetics

+

C2000:
- Flexible high-resolution PWM generation and premium analog to digital conversion
- Processing performance for highest possible control loop frequencies

Silicon PFC @ 2kW



Full system: 15 W/in^3

3x
Higher Density

GaN + C2000 PFC @2kW

Full system: 48 W/in^3

LMG3410x GaN + C2000: Eliminate Fans

TI GaN:
- 99% efficiency
- 90% reduction in cabling
- 75% smaller cabinets

** In 6 axis motor systems*

\+

C2000:
- Fast Control Loop, ADC and Sigma Delta Filter interfaces
- Linear and absolute encoder feedback
- Industrial low-latency communications
- FPGA-like protection and customizable logic for high-frequency GaN based servo drives.

Silicon Motor Drive @1.25kW

Heatsink: 145 x 82 x 42 mm
+ Fan

85% smaller heatsink
with **NO fan**

Integrated GaN Drive w/ C2000 @1.5kW

Heatsink: 80 x 46 x 20 mm
No Fan

Example of TI C2000 + GaN:
900V Bidirectional Energy Storage System with 99% Efficiency

900V-5kW Bidirectional ACDC Converter with TI-GaN

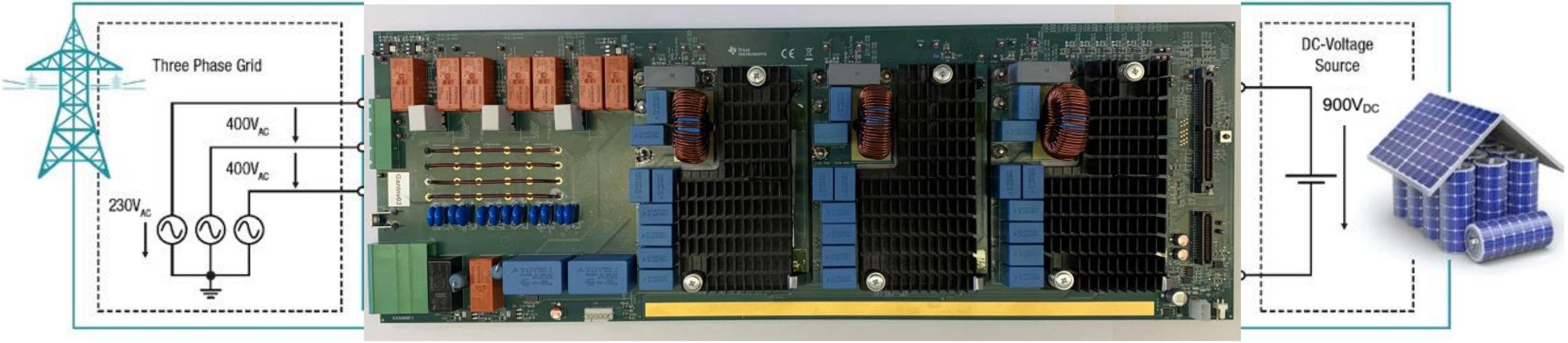
Design Features

- DC voltage up to **1400V**, AC voltage up to 480V L-L
- Peak efficiency of **99.2%**
- **Convection cooled** with no fan
- Scalable **multi-level** solution for >**5kW**
- Total harmonic distortion **(THD) < 3%**
- **Surface-mount devices** to reduce manufacturing cost
- **LMG3410R050**, 600V, 50mΩ GaN FET with integrated Driver & Protection
- **Leverages TI C2000** controller: **TMS320F28379D**

Design Benefits

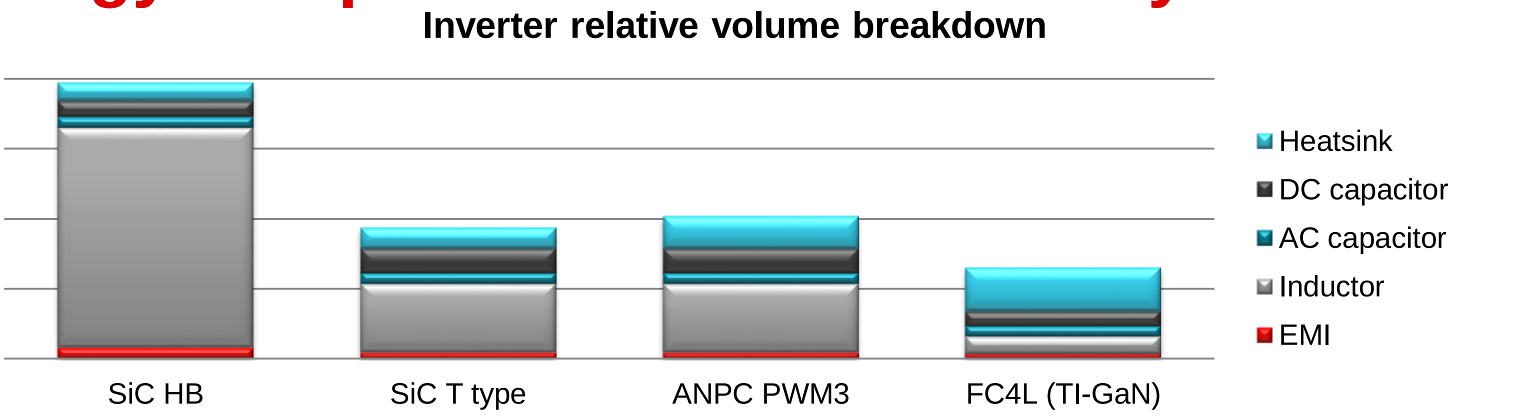
- **3X power density improvement over IGBT** and 1.25X over SiC

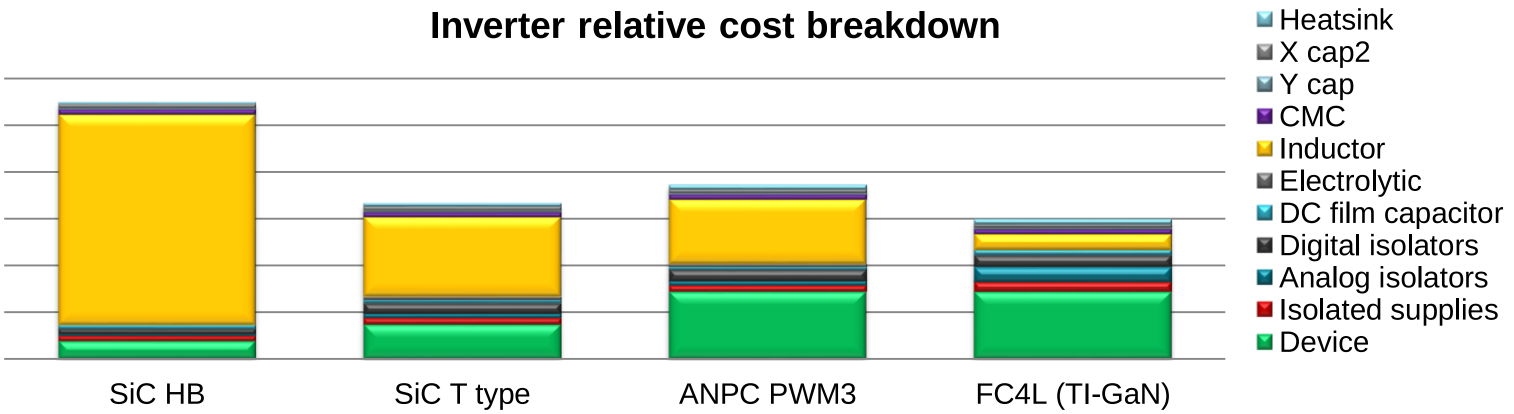
Typical Operating conditions	IGBT	SiC	TI-GaN
Frequency (kHz)	20	100	**140**
Open frame Power Density (W/in³)	73	170	**211**
Efficiency (%)	98.3	98.9	**99.2**



470 mm x 162 mm x 51 mm

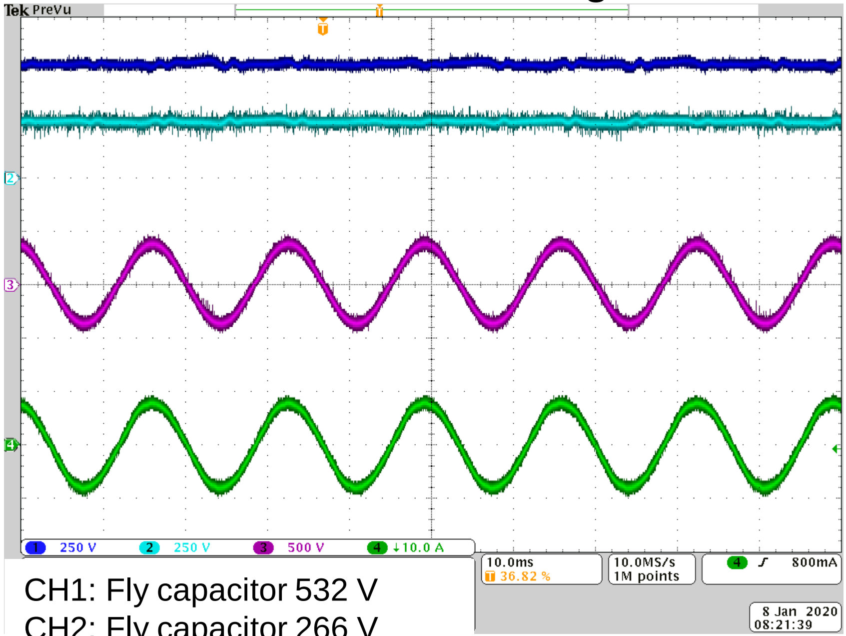
Topology comparison at 99% efficiency



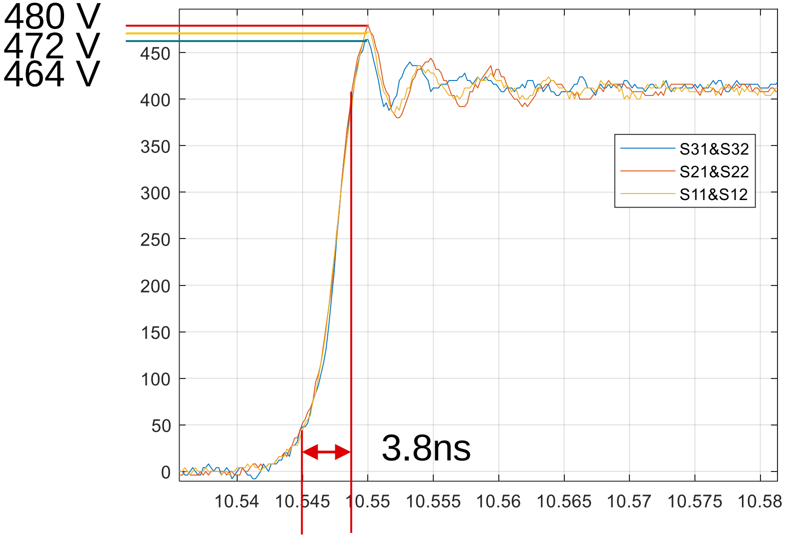


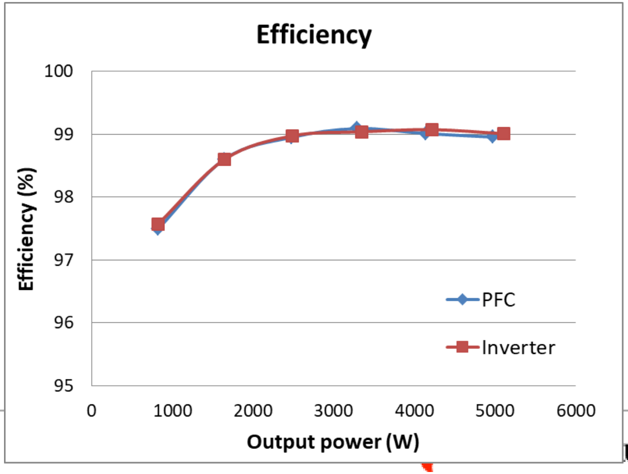
Results

- 99 % efficiency 3 kW to 5 kW natural convection cooling



CH1: Fly capacitor 532 V
CH2: Fly capacitor 266 V
CH3: Grid voltage 270 V
CH4: Grid current 6 A





Example of TI C2000 + GaN:

Bi-directional 3.3kW Interleaved CCM Totem-Pole PFC

TIDM-02008

Bi-Directional 3Ph Interleaved Totem-Pole CCM PFC/Inverter Reference Design TIDM-02008 (Leveraging TIDM-1007) http://www.ti.com/tool/TIDM-1007

Features

- GaN-based 3 phase interleaved totem pole bidirectional PFC
- Rated Power : 3.3 kW (at 230 V_{rms})
- Peak efficiency : 98.7 % (at 230 V_{rms})
- Total Harmonic Distortion (THD) < 2% (at low line)
- PWM switching frequency : 100 kHz
- PFC mode specification: 120/230 V_{ac_in}, 380 V_{dc_out}
- Inverter mode specification : 380 V_{dc_in}, 120/230 V_{ac_out}
- Soft starting for totem-pole bridge
- Phase shedding and adaptive dead time control for higher efficiency
- F28004x CPU + CLA (co-processor) support

Benefits

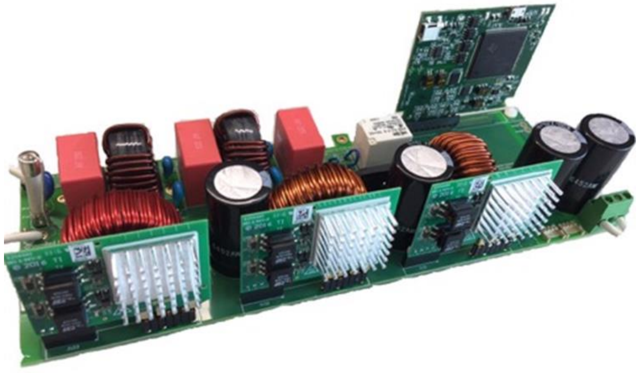
- **High power density** design while maintaining OEM specified form factor
- Further **system integration** through latest TI-GaN gate drivers
- Enables **superior control and implementation of advanced control schemes** brought by high performance C2000™ MCU
- Enables **simple adaptation of software** through powerSUITE™ support

Target Applications

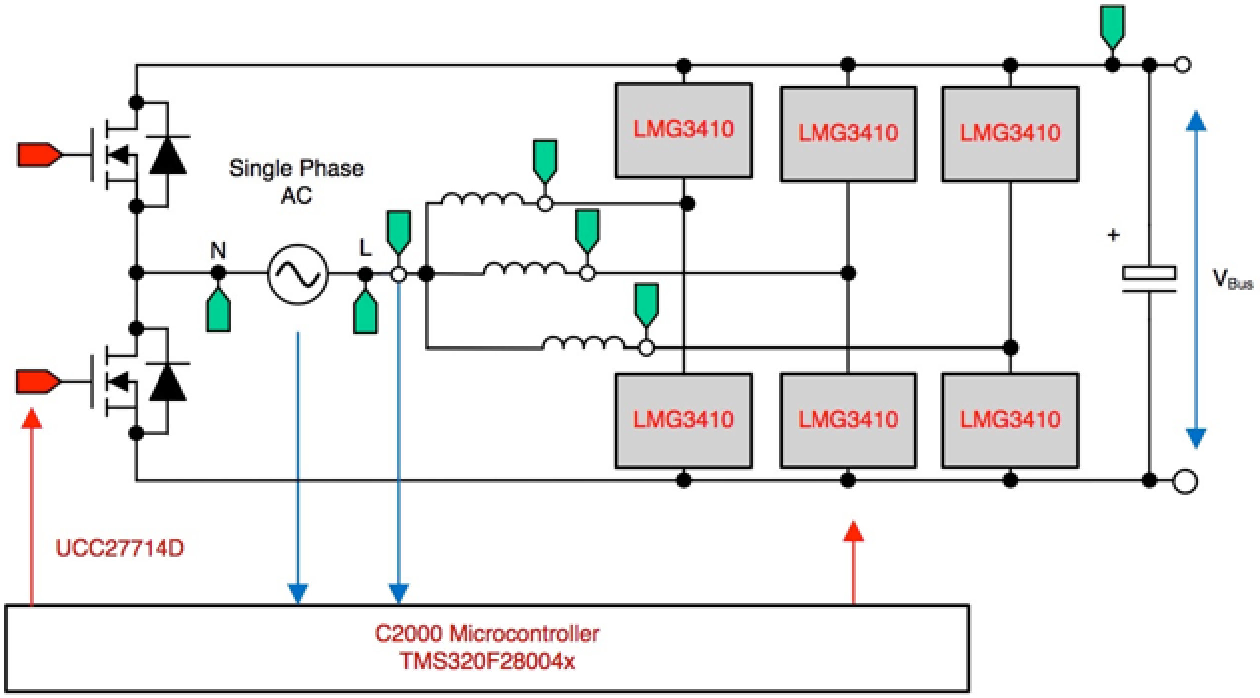
- Energy storage system
- Onboard charger
- Industrial power supply

Tools & Resources

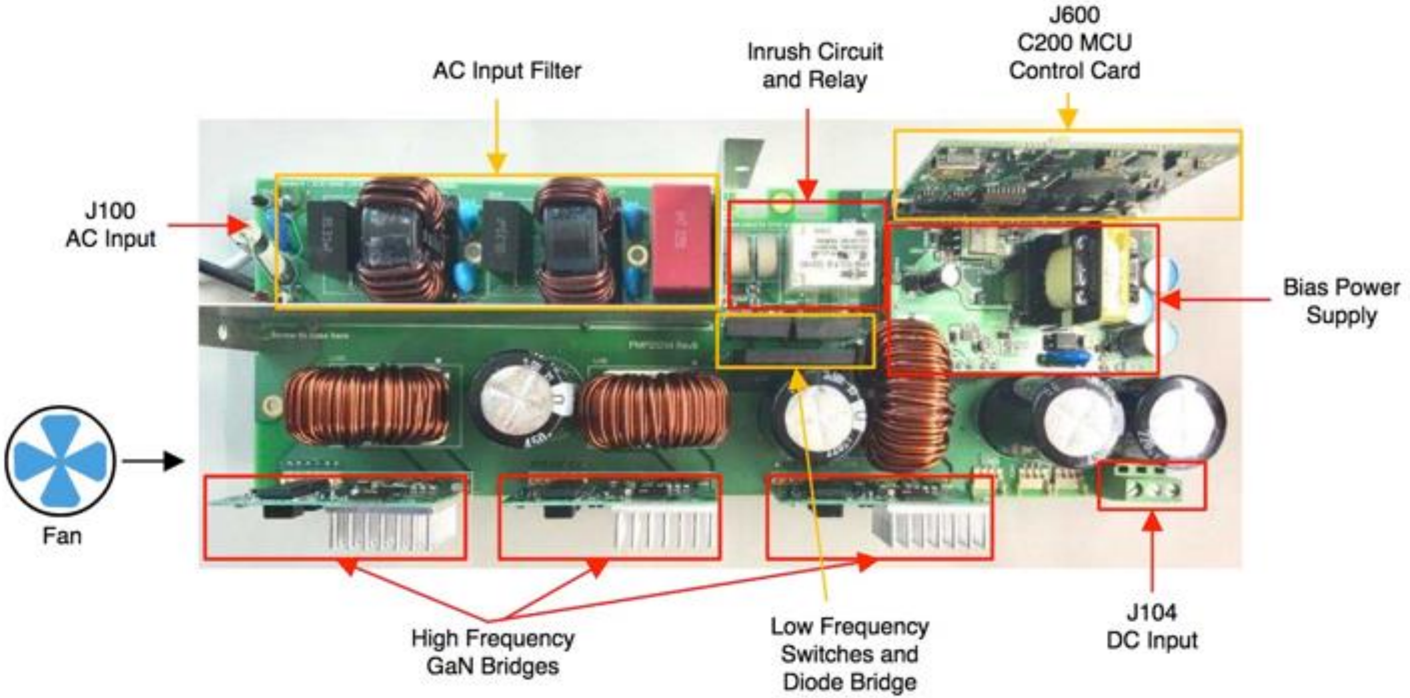
- **TIDM-02008 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM, Design Files
- **Key TI Devices:** TMS320F280049, TMS320F28075, LMG3410R070, UCC27714, OPA2376, SN74LVC1G3157, ISO7831, TLV713



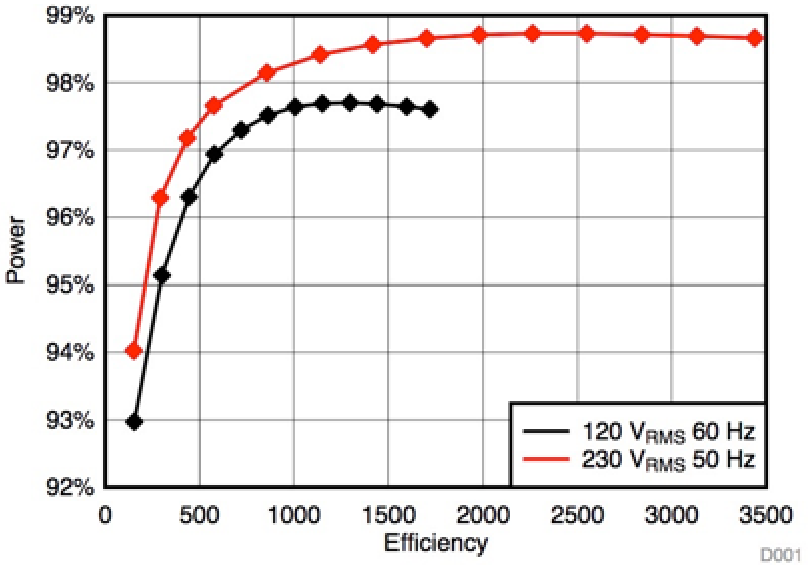
TIDM-02008: Block Diagram

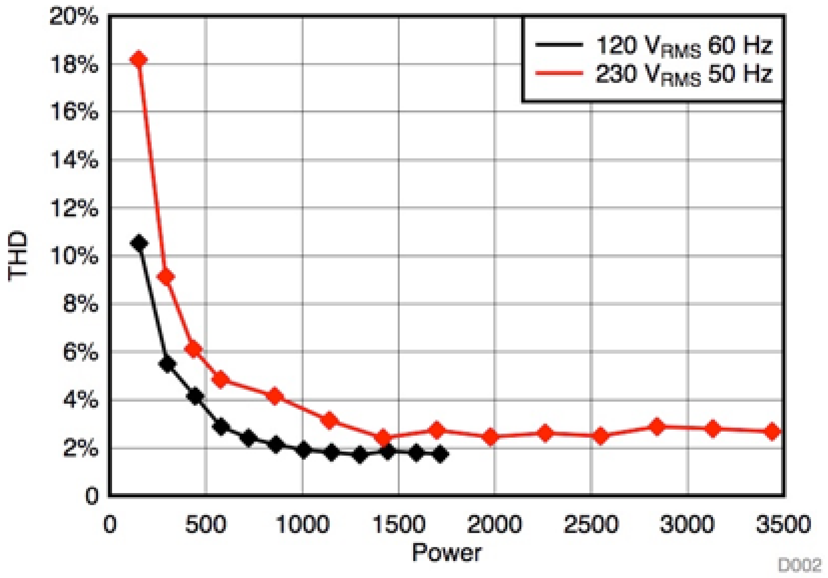


TIDM-02008: Design Overview



TIDM-02008: Measured Efficiency and THD





Backup

C2000 MCU ideal for high switching frequency control

C2000 MCU DNA	Scalable MCU architecture from high to low end power stages with high frequency control & processing capabilities	Ideal For WBG (GaN/SiC) Switching/control/system
32-bit -28xCPU Up to 200MHz	• Industry's leading real time control CPU • Single/double floating point precision • Tightly integrated accelerators & control peripherals	• Efficient low latency, precision control algorithms • Widely adopted in Motor drive/Solar inverters/Automotive power stages
CLA/TMU/NLPID Up to 200MHz	• Industry's low latency event/algorithm processing engine • Executes in floating point precision and in parallel to the CPU • Fast trigonometric and non-linear algorithm processing engine	• Enabling multi-phase & multi-level control topologies • Ideal for low latency non-linear control
PWM/Capture engine	• Industry's proven best in class and flexible PWM generation • Up to 200/MHz PWM clock with protection • Up to 150ps pulse width resolution with high resolution dead band • Tightly integrated with the Analog sub-system	• Multi-phase & multi-level control topologies • Protects shoot-through/short circuit • Efficient switching of GaN/SiC power stage • Glueless interface to TI Gate Driver family
Analog sub-system	• Up to x4 high-precision, just-in time 12/16bit ADCs • Flexible Analog comparator & DAC subsystems • Pre-processing blocks to minimize latency in sensing	• Enables fast current/voltage sensing scheme • Enables customizable Peak-current mode control • Minimizes data analog preconditioning/latency
Delta Sigma- SDFM	• Up to 8 programmable Delta sigma filters, with digital comparators	• Enables isolated current/voltage sensing
CLB Configurable Logic	• Configurable logic to add customizable protection • Custom peripheral events using Analog and digital triggers	• Enables power stage protection • Develop advanced switching topologies
Fast Serial interface	• Supports low cost fast serial interface up to 200Mbps	• Enables isolated current sensing with low latency. • Allows distributed power stage architectures
Communication ports	• Connectivity ports 50MHz SPI, CAN/CANFD/Ethernet/Ethercat	• Enables External host links for monitoring/control

Red- Unique to C2000 MCU only Green – Showcased in TIDesigns/examples

Visit www.ti.com/npu

For more information on the New Product Update series, calendar and archived recordings

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