TI C2000™ MCUs for EV/HEV Powertrain

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C2000™ Real-time Control Applications

Renewable Energy
- Wind Power Inverters
- Solar Power Inverters

Digital Power
- Telecom / Server AC/DC Rectifiers
- Uninterruptable Power Supplies
- DC/DC Converters

Motor Control
- Motion Control
- Appliances
- E-Bike

Industrials
- Elevator Escalator
- Automation & Sensors
- Industrial Drives

EV/HEV Auto
- Power
- Motor
- HV DCDC
- Charging Stations
- Traction Drive
- Compressors
- Pumps/Power-Steering

Motor Control
- Manufacturing / Robotics

Lighting
- On-Board Charging

Motor Control
- EV/HEV Auto

Digital Power
- Renewable Energy

Motor Control
- Industrial

Digital Power
- Motor Control

EV/HEV Auto
- Power

Motor Control
- Industrial

Digital Power
- Renewable Energy

Motor Control
- Industrial

Digital Power
- Renewable Energy

Motor Control
- Industrial
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)

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

ex: flexible syncing of ADC triggers anyway in PWM cycle
TI C2000™ Real-time MCUs @ a glance

Designed for EV

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

Digital Power

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

Motor Control

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

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

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

## C2000 TI Designs

<table>
<thead>
<tr>
<th>Type</th>
<th>Topology</th>
<th>TI Design #</th>
<th>Orderable Kit</th>
<th>Power Rating</th>
<th>Input</th>
<th>Output</th>
<th>Efficiency</th>
<th>Supported C2000 Products</th>
<th>Powersuite</th>
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<tbody>
<tr>
<td><strong>Charging Station</strong></td>
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<tr>
<td>Isolated DC/DC</td>
<td>Phase-Shifted Full Bridge</td>
<td>TIDM-PSFB-DCDC</td>
<td>TMDSHVPSTKIT</td>
<td>600W</td>
<td>400 VDC</td>
<td>12 VDC</td>
<td>95% peak</td>
<td>F28027</td>
<td></td>
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<tr>
<td>AC/DC</td>
<td>Totem Pole PFC (w/ GaN)</td>
<td>TIDA-000961 (CRM)</td>
<td>TIDM-1007 (CCM)</td>
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<td>NEW!!</td>
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<td></td>
<td></td>
<td>3KW at 220Vrms and 1.5KW at 110Vrms</td>
<td>Input: 80-260 Vac, 50/60Hz</td>
<td>400V DC</td>
<td>&gt; 99% peak efficiency</td>
<td></td>
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<tr>
<td>AC/DC</td>
<td>3PH Vienna Rectifier</td>
<td>TIDM-PFC-3PH-VIENNA</td>
<td>NEW!!</td>
<td></td>
<td>1.2KW at 110Vrms and 2KW at 220Vrms</td>
<td>3PH 110/220Vac</td>
<td>700VDC</td>
<td>98% peak</td>
<td>F28377D</td>
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<tr>
<td>DC/DC</td>
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<tr>
<td>Isolated DC/DC</td>
<td>Phase-Shift FB/Push-Pull</td>
<td>TIDM-BIDIR-400-12</td>
<td></td>
<td></td>
<td>300W</td>
<td>200VDC-400VDC</td>
<td>9VDC-13.5VDC</td>
<td>F28035</td>
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<tr>
<td>Isolated DC/DC</td>
<td>Resonant LLC</td>
<td></td>
<td>TMDSHVRESLLCKIT</td>
<td>300W</td>
<td>375-405 VDC</td>
<td>12 VDC</td>
<td>93% peak; 90%</td>
<td>F28027</td>
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<tr>
<td>Isolated DC/DC</td>
<td>Phase-Shift FB</td>
<td>TIDM-PSFB-DCDC</td>
<td>TMDSHVPSTKIT</td>
<td>600W</td>
<td>400 VDC</td>
<td>12 VDC</td>
<td>95% peak</td>
<td>F28027</td>
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<td>Non-Isoalted DC/DC</td>
<td>Buck/Boost</td>
<td>TIDA-00558</td>
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<td>600W</td>
<td>48VDC/12VDC</td>
<td>12VDC/48V</td>
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<tr>
<td>Isolated DC/DC</td>
<td>2PH IL Resonant LLC</td>
<td>TIDM-1001</td>
<td>NEW!!</td>
<td>500W</td>
<td>400VDC</td>
<td>12VDC</td>
<td>93% peak</td>
<td>F28377D</td>
<td></td>
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<tr>
<td>AC/DC</td>
<td>Dual IL PFC</td>
<td>TIDM-2PHILPFC</td>
<td>TMDSILPFCKIT</td>
<td>700W</td>
<td>(110/220Vac)</td>
<td>400 VDC</td>
<td>0.99; &lt;1.5% THD</td>
<td>F28035</td>
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<tr>
<td>Isolated DC/DC</td>
<td>Phase-Shift FB/Push-Pull</td>
<td>TIDM-BIDIR-400-12</td>
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<td>300W</td>
<td>200VDC-400VDC</td>
<td>9VDC-13.5VDC</td>
<td>F28035</td>
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<tr>
<td>Non-Isoalted DC/DC</td>
<td>Inverter</td>
<td>TIDM-HV-1PH-DCAC</td>
<td>TieV-HV-1PH-DCAC</td>
<td>600VA</td>
<td>400VDC</td>
<td></td>
<td>(110/220Vac)</td>
<td>98% peak; &lt;5% THD</td>
<td>F28377D</td>
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<td><strong>AC Output</strong></td>
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## C2000™ Motor Solutions

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Type</th>
<th>Topology</th>
<th>Collateral</th>
<th>Power Rating</th>
<th>Input</th>
<th>Supported C2000 Products</th>
<th>System Solution</th>
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<tbody>
<tr>
<td><strong>Traction</strong></td>
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<tr>
<td>Fast Current Loop Motor Winding Fault Diagnostics Virtual Resolver</td>
<td>QM + ASILD</td>
<td>C2000+570</td>
<td>Detailed FMEDA</td>
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<td>F2837xD, F2837xS, F28075</td>
<td>PGA411, DRV3201, PMIC TPS65381</td>
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<td></td>
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<td></td>
<td>Functional Safety Manual</td>
<td></td>
<td></td>
<td>F28337D, F2837xS, F28075</td>
<td>PGA411, DRV3201, PMIC TPS65381</td>
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<tr>
<td><strong>EV Compressor</strong></td>
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<tr>
<td>EV battery savings (run the motor at slower speed at full torque)</td>
<td>Hot-side Controller</td>
<td>3PH Half-bridge</td>
<td>TIDA-01418 New!</td>
<td>3.5KW</td>
<td>400V 8A</td>
<td>F28054F</td>
<td>InstaSPIN FOC</td>
</tr>
</tbody>
</table>
OBC & HV DCDC Architectures
Microcontroller System Architecture

- **Option 1**
- **Option 2**
Microcontroller System Architecture

Option 3

Option 4
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 to Accelerate Time to Market

High Power Density, High Efficiency Totem Pole Bridgeless PFC Topologies

**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))

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)

Isolated DC-DC Topologies

**Interleaved LLC**

**PSFB**
**New Design in Concept Phase targeting specifically OBC application**
OBC Topologies : AC-DC

Conventional PFC

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

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

TIDM-2PHILPFC
TIDM-1007
TIDA-0961
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

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

Tools & Resources
- Key TI Devices: TMS320F28075, LMG3410, UCC27714D, UCC28740, UCC24636

**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

### 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

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

**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

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

Option 1
Totem Pole based
Three Phase PFC

Option 2
Vienna rectifier based
Three Phase PFC
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

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

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
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

**Applications**

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**Tools & Resources**

- C2000 Microcontroller TMS320F28004x
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
- 3PH Vienna Rectifier Based PFC
  - F2837x, F28004x (CLA enabled)
  - TIDA-01604
  - TIDM-1000

**DC-DC**
- CLLLC Isolated DC-DC
  - F28004x (uses CLA)
  - TIDM-02002

**DC-AC (Inverter)**
- 1PH Full Bridge Inverter
  - F2837x, F28004x
  - TIDM-HV-1PH-DCAC

Also see Bi-directional DC-AC TIDA-010039
PowerSUITE digital power software tools make digital power control easier

1. Adapt TI source code to create a customized version of the TI development kit power topology using the Solution Adapter.

2. Design a compensator using the Compensation Designer based on the plant information entered into the Solution Adapter.

3. The compensator coefficients from the Compensation Designer are imported into the source code of the Code Composer Studio project.

4. Compile and load the source code with the new coefficients to control the power stage.

5. Use the Software Frequency Response Analyzer (SFRA) to measure the closed loop performance by measuring open loop gain and the plant frequency response.

6. Load the measured SFRA Data CSV file into the Compensation Designer to design and tune the compensator.

Project in Code Composer Studio

Power Stage Controlled by C2000 MCU

Get started adapting TI code to your digital power design!
New! **Software Frequency Response Analyzer**

- 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!
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!

**System Requirements**
- Increasing ASIL Levels
- Increasing I/O for Housekeeping
- Increasing AutoSAR overhead
- Advanced security standards (EVITA, SHE)
- Advanced Comms requirements
- Increasing Flash Overhead

**Real-Time Control Implications**
- Higher MIPS and control loop requirements
- Advanced control techniques and topologies for high power applications requiring higher MIPS and Control Peripherals
- Increasing Switching Frequency using SiC/GaN FET’s
- Multiple and emerging control functions required (e.g. OBC+DCDC, motor + DCDC, traction boost)

**Increasing Host MCU requirements**
- Increasing Motor Speed
- Increasing System Efficiency
- Increasing Power Density
- Consolidating Control Functions

**Increasing Real-time Performance for Motor Control and Digital Power**
ASIL-Decomposition

- Supported by ISO-26262

ISO 26262-9:2011(E)

For Example

a) An ASIL \( \text{D} \) requirement shall be decomposed as one of the following:
   1) one ASIL \( \text{C} \) requirement and one ASIL \( \text{A} \) requirement; or
   2) one ASIL \( \text{B} \) requirement and one ASIL \( \text{B} \) requirement; or
   3) one ASIL \( \text{D} \) requirement and one \( \text{CM} \) 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

- **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

### Hercules TMS570 MCU Benefits

- 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

Less than 1 microsecond current loop from Start of Conversion to PWM update

$999 (no motors, no SFRA)

2018 – March - 15

Performance Analysis of FCL Based Dual Motor Control Using SFRA on F28379D Launch Pad

FCL Performance Report Release (SPRT735)

2018 - April

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 45° phase margin (typ)
• Unprecedented for any MCU – challenging for FPGAs!
• Measured by SFRA
Why C2000 for EV Traction? (Virtual Resolver)

Safe Motor Control

ADC1 → Control Channel → C2000 → PWM

θ/ω

Virtual Resolver (Sensorless)

PGA411-Q1 Resolver Interface

16-bit ADC

SIN/COS/EXC

Critical
Why C2000 for EV Traction? (Virtual Resolver)

Motor Speed Estimation Noise with 12-bit ADC

Motor Speed
Estimated Speed

Motor Speed Estimation Noise with 16-bit ADC

Motor Speed
Estimated Speed
TIDA-01418
400V EV Compressor

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 (-40°C~85°C)
- CAN/LIN Auto Communication Protocol

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

Tools & Resources

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

Performance

TMS320F2833x
Delfino™ MCUs

TMS320F2802x
Piccolo™ MCUs

TMS320F2808x
Piccolo™ MCUs

TMS320F2807x
Piccolo™ MCUs

TMS320F2837xS
Delfino™ MCUs

TMS320F2837xD
Delfino™ MCUs

Features

Piccolo™

Delfino™

Generation compatible

New!
The Real-Time Control Portfolio

Delfino™
- F2833x/23x
- C2834x
- F2837xS
- F2837xD

- 100 MIPS
- 12 PWM ch., Type 1
- 1x 12-bit, 2 S/H
- 12.5 MSPS ADC

- 800 MIPS
- 24 PWM ch. Type 4
- 4x 12/16-bit, 4 S/H
- 3.5/1.1 MSPS per ADC

Piccolo™
- F2802x
- F2803x
- F2805x
- F2806x
- F28004x
- F2807x

- 40 MIPS
- 8 PWM ch., Type 1
- 1x 12-bit, 2 S/H
- 2 MSPS ADC

- 240 MIPS
- 24 PWM ch. Type 4
- 3x 12-bit, 3 S/H
- 3.1 MSPS per ADC

Texas Instruments
**Piccolo™ F28004x**

### 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

### Tools

F28004x Experimenter’s Kit
Part Number: TMDXDOCK280049M
http://www.ti.com/tool/TMDXDOCK280049M

### Packages

<table>
<thead>
<tr>
<th>Package</th>
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<tr>
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### Software

- TI RTOS
- C2000Ware Software Package
- Code Composer Studio (CCS) IDE

### Packages

- C28x™ DSP core
- 100 MHz
- FPU
- TMU
- VCU-I

### 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)

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In production

F280049 Product Folder
## Piccolo™ F28004x

### Optimization for Power Control Applications

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### Tools

- F28004x Experimenter’s Kit
  - Part Number: TMDXDOCK280049M

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- TI RTOS
- Code Composer Studio (CCS) IDE
- C2000Ware Software Package

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### F28004x

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<th>Sensing</th>
<th>Processing</th>
<th>Temperatures</th>
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<tr>
<td>ADC1: 12-bit, 3.5 MSPS, 8ch</td>
<td>C28x™ DSP core</td>
<td>125°C Q100</td>
</tr>
<tr>
<td>ADC2: 12-bit, 3.5 MSPS, 8ch</td>
<td>FPU</td>
<td></td>
</tr>
<tr>
<td>ADC3: 12-bit, 3.5 MSPS, 8ch</td>
<td>TMU</td>
<td></td>
</tr>
<tr>
<td>7x Windowed Comparators w/ Integrated 12-bit DACs</td>
<td>VCU-I</td>
<td></td>
</tr>
<tr>
<td>7x PGAs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4x Sigma Delta Channels</td>
<td>CLA core</td>
<td></td>
</tr>
<tr>
<td>(2x Filters per channel)</td>
<td>100 MHz</td>
<td></td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>Floating Point Math</td>
<td></td>
</tr>
<tr>
<td>2x eQEP</td>
<td>6ch DMA</td>
<td></td>
</tr>
<tr>
<td>7x eCAP (2x HRCAP)</td>
<td></td>
<td></td>
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### System Modules

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

### 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

### 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)
**Piccolo™ TMS320F2807x**

**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

**Tools**
- **TMS320F2807x Isolated controlCARD**
  Part Number: TMDXCNC28075
- **TMS320F2807x Experimenter’s Kit**
  Part Number: TMDXDOCK28075

**Package Dimensions**
- 100-pin HTQFP: 14x14mm
- 176-pin HLQFP: 24x24mm

**Software**
- controlSUITE™ Software
- Code Composer Studio (CCS) IDE

**Packages**
- F28075 Product Folder
- Datasheet

**In production**
Delfino™ TMS320F2837xS

**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

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

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

**Processing**
- C28x™ DSP core
- 200 MHz
- FPU
- TMU
- VCU-II

**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
- 2x 10 MHz Ext OSC Input

**Debug**
- Real-time JTAG

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

**Processing**
- CLA DSP core
- 200 MHz
- Floating-Point Math
- 6ch DMA

**Software**
- controlSUITE™ Software
- Code Composer Studio (CCS) IDE

**Packages**
- Package Dimensions
  - 100-pin HTQFP: 14x14mm
  - 176-pin HLOFP: 24x24mm
  - 337-pin NFPGA: 15x15mm

**View Configurations**
- F28377S Product Folder
- Datasheet
**Delfino™ TMS320F2837xD**

**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

**Processing**

- **C28x™ DSP core**
  - 200 MHz
  - FPU
  - TMU
  - VCU-II

**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

**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
- Ext OSC Input

**Debug**

- Real-time JTAG

**Memory**

- Up to 512 KB Flash
- Up to 102 KB SRAM
- 2x 128-bit Security Zones
- Boot ROM
- 2x EMIF

**System Modules**

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

**Software**

- controlSUITE™ Software
- Code Composer Studio (CCS) IDE

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**In production**

**View Configurations**

[F28377D Product Folder](#)

Datasheet
Thank you