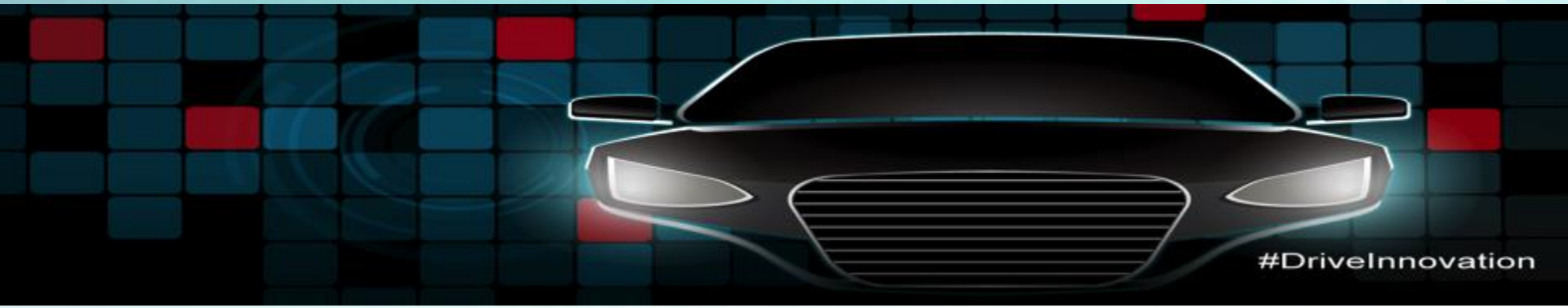
Accelerating China Auto growth

- Functional safety solution in EV/HEV



Texas Instruments

We help accelerate the future of automotive systems

Our products and system expertise help you solve complex design challenges to get electrified, connected and automated cars to market faster.

Product innovation

7,000 automotive-qualified analog and embedded products

Hundreds of new ICs introduced annually since 2014

Decades of advancing automotive electronics

System expertise

150 automotive systems

350+ fully tested, circuit-based reference designs

Meets rigorous quality requirements, including IATF, ISO and OHSAS certifications

Commitment to long-term supply

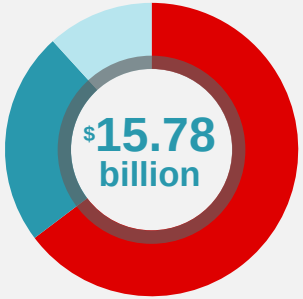
14 manufacturing sites worldwide

Proprietary processes and packaging

Proven track record of on-time delivery for product orders estimated ship date

Our company at a glance

Updated April 30, 2019



Revenue in 2018:

- Analog: $10.80 billion
- Embedded: $3.55 billion
- Other: $1.43 billion

Capital expenditures: $1.13 billion
R&D: $1.56 billion

Automotive and Industrial comprised 56% of TI's 2018 revenue

- Industrial: 36%
- Automotive: 20%
- Personal electronics: 23%
- Communications equipment: 11%
- Enterprise systems: 7%
- Other: 3%

Employee information:

Approximately 30K worldwide

12K in the Americas

16K in Asia-Pacific

2K in Europe

80,000+ products for ~100,000 customers

14 manufacturing sites worldwide, tens of billions of chips produced each year

TI.com

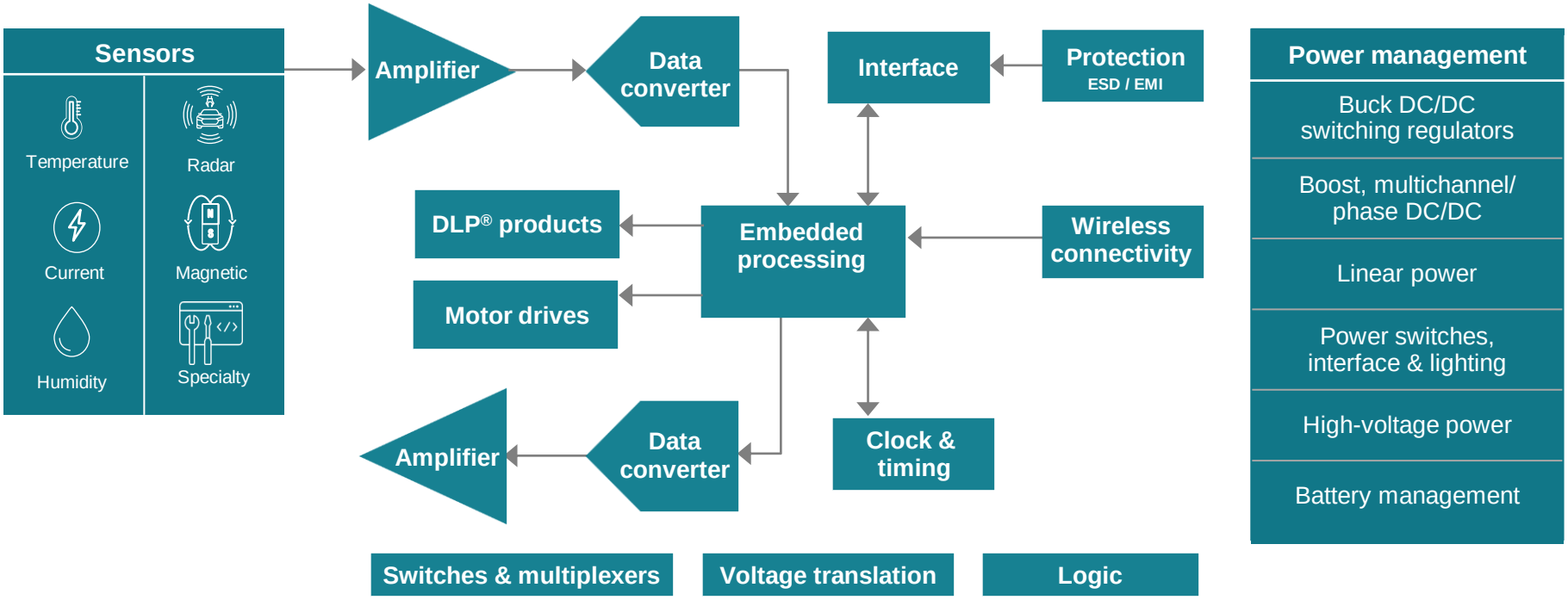
Web presence, 120+ Sales & Applications sites across the globe

World's Most Ethical companies

Top 100 Best Corporate Citizens

Recognized by the Dow Jones Sustainability Index

Analog and embedded products for system design



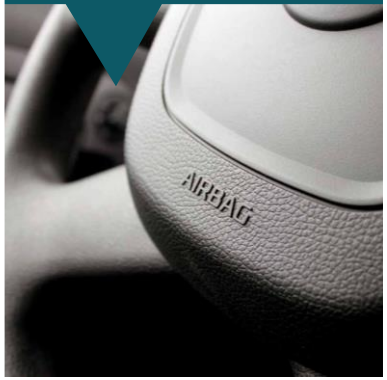
Engineer more electrified, connected and automated designs

Advanced driver assistance system

Advanced-assist and autonomous-driving capabilities for reducing human error

Passive safety systems

Reliable solutions to increase passenger safety



Body electronics and lighting

Innovative analog and embedded processors to optimize comfort and convenience

Infotainment and cluster

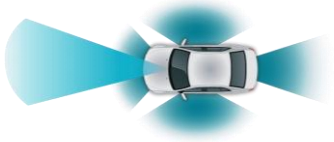
Immersive systems that keep drivers more informed and less distracted

Hybrid and electric vehicles

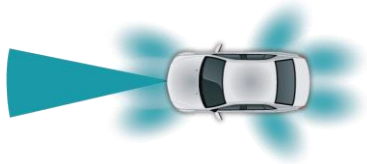
Reducing emissions by electrifying systems from the car to the grid

Advanced driver assistance systems

Road to autonomy. Enable assisted, automated driving features by accelerating ADAS design for a safer, less stressful driving experience.

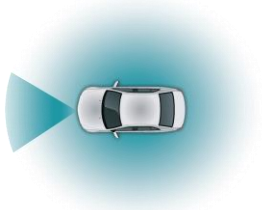


Camera



Radar

Sensor fusion



LIDAR

Ultrasound

Infotainment & cluster systems

The next-generation digital cockpit. Enable infotainment, display and V2X systems that minimize distractions, and help drivers stay informed and connected to the world.

Cluster

Telematics

Display

Integrated cockpit

Head unit

Media interface

Premium audio

BEL Solution - Innovative Lighting Enabled by DLP Technology

- Highest resolution >1 million pixels
- Programmable lighting technology

ENHANCES DRIVER VISIBILITY, MINIMIZE GLARE, AND COMMUNICATE WITH LIGHT

- On-road symbol projections
- Driver assistant

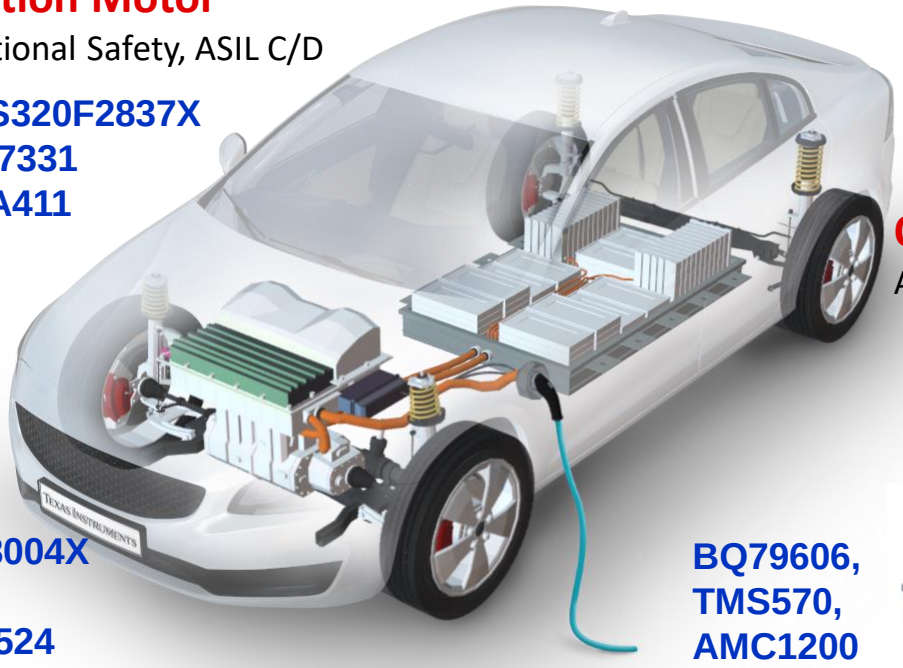
- Future-proof , V2X
- Dynamic lighting

HEV/EV & Powertrain solution

Traction Motor

Functional Safety, ASIL C/D

TMS320F2837X
ISO7331
PGA411



Functional Safety ISO26262

On-board Charger (OBC)

Analog & EP solution

TMS320F28004X
UCC2742X
UCC21520/30
ISO72XX

TMS320F28004X
LM5170
UCC27424/524
UCC27712/4

Bi-Directional DCDC

400V-12V, 48V-12V DC/DC

BQ79606,
TMS570,
AMC1200

Battery Management System (BMS)

HV/LV BMS, ASIL C/D BMS

C2000™ @ FS Compliant OBC

EV/HEV power electronics: what does the market require?

Make the adoption of Electric Vehicles easier for consumers (who expect the same experience as ICE vehicles)

Longer Range, faster charging, and Lower overall vehicle cost

1

Faster time to market to meet new EV deployment goals around the world

2

Develop with advanced power topologies in order to maximize efficiency, increase power density to support larger batteries and longer range per charge.

3

Lower development cost by scaling platforms – software reuse is vital

4

Safety critical robustness and diagnostics need to be re-thought to drive system integration that enables a safe and secure driving experience

5

Reduce space and save cost by combining power electronic modules

Immediate need for customers to scale their investment in EV designs to service the needs of a complete EV model lineup

C2000 MCUs help customers achieve higher power levels with best in class efficiency, increased power density, and system robustness (safety)

C2000 Differentiation for EV power electronics

Power Conversion

1 On-Board Battery Charger
- Improve Power Density
  - Support for GaN/SiC
  - Advanced PFC Topologies for PFC

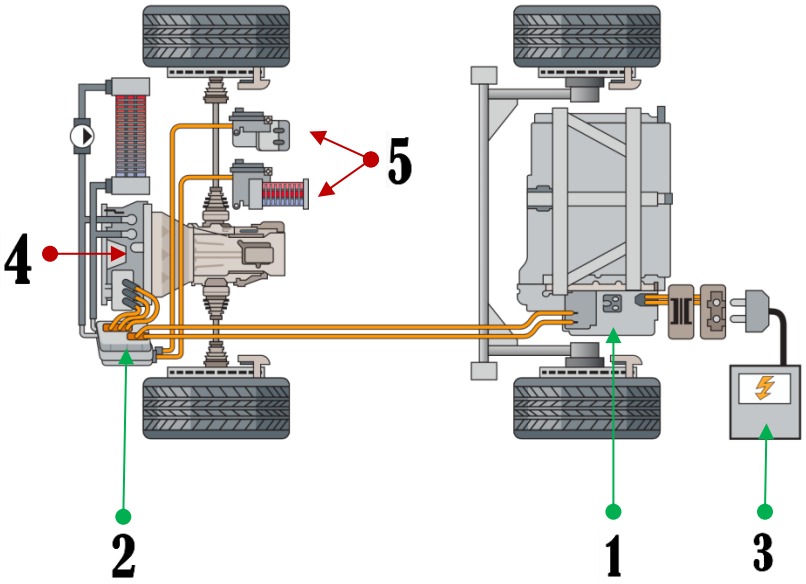
2 High Voltage DCDC
- Improve Efficiency & EMI
  - Zero Voltage Switching over wide load range (ex: PSFB >10% to higher)
  - Phase-shedding methods for interleaving (ex: LLC improved over light load)
  - Mode transition techniques with different switching patterns (Current to Voltage)
  - Variable frequency control (frequency dithering)

3 Charging Station
- High Power & Efficiency
  - 3 Phase Vienna Rectifier or Totem Pole PFC

Motor Control

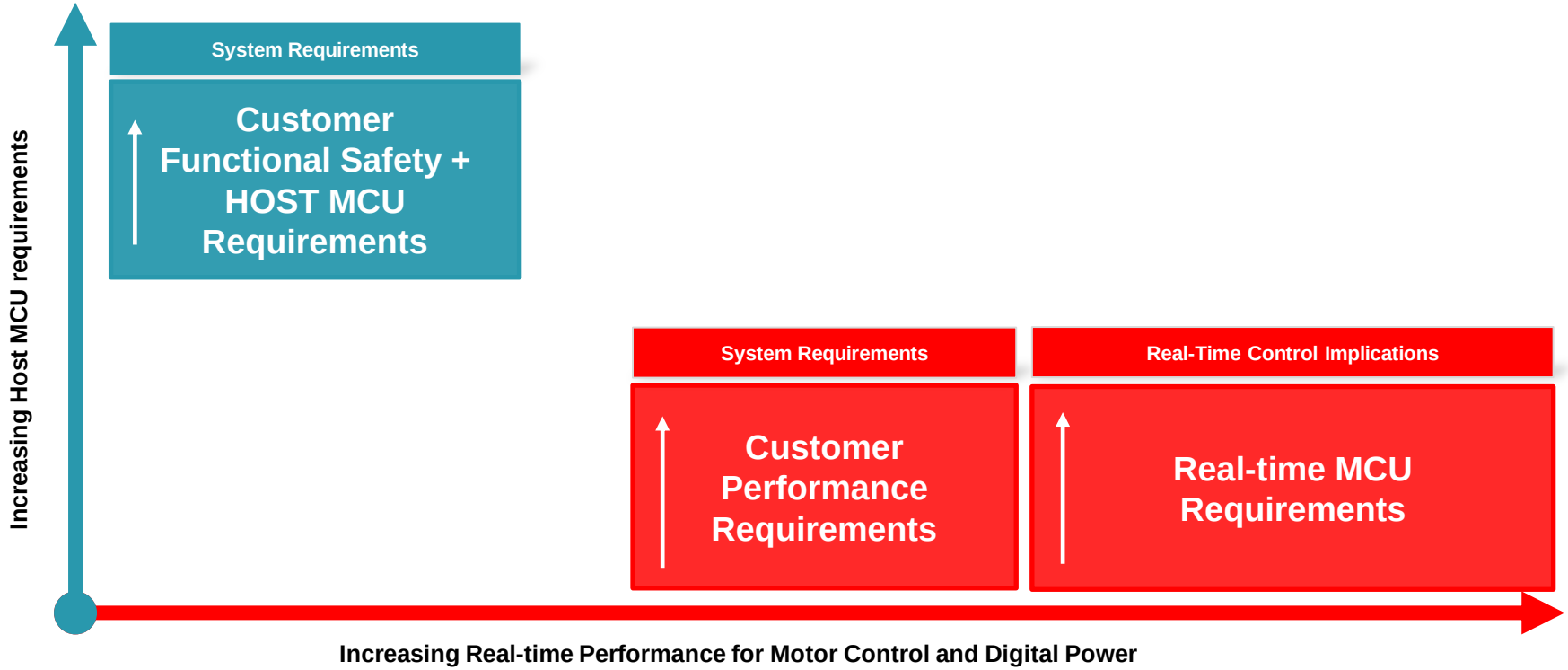
4 Traction Inverter
- Improve Acceleration or Save Battery Life
  - Integrate DC/DC Boost
  - Fast current loop algorithms (3x current-loop bandwidth)
  - Fast current loop algo (1/3 PWM frequency)
- Detect Motor Winding Faults
  - Motor Winding Fault Detection Algorithm (Kilby Labs)
- Back-up Virtual Resolver (lower-cost safety)

5 Compressor & Pumps
- Save EV Battery Life & Time to Market
  - InstaSPIN algorithm with low speed full torque (<500 rpm)
  - Observer algorithm for high speed heavy load



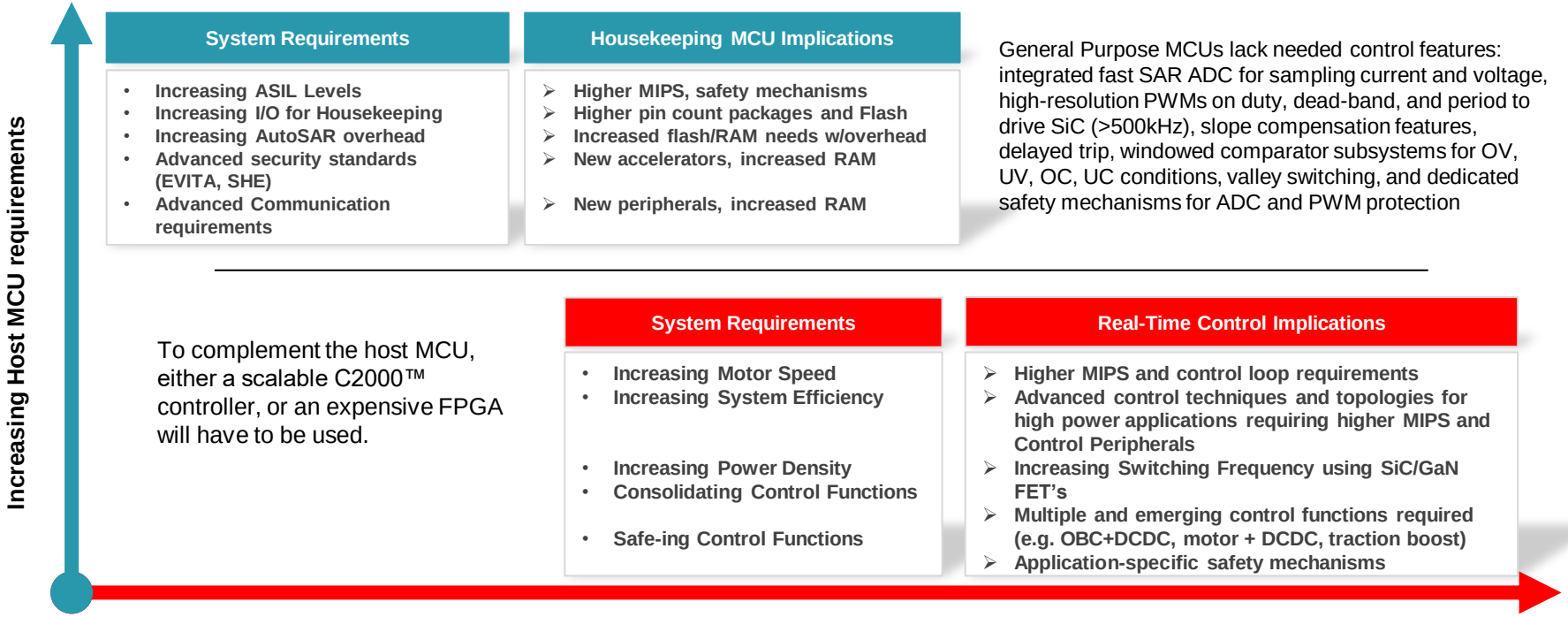
Electric Vehicle (EV) trends

Diverging requirements for Host MCU and Real-Time Control demands driving the need to adopt separate MCU's for each. Both vectors are increasing!



Real-time control performance increasing

General-purpose MCUs lack optimized real-time control architecture and peripherals/performance for realizing advanced real-time control.



ASIL-Decomposition

- Supported by ISO-26262

ISO 26262-9:2011(E)

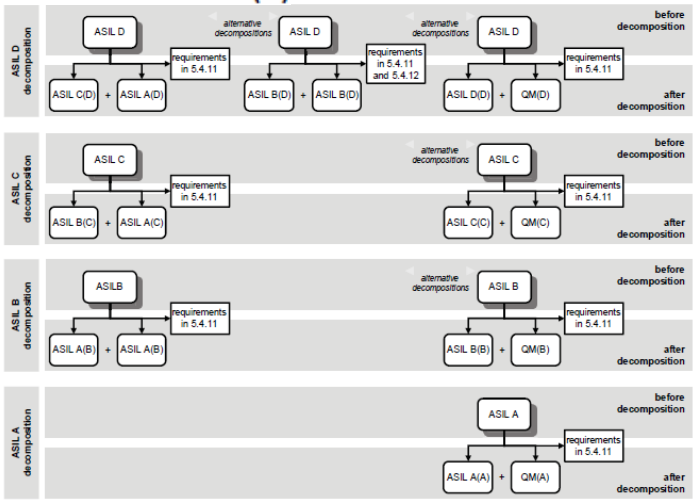


Figure 2 — ASIL decomposition schemes

5.4.9 When applying ASIL decomposition to a safety requirement, then:

a) ASIL decomposition shall be applied in accordance with 5.4.10;

b) ASIL decomposition may be applied more than once;

c) each decomposed ASIL shall be marked by giving the ASIL of the ASIL of the safety goal in parenthesis.

For Example

a) An ASIL D requirement shall be decomposed as one of the following:

1) one ASIL C(D) requirement and one ASIL A(D) requirement; or

2) one ASIL B(D) requirement and one ASIL B(D) requirement; or

3) one ASIL D(D) requirement and one QM(D) requirement.

Benefits *for Safety*

The advantages decomposed system (control + safety observer MCU) over a single chip are:

- A true ***dual-channel*** implementation
- A potential to implement ***fail-operational*** capability. i.e. if power to main power to control MCU is lost, then the safety observer may still provide limp mode functionality.
- Ease SW certification burden

C2000 F28004x

Production Now:

http://www.ti.com/product/TMS320F280049

Adv. IP

Differentiation

Optimized for Power Control Applications

Streamlined performance and power

- 100 MHz / 256 kB flash / 100 kB SRAM
- Floating Point and Trigonometric Math Unit
- Next Generation CLA; support for continuous background task
- 60% lower power consumption vs. F2806x + DC-DC option

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 most advanced control and protection mechanisms

Integrated analog and protection

- 3 12-bit 3.45MSPS ADC with post processing and threshold actions
- 7 on-chip PGA(3/6/12/24) with post gain filtering and bypass option
- 7 Windowed Comparators + 2 12-bit output DACs
- 4 Sigma Delta Demodulation Channels

F28004x

Temperatures: 125C | Q100

Sensing
- ADC1: 12-bit, 3.5 MSPS, 8ch
- ADC2: 12-bit, 3.5 MSPS, 8ch
- ADC3: 12-bit, 3.5 MSPS, 8ch
- 7x Windowed Comparators w/ Integrated 12-bit DAC
- 7x PGAs
- 4x Sigma Delta Channels (2x Filters per channel)
- Temperature Sensor
- 2x eQEP
- 7x eCAP (2x HRCAP)

Processing
- C28x™ DSP core 100 MHz
- FPU
- TMU
- VCU-I
- CLA core 100 MHz
- FPU
- 6ch DMA
- CRC

Actuation
- 8x ePWM Modules 16x Outputs (16x High-Res)
- Fault Trip Zones
- 2x 12-bit DAC

Connectivity
- 3x UART
- 2x I2C (1x true PMBus)
- 2x SPI
- FSI (Fast Serial Interface)
- 2x CAN 2.0B

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

Debug
- cJTAG / Real-time JTAG

Memory
- Up to 256 kB Flash +ECC
- Up to 100 kB SRAM +parity
- 2x 128-bit Security Zones
- Boot ROM
- InstaSPIN™ Motor ROM

Power & Clocking
- 2x 10 MHz OSC
- 4-20 MHz Ext OSC Input
- 1.2V VREG
- POR/BOR Protection

Configurable Logic Block
- 4 Tiles

Tools

F28004x Experimenter's Kit

Part Number: **TMDSCNCD280049C**
http://www.ti.com/tool/TMDSCNCD280049C

F28004x LaunchPad

Part Number: **LAUNCHXL-F280049C**
http://www.ti.com/tool/LAUNCHXL-F280049C

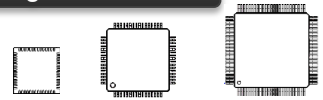
Software

C2000Ware™ Software Package

Application SDKs

SafeTI IEC60730

Packages

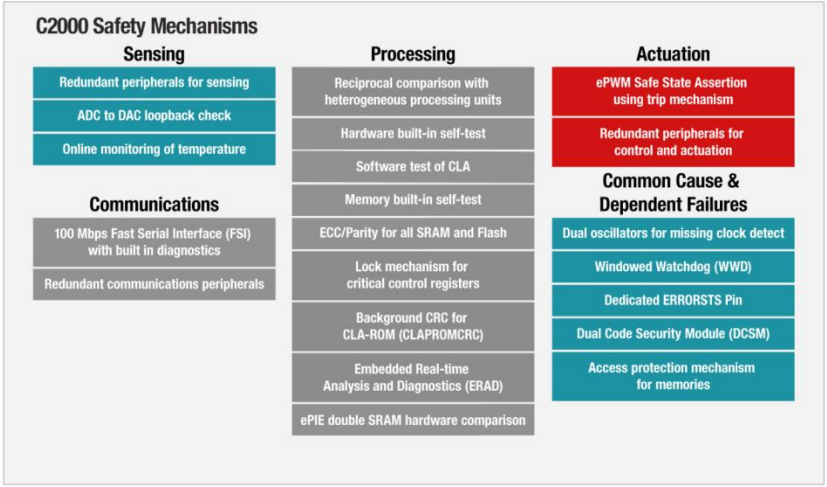


Package	Dimension
56-pin QFN	7x7mm
64-pin LQFP	12x12mm
100-pin LQFP	16x16mm

C2000 Functional safety overview

- C2000 Automotive MCUs are:
  - Developed using an ISO 26262 compliant HW development process that is independently assessed (by TUV-SUD) to meet systematic capability of ASIL-D
    - Download TUV-SUD certificate
  - F28004x and F2807x/37x have over 300 safety mechanisms described in functional safety manuals: (overview of C2000 Functional Safety Mechanisms)
    - Download F28004x Functional Safety Manual
    - Download F2807x/37x Functional Safety Manual
  - SafeTI™ Diagnostics Libraries: SW that accelerates designing for functional safety applications (available for F2807x/37x).
    - (Free) Access may be requested at: http://www.ti.com/tool/C2000-SAFETI-DIAGNOSTICS-LIB
  - Access tunable FMEDA with 5-part video training on how to tune FMEDA for your system
    - Request FMEDA access at: http://www.ti.com/lit/ug/spruic8b/spruic8b.pdf
    - FMEDA Tuning Video training at: https://training.ti.com/c2000-safeti-tunable-fmeda-training
  - C28x and CLA Compiler Qualification kit assists customers in qualifying their use of the TI C2000/CLA C/C++ Compiler to ISO 26262:
    - http://www.ti.com/tool/safeti_cqkit
  - C2000 MCUs are supported by Mathworks Simulink and embedded coder – learn more

All available on the web at:
www.ti.com/c2000safeti



Overview of C2000 Functional Safety Mechanisms

Streamline your system safety certification

SafeTI Diagnostic Library (SDL)

- (SDL) provides simple interfaces and a framework for
  - Initializing and enabling the functional safety mechanisms described in the functional safety manuals
  - Fault injection to allow testing of application fault handling
  - Profiling for measuring time spent in diagnostic test/fault handling
- Accompanying Compliance Support Packages (CSP) provide necessary documentation and reports to assist with compliance to a wide range of standards for automotive, industrial, and other applications

Detailed application reports available on ti.com:

C2000™ Hardware Built-In Self-Test
http://www.ti.com/lit/an/spraca7/spraca7.pdf

C2000™ CPU Memory Built-In Self-Test
http://www.ti.com/lit/an/spracb9/spracb9.pdf

Error Detection in SRAM
http://www.ti.com/lit/an/spracc0/spracc0.pdf

C2000™ CLA Self-Test Library
http://www.ti.com/lit/an/spraci3/spraci3.pdf

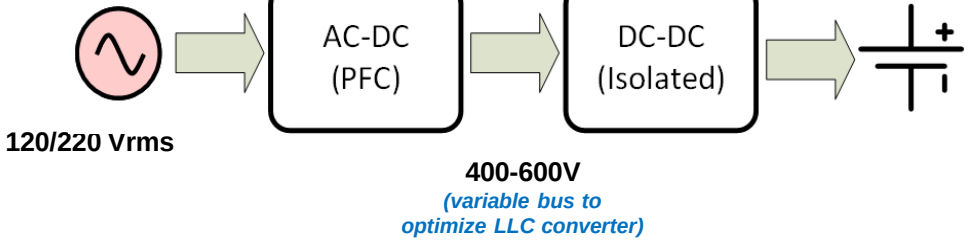
C2000™ Memory Power-On Self-Test (M-POST)
http://www.ti.com/lit/an/spraci7/spraci7.pdf

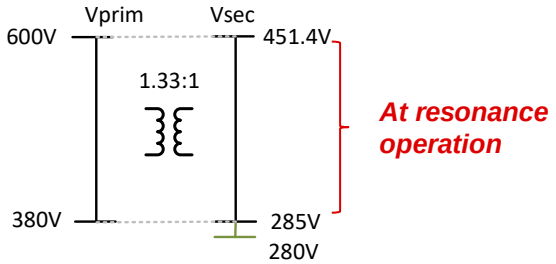
An introduction to ASIL decomposition and SIL synthesis
http://www.ti.com/lit/wp/sway028/sway028.pdf

Achieving Coexistence of Safety Functions for EV/HEV Using C2000™ MCUs
http://www.ti.com/lit/wp/swry027/swry027.pdf

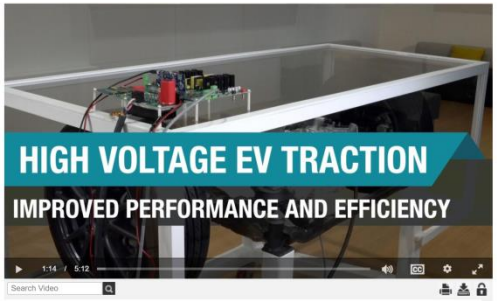
Variable DC Bus to optimize DC-DC converters

- LLC converters when operating away from resonance have high circulating currents and hence lower efficiency during that operation.
- As the battery voltage varies widely, a variable PFC link voltage concept can increase the region of operation at resonance and thus improve efficiency
- PFC efficiency will degrade but not significantly, specially if CRM mode PFC is used efficiency drop will be very low owing to ZVS operation. Even for CCM PFC efficiency drop from 400V to 600V is around 0.3% with SiC based design.

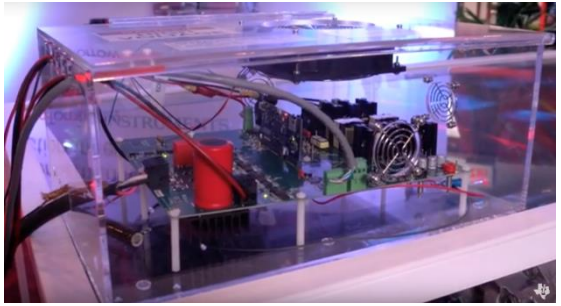




Demonstrating integrated HV Traction + DC/DC (CES 2019)



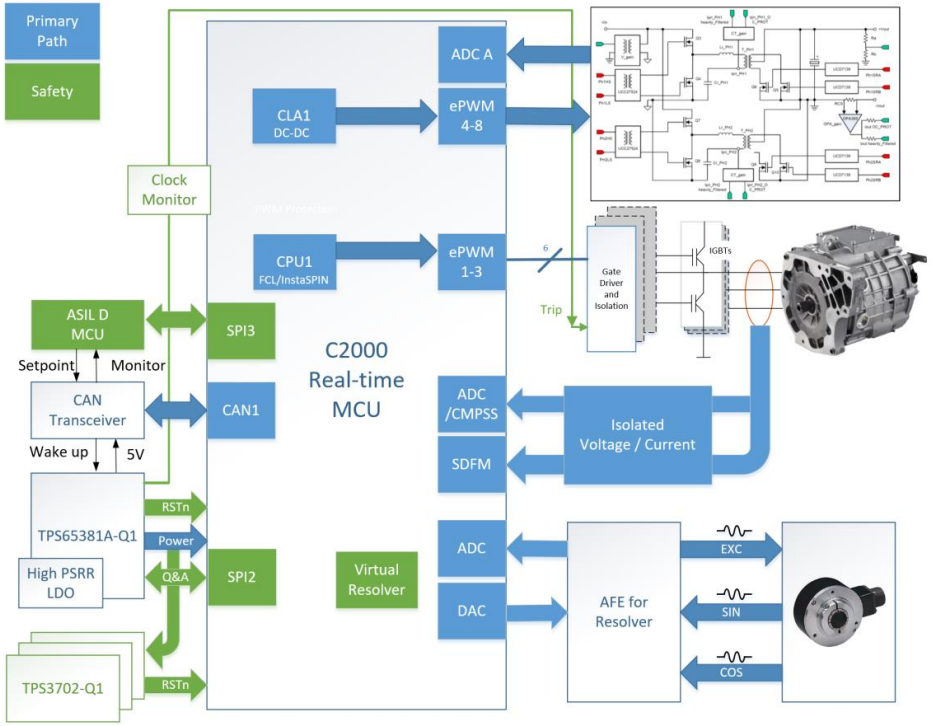
Video link



HV DCDC (400-12V) + 60kW HV Traction Inverter on single C2000 Real-Time Controller

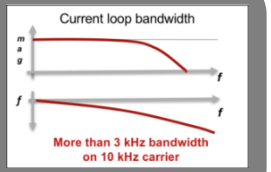
Formula 1: 150kW HV Traction Inverter + 400-48V DCDC >400kHz PWM switching with GaN on single C2000 Real-Time Controller in tight form factor

CES 2019 block diagram with C2000



Fast Current Loop for Performance

- Down to <1us current loop
- Allows for slower PWM switching frequency (better efficiency)
- Increase RPM and performance to reduce motor size

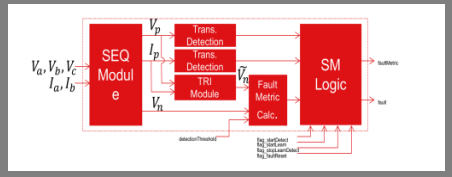


Integrate DC/DC for Performance & Cost Savings

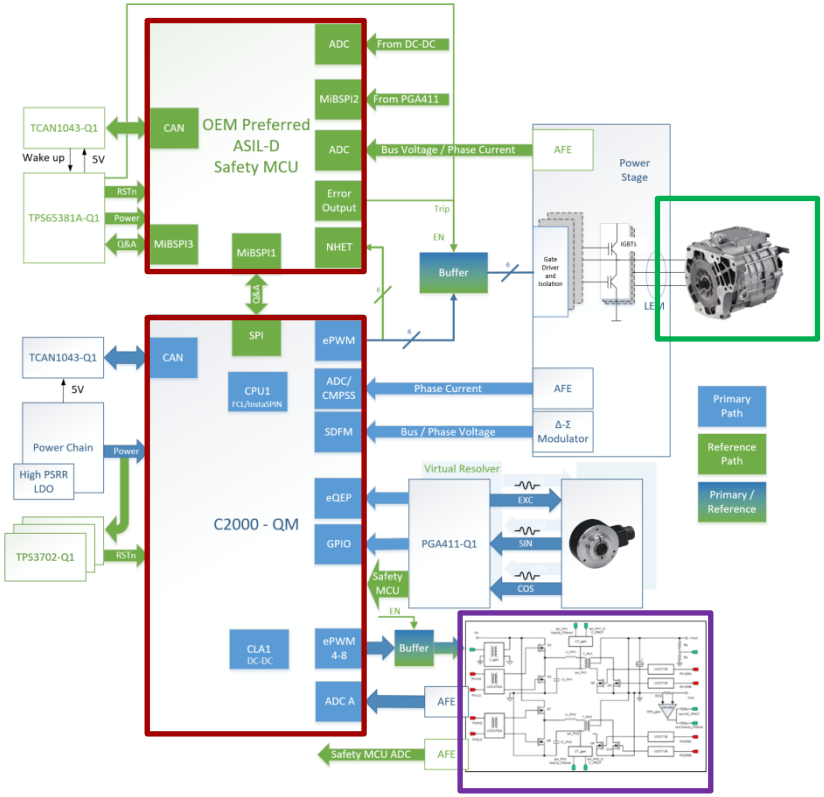
- DCDC (400-600V) to improve performance
- DCDC (400 to 12V) to save on cost
- Remove expensive relays with bi-directional DCDC
- SiC for increased power density (>500 kHz PWM)

Motor Diagnostics and Back-up for Improved Quality

- Detect winding faults
- Virtual back-up resolver

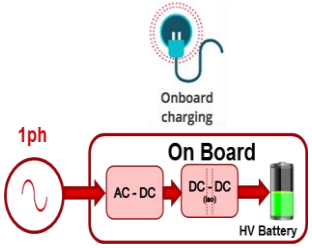


Integrated traction inverter proposal



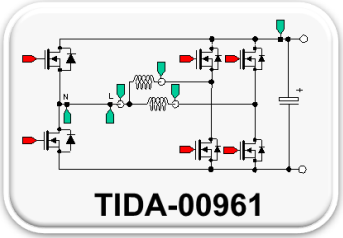
- **Opportunity to reduce cost with ASIL D Decomposition Architecture**:
  - ASIL-D(D) = ASIL-B(B) + ASIL-B(D)
  - ASIL-B MCU lower cost
  - Lower cost of ASIL-B AUTOSAR license
  - C2000 being certified for device level ASIL-B
- **Reduce Bill Of Material**
  - Integrate CPLD with expanded CLB-enabled C2000 devices
  - Leverage lower cost C2000 devices
- **Opportunity to integrate digital power into one mechanical box**
  - DCDC (400-12V) + Traction
  - OBC + DCDC + Traction
  - DCDC Boost (400-600V) + Traction
- **Opportunity to Increase Motor Performance & Efficiency**
  - Dual Motors
  - Motor Speed (>20k rpm)
  - DCDC Boost removes back EMI techniques

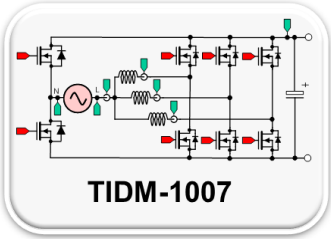
Reference designs to accelerate time to market



High Power Density, High Efficiency Totem Pole Bridgeless PFC Topologies

AC - DC





CRM PFC

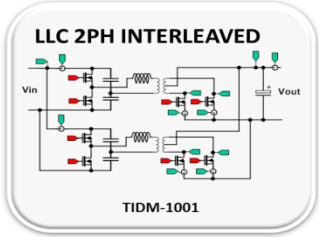
Fsw 200Khz to 1.2MHz with F28004x
Universal AC input, 400V DC Bus, Upto 1.6kW

CCM PFC

Fsw 100kHz with F28004x
Universal AC input, 400V DC Bus, Upto 3.3kW
*(*6.6kW SiC version TIDA-01604)*

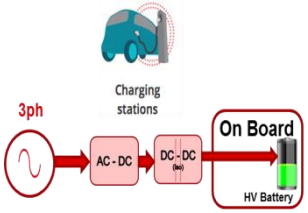
High Power Density, High Efficiency Isolated DC-DC Topologies

DC - DC (iso)

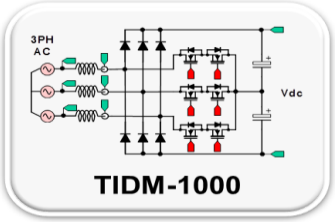


Interleaved LLC

with F28377D
400V DC Input, 12V DC Ouptut, 500W

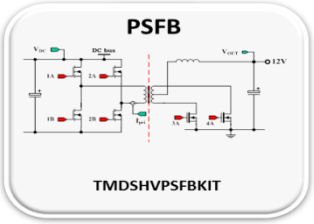


High Efficiency, Low EMI, Three Level Switching, Three Phase PFC Topologies



Vienna Rectifier based Three Phase PFC

Fsw 50kHz with F28377D
Universal three phase AC input, 600-700V DC Bus, Upto 2.4kW
(F28004x Version planned for 2Q Digital Power SDK Release)*



PSFB

with F28035
400V DC Input, 12V DC Ouptut, 600W

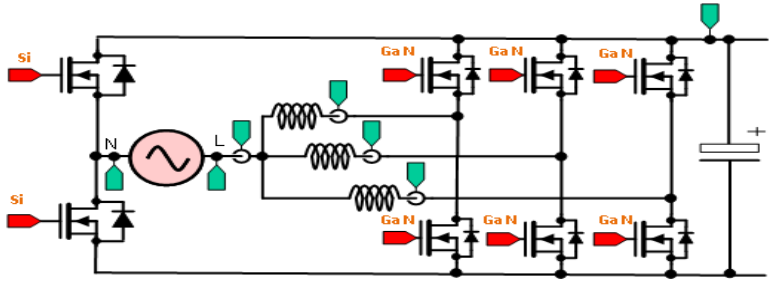
98.73% Efficiency, 3.3kW GaN based CCM Totem Pole PFC reference design for HEV & EV chargers/

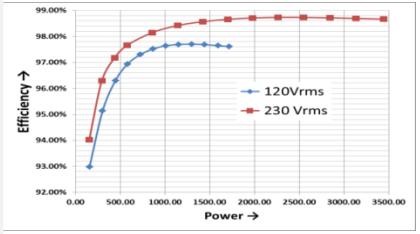
Reference design: TIDM-1007

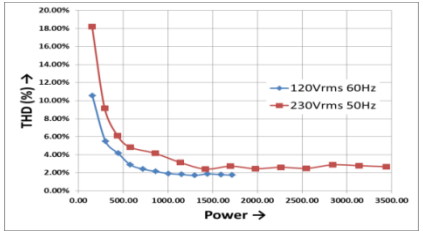
Features & Benefits

- Interleaved, 3.3-kW, Single-Phase, Bridgeless CCM Totem Pole PFC Stage using GaN
- 100-kHz Pulse Width Modulation (PWM) switching
- Programmable Output Voltage, 380-V DC Nominal
- Greater than 98% peak efficiency
- Less than 2% Total Harmonic Distortion (THD)
- poweSUITE support enables easy adaptation of software
- High power density design
- High performance C2000™ controller enables superior control and enables advanced control scheme to be implemented such as
  - Soft starting for totem pole bridge
  - Phase shedding to enable higher efficiency
  - Non Linear control loop to reduce voltage spikes
  - Adaptive deadtime for improved efficiency
  - Input cap PF loss compensation

http://www.ti.com/tool/tidm-1007





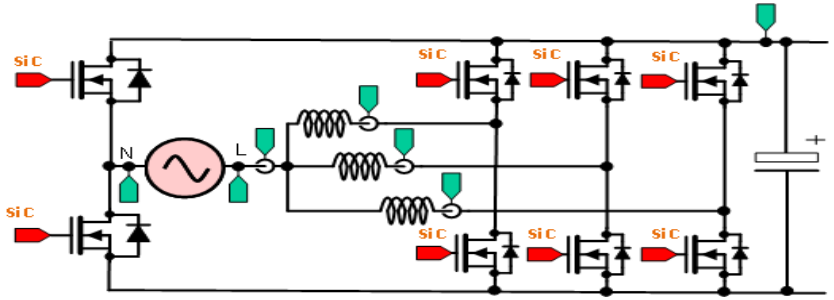


98.75% Efficiency, 6.6kW SiC based CCM Totem Pole PFC reference design for HEV & EV chargers

Reference design: TIDA-01604

Features & Benefits

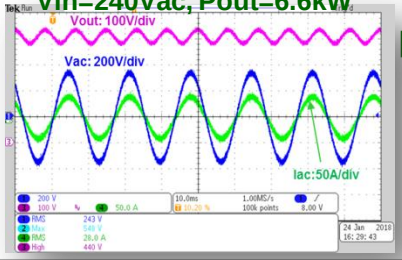
- Interleaved, 6.6-kW, single-phase, bridgeless CCM totem pole PFC stage using SiC
- 100-kHz Pulse Width Modulation (PWM) switching
- Variable output voltage for optimizing DC/DC stage efficiency, 400-600V DC
- Greater than 98% peak efficiency
- Less than 2% Total Harmonic Distortion (THD)
- High power density design
- High performance C2000™ controller enables superior control and enables advanced control scheme to be implemented
- High Common Mode Transient Immunity (CMTI) of >100V/ns



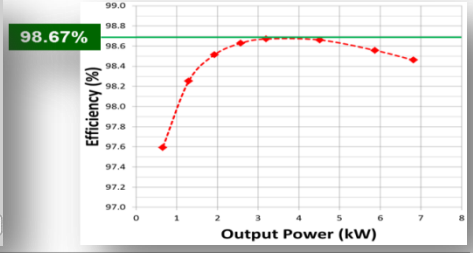
Size: 235mm X 85mm X 85mm

Measured Waveforms

Vin=240Vac, Pout=6.6kW



Measured Efficiency (vs) Load



http://www.ti.com/tool/tidm-01604

Texas Instruments

Bi-Directional CLLLC Resonant Dual Active Bridge (DAB) Reference design for HEV/EV onboard charger

Features

- V1: 400-600V DC (HV-Bus voltage/ PFC output)
- V2: 280-450V (battery)
- Power Level: 6.6kW
- CLLC symmetric tank capable of bi-directional operation
- Soft switching, across load, close to resonance operation achieves high efficiency, 98% Efficiency
- Snubber less design enables higher density
- Switching Frequency 500kHz nominal, 300-700kHz range
- Active synchronous rectification scheme implemented using Rogowski coil based current sensor
- Power Density of 40W/inch^3

Applications

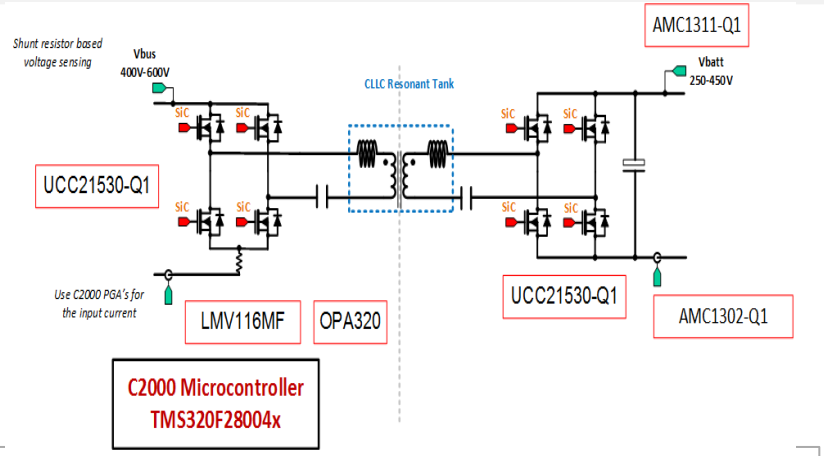
- On Board Chargers,
- Off Board Chargers
- Grid Storage

Tools & Resources

- **TI Devices**: TMS320F280049C, UCC21521, ISO7721-Q1,AMC1311-Q1, OPA320, LMV116MF, SN6505BDBVR, TPS7B6950QDCYRQ1

Benefits

- Type 4 PWM with Hi-Resolution on C2000 MCU enable high frequency resonant converters control.
- CMPSS, X-Bar and PWM enable active synchronous rectification for better efficiency.
- CLA enables integrated OBC with AC-DC and DC-DC controlled using one MCU
- SFRA enables quick verification of control design on resonant converters where mathematical model is not known



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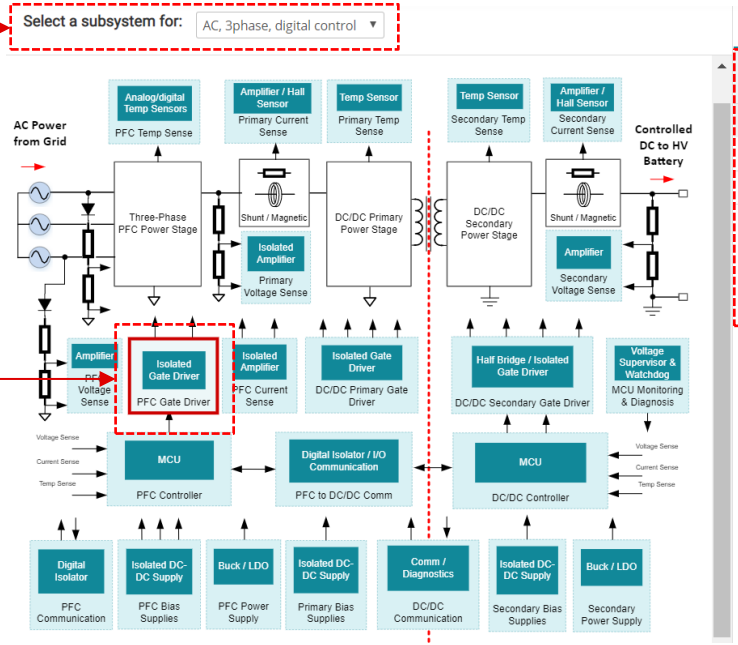
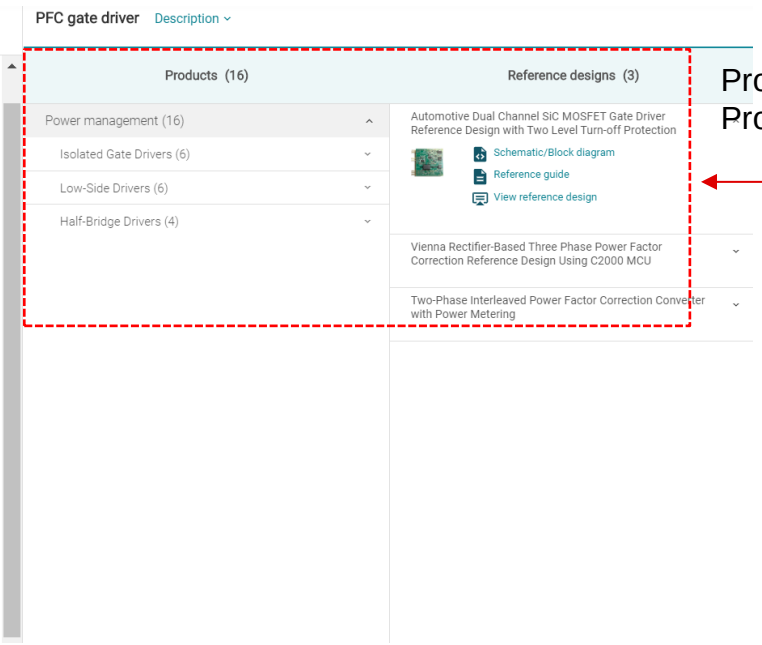
On-Board(OBC) & Wireless charger

TI Home > Applications > Automotive > Hybrid, Electric & Power Train Systems > On-Board(OBC) & Wireless Charger

Different Variants

Subsystems (clickable)





Product/Design Proposals

Thanks!