TI C2000™ MCUs for EV/HEV Powertrain

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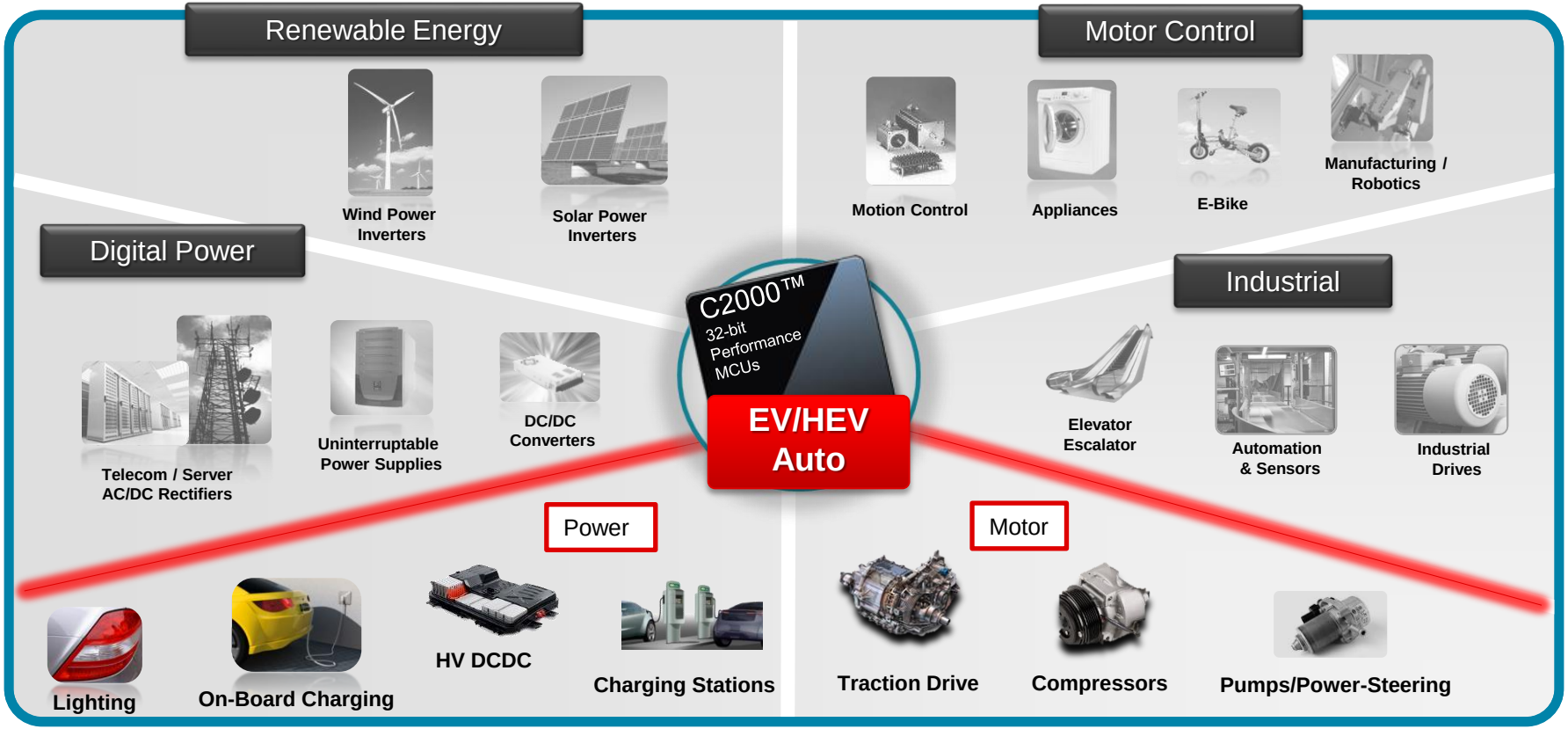
Apr, 2019

C2000™ Real-time Control Applications



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

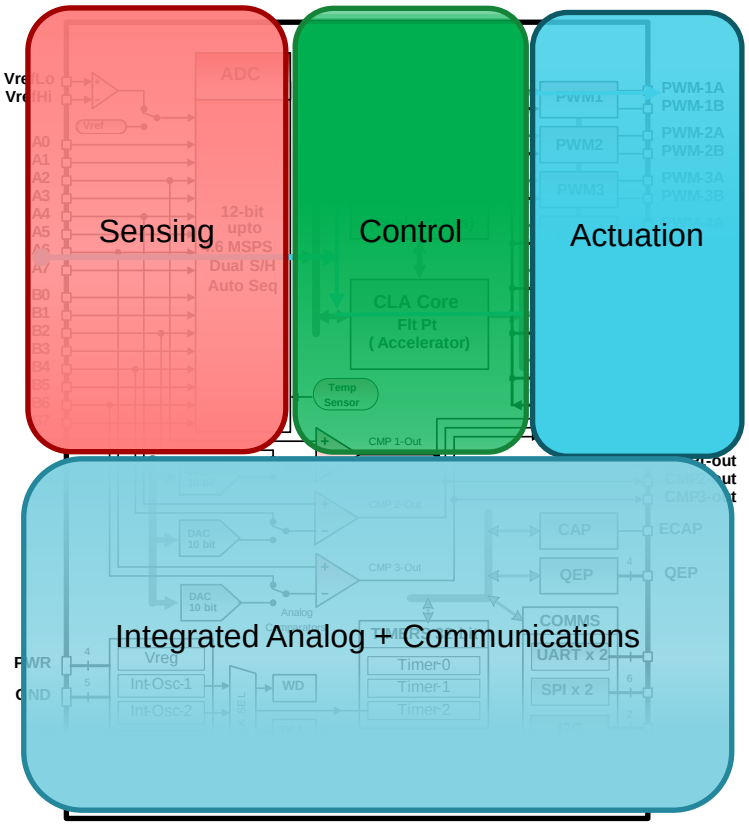
5

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)

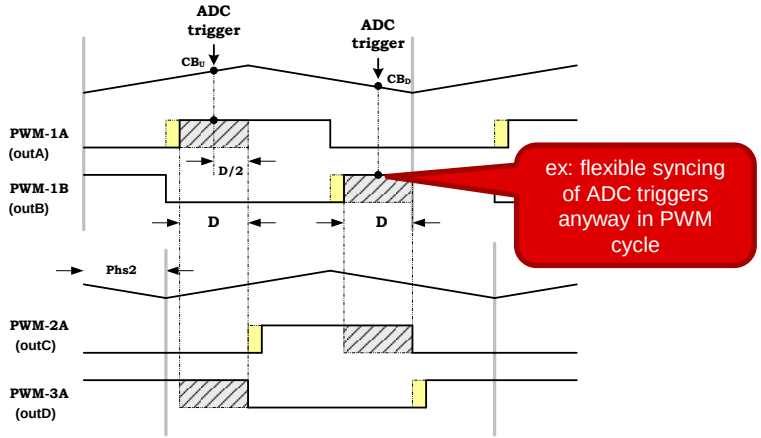
Why C2000? Architected for Power Electronics



Leading real-time control performance

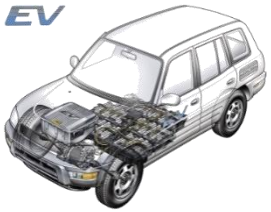
- High-performance C28x DSP Core for math intensive control algorithms
- Intelligent peripherals (PWMs & ADC) optimized over 20 years for control applications
- On-chip analog integration
- Robust software libraries (Digital Power / Motor Control)

Key to real-time control - ***cycle scavenging***



TI C2000™ Real-time MCUs @ a glance

Designed for EV



Digital Power

- On-Board Charging
- High voltage DCDC
- Charging Stations

Motor Control

- Traction Drive
- Compressor
- Pumps
- E-Turbo Charger
- Power Steering

About TI's C2000 MCUs

50+ million
C2000™ MCUs shipped in automotive industry

Started
with motor control for EPS systems

Roadmap
Enhancing real-time control performance, analog integration, and safety

EV/HEV Momentum

C2000 shipping in the top 10 EV OEMs Today

C2000 Designed for EV Vehicles

Power Conversion

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

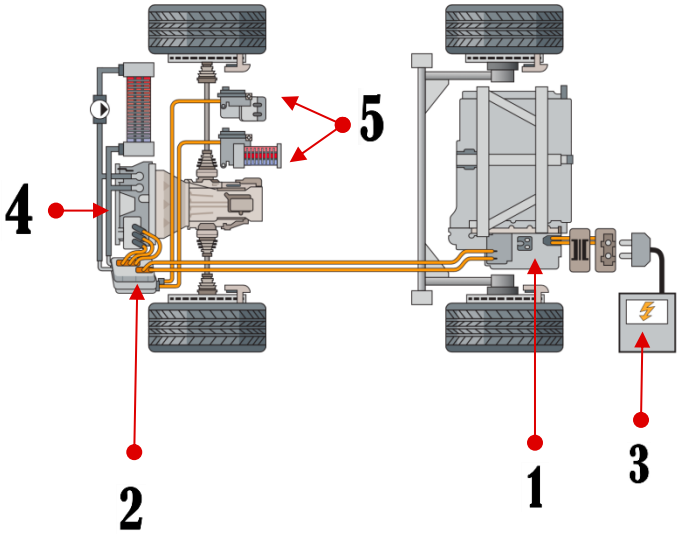
2 High Voltage DCDC
- Improve Efficiency & EMI
  - Zero Voltage Switching over wide load range (ex: PSFB >10% to higher)
  - Phase-shedding methods for interleaving (ex: LLC improved light load)
  - Mode transition techniques with different switching patterns (Current to Voltage)
  - Variable frequency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

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

Motor Control

4 Traction Inverter
- Improve Performance and Save Space
  - Integrate HV Bidirectional DC/DC with SiC
  - 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

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



C2000™ Applications Focus

Digital Power

EV Charging Stations, OBC, 400V-12V DCDC



Customer Benefits:

Fast Charging
High Performance DSP, Accelerators, Integrated Advanced Analog, and PWMs for 3PH PFC (AC/DC) Topologies

Power Density
F28377D/F28004x Integration allows for controlling multiple control loops and reducing size and BOM; Integrated DCDC on F28004x for lower active power consumption

Efficiency (>99%)
Many efficient power topologies proven by TI Designs (IL DCDC, IL PFC, Vienna Rectifier)

Motor Control

EV Traction Inverter, Compressors


Customer Benefits:

Time to Market
Motor SDK and example compressor applications allows full development with InstaSPIN.

Robust / High Performance
Algorithms for improving acceleration, reducing energy draw from the battery, and providing motor system diagnostics.

Motor Expertise
Decades of consistent motor control problem solving from C2000 product line

C2000™ EV Power Solutions

TIDesigns C2000 TI Designs	Type	Topology	TI Design #	Orderable Kit	Power Rating	Input	Output	Efficiency	Supported C2000 Products	Powersuite
 Charging Station	Isolated DC/DC	Phase-Shifted Full Bridge	TIDM-PSFB-DCDC	TMDSHVPSFBKIT	600W	400 VDC	12 VDC	95% peak	F28027	
	AC/DC	Totem Pole PFC (w/ GaN)	TIDA-00961 (CRM) TIDM-1007 (CCM) NEW!!		3KW at 220Vrms and 1.5KW at 110Vrms	Input: 80-260 Vac, 50/60Hz	400V DC	> 99% peak efficiency	F280049	Yes
	AC/DC	3PH Vienna Rectifier	TIDM-PFC-3PH-VIENNA NEW!!		1.2KW at 110Vrms and 2KW at 220Vrms	3PH 110/ 220Vac	700VDC	98% peak	F28377D	Yes
 DC/DC	Isolated DC/DC	Phase-Shift FB/Push-Pull	TIDM-BIDIR-400-12		300W	200VDC - 400VDC	9VDC- 13.5VDC		F28035	
	Isolated DC/DC	Resonant LLC		TMDSHVRESLLCKIT	300W	375-405 VDC	12 VDC	93% peak; 90%	F28027	
	Isolated DC/DC	Phase-Shift FB	TIDM-PSFB-DCDC	TMDSHVPSFBKIT	600W	400 VDC	12 VDC	95% peak	F28027	
	Non-Isolated DC/DC	Buck/Boost	TIDA-00558		600W	48VDC/ 12VDC	12VDC/48V		F28069	
 On-Board Charging	Isolated DC/DC	2PH IL Resonant LLC	TIDM-1001 NEW!!		500W	400VDC	12VDC	93% peak	F28377D	Yes
	AC/DC	Dual IL PFC	TIDM-2PHILPFC	TMDSILPFCKIT	700W	(110/ 220Vac)	400 VDC	0.99; <1.5% THD	F28035	Yes
	Isolated DC/DC	Phase-Shift FB/Push-Pull	TIDM-BIDIR-400-12		300W	200VDC - 400VDC	9VDC- 13.5VDC		F28035	
 AC Output	Non-Isolated DC/AC	Inverter	TIDM-HV-1PH-DCAC	TIEVM-HV-1PH-DCAC	600VA	400VDC	(110/ 220Vac)	98% peak; <5% THD	F28377D	Yes

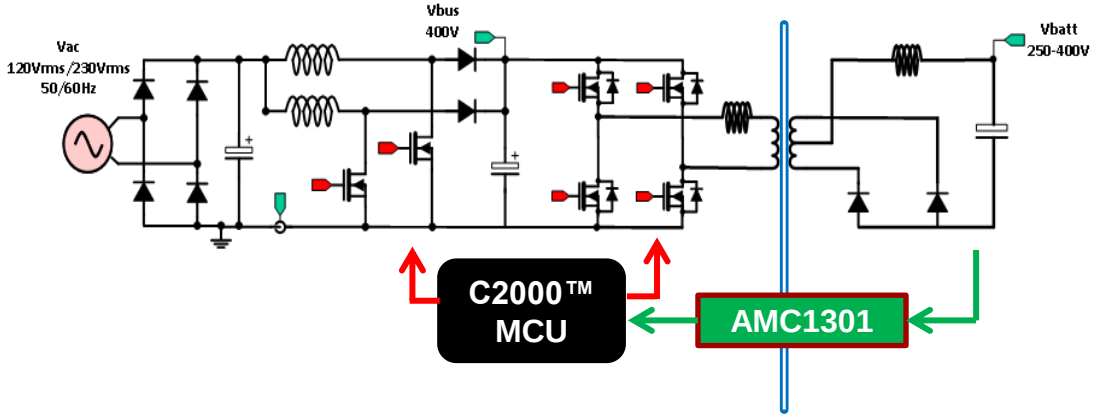
C2000™ Motor Solutions

TIDesigns C2000 TI Designs or Collateral	Benefits	Type	Topology	Collateral	Power Rating	Input	Supported C2000 Products	System Solution
 Traction	Fast Current Loop Motor Winding Fault Diagnostics Virtual Resolver	QM + ASILD	C2000+570	Detailed FMEDA			F2837xD, F2837xS, F28075	PGA411, DRV3201, PMIC TPS65381
				Functional Safety Manual			F28337D. F2837xS, F28075	PGA411, DRV3201, PMIC TPS65381
 EV Compressor	EV battery savings (run the motor at slower speed at full torque)	Hot-side Controller	3PH Half-bridge	TIDA-01418 New!	3.5KW	400V 8A	F28054F	InstaSPIN FOC

OBC & HV DCDC Architectures

Microcontroller System Architecture

❑Option 1



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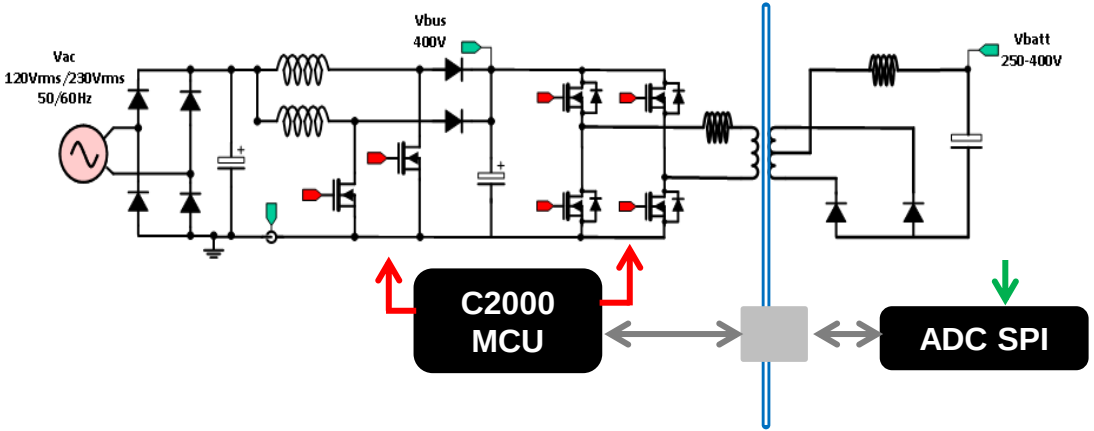
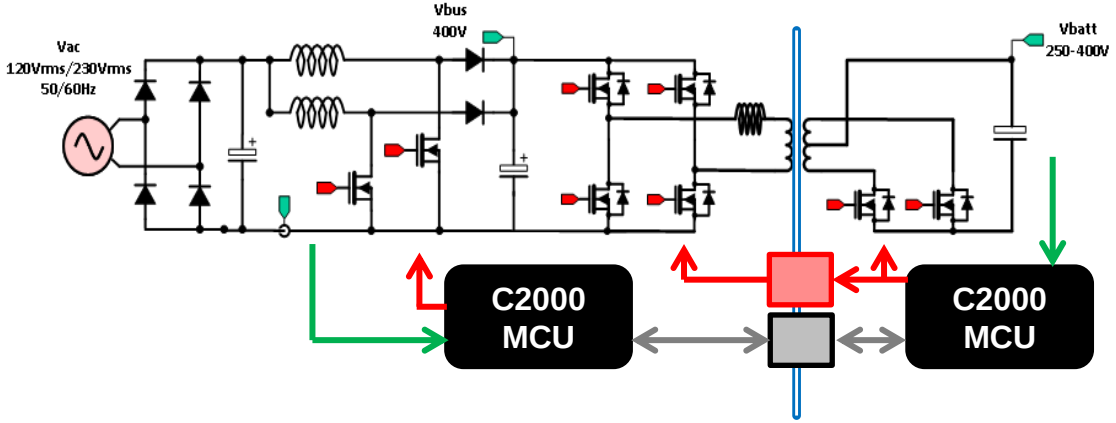
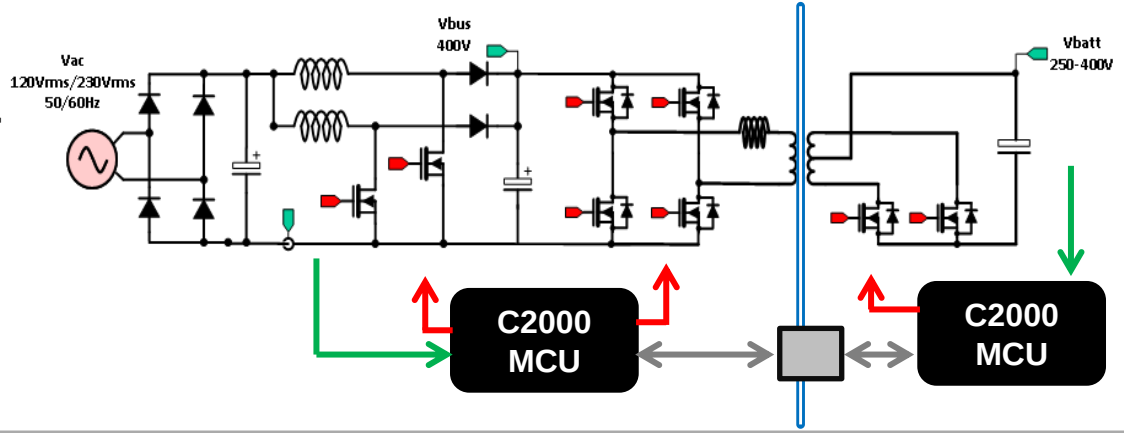


Microcontroller System Architecture

❑Option 3

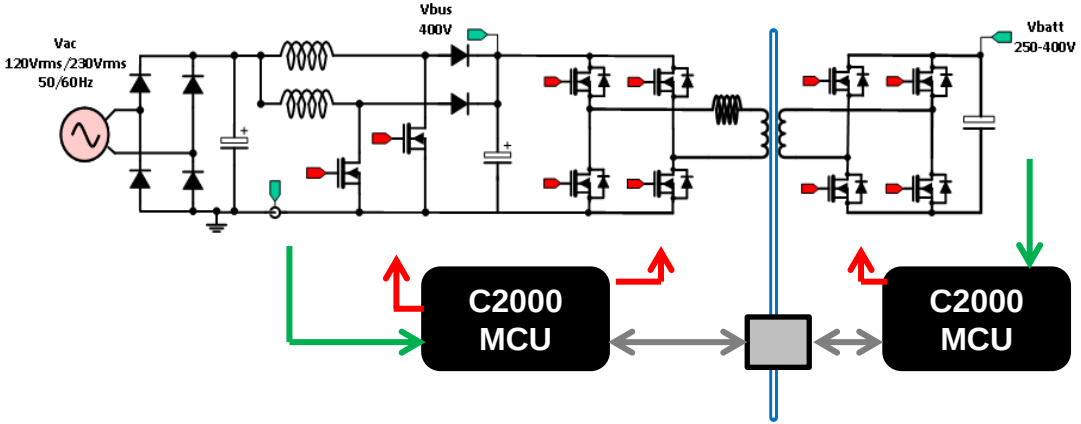


❑Option 4

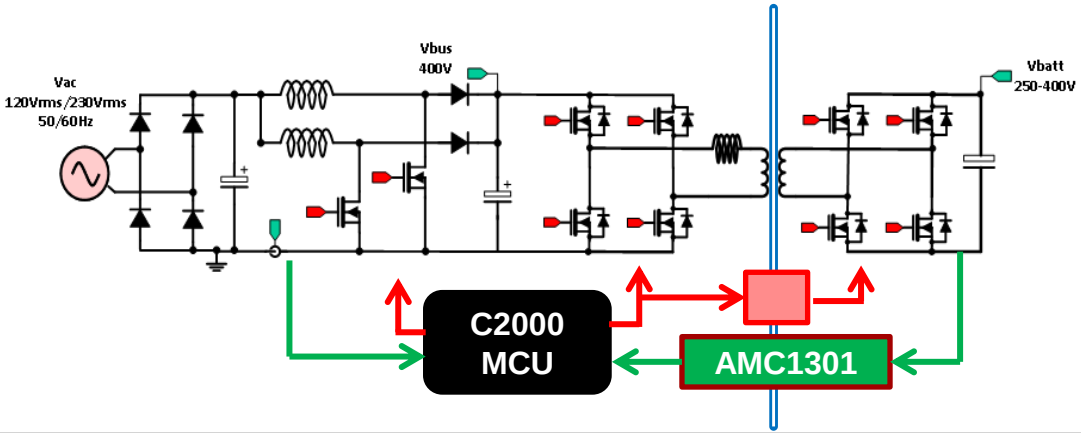


Microcontroller System Architecture

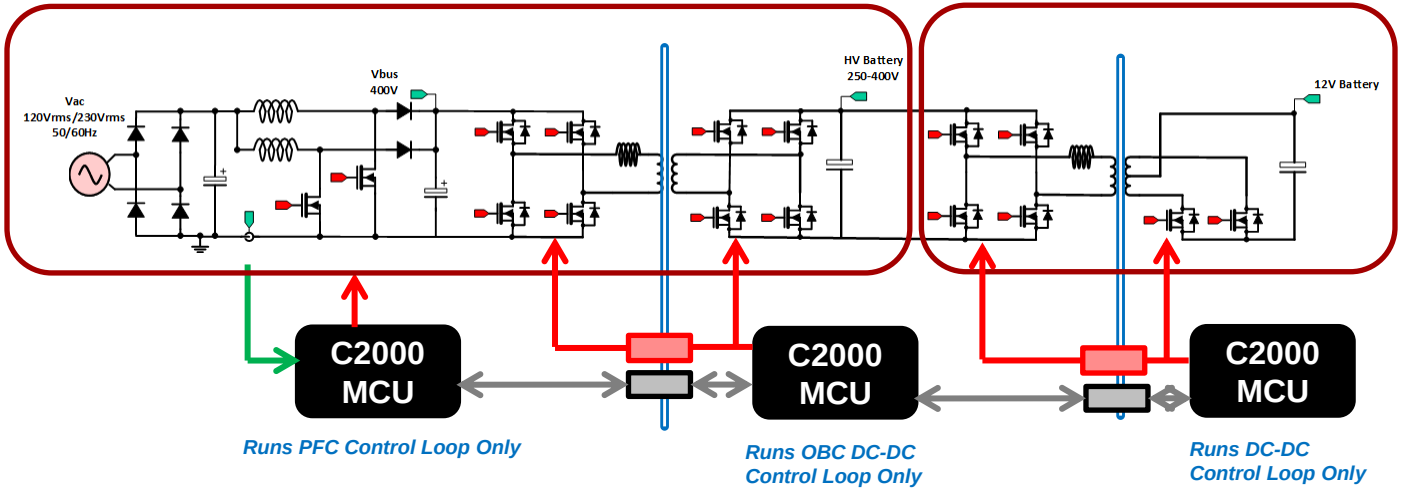
❑Option 5



❑Option 6

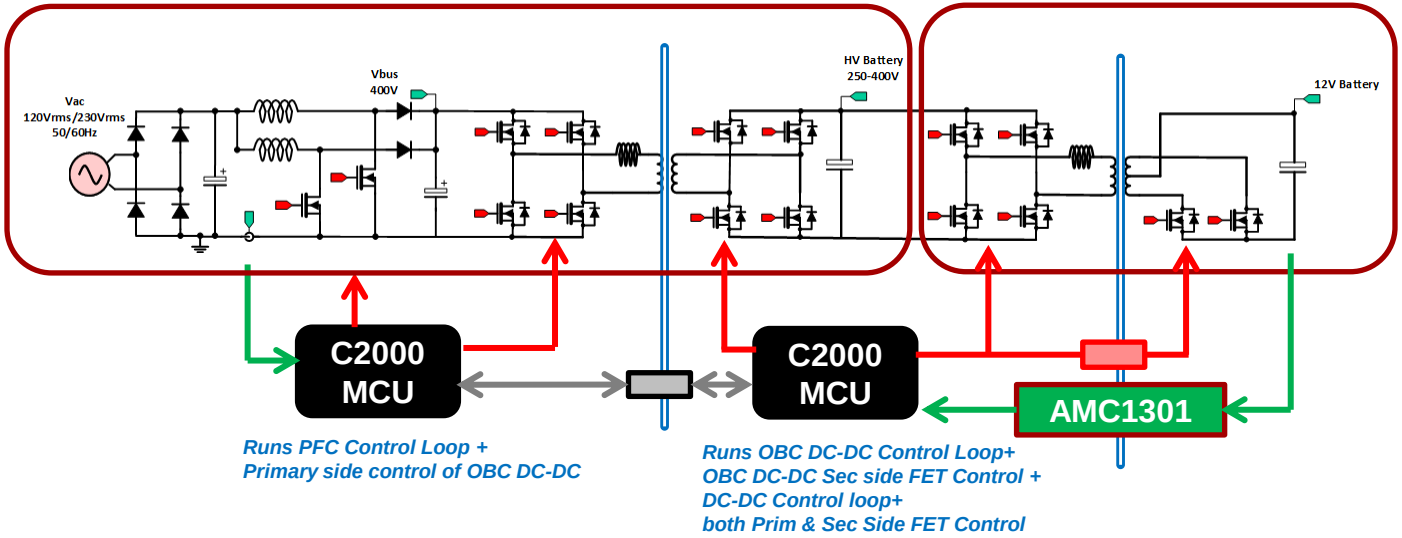


OBC + DC-DC



- No Analog Isolators
- Modular SW development
- 3 MCU solution

OBC + DC-DC Optimized



- 2 MCU solution
- Least number of digital isolators
- At least 1 iso-opamp needed

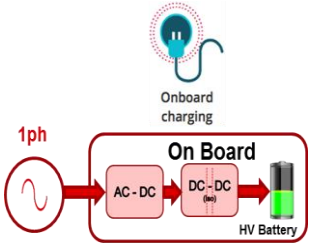
TI Reference Designs

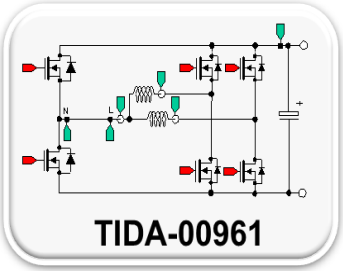
TI Reference Designs to Accelerate Time to Market

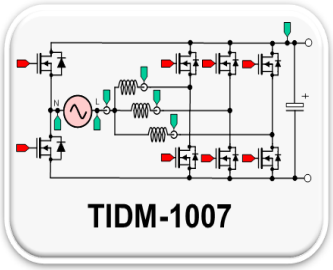
High Power Density, High Efficiency Isolated DC-DC Topologies

High Power Density, High Efficiency Totem Pole Bridgeless PFC Topologies

AC - DC







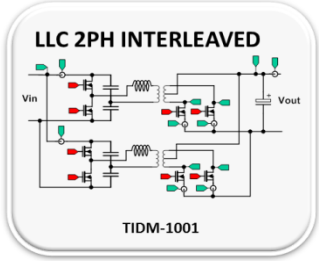
CRM PFC

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

CCM PFC

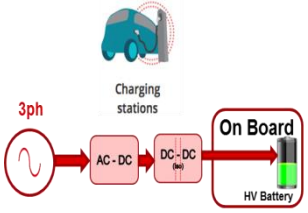
Fsw 100kHz with F28004x
Universal AC input, 400V DC Bus, Upto 3.3kW
*(*6.6kW SiC version being worked on TIDA-01606))*

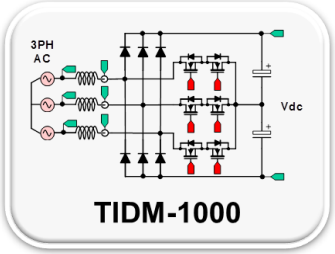
DC - DC (iso)



Interleaved LLC

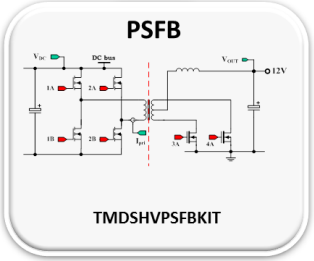
High Efficiency, Low EMI, Three Level Switching, Three Phase PFC Topologies





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)*

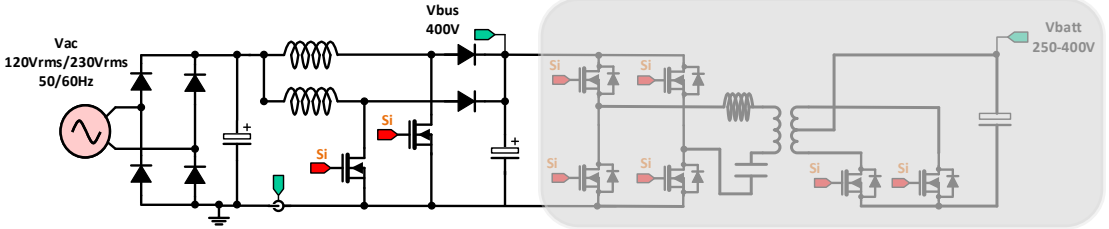


PSFB

***New Design in Concept Phase targeting specifically OBC application*

OBC Topologies : AC-DC

Conventional PFC

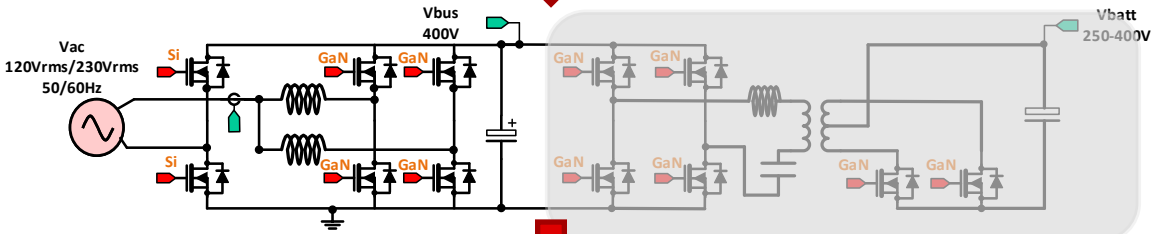


TIDM-2PHILPFC

PFC Efficiency Improvements

- Diode Bridge Losses improvement with interleaved totem pole bridgeless PFC (**CCM**)
- Optimized ZVS & ZCS (**CRM**)
- Switching loss optimization

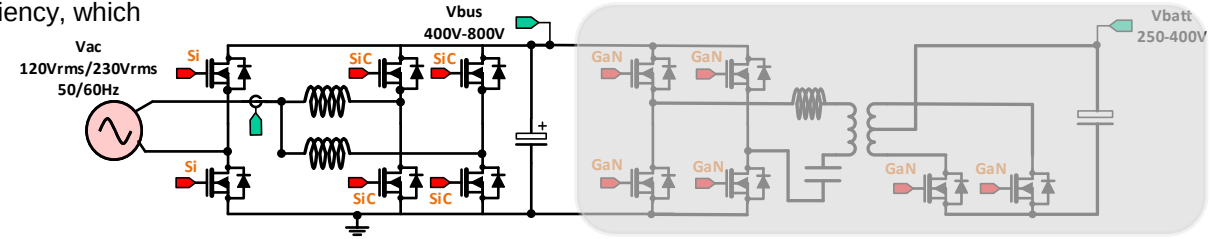
With migration to GaN



TIDM-1007
TIDA-0961

DC-DC ZVS ZCS Optimization

- Variable Bus Voltage allows for ZVS and ZCS across a greater range, thus improving efficiency, which necessitates switch to **SiC**



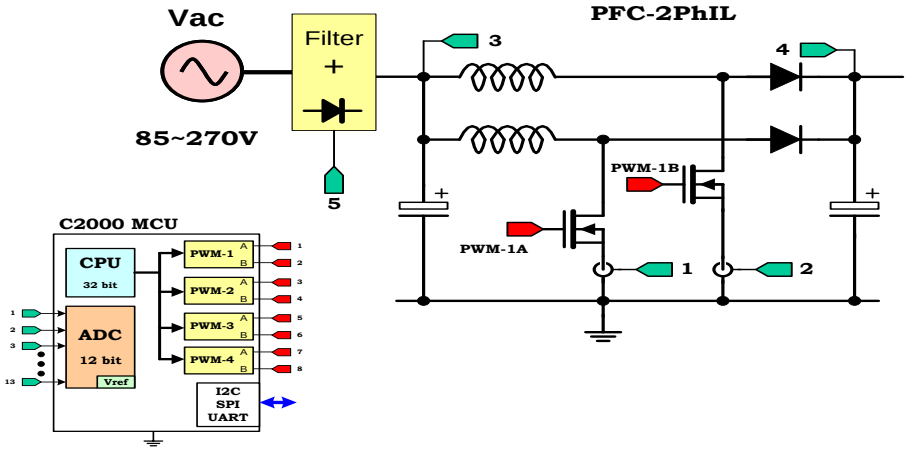
TIDA-01604

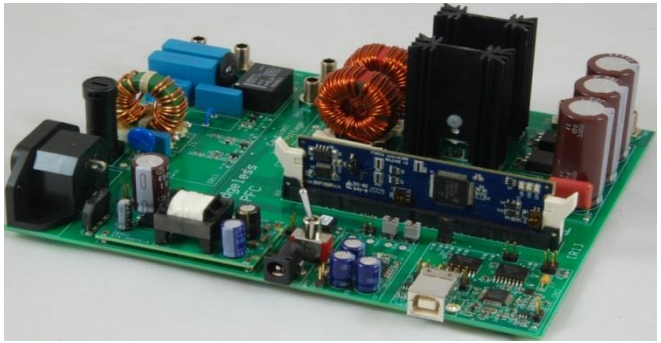
TIDM-2PHILPFC: 2-Phase Interleaved Boost PFC

Description

- 750W Pout, 400V DC Bus
- 90~264Vrms, 47~63Hz
- 2 phase interleaved Boost PFC
- Isolated JTAG
- High Efficiency (LL, HL – 94%, 96%)
- PF 0.99, HL Light Load - 0.92(Min)
- 200kHz Switching Frequency
- Fast Vin Feed Forward
- Adaptive current loop, Non-linear voltage loop
- OVP, Soft-start, Inrush current limit
- Input RMS current, voltage, power & frequency measurement

http://www.ti.com/tool/TIDM-2PHILPFC





TIDM-1007 Interleaved CCM TTPL PFC

Features

- GaN based Totem Pole 1PH PFC with three interleaved phases using LMG3410 & controlled using C2000 MCU
- Power Spec
  - Input: 80-260 Vac , 50/60Hz
  - Output: 400V DC
  - Power: 3KW at 220Vrms and 1.5KW at 110Vrms
  - Efficiency : > 99% peak efficiency
- Low total harmonic distortion (THD) < 1% (at low line)
- 100-140kHz PWM switching
- Soft starting for totem pole bridge
- Phase shedding to enable higher efficiency
- Non Linear control loop to reduce voltage spikes

Applications

- On –board chargers for EV
- Telecom Rectifiers
- Other industrial applications

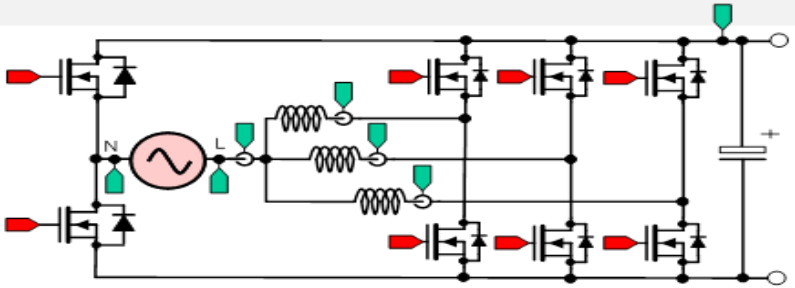
Tools & Resources

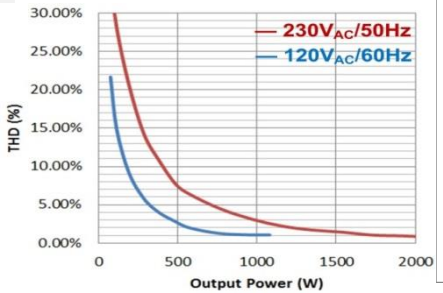
- **Key TI Devices:** TMS320F28075, LMG3410, UCC27714D, UCC28740, UCC24636

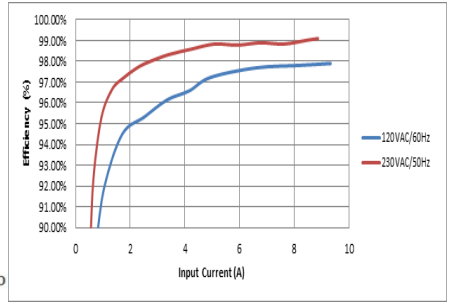
Available Today!! http://www.ti.com/tool/tidm-1007

Benefits

- High power density design, with form factor matching OEM specifications
- Using latest TI-GaN with integrated gate drivers offering greater integration for the customers.
- High performance C2000 controller enables superior control and enables advanced control scheme to be implemented







TIDA-01604

6.6kW Totem-Pole PFC with SiC MOSFETs for High Voltage Battery On Board Charger

Design Features

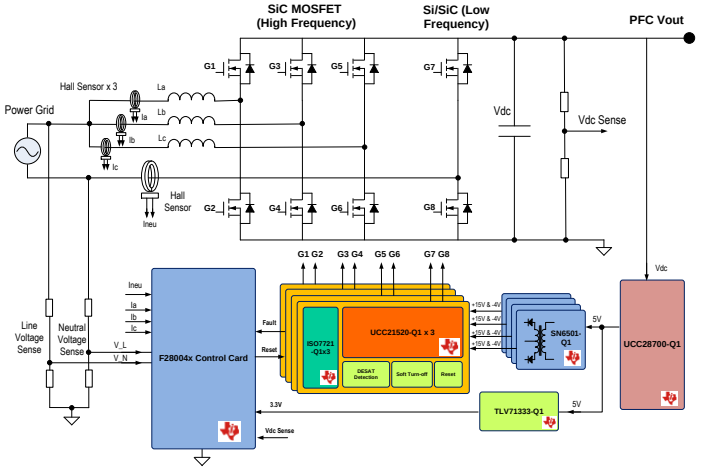
- Using UCC21520-Q1 with SiC FETs & C2000 MCU controller
- Power Spec
  - Input: 85-264 Vac , 50/60Hz
  - Output: 400V-600V DC
  - Power: 6.6KW at 240Vrms
  - Efficiency : > 98.5% peak efficiency
- 70-100kHz PWM switching
- Low total harmonic distortion (THD) ~ 1-2% (at low line)
- Soft start for totem pole bridge
- *Short circuit protection with two-level turn off*
- *High Common Mode Transient Immunity (CMTI) of > 100 µV/ns*
- Phase shedding to enable higher efficiency
- Variable output voltage for optimizing DC/DC stage efficiency

Tools & Resources

- **TIDA-01605 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** TMS320F28004x, UCC21520-Q1, SN6501-Q1, ISO7721-Q1, UCC28700-Q1

Design Benefits

- High power, high efficiency power design with liquid cooling for powering the systems up to 6.6kW
- Using SiC MOSFETs with TI Drivers offering greater integration for the customers
- Synchronize for multiple phase operation
- High power factor and low total harmonic distortion (THD)
- High performance C2000 controller enables superior control and enables advanced control scheme to be implemented



TIDM-00961 : >99% Efficiency, Compact Size, 1.6KW, Totem Pole PFC Reference design for Telecom & Server Power Supplies

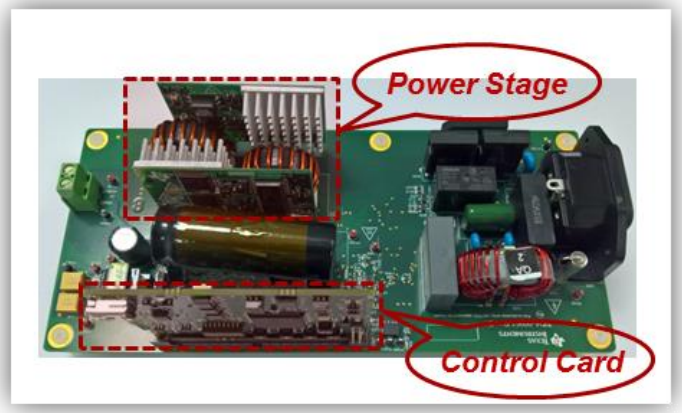
TIDesigns

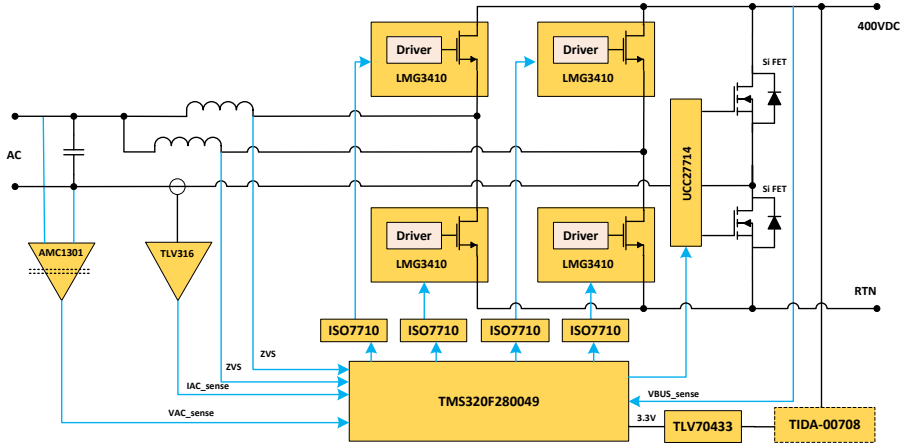
Features

- TMS320F28004x Controller based fully programmable solution
- Wide input voltage range: 85 – 265 VAC
- Output Power: 1.6 KW, 4.1A @ 390V
- Efficiency: > 99% ; Power Factor : >0.99
- Compact Form Factor (65 x 30 x 40 mm)
- Meets Norms: IEC 61000-3-2 (iTHD) EN 55011 class A (CE), IEC6000-4-4 (EFT), and Surge IEC61000-4-5
- Precise input power consumption measurement

Benefits

- **Super High Efficiency** makes thermal design simpler
- **Extremely compact** solution with low component count
- Makes compliance with **80 Plus Titanium specs** easier
- Addresses universal AC input requirements
- Integrated GaN FET and driver eases layout constraints
- High power factor > 0.99 and less than 5% THD for 20% to full load





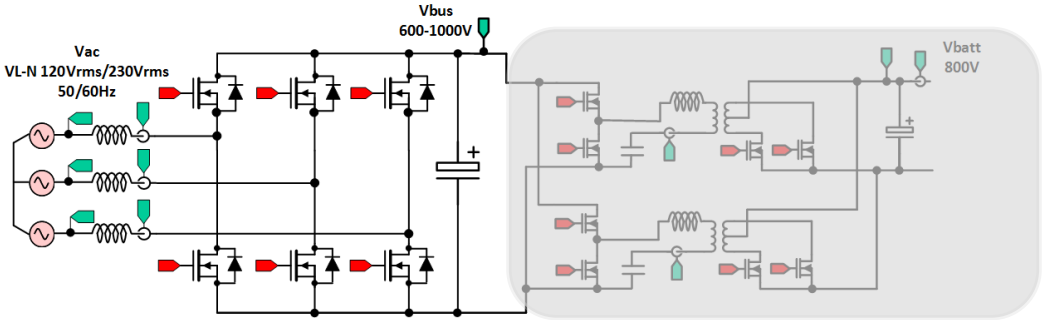
Available Today!! http://www.ti.com/tool/tida-00961

High Power OBC & Fast Chargers: AC-DC

TIDesigns

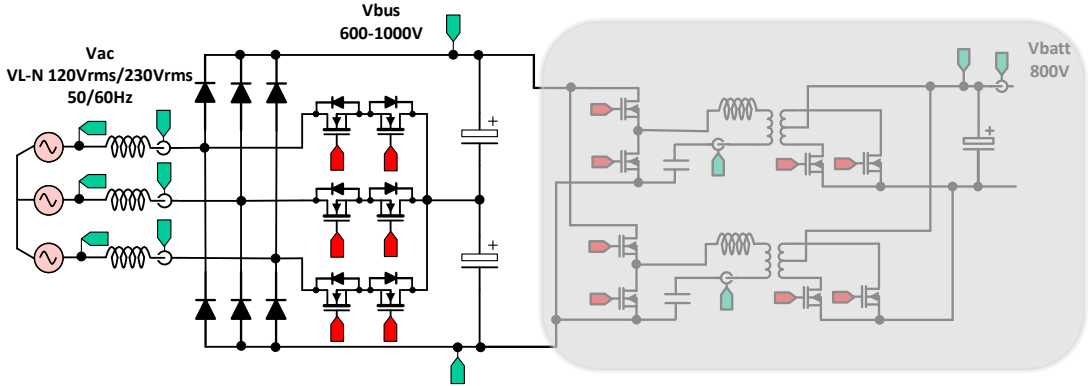
Higher power OBC or Off-Board / **Fast Chargers** require three phase PFC

Option 1
Totem Pole based
Three Phase PFC



Concept Phase

Option 2
Vienna rectifier based
Three Phase PFC



TIDM-1000

3Ph VIENNA Rectifier PFC - TIDM-1000

Features

- Three Phase Power Factor Correction Rectifier Design using Vienna Rectifier controlled using C2000 MCU
- Power Spec
  - Input: Three Phase 110Vrms/50Hz or Three Phase 220Vrms/60Hz
  - Output: 500V-700V DC with 110Vrms Input 700V DC with 220Vrms Input
  - Power Max: 1.2KW at 110Vrms or 2KW at 220Vrms
- Efficiency Target : 98% peak efficiency
- Low total harmonic distortion (THD) <4%
- 50kHz PWM switching

Applications

- EV Charging Stations
- Telecom Rectifiers
- Drives, Welding and Other industrial applications

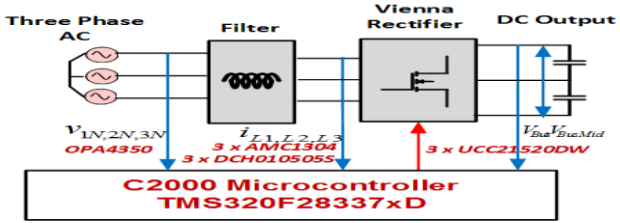
Tools & Resources

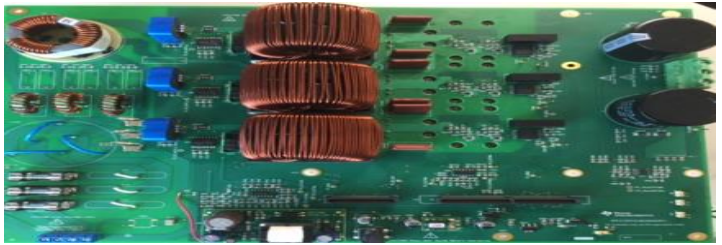
- **TI Devices**: TMS320F28377D, UCC21520DW, OPA4350UA, AMC1304, AMC1301, OPA320, DCH010505SN7, PTH08080WAH, TLV1117-33CDCYR, TPS71501DCKR

Available Today!! http://www.ti.com/tool/tidm-1000

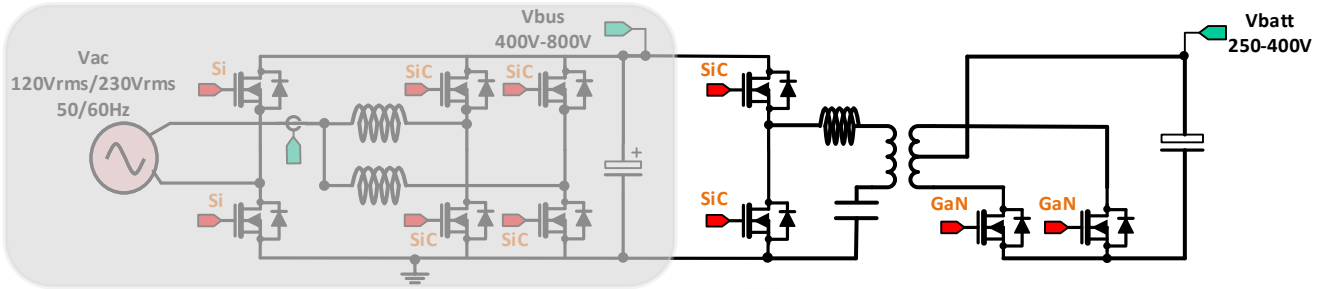
Benefits

- powerSUITE enables easy adaptation of the TI Design to a custom power level and tuning of loops
- TMU accelerator enables fast control loop execution
- In built Sigma Delta Demodulators enables accurate current sensing
- On chip windowed comparators reduced components required for protection
- SFRA enables quick verification of control design

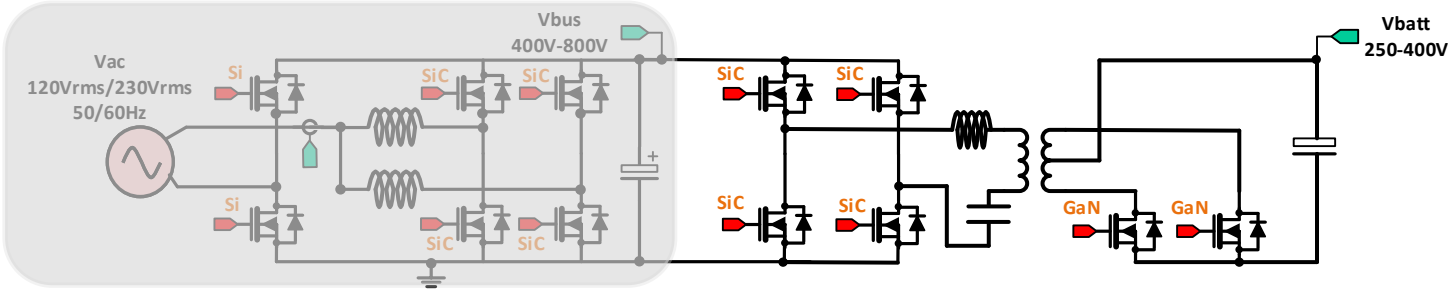




OBC DC-DC: Isolated HV DC-DC Topologies



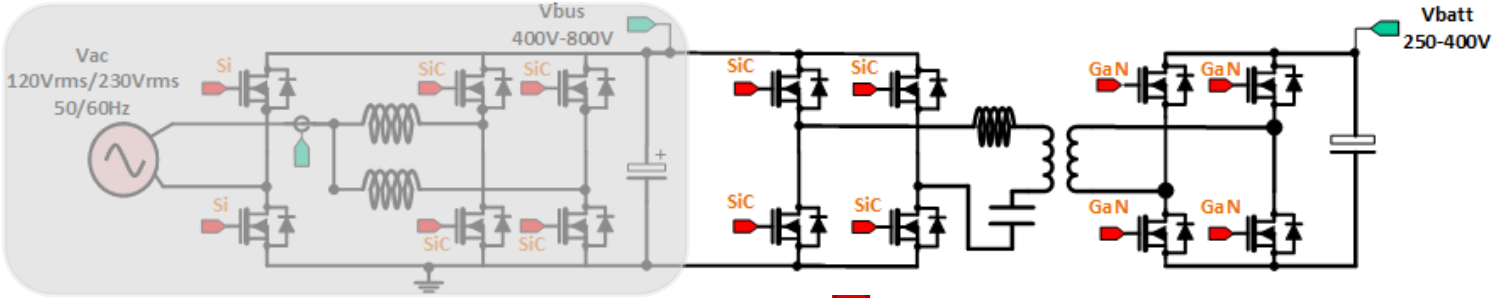
Higher Power , higher efficiency requirements require **full bridge** so that the current stress are reduced, transformer magnetics are better utilized.



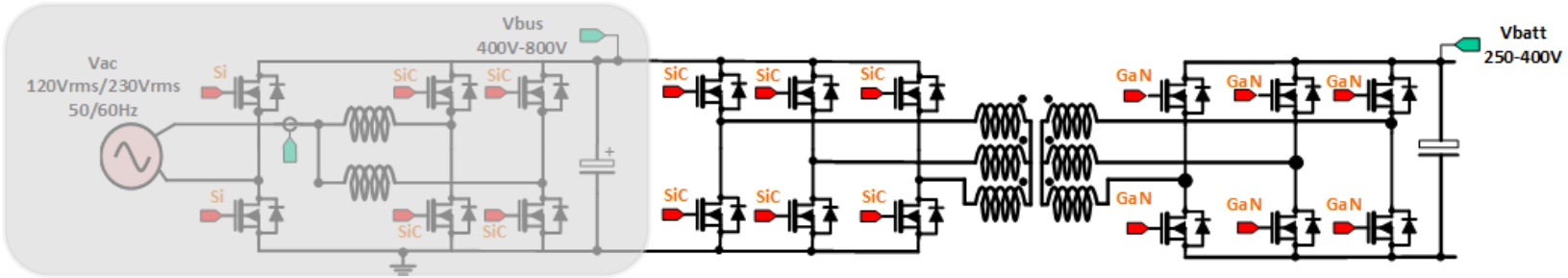
Center tap transformer adds cost and does not utilize the magnetics fully, hence a full bridge on the secondary side that **avoids the center tap transformer** is preferred for high power, high voltage application

OBC DC-DC: Isolated HV DC-DC Topologies

Dual Active Bridge (DAB)



Further higher power can mandate use of
multi phase DAB



TIDM-02002 - Bidirectional CLLLC resonant dual active bridge (DAB) reference design for HEV/EV onboard charger

Features

- V1: 380-600V DC (HV-Bus voltage/ PFC output)
- V2: 280-450V (battery)
- Power Level: 6.6kW
- CLLLC 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

Applications

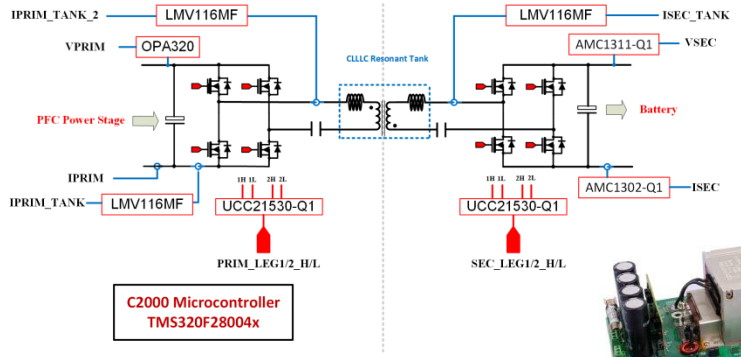
- On Board Chargers,
- Off Board Chargers
- Grid Storage

Tools & Resources

- **TI Devices**: TMS320F280049C, UCC21530, 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



C2000Ware DigitalPower SDK

Texas Instruments

SFRA | Compensation Designer | Solution Adapter

Industry's Most Comprehensive Digital Power Solutions

AC-DC (PFC)

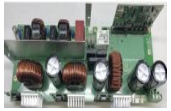
1PH Diode Bridge based Valley Switching PFC
F28004x (uses CLA)

TIDM-1022

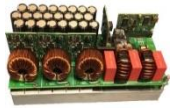
1PH Totem-pole PFC Critical Mode (CRM)
F28004x

TIDA-00961

1PH Totem-pole PFC Continuous Conduction Mode (CCM)
F28004x (CLA enabled)



TIDM-1007



TIDA-01604

3PH Vienna Rectifier Based PFC
F2837x, F28004x
(CLA enabled)

TIDM-1000

Also see Bi-directional DC-AC TIDA-010039

DC-DC

CLLLC Isolated DC-DC
F28004x (uses CLA)

TIDM-02002

DC-AC (Inverter)

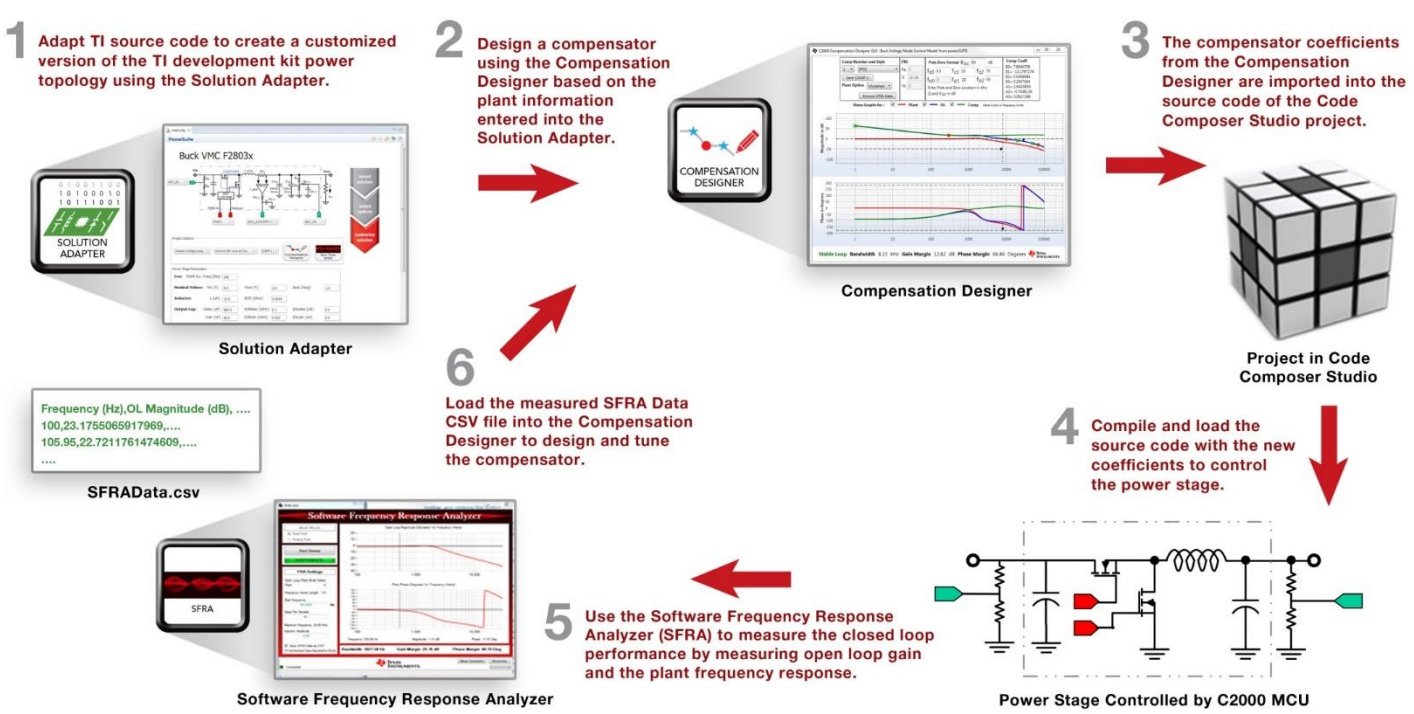
1PH Full Bridge Inverter

F2837x, F28004x

TIDM-HV-1PH-DCAC

PowerSUITE digital power software tools make digital power control easier

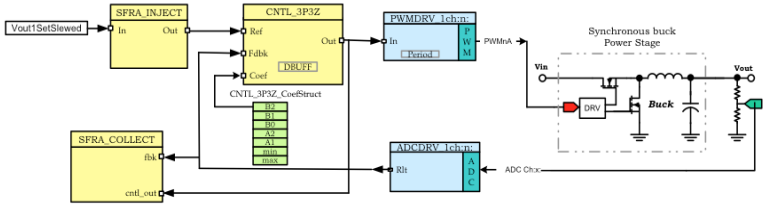
Get started adapting TI code to your digital power design!

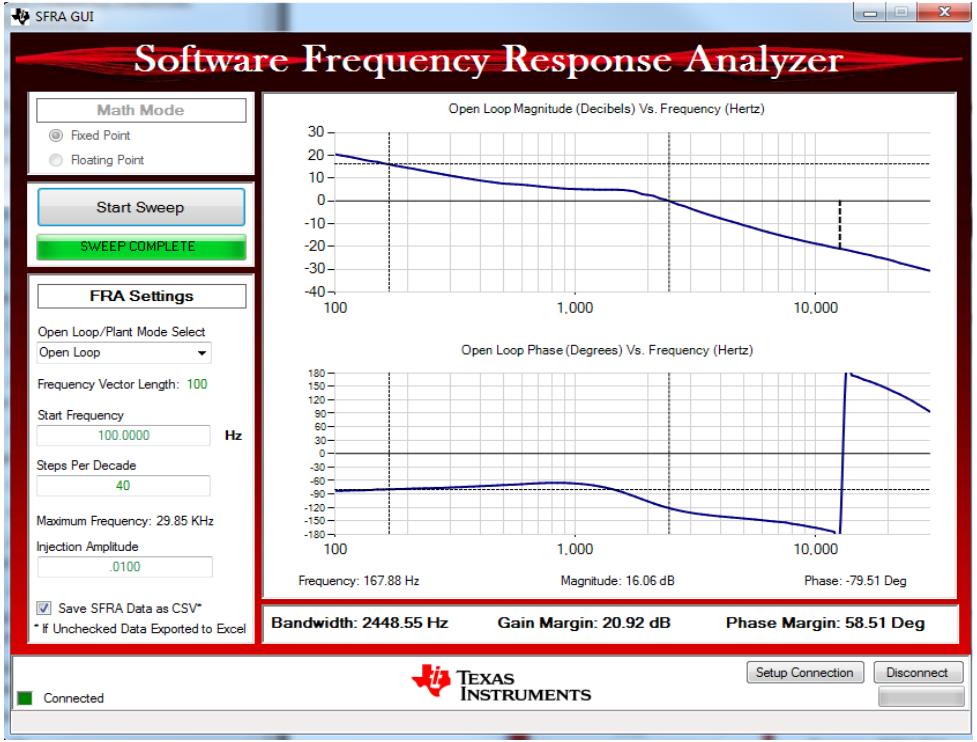


New! Software Frequency Response Analyzer

ISR (Timing Critical)

```
//Read ADC and computer Fbk Value
cntl3p3z_vars1.Fdbk= _IQsat((((int32)Vout1R<<12)-offset_Vout),_IQ24(1.0),_IQ24(0.0));

//Add SFRA injection into the reference of the controller
cntl3p3z_vars1.Ref= SFRA_IQ_INJECT(Vout1SetSlewed);

// Call the controller
CNTL_3P3Z_IQ_ASM(&cntl3p3z_coeff1,&cntl3p3z_vars1);

//Update PWM value
EPwm1Regs.CMPA.half.CMPA=_IQ24mpy((long)(BUCK_PWM_PERIOD),cntl3p3z_vars1.Out);

SFRA_IQ_COLLECT(&cntl3p3z_vars1.Out,&cntl3p3z_vars1.Fdbk);
```



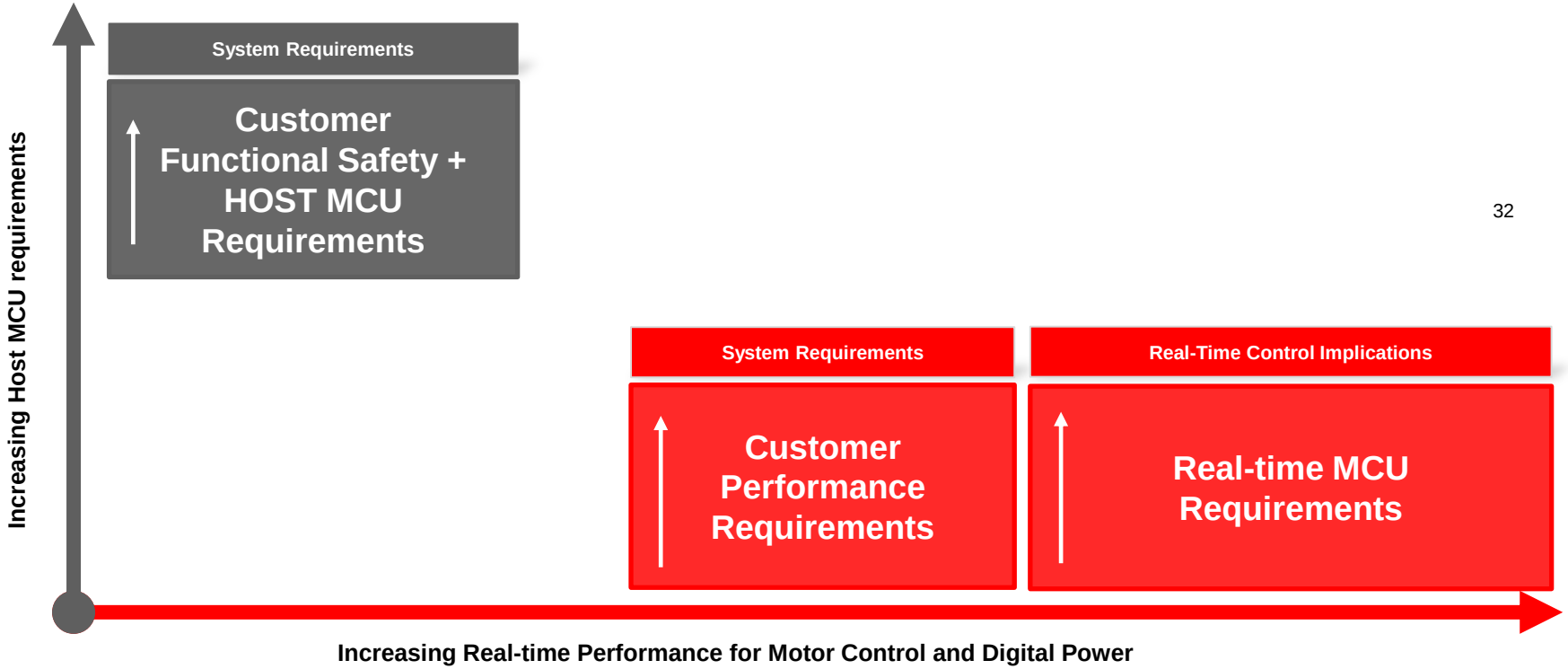


- Remove Cost of Hardware Analyzer
- Tune Control Loops in Software
- Design Stable Controller/Compensator Faster
  - No need to hand tune analog based solutions

Traction and HVAC

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!



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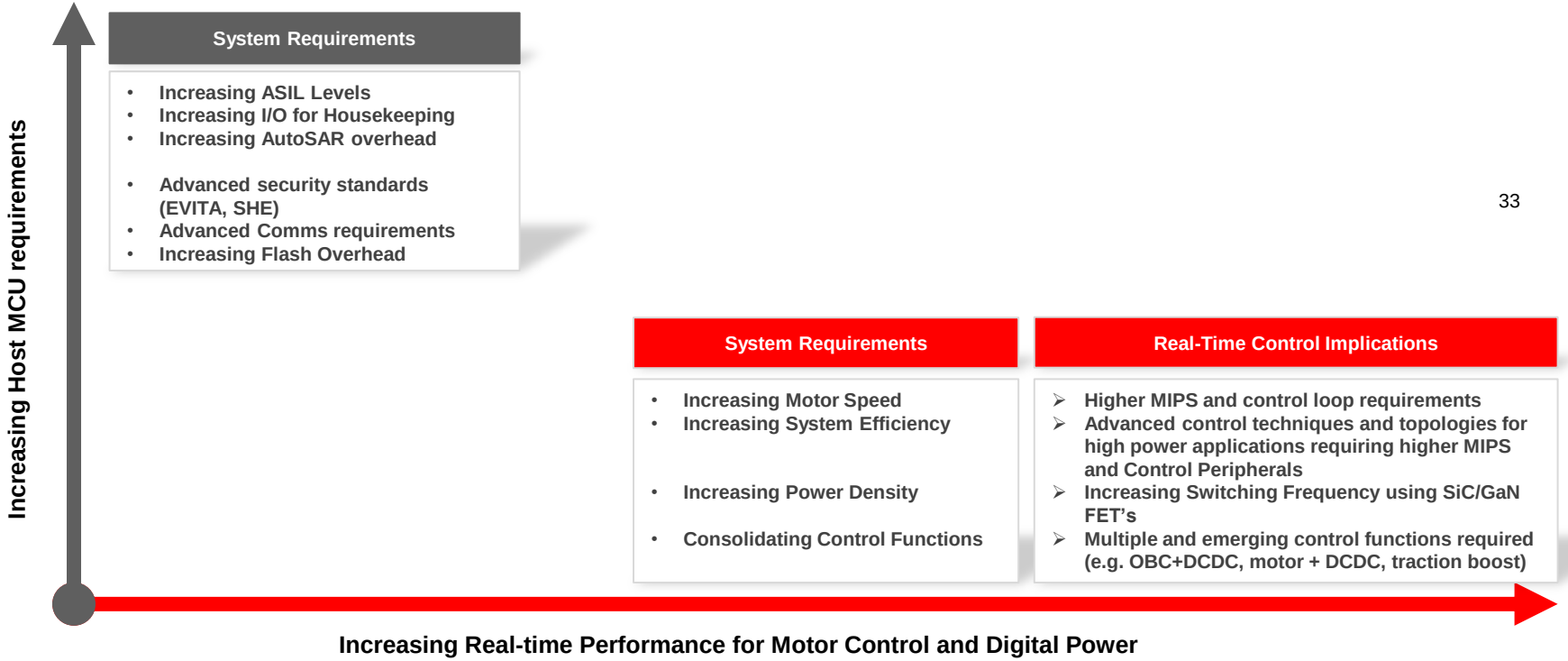


ASIL-Decomposition

- Supported by ISO-26262

ISO 26262-9:2011(E)

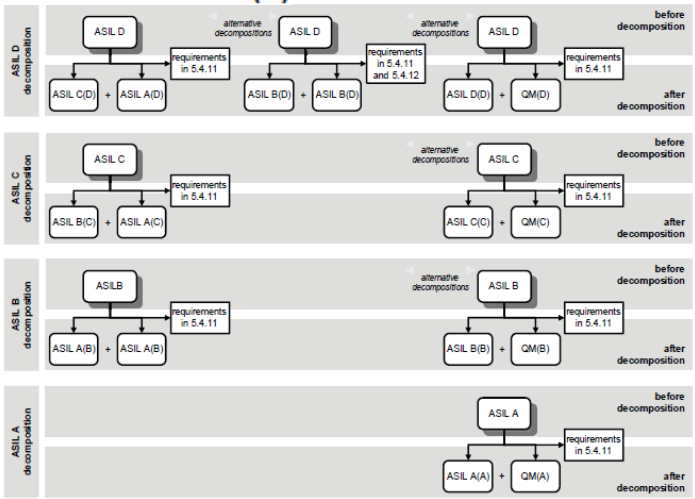


Figure 2 — ASIL decomposition schemes

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.

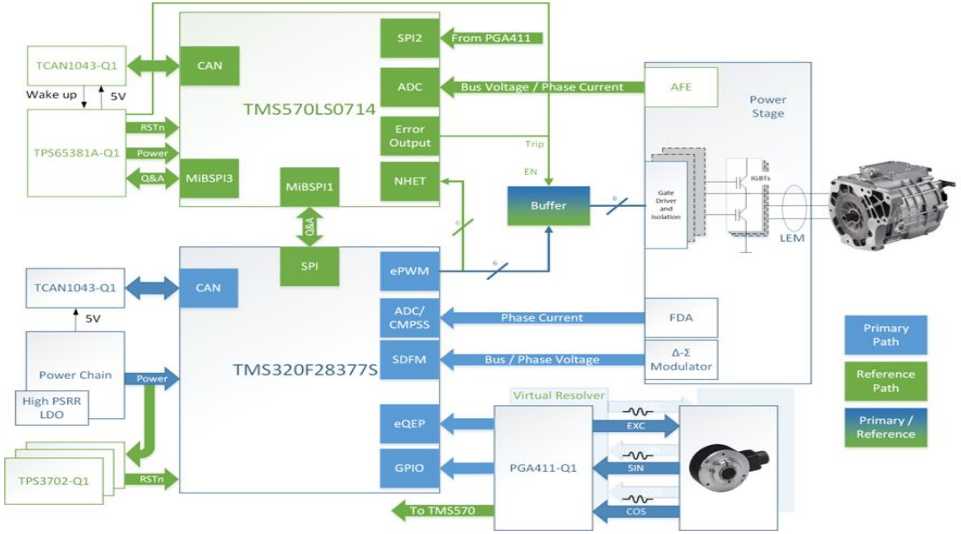
Benefits *for Safety*

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.

C2000 + TMS570 for ASIL-D

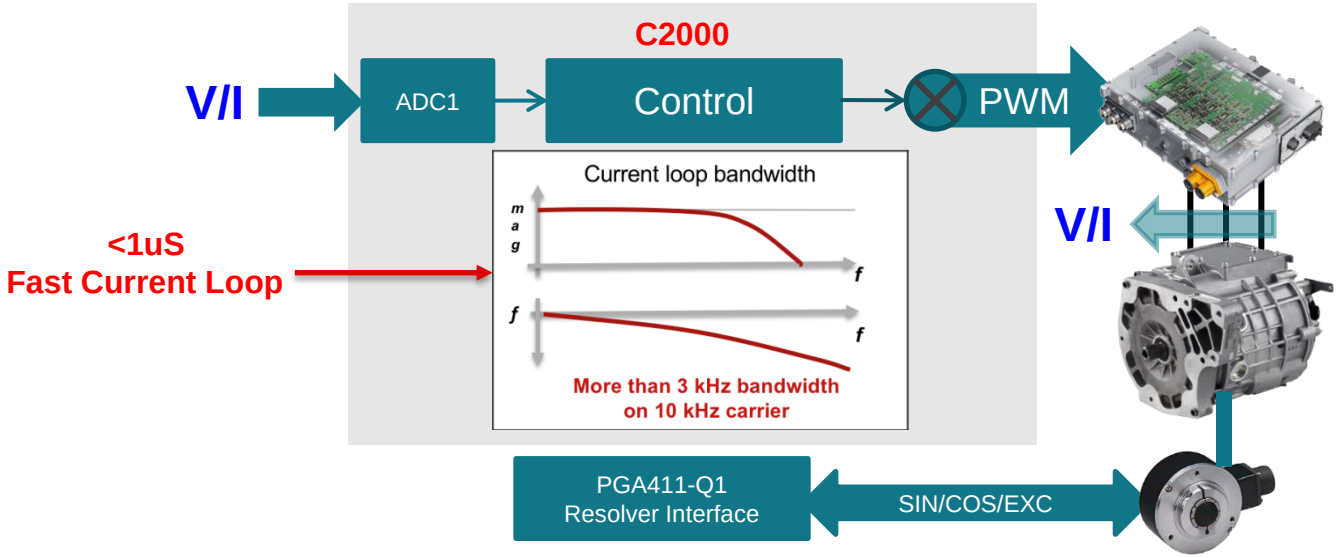
Uncompromised motor control performance paired with pre-certified ASIL-D microcontroller



C2000 MCU Benefits	Hercules TMS570 MCU Benefits
• Best In Class Real-time Control MCU for Traction Inverter (>24k rpm Motor Speed with fast current loop SW) • Ability to add integrated Bi-directional HV DC/DC (>800V with SiC) for Traction Drive (Saves cost on bulky relays to charge DC Link Capacitor at start-up) • Enhanced System Robustness: Virtual Back-up Resolver, Motor Fault Diagnostics	• Safety MCU device certification upto ASILD • Safety Diagnostic Libraries • AutoSAR support

- Add Functional Safety to EV Traction System to support up to ISO26262 ASILD
- Leveraging ASIL decomposition (ASIL-D -> ASIL-D(D) + ASIL-QM(D), customers can reuse existing motor control code that may not been developed for ISO26262 when running on the QM device

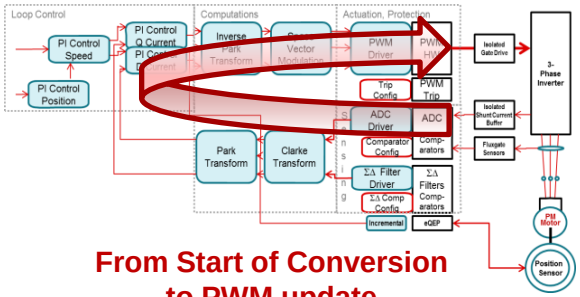
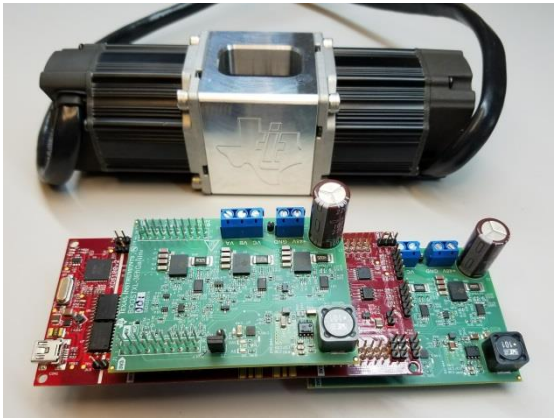
Why C2000 for EV Traction? (Saves Battery Life)



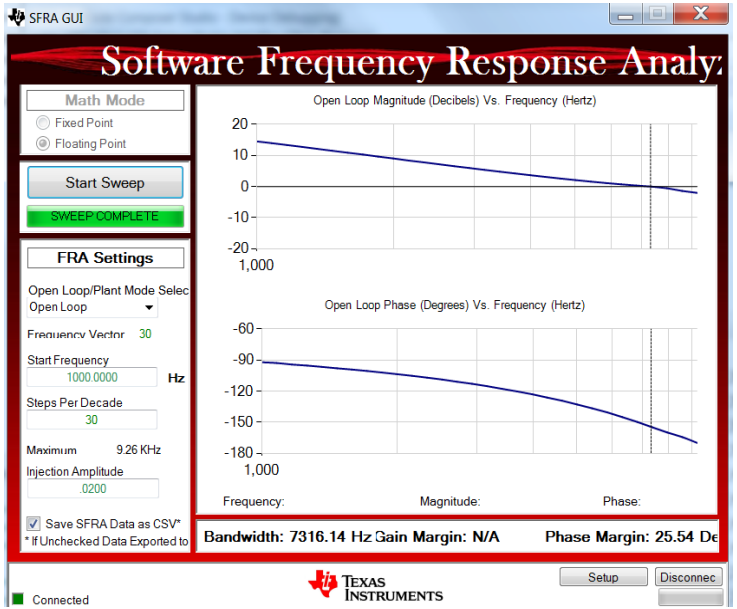
Fast Current Loop (FCL) Technology provides 3X higher current loop bandwidth than traditional methods in the same carrier frequency;

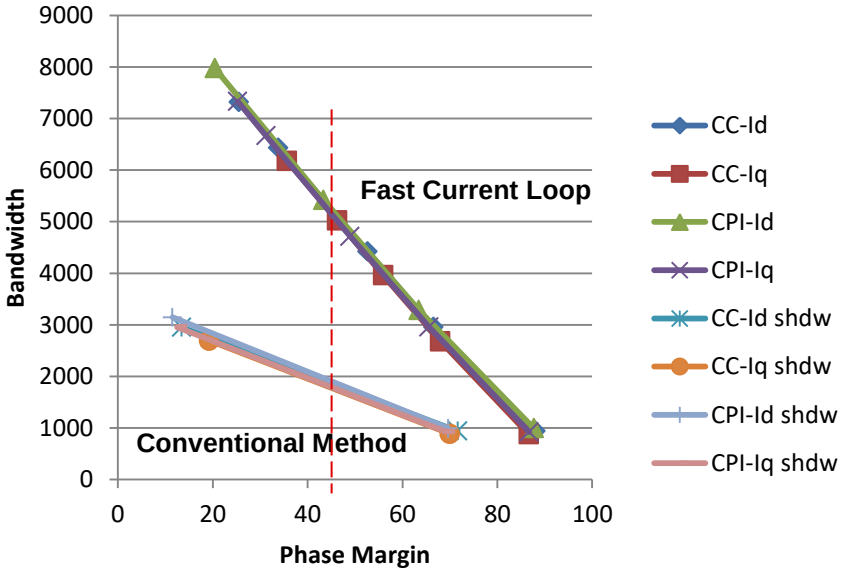
If traditional current loop is running at 3KHz (assuming 30KHz carrier); FCL can reduce PWM frequency to 10 KHz for improved efficiency

Fast Current Loop Update

2017 – June	2018 – March - 15	2018 - April
Less than 1 microsecond current loop  **From Start of Conversion to PWM update**  $999 (no motors, no SFRA)	*Performance Analysis of FCL Based Dual Motor Control Using SFRA on F28379D Launch Pad* Author(s): Ramesh T Ramamoorthy Texas Instruments, Inc. Beta Release - v1.0 FCL Performance Report Release (SPRT735)	 **LP379D-BPGAN-2MTR-BNDL in TI eStore -- $560** **(Dual Axis)**

Single-axis Bandwidth and Phase Margin Measurements
Using C2000 Software Frequency Response Analyzer (SFRA) tools

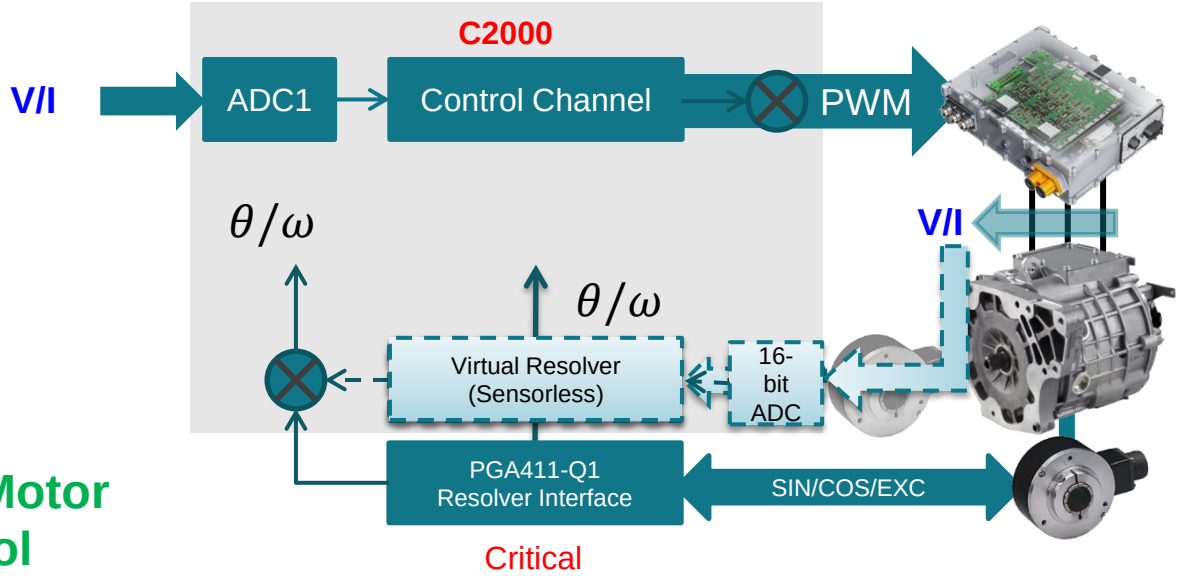




- PowerSUITE tool updated for motors
- Real time data collection
- PC-based analysis tools
- Integrated into Fast Current Loop release

- FCL delivers 3 times the control bandwidth
- > 5 kHz on 10kHz carrier at 45º phase margin (typ)
- Unprecedented for any MCU – challenging for FPGAs!
- Measured by SFRA

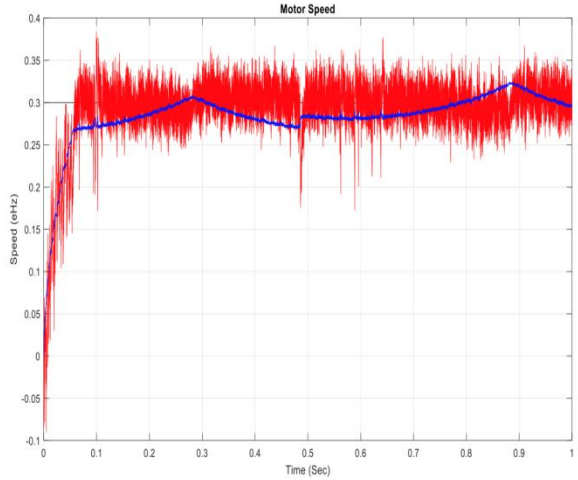
Why C2000 for EV Traction? (Virtual Resolver)



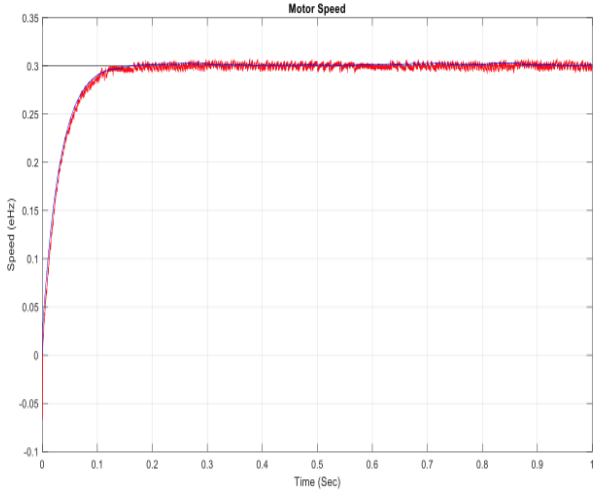
Safe Motor Control

Why C2000 for EV Traction? (Virtual Resolver)

Motor Speed Estimation Noise with 12-bit ADC



Motor Speed Estimation Noise with 16-bit ADC



TIDA-01418
400V EV Compressor

TIDesigns

Features

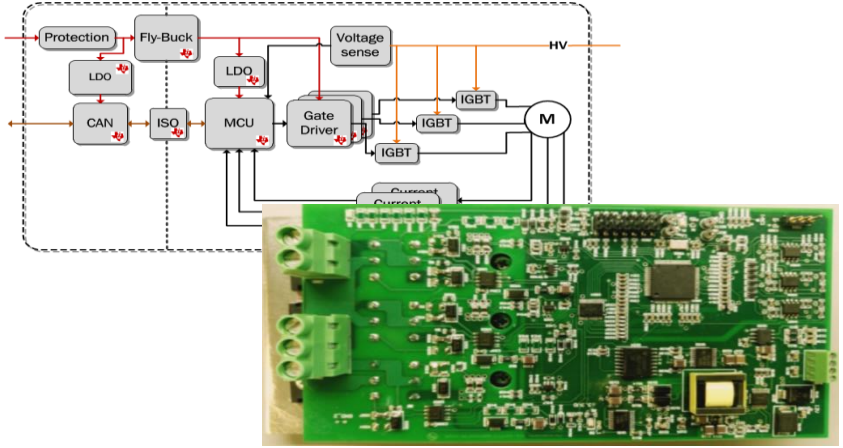
- Power Input Voltage: 200~400VDC
- Output Power: 100W~5000W
- Rated Power Efficiency: >85%.
- Speed Range: 100rpm~6000rpm
- Speed Ripple: <+/-30rpm
- Multi Protection Features:
  - ✓ Over Current Protection (OCP)
  - ✓ Over/Under Voltage Protection (OVP/UVP)
  - ✓ Over Load, Under Load
  - ✓ Motor Lost Phase, Phase Unbalance, Stall
  - ✓ Motor and Inverter Over Temperature
  - ✓ Lost Communication
- Wide Environment Temperature Test (-40ºC~85ºC)
- CAN/LIN Auto Communication Protocol

Tools & Resources

- **TI Devices**: TMS320F2805x
- **TI SW**: Motorware (www.ti.com/tool/motorware)

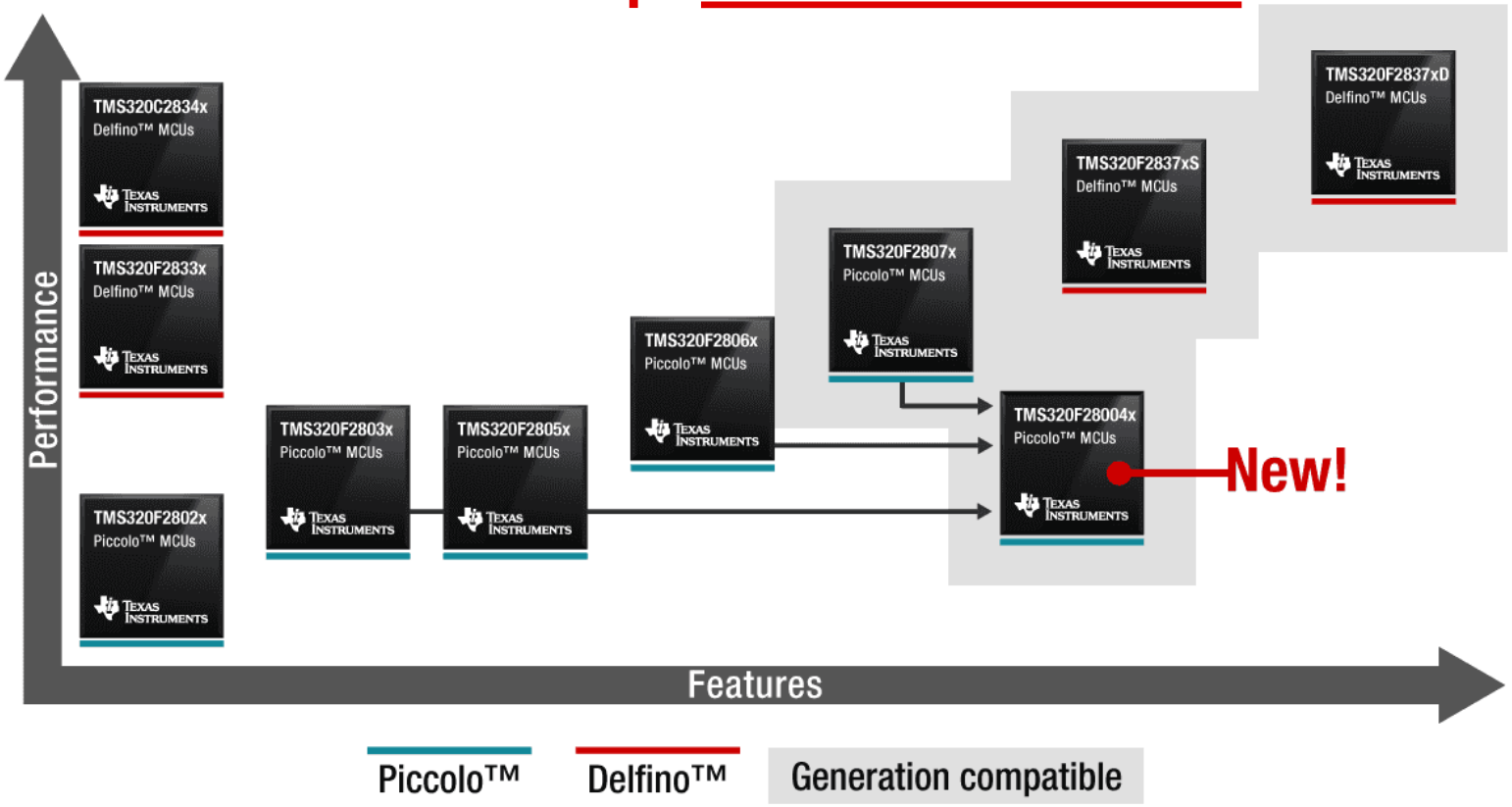
Benefits

- Low Noise, High reliability, High efficiency.
- Identify motor parameters automatically to use different motors quickly.
- PID regulator parameters automatically modification to optimize energy efficiency.
- Auto torque compensation for low speed with slight vibration
- Sensorless FOC to implement low system cost
- Stable & secure software by dual CSM

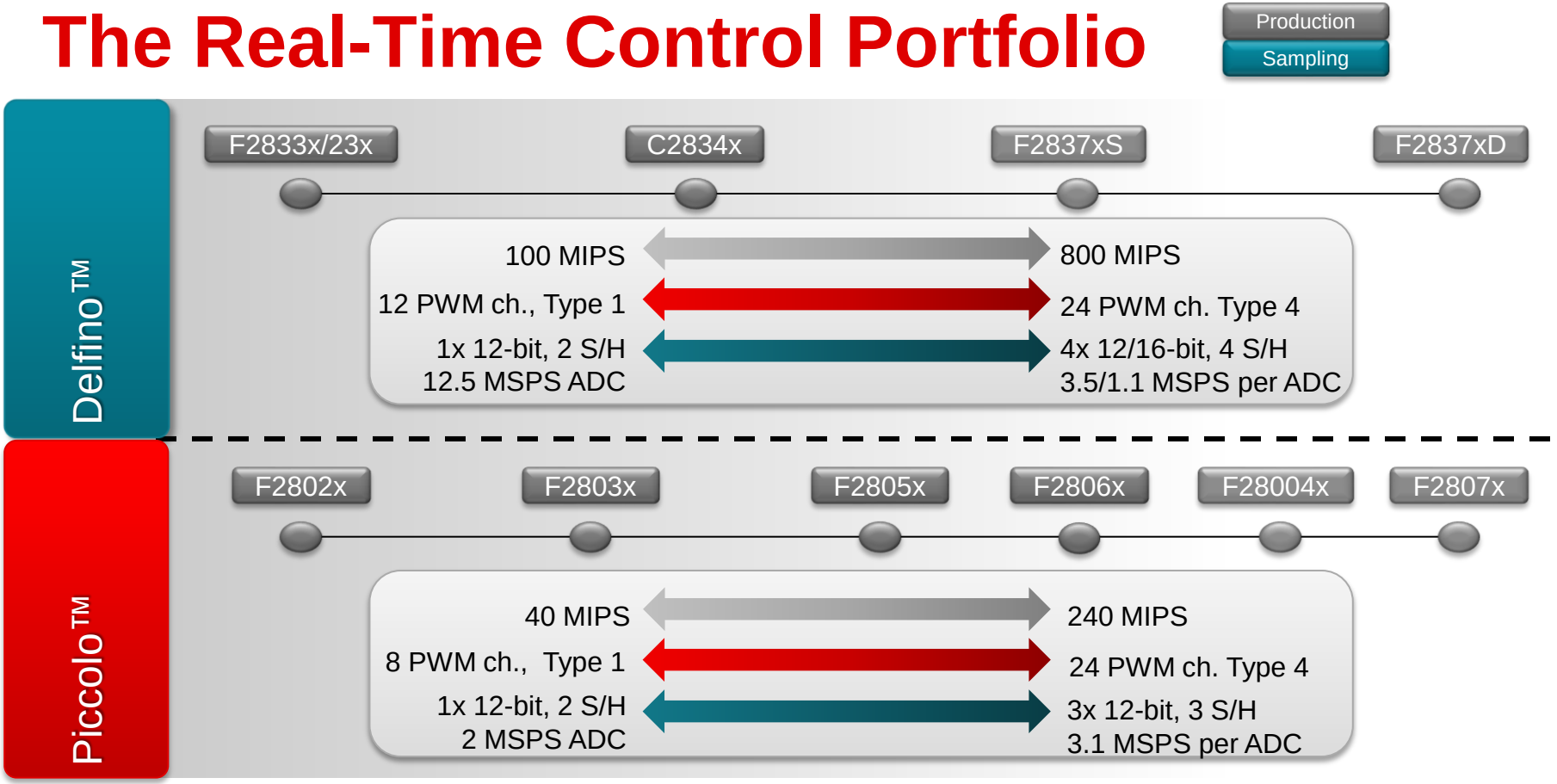


Key Devices

C2000 Product roadmap: www.ti.com/c2000



The Real-Time Control Portfolio



Piccolo™ F28004x

In production

Differentiation

Optimized for Power Control Applications

Streamlined performance and power

- 100MHz / 256KB 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 3.5MSPS 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)

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

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

Memory
- Up to 256 KB Flash (dual-bank) +ECC
- Up to 100 KB SRAM +parity
- 2x 128-bit Security Zones
- Boot ROM
- InstaSPIN™ Motor ROM

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

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

Power & Clocking
- 2x 10 MHz 0-pin OSC
- 1.2V VREG
- POR/BOR Protection

Debug
- cJTAG / Real-time JTAG
- Embedded Real -time Analysis And Diagnostic unit (ERAD)

Tools

F28004x Experimenter's Kit

Part Number: TMDXDOCK280049M
http://www.ti.com/tool/TMDXDOCK280049M

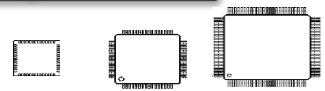
Software

TI RTOS

C2000Ware Software Package

Code Composer Studio (CCS) IDE

Packages



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

'F280049 Product Folder

Piccolo™ F28004x

In production

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- Floating Point and Trigonometric Math Unit
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- 4 Sigma Delta Demodulation Channels

F28004x

Temperatures | 125C | Q100

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- Temperature Sensor
- 2x eQEP
- 7x eCAP (2x HRCAP)

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- FPU
- TMU
- VCU-I
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F28004x Experimenter's Kit

Part Number: TMDXDOCK280049M
http://www.ti.com/tool/TMDXDOCK280049M

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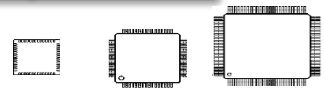
TI RTOS

C2000Ware Software Package

Code Composer Studio (CCS) IDE

Packages



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

'F280049 Product Folder

Piccolo™ TMS320F2807x

In production

Differentiation

- Real-time performance of C28x core with CLA co-processor to run parallel control loops
- 3 differential 12-bit ADC, 3.5MSPS each, 16 channels total
- 12-bit DAC (external)
- Trigonometric Math Unit (TMU) – 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
- 8x Windowed Comparators w/ 12b DAC which can be used as peak current mode comparators (PCMC)
- 8 Sigma Delta Decimation Filters

TMS320F2807x

Temperatures: 105C | 125C | Q100

Sensing
- ADC1: 12-bit, 3.1 MSPS
- ADC2: 12-bit, 3.1 MSPS
- ADC3: 12-bit, 3.1 MSPS
- 8x Windowed Comparators w/ Integrated 12-bit DAC
- 8x Sigma Delta Channels (2x Filters per channel)
- Temperature Sensor
- 3x eQEP
- 6x eCAP

Debug
- Real-time JTAG

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

Processing
- C28x™ DSP core 120 MHz
- FPU
- TMU
- CLA DSP core 120 MHz Floating-Point Math
- 6ch DMA

Memory
- Up to 512 kB Flash +ECC
- Up to 100 kB SRAM +parity
- 2x 128-bit Security Zones
- Boot ROM
- EMIF

Actuation
- 12x ePWM Modules (Type 4) 24x Outputs (10x High-Res)
- Fault Trip Zones
- 12-bit DAC

Connectivity
- 4x UART
- 2x I2C (2x true PMBus)
- 3x SPI
- 2x McBSP
- 2x CAN 2.0B
- USB 2.0 OTG FS MAC & PHY

Power & Clocking
- 2x 10 MHz OSC
- 4-20 MHz Ext OSC Input

Tools

TMS320F2807x Isolated controlCARD

Part Number: TMDXCNCD28075

TMS320F2807x Experimenter's Kit

Part Number: TMDXDOCK28075

Software

controlSUITE™ Software

Code Composer Studio (CCS) IDE

Packages

Package	Dimension
100-pin HTQFP	14x14mm²
176-pin HLQFP	24x24mm²

View Configurations

'F28075 Product Folder

Datasheet

Texas Instruments

Delfino™ TMS320F2837xS

In production

Differentiation

- Real-time performance of dual C28x core with dual CLA co-processors to run parallel control loops
- 4 differential 16-bit ADC, 1MSPS each
- 3x 12-bit DAC (external outputs)
- Trigonometric Math Unit (TMU) - 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
- 8x Windowed Comparators w/ 12b DAC which can be used as peak current mode comparators (PCMC)
- 8 Sigma Delta Decimation Filters

Tools

TMS320F2837xD Isolated controlCARD

Part Number: TMDXCNCD28377D

TMS320F2837xD Experimenter's Kit

Part Number: TMDXDOCK28377D

TMS320F2837xS

Temperatures	105C	125C	Q100

Sensing

- ADC1: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC2: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC3: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC4: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- 8x Windowed Comparators w/ Integrated 12-bit DAC
- 8x Sigma Delta Interface
- Temperature Sensor
- 3x eQEP
- 6x eCAP

System Modules

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

Processing

C28x™ DSP core
200 MHz

- FPU
- TMU
- VCU-II

CLA DSP core
200 MHz
Floating-Point Math

- 6ch DMA

Memory

- Up to 1 MB Flash +ECC
- Up to 164 kB SRAM +parity
- 2x 128-bit Security Zones
- Boot ROM
- 2x EMIF

Actuation

- 12x ePWM Modules (Type 4) 24x Outputs (16x High-Res)
- Fault Trip Zones
- 3x 12-bit DAC

Connectivity

- 4x UART
- 2x I2C (w/ true PMBus)
- 3x SPI
- 2x McBSP
- 2x CAN 2.0
- USB 2.0 OTG FS MAC & PHY
- uPP

Power & Clocking

- 2x 10 MHz OSC
- 4-20 MHz Ext OSC Input

Debug

- Real-time JTAG

Software

controlSUITE™ Software

Code Composer Studio (CCS) IDE

Packages

Package	Dimension
100-pin HTQFP	14x14mm²
176-pin HLQFP	24x24mm²
337-pin NFBGA	16x16mm²

View Configurations

'F28377S Product Folder

Datasheet

TEXAS INSTRUMENTS

Delfino™ TMS320F2837xD

In production

Differentiation

- Real-time performance of dual C28x core with dual CLA co-processors to run parallel control loops
- 4 differential 16-bit ADC, 1MSPS each
- 3x 12-bit DAC (external)
- Trigonometric Math Unit (TMU) - 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
- 8x Windowed Comparators w/ 12b DAC which can be used as peak current mode comparators (PCMC)
- 8 Sigma Delta Decimation Filters

Tools

TMS320F2837xD Isolated controlCARD

Part Number: TMDXCNCD28377D

TMS320F2837xD Experimenter's Kit

Part Number: TMDXDOCK28377D

TMS320F2837xD

Temperatures	105C	125C	Q100

Sensing
- ADC1: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC2: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC3: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- ADC4: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS
- 8x Windowed Comparators w/ Integrated 12-bit DAC
- 8x Sigma Delta Interface
- Temperature Sensor
- 3x eQEP
- 6x eCAP

System Modules
- 3x 32-bit CPU Timers
- NMI Watchdog Timer
- 2x 192 Interrupt PIE

Processing
- C28x™ DSP core 200 MHz
- FPU
- TMU
- VCU-II
- CLA DSP core 200 MHz Floating-Point Math
- 6ch DMA

Memory
- Up to 512 KB Flash
- Up to 102 KB SRAM

Processing
- C28x™ DSP core 200 MHz
- FPU
- TMU
- VCU-II
- CLA DSP core 200 MHz Floating-Point Math
- 6ch DMA

Memory
- Up to 512 KB Flash
- Up to 102 KB SRAM

- 2x 128-bit Security Zones
- Boot ROM
- 2x EMIF

Actuation
- 12x ePWM Modules (Type 4) 24x Outputs (16x High-Res)
- Fault Trip Zones
- 3x 12-bit DAC

Connectivity
- 4x UART
- 2x I2C (w/ true PMBus)
- 3x SPI
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- 2x CAN 2.0
- USB 2.0 OTG FS MAC & PHY
- uPP

Power & Clocking
- 2x 10 MHz OSC
- Ext OSC Input

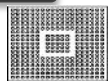
Debug
- Real-time JTAG

Software

controlSUITE™ Software

Code Composer Studio (CCS) IDE

Packages



Package	Dimension
176-pin HLQFP	24x24mm²
337-pin NFBGA	16x16mm²

View Configurations

'F28377D Product Folder

Datasheet

Thank you