C2000™ 32-bit MCU Family

High Performance MCUs for Real-Time Control in Cost-Sensitive Applications
Agenda: TMS320C2000

C2000 Overview
• Value Proposition
• Target Applications
• Architecture & Key Features
• Product Portfolio
  – Piccolo™
  – Delfino™

How to Get Started
• controlSUITE
• controlCARD Concept
• Application Developer’s Kits
• Piccolo controlSTICK
• Software Libraries & Examples
• 3rd Party Solutions & Additional Resources
# Embedded processing portfolio

## TI Embedded Processors

<table>
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<th>Microcontrollers (MCUs)</th>
<th>ARM®-Based Processors</th>
<th>Digital Signal Processors (DSPs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>16-bit ultra-low power MCUs</strong></td>
<td><strong>32-bit ARM Cortex™-M3 MCUs</strong></td>
<td><strong>DSP DSP+ARM</strong></td>
</tr>
<tr>
<td><strong>32-bit real-time MCUs</strong></td>
<td><strong>ARM Cortex-A8 MPUs</strong></td>
<td><strong>Multi-core DSP</strong></td>
</tr>
<tr>
<td><strong>Embedded processing portfolio</strong></td>
<td><strong>Ultra Low-power DSPs</strong></td>
<td></td>
</tr>
</tbody>
</table>

### MSP430™
- **C2000™ Delfino™ Piccolo™**
  - Up to 25 MHz
  - Flash 1 KB to 256 KB
  - Analog I/O, ADC LCD, USB, RF
  - Measurement, Sensing, General Purpose
  - $0.25 to $9.00

### C2000™
- **Stellaris® ARM® Cortex™-M3**
  - 40 MHz to 300 MHz
  - Flash, RAM 16 KB to 512 KB
  - PWM, ADC, CAN, SPI, PC
  - $1.50 to $20.00

### Sitara™
- **ARM® Cortex™-A8 & ARM9**
  - Up to 100 MHz
  - Flash 8 KB to 256 KB
  - USB, ENET MAC+PHY CAN, ADC, PWM, SPI
  - Connectivity, Security, Motion Control, HMI, Industrial Automation
  - $1.00 to $8.00

### C6000™
- **DaVinci™ Video processors OMAP™**
  - 300 MHz to >1 GHz
  - Cache, RAM, ROM
  - USB, CAN, PCIe, EMAC
  - Industrial computing, POS & portable data terminals
  - $5.00 to $20.00

### C6000™
- **AMC™**
  - 24,000 MMACS
  - Cache RAM, ROM
  - USB, ENET, PCIe, SATA, SPI
  - Floating/Fixed Point, Video, Audio, Voice, Security, Conferencing
  - $5.00 to $200.00

### C5000™
- **Up to 300 MHz + Accelerator**
  - Up to 320KB RAM
  - Up to 128KB ROM
  - USB, ADC McBSP, SPI, I²C
  - Port. Telecom, audio, medical monitor & diag, industrial
  - $3.00 to $10.00

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MPUs – Microprocessors
Thinking MCU? Think TI

<table>
<thead>
<tr>
<th>Lowest Power</th>
<th>High Performance</th>
<th>Cortex M3 Scalable MCU’s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MSP430</strong></td>
<td><strong>C2000</strong></td>
<td><strong>Stellaris M3</strong></td>
</tr>
<tr>
<td>World’s lowest power MCU RTC modes in 100’s of nA Active power at 160uA/MHz</td>
<td>High performance core + Analog MCU starting at &lt;$2.00 Up to 300 MHz Floating Point</td>
<td>The world’s largest Cortex M3 MCU portfolio</td>
</tr>
<tr>
<td><em>Over 200 MCU’s</em></td>
<td><em>Over 80 MCU’s</em></td>
<td><em>Over 169 MCU’s</em></td>
</tr>
<tr>
<td>High performance integration: A/D, Opamps, LCD Control, DAC</td>
<td>12.5MSPS A/D, High Resolution PWM, Internal Oscillator</td>
<td>A/D’s, Motor Control Hardware, Precision Oscillator, RTC</td>
</tr>
<tr>
<td>SPI, I2C, UART/LIN, and now with USB &amp; RF</td>
<td>Serial, CAN, LIN, EMIF</td>
<td>CAN, I2S, Ethernet MAC &amp; PHY, USB H/D/OTG, EPI</td>
</tr>
<tr>
<td>Starter tools as low as $20.00 Full peripheral explorer kits only $149.00</td>
<td>Accelerated design with &lt;$40.00 tools, plus complete reference design kits for multiple apps</td>
<td>Complete Eval tools &lt;$100.00 Full reference designs Complete software &amp; driver libraries</td>
</tr>
</tbody>
</table>

We offer the most breadth & depth in Microcontrollers
What is C2000?
The 32-bit real-time microcontroller family

- **DSP performance within a Microcontroller architecture**
  - 40-300MHz C28x CPU
  - Built-in DSP functions
  - Single Cycle 32x32-bit MAC
  - Control Law Accelerator
  - Floating-Point Unit
  - Embedded Flash

- **Fine-tuned for real-time control**
  - Optimized core
  - Fast interrupts
  - Flexible interrupt system
  - Real-time debugging

- **Comprehensive Peripheral Set**
  - Best in class ADC performance
  - Flexible high resolution PWMs
  - Advanced Capture, Quadrature Encoder Interfaces
  - CAN, LIN, SPI, I2C, SCI/UART, McBSP

- **Broad portfolio of configurations**
  - 40-300 MHz
  - Fixed and Floating-point devices
  - 32-512KB of Flash
  - From sub $2 to $20
  - Software compatibility across C2000 family
C2000 Sample Applications

Renewable Energy
- Solar Power Inverters
- Wind Power Inverters

Digital Motor Control
- Power Tools
- Industrial Drives & Motion Control
- White Goods

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

Lighting
- LED Street Lighting
- Auto HID
- LED TV Backlighting

Automotive
- Hybrid Electric Vehicles
- Electric Power Steering
- Radar / Collision Avoidance

Precision Sensing & Control
- Power Line Communication
- Laser Ranging
- Medical Oxygen Concentrators
- Optical Networking
- RFID Readers
C2000 Architecture & Peripherals

- C28x Core
- Floating Point Unit
- Control Law Accelerator
- Control Peripherals
  - PWM, ADC, Comparator, Capture, Quadrature Encoder
C2000: The Solution for Real-Time Control

Driving Efficiency in Real-Time Control Systems

• Best CPU for Precision Math/Control
  – Fixed & Floating Point
  – Control Law Accelerator
  – Broadest Offering
    • 40 to 300 MHz
    • 38 to 256 Pins
    • $1.85 to $16 1Ku

• Highest Speed
• Best Resolution
• Lowest Latency
• Most Flexible Triggering & Synch

D→A

Control

D←A

Plant

Endless Possibilities
C2000 Highlights*  
- 32-bit 28x DSP Core w/ FPU  
- Floating-Point Control Loop Accelerator  
- ROM for Boot, IQMath, Trig Tables, Flash API  
- Single 3.3V supply  
- Fast 12-bit Hybrid SAR ADC w/ low latency trigger  
- Analog comparators  
- 10 bit DAC references  
- Enhanced PWM Modules  
- Input Capture  
- QEP Module  
- Dual on-chip 10MHz oscillators  
- Power on Reset  
- Brown Out Reset

Please Check C2000 Product Bulletin to see which features are available on either Delfino or Piccolo Families
The 32-bit C28x core is at the heart of every C2000 C28x microcontroller. Offering DSP class performance, the core is optimized to quickly execute math-based operations, but can also handily process general-purpose code.

C28x CPU
- 32-bit fixed-point processor
- RISC instruction set
- 8-stage protected pipeline
- 32x32 bit fixed-point MAC for single-cycle 32-bit multiplies
- Dual 16x16 bit fixed-point MACs
- Single-cycle instruction execution

Modified Harvard Bus Architecture
- Separate data and instruction bus
- Read and Write data buses
- Enables fetch, read, and write in a single cycle

Emulation Logic
- Real-time emulation allows interrupt servicing even when main program is halted
- Debug host has direct access to registers and memory
- Enables data logging to the debug host
- Multiple hardware debug events and breakpoints
Code Security Module (CSM)

Main Features
- Protects on-chip memory from unauthorized access/visibility
- 128-bit password programmed into flash
- Achieved without interruption or stalling of CPU execution
- CSM protects the flash/OTP and portions of SARAM
- Emulation Code Security Logic (ECSL) prevents unauthorized users from stepping through secure code*
- Write password to KEY register to unlock
- Secure code can access secure data
- Unsecure code cannot access secure data

28x Code Security Module Access Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>CSM Contents</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1:</td>
<td>Secure</td>
<td>CSM-protected code can be executed but not read</td>
</tr>
<tr>
<td>No password, execution code located outside secure memory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode 2:</td>
<td>Secure</td>
<td>No JTAG access*; CPU has full access</td>
</tr>
<tr>
<td>No password, execution code located inside secure memory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode 3:</td>
<td>Open</td>
<td>Full CPU and JTAG access</td>
</tr>
<tr>
<td>Correct password</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Differences Across C2000 Devices

- **281/0x** – CSM-based; 128-bit password
- **Delfino** – Adds Emulator disconnection upon secure memory access attempt (ECSL)
- **Piccolo** – Same as 282x/3x

* Feature only present on 282x and later devices
Enhanced PWM (ePWM)
Each ePWM module has two outputs, EPWMxA and EPWMxB (same frequency, independent duty)
Each module is independent frequency, but can be synched or phase delayed

**Dedicated 16-bit Time Base**
- Uses pre-scaled CPU system clock; Registers are shadowed
- Up, Up-Down, Down-Up
- Events: Zero, Period
- ePWMx modules can be synched or phase delayed

**Counter Comparator (CC)**
- Registers and comparators eliminate the need to interrupt the CPU in PWM generation
- Events: CMPA (rising & falling), CMPB (rising & falling)

**Action Qualifier feeds Event Triggering**
- At any Event: Set PWMxA/B (High, Low, Toggle, Do Nothing); Trigger a programmable Event or Interrupt

**Programmable Dead-Band Generator**
- Programmable rising-edge and falling-edge delay

**PWM Chopper**
- Allows a high-frequency carrier signal to modulate PWM waveforms
- Programmable chopping frequency, duty cycle, and first pulse width

**Programmable Trip Zone Generator**
- Quickly overrides PWM signals to Hi, Low, or Hi-Z
- One-shot or cycle-by-cycle (current limiting) operation
- Can generate events, filtered events, or trip conditions

*Piccolo only*
# High Resolution PWM

## High Resolution PWM output

- Based on micro edge positioner (MEP) technology, which finely positions an edge by subdividing the PWM clock
- Allows high resolution control of both duty cycle and phase
- Piccolo adds high resolution period control
- Finer edge positioning control
- Self-check diagnostics
- Step size down to 65ps for Delfino C2834x

- Most useful for high frequency PWM requirements of power conversion topologies such as:
  - Single-phase buck, boost, and flyback
  - Multi-phase buck, boost, and flyback
  - Phase-shifted full bridge
  - Direct modulation of D-Class power amplifiers

### C2834x HRPWM Effective Resolution (at 300MHz)

<table>
<thead>
<tr>
<th>PWM (kHz)</th>
<th>Standard PWM</th>
<th>HR-PWM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bits %</td>
<td>bits  %</td>
</tr>
<tr>
<td>50</td>
<td>12.6 0.02</td>
<td>18.3 0.000</td>
</tr>
<tr>
<td>100</td>
<td>11.6 0.03</td>
<td>17.3 0.001</td>
</tr>
<tr>
<td>250</td>
<td>10.2 0.09</td>
<td>16.0 0.002</td>
</tr>
<tr>
<td>500</td>
<td>9.2 0.17</td>
<td>15.0 0.003</td>
</tr>
<tr>
<td>1000</td>
<td>8.2 0.34</td>
<td>14.0 0.006</td>
</tr>
<tr>
<td>2000</td>
<td>7.2 0.68</td>
<td>13.0 0.012</td>
</tr>
</tbody>
</table>

### Piccolo HRPWM Effective Resolution (at 60MHz)

<table>
<thead>
<tr>
<th>PWM (kHz)</th>
<th>Standard PWM</th>
<th>HR-PWM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bits %</td>
<td>bits  %</td>
</tr>
<tr>
<td>50</td>
<td>11.0 0.05</td>
<td>16.8 0.001</td>
</tr>
<tr>
<td>100</td>
<td>10.0 0.10</td>
<td>15.8 0.002</td>
</tr>
<tr>
<td>250</td>
<td>8.6 0.25</td>
<td>14.4 0.005</td>
</tr>
<tr>
<td>500</td>
<td>7.6 0.50</td>
<td>13.4 0.009</td>
</tr>
<tr>
<td>1000</td>
<td>7.1 0.75</td>
<td>12.4 0.018</td>
</tr>
<tr>
<td>2000</td>
<td>6.6 1.00</td>
<td>11.4 0.036</td>
</tr>
</tbody>
</table>
12-bit ADC
Fast and Flexible 16-channel ADC

Start-of-Conversion (SOC) Triggers
• Triggered by software, ePWMs, or GPIO

Sequencer
• Sequencers allow up to 16 conversions without CPU intervention
• Allows easy oversampling for more accuracy and precision
• Flexible sequencing and SOC triggers (see specific families)

Up to 16 Analog Inputs
• 16 channel, multiplexed analog inputs

Dual Sample and Hold
• Dual sample/hold enable simultaneous sampling or sequencing sampling modes

12-bit Analog-Digital Converter
• Fast conversion rate: Up to 80ns, 12.5 MSPS

Result Registers
• Sixteen result registers (individually addressable) to store conversion values

Calibration Circuitry & Software
Input Capture (eCAP)

Advanced capture can record up to four different events (useful for applications such as remote control signal capture). Can also function as a PWM output.

**Dedicated 32-bit Time Base**
- Uses prescaled CPU system clock.
- Phase register allows synchronization with other counters.
- Event Qualifier can reset the counter on any of the four event loads.

**Mode Select**
- Enables ECAPx pin as an input capture or PWM output.

**Event Qualifier**
- Records event time stamps in absolute or delta modes.

**Capture Control**
- Tells Event Qualifier which CAPx register to store data.
- Controls input capture in one-shot or continuous modes.

**32-bit CAP1-4 Registers**
- Four independent registers, one for each event.
- In PWM mode, two can be used as shadow registers.

**Interrupt and Flag Control**
- 7 different events can be configured to trigger an interrupt.

**PWM Output**
- Timer-based PWM output option.
- Regular PWM with shadow loading.
Quadrature Encoder Pulse Module (eQEP)

QEP modules take in feedback signals from a motor to determine position and/or speed.

Four QEP input signals
- eQEPA/B signals used to derive direction and quadrature-clock when they are not provided
- Index signal indicates one whole revolution
- Strobe input can be connected to an outside sensor to receive notifications about position (such as end-of-line on a typewriter)

Quadrature Decoder Unit
- Generates direction and clock for the position counter
- Four modes for different inputs and measurements

Position Counter / Control Unit
- Keeps track of motor position in four different manners
- Records event time stamps in absolute or delta modes
- Pulse stretcher increases event pulse duration to ensure proper timing

Quadrature Capture Unit
- Integrated edge capture unit for low speed measurement

Unit Timer Base
- 32-bit timer to generate periodic interrupts for velocity calculations

QEP Watchdog
- Monitors quadrature-clock to indicate proper operation of the motion-control system.
# Low Power Modes

C28x processors have three different power modes. Across different processors, these modes are basically the same, with the exception of the watchdog on Piccolo.

## IDLE

<table>
<thead>
<tr>
<th>Device</th>
<th>Typical Current Consumption</th>
<th>Worst-case Wakeup Time*</th>
<th>PLL</th>
<th>WD</th>
<th>CPU Clock</th>
<th>Osc</th>
<th>Periphs</th>
<th>Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piccolo</td>
<td>14.1 mA @ 40MHz</td>
<td>26us from Flash</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>User Select</td>
<td>Off</td>
</tr>
<tr>
<td>Delfino</td>
<td>100 mA @ 150MHz</td>
<td>7us from Flash</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>User Select</td>
<td>Off</td>
</tr>
</tbody>
</table>

## STANDBY

*See speaker notes for clarification

<table>
<thead>
<tr>
<th>Device</th>
<th>Typical Current Consumption</th>
<th>Worst-case Wakeup Time*</th>
<th>PLL</th>
<th>WD</th>
<th>CPU Clock</th>
<th>Osc</th>
<th>Periphs</th>
<th>Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piccolo</td>
<td>4.25 mA @ 40MHz</td>
<td>29us from Flash</td>
<td>On</td>
<td>On</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Delfino</td>
<td>8.08 mA @ 150MHz</td>
<td>7.8us from Flash</td>
<td>On</td>
<td>On</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
</tr>
</tbody>
</table>

## HALT

<table>
<thead>
<tr>
<th>Device</th>
<th>Typical Current Consumption</th>
<th>Worst-case Wakeup Time*</th>
<th>PLL</th>
<th>WD</th>
<th>CPU Clock</th>
<th>Osc</th>
<th>Periphs</th>
<th>Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piccolo</td>
<td>125 uA @ 40MHz</td>
<td>13ms from Flash</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Delfino</td>
<td>232 uA @ 150MHz</td>
<td>13ms from Flash</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
</tbody>
</table>

*See speaker notes for clarification
IQMath

- Library and Compiler Intrinsic

Don’t take my word for it....

“We have used IQMath in our real-time motor control applications on TI’s C2000 MCU for more than 5 years. IQMath makes coding a fixed-point device simpler since you don’t have to worry about scaling or saturation; quicker by providing an efficient set of libraries and allowing you to write in or directly integrate floating point code; and more robust as it enables you to vary your dynamic range and choose the precision needed. The correct range and precision is critical in creating stable control systems for the complex power electronics that I design. And the same code can then be targeted to the C2000 floating point devices that are now available.”

- Dr. Dal Ohm, Drivetech, Inc.
The user selects a “Global Q” value for the entire application:

```c
#define GLOBAL_Q 24  // set in “IQmathLib.h” file
_iq  Y, M, X, B;
Y = _IQmpy(M,X) + B;  // all values are in I8Q24
```

The user can also explicitly specify the IQ value to use:

```c
_iq20  Y, M, X, B;
Y = _IQ20mpy(M,X) + B;  // all values are in I12Q20
```
C2000 Product Portfolio

- Piccolo™ MCU Series
- Delfino™ MCU Series
C2000 Roadmap

100+ Code Compatible Devices

Performance
Connectivity
Safety Enhancements

NEXT

Delfino™
(176-256 Pins)
$9 - $16

C2834x
Floating Pt
Performance

F2833x
CAN

Next

F2834x
Upto 600 MFLOPS
196-516kB SRAM
External ADC
Low Active Power

C2834x
Upto 300 MFLOPS
128-512kB Flash
52-68kB SRAM

Piccolo™
(38-100 Pins)
$<2 - $5

F280x
Floating Pt
Low Cost

Next

F2801x

F2803x
Fixed Pt w/ Co-Processor Options

CAN

Next

F2803x
60MHz – CLA,
64-128kB Flash,
20kB RAM

F2802x
Fixed Pt
Low Cost

Next

F2802x
40-60MHz,
32-64kB Flash,
6-12kB RAM

Endless Possibilities

All Pricing is to be considered budgetary and subject to change. Pricing is 1KU SRP -40 to 105C

ARROW ELECTRONICS AND TEXAS INSTRUMENTS
Piccolo MCU Architecture
MCU for Cost-Sensitive Real-Time Control

- **High-performance C28x CPU**
  - Up to 60MHz performance
  - Single cycle 32-bit MAC
  - Fast interrupt response and minimal latency

- **Control Law Accelerator**
  - 32-bit floating point math accelerator
  - Operates independent of C28x CPU
  - Up to 5X performance boost

- **Power & Clocking**
  - 150ps resolution on PWM frequency & duty cycle
  - 12-bit ratio-metric ADC with individual channel triggers
  - Up to 3x analog comparators with 10-bit reference

- **Enhanced Architecture**
  - High accuracy on-chip oscillators (10MHz)
  - Single 3.3V supply with BOR/POR supervision

- **Intelligent Peripherals**
  - 150ps resolution on PWM frequency & duty cycle
  - 12-bit ratio-metric ADC with individual channel triggers
  - Up to 3x analog comparators with 10-bit reference

- **30+ configurations bring a wide range of performance, package, and memory**

- **Available on “Piccolo” F2803x series**

Note: See detailed block diagram for device variations

*Click here for detailed block diagrams*
Control Law Accelerator (CLA)

Turbo Charge Control Systems

**Independent 32-bit floating-point math accelerator**

- Operates independently of the C28x CPU
  - Independent register set, memory bus structure & processing unit
  - Low interrupt response time

**Direct access to PWM, ADC/CMP**
- Execution of algorithms in parallel with the C28x CPU

**Fully programmable: 32-bit FPU**
- Removes scaling and saturation burden

**Math/trig/control Blocks**
- Sin, Cos, Div, Atan, Atan2, Sqr, iSqr, SineCosine, DMCLib, DPLib, Peripherals

- Reduced sample-to-output delay
- Faster system response & higher MHz control loops
- Improved support for multi-channel (phase/freq) loops
- Improved System Robustness
- Free-Up C28x CPU For Other Tasks (communication, diagnostics)

Digital Power Applications
Automotive, White-goods
General Purpose MCU Applications
Benefits of CLA

F280x

CPU

CONTROLLER ISR

Sample

A/D Conversion

H/w trigger

Controller u/d

Sample

time

Piccolo F2803x

CLA

CONTROL LAW

CPU

Sample

A/D Conversion

H/w trigger

Controller u/d

Sample

time

1. Reduced interrupt latency / jitter
2. Reduced control loop delay
3. CPU bandwidth increased

Endless Possibilities

ARROW ELECTRONICS AND TEXAS INSTRUMENTS

END
ADC Enhancements: Flexibility

Piccolo’s hybrid ADC allows even more flexible creation of conversion sequences.

Start of Conversion (SOC) Configuration and Logic Block
- 16 SOC triggers from Software, CPU timers, ePWMs, and GPIOs
- Allows easy creation of conversion sequences
- Multiple conversions can be processed in Round Robin or Priority Modes
- 9 flexible interrupts

Up to 16 Analog Inputs
- 16 channel, multiplexed analog inputs.
- Supports both 0-3.3V fixed range and ratio-metric input range

Analog Mux & Sequencer
- Each SOC can have its own trigger, channel, and acquisition window

Dual Sample and Hold
- Dual sample/hold enable simultaneous sampling or sequential sampling modes
- Adjustable acquisition window for each SOC

12-bit Analog-Digital Converter
- Fast conversion rate: Up to 80ns, 4.6 MSPS

Result Registers
- Sixteen result registers (individually addressable) to store conversions
- Just-In-Time feature pre-triggers Result Interrupt to reduce latency for CPU/CLA read
Comparators

Analog Comparators on Piccolo devices bring instant protection

10-bit DAC
- Analog DAC can provide input to comparator

Analog Comparator
- True analog voltage comparator in VDDA domain
- 30ns response time to PWM Trip Zone

Sync/Qualification
- Comparator output can be passed directly or synchronized with the system clock
- Qualification logic can delay output for multiple clock cycles

EPWM and GPIO Mux Outputs
- Output can be routed to ePWM Trip Zone Module as well as GPIO output
Voltage Regulator and Reset System

- **Lower System Cost**
  - On-chip regulator eliminates requirement for external 1.8V rail
  - BOR/POR protection eliminates requirement for external supervisor

- **Increased System Reliability**
  - Eliminates any start-up glitches on PWM outputs
Clocking System - Piccolo

Piccolo’s clocking system provides two zero-pin on-chip oscillators to eliminate the need for external clock circuitry. The high accuracy, high speed internal clocks are also a part of an extensive clock protection system.

**Lower System Cost**
- No external clock circuitry or crystal required
- Includes secondary internal oscillator for backup or alternate clock source

**Increased System Reliability**
- Backup internal oscillator automatically triggered in case of error
- Configurable clock sources allows independent CPU, CPU Timer 2 and Watchdog clocks
- Watchdog support standards such as IEC-60730
- Automatic PWM trip in case of clock failure

**3-tier Clock Protection**
- If clock failure is detected, CLKIN and WDCLK automatically switches to backup oscillator
- Two internal high-speed oscillators
- If both internal clocks fail, PLL clock automatically goes into “limp mode” to facilitate shut-down procedures. (5 MHz only)

**Internal Oscillator Accuracy**
- ~3% (85C to 125C)
Piccolo Analog Integration

Lower System Cost / Increased System Reliability

• On-Chip Voltage Regulation
  – On-chip regulator eliminates requirement for external 1.8V rail
  – BOR/POR protection eliminates requirement for external supervisor
  – Eliminates any start-up glitches on PWM outputs

• Dual On-Chip Oscillators
  – No external clock circuitry required
  – Independent time bases for main CPU and Watchdog support standards such as IEC-60730

• Analog Comparators
  – Trip PWM Outputs, Generate Interrupts, Sync PWM Outputs, Generate ADC SOC, Route to GPIO Pins

• Analog-to-Digital Converter
  – Continuous sampling up to 5 MSPS
  – Ratio metric across full 3.3V input range
  – No support pins

• High Resolution PWM
  – High Resolution Duty Cycle Modulation with 150ps Steps
  – High Resolution Frequency Modulation with 150ps Steps
Piccolo™ is the right solution for Real-Time Control

Core Performance Benchmark

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Cortex-M3 (72 MHz)</th>
<th>28x (60MHz)</th>
<th>28x+CLA (60MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General purpose (Dhrystone)</td>
<td>786</td>
<td>482</td>
<td>482 / 0</td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control algorithm (PID16) cycles</td>
<td>1762</td>
<td>1081</td>
<td>0 / 550</td>
</tr>
<tr>
<td>Control algorithm (PID32) cycles</td>
<td>2548</td>
<td>1563</td>
<td>482 / 550</td>
</tr>
<tr>
<td>Digital power (Buck loop) cycles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced control filter (FIR) cyc/tap</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Operation MHz used (20 kHz loop)

- Feedforward control cycles: ~51MHz
- Feedback control cycles: ~32MHz
- Total Control Law cycles: ~10MHz (28x) + 11MHz (CLA)

Control Application Performance Benchmark

- Dhrystone benchmark is industry standard, does not benchmark the math performance of a processor

- 30% headroom
- 20% faster, lower frequency, 50% headroom
- 5X faster, lower frequency, 80% headroom
Piccolo Sample Applications

**Solar Micro Inverters**
- Simpler wiring and reduced installation costs
- More reliable power production
- Better panel and system monitoring through networking

**Commercial LED Lighting**
- More efficient than traditional lighting, less heat dissipation
- Longer bulb life, less maintenance
- Brighter than traditional lighting

**Hybrid Electric Vehicles**
- Reduces emissions and improves fuel economy
- Increased demands to improve power conversion efficiency
- Sophisticated and fast control required for battery management

**Appliances**
- Must meet stringent energy efficiency standards
- Safety standards being mandated such as IEC60730
- Smarter systems requiring complex algorithms and control techniques
**Delfino Floating Point MCU**

**MCU for Advanced Real-Time Control**

### High-performance C28x CPU
- Up to 300MHz performance
- Single cycle 32-bit MAC
- Fast interrupt response and minimal latency

### 32-bit floating point
- IEEE 32-bit single precision
- Eliminates scaling & saturation burden
- Magnitude calculations (division & square root)
- Park & Clark type algorithms (sin and cos)
- FFT and IIR performance improvements

### Pin-compatible Fixed-point options available for F2833x series

### Click here for detailed block diagrams

---

### Delfino

**C28x 32-bit CPU**
- Up to 60 MHz
- 32x32-bit Multiplier
- RMW Atomic ALU

**Memory**
- 0-512 KB Flash
- 52-516 KB RAM
- Boot ROM

**Memory Interface**
- 16/32-bit EMIF

**Analog to Digital Converter**
- 12-bit 2-S/H 12.5 MSPS
- Or External with Triggering

### Peripherals

**128-Bit Security Key/Lock**

**Serial Interfaces**
- 2x SPI
- 3x SCI
- 1x I²C
- 3x CAN
- 2x McBSP

### Timer Modules

**9x ePWM Modules:**
- 18x PWM outputs (9x 65ps high-res)
- 6 x 32-bit eCAP
- 3 x 32-bit eQEP
- Watchdog Timer
- 3x 32-bit CPU Timers

### Connectivty
- 88 I/Os

---

### Control-oriented architecture
- Asynchronous external memory interface
- External ADC interface
- DMA controller

### Intelligent peripherals
- Flexible PWM modules
  - Programmable period, frequency and phase control
  - Dead-band generation
  - Programmable trip zone allocation
- Hi-Res PWM modules with up to 65ps resolution
- 32-bit QEP modules for hardware decoding
- 32-bit capture modules

---

**Note:** See detailed block diagram for device variations

**F2833x series**
- on-chip Flash only
- on-chip ADC
- 150 MHz C28x CPU

**C2834x series**
- on-chip SRAM only
- external ADC
- 300 MHz C28x CPU

---

**ARROW ELECTRONICS AND TEXAS INSTRUMENTS**

---

**Endless Possibilities**
Floating Point Unit

The FPU on Delfino devices is a logic unit that extends the C28x core to include floating-point instructions. Supports full IEEE single-precision 754 (most widely used format).

### C28x + FPU Pipeline

<table>
<thead>
<tr>
<th>Fetch</th>
<th>Decode</th>
<th>Read</th>
<th>Exe</th>
<th>Write</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>F2</td>
<td>D1</td>
<td>D2</td>
<td>R1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>W</td>
</tr>
</tbody>
</table>

### C28x + FPU

- Full floating-point or fixed-point support
- FPU instructions share same first half of pipeline as fixed-point instructions, but has its own second half
- Floating-point
  - Is inherently more robust
  - Removes scaling & saturation burden
  - Reduces time-to-market
- Using floating point can reduce the cycle count for math functions by 52%. In addition, C2834x devices have reduced memory access time, resulting in 64% cycle reduction over other 28x devices.

### FPU compilation and execution

- Fixed-point C2000 processors use support libraries to simulate floating-point math, store variables in stack
- Floating-point C2000 processors natively support single-precision floating-point instructions, store variables in floating-point registers
- Use simple compiler switch to assemble code using FP instructions
- Separate floating-point version of IQMath, Flash API, etc.
- FPU Optimized Math Library

### Documentation and Software

- [TMS320C28x Floating Point Unit Instruction Set Reference Guide](#)
- [C28x FPU Primer App Note](#)
- [C28x FPU Library](#) and [C28x FPU FastRTS Library](#)
Floating-point Performance for Demanding Applications

- Up to 70% reduction in memory access time
- Up to 64% reduction in cycles
- Up to 52% code reduction

*State Estimator shown in 10s of cycles*
Multichannel Buffered Serial Port (McBSP)

The McBSP provides a direct interface to industry-standard codecs, analog interface chips, and other serially connected A/D and D/A devices. For example, the McBSP can be used to connect to T1/E1 lines (framers), phone-quality codecs for modem applications or high-quality stereo audio DAC devices.

Compliant with: T1/E1, IOM-2, AC97, I2S, and can also be used as an SPI.

Transmit and Receive signals
- Three pins required for each direction (6 pins total): Data, Clock, and frame synchronization

McBSP Main Logic Block
- Full-duplex, double-buffered transmission and triple-buffered reception, which allows continuous data streams
- Contains transmit buffer and receive buffer, supports up to 32-bit word sizes
- Direct Memory Access on F282x and Delfino devices
- 16 word FIFO on F281x devices (with no DMA) decreases CPU time
- Communicates with interrupt logic as well as the CPU through DMA or peripheral bus
- Compression via μ-law or A-law formats

Transmit/Receive Interrupt Select Logic Blocks
- Interrupts are generated on data conditions and error conditions
- Data conditions are programmable
- Interrupts trigger either CPU or DMA to send/read data
Direct Memory Access (DMA)

F282x and Delfino devices contain a 6-channel DMA

**DMA Controller**
- Used to free CPU bandwidth and rearrange data for easy processing
- 6 channels with independent PIE interrupts
- Event-based machine: requires peripheral trigger to activate
- Channel 1 has the ability to be a high-priority channel
- 4 cycles/word throughput (5 for McBSP)
- Arbitration handing when CPU and DMA both try to access the same interface concurrently

**Peripheral Interrupt Trigger Sources**
- ADC sequencers
- McBSP
- External Memory (XINTF)
- CPU Timers
- ePWM Start-of-conversion signals (F2833x/F2823x only, excl. Rev0)
- Software

**Data Sources / Destinations**
- Some RAM zones
- External Memory zones
- ADC result registers
- McBSP transmit/receive buffers
- ePWM 1-6 registers

*F2833x/F2823x RevA and up only*
External Interface (XINTF)

The external interface represents zones in the 28x memory map that are connected to external memory or peripherals. The CPU can then directly access that external resource.

Features

- 4.008MB of address space (2.008MB for F281x devices)
- Zones can be configured individually to use a 16-bit or 32-bit data bus
- Connected to the on-chip DMA module on F283x, F282x, and C2834x devices
- Ability to extend DMA to external memory
- Programmable wait states, chip-select, and strobe timing enables glueless interface to external memories and peripherals
- XINTF clock can be disabled to save power
- Automatic read-after-write hazard protection
- Up to three stage write buffer to decrease CPU load

External Interface Module Guide

F281x – SPRU067
F2833x, F2823x – SPRU949
C2834x – SPRUFN4

<table>
<thead>
<tr>
<th>Devices</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>F281x</td>
<td>16-bit bus only</td>
</tr>
<tr>
<td>F2833x, F2823x,</td>
<td>16 or 32-bit bus, DMA access, XINTF Clock Disable</td>
</tr>
<tr>
<td>C2834x</td>
<td></td>
</tr>
</tbody>
</table>
Delfino Floating Point Applications

Industrial Power Electronics
• AC Servos, Inverters, CNC
• Motor control for industrial and aerospace
• Soft Starters, Circuit Protection
• Process Controls
• Plasma Cutters & Welders

Power Delivery
Real-time analysis, conversion, or battery charging
• Line monitoring & protection
• UPS for large systems
• Battery charging
• Power line metering

Renewable energy
Controls power conversion & interface to grid or battery
• Windmill & Turbine Inverters
• Solar Inverters
• Generators
• Fuel Cells

Smart Sensing
• Radar, Laser, Doppler, Flow Meters, Infrared Sensors
• Precision Measurements
• Gyroscopes, MEMS Sensors
• Chemical, Spectral, Electro, Photo, Reflective, Radiation Analysis
• Oscilloscopes, Medical Ultrasound and EKG
### CLA vs. Floating-Point Unit

<table>
<thead>
<tr>
<th>Control Law Accelerator</th>
<th>Floating-Point Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent 8 Stage Pipeline</td>
<td>F1-D2 Shared with the C28x Pipeline</td>
</tr>
<tr>
<td>Single Cycle Math and Conversions</td>
<td>Math and Conversions are 2 Cycle</td>
</tr>
<tr>
<td>No Data Page Pointer. Only uses Direct &amp; Indirect with Post-Increment</td>
<td>Uses C28x Addressing Modes</td>
</tr>
<tr>
<td>4 Result Registers 2 Independent Auxiliary Registers No Stack Pointer or Nested Interrupts</td>
<td>8 Result Registers Shares C28x Auxiliary Registers Supports Stack, Nested Interrupts</td>
</tr>
<tr>
<td>Native Delayed Branch, Call &amp; Return Use Delay Slots to Do Extra Work No repeatable instructions</td>
<td>Uses C28x Branch, Call and Return Copy flags from FPU STF to C28x ST0 Repeat MACF32 &amp; Repeat Block</td>
</tr>
<tr>
<td>Self-Contained Instruction Set Data is Passed Via Message RAMs</td>
<td>Instructions Superset on Top of C28x Pass Data Between FPU and C28x Regs</td>
</tr>
<tr>
<td>Supports Native Integer Operations: AND, OR, XOR, ADD/SUB, Shift</td>
<td>C28x Integer Operations</td>
</tr>
<tr>
<td>Programmed in Assembly</td>
<td>Programmed in C/C++ or Assembly</td>
</tr>
<tr>
<td>Single step moves the pipe one cycle</td>
<td>Single step flushes the pipeline</td>
</tr>
</tbody>
</table>
C2000 Product Portfolio

• controlSUITE
• controlCARD Concept
• Application Developer’s Kits
• Piccolo controlSTICK
• Software Libraries & Examples
• 3rd Party Solutions & Additional Resources
controlSUITE™

What does controlSUITE solve?

*I never know if I am aware of every resource that’s available*
Install controlSUITE once and it delivers a comprehensive package of every resource available for your device or application

*I am never sure I am using the latest version of software, or if something completely new has been released*
controlSUITE can automatically or manually synchronize with a central repository, keeping you up to date with the latest revisions or newest offerings

*My current vendor provides resources that are a) good, but expensive b) free, but aren’t properly supported c) licensed, and won’t provide source*
Everything in controlSUITE is completely free, meticulously documented, under version control, and nearly 100% open source on all software and hardware

*I like to explore a system example, then tweak to my needs vs. I like to build my application from the ground up, bit by bit*
controlSUITE offers the complete solution, with 4 levels of hardware abstraction, libraries, software examples, full systems, and GUIs you can jump in at any level depending on your experience and comfort.
What is controlSUITE?

CONTENT

+ 

CONTENT MANAGEMENT
controlSUITE Content Snapshot

Series
- Piccolo F2802x
- Piccolo F2803x
- Delfino C2834x
- Delfino F2833x

Device
- Bit Fields
- API
- Examples

Libraries
- Math
- DSP
- Utilities
- Applications

Kits
- Hardware
- Systems
- GUI
- Applications

Infrastructure
- IDE
- RTOS
- Real-time
- Network

Endless Possibilities
Device: Bit Fields & API

Level 1 – Registers and Addresses
Baseline assembly communication to all hardware registers and addresses

Level 2 – Bit Fields
- Bit fields can be manipulated without masking
- Flexibility to access a register as a whole or by bits
- Advanced CCStudio™ IDE features for ease-of-use

Programming F28x Peripherals in C/C++

Level 3 – API Drivers
- C functions that automatically set register bit fields
- Further reduces learning curve for new embedded programmers
- Common tasks and peripheral modes supported

<table>
<thead>
<tr>
<th>ADC</th>
<th>SPI</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNTRL</td>
<td>SYS</td>
<td>PWM</td>
</tr>
<tr>
<td>GPIO</td>
<td>TIME</td>
<td>WDG</td>
</tr>
<tr>
<td>I2C</td>
<td>UART</td>
<td></td>
</tr>
</tbody>
</table>

Level 4 – Framework
- State Machine / ISR Based OS
- Function-based device initialization
- Built-in task management
- Ability to connect to an external GUI
- Simple switching between RAM and Flash
Device: Examples

Each device support package includes examples demonstrating how to utilize the bit fields or drivers to its maximum potential
- Up to 45 Bit Field examples per device
- Full example set for API Drivers

Using direct register access

```assembly
//Interrupts set up elsewhere

//Set duty cycle
MOVB     09,#0x0F,UNC

//Set PWM1A on Zero Event
AND      AL,#0xFFFC
ORB      AL,#0x02
MOV      011,AL

//Clear PWM1A on Up-count //CompareA event
AND      AL,#0x00FCF
ORB      AL,#0x10
MOV      011,AL
```

Using Bit Field Headers

```c
interrupt void IsrAdc( void )
{
    // Period of ePWM1 is set in init;
    // Multiply period by desired duty
    // to get CMPA value;
    EPwm1Regs.CMPA Half.CMPA =
    EPwm1Regs.TBPRD * duty;
}
```

Using API Driver

```c
interrupt void IsrAdc( void )
{
    /* set a new pwm value */
    PWM_setDutyA(PWM_MODULE_2, duty);
}
```

Resources:
- Bit Field Example: Piccolo F2802x Quick Start Guide
- Coming Soon: Piccolo F2802x API Drivers Guide
Libraries: Applications

- C or Assembly SOURCE Provided for all
- Modular structures or macros with variable inputs and variable outputs
- At initialization all variables are defined and outputs of one block are set as inputs to the next
- At run-time the structures or macro functions are called
- Complete documentation – including equations and theory – is provided for every module

**Motor Control**

**Peripheral Blocks**
- BLDC PWM
- HALL CAP
- HALL GPIO
- QEP
- PWM DAC
- Data Log

**Control Blocks**
- PID
- Speed Estimators
- Speed Freq/Period
- Clarke / iClarke
- Park / iPark
- SVGen
- Commutation Trig
- Impulse
- Mod6 Counter
- Phase Voltage Calc
- Ramp Controllers
- Sliding Mode Observer
- ACI Flux/Speed Estimators
- CLA Versions

**Ex: Using “Park” from DMC Library**

```c
#define PARK_MACRO(v)
  v.Ds = _IQmpy(v.Alpha,v.Cosine) + _IQmpy(v.Beta,v.Sine);
  v.Qs = _IQmpy(v.Beta,v.Cosine) - _IQmpy(v.Alpha,v.Sine);

park1.Alpha = clarke1.Alpha;
park1.Beta = clarke1.Beta;

PARK_MACRO(park1)
```

---

**Power**

**Peripheral Blocks**
- ADC Conversion
- PWM DAC

**Control Blocks**
- 2P2Z
- PID
- Ramp Gen
- Sine Gen
- Slew Limit
- CLA Versions

**Topology Blocks**
- Buck (regular + HiRes)
- PSFB (regular + HiRes)
- Multi-phase Interleaved Buck
- PFC 2 Phase Interleaved
- PFC Current Command

**Power Line Modem**
- plcSUITE: SFSK, OFDM, G3, PRIME

---
Kits: Systems of Lib Implementations

Library Blocks are “Wired” into Systems Inside a full System Framework (OS)

1. Initialization of Device
2. Instance & Initialize Blocks
3. Run Framework / OS
4. Incremental Build Levels
5. Connect & Call Blocks

Example:
Sensor-less FOC Motor Control

**Build Level 1:** Verify Space Vector and PWMs
**Build Level 2:** Verify ADC conversion & Phase Voltage
**Build Level 3:** Tune PID for current control
**Build Level 4:** Verify Sensorless estimator
**Build Level 5:** Tune PID speed control
**Build Level 6:** Close all loops
Infrastructure: IDE CCStudio v4
FREE with XDS100 Emulators or 32KB Version
Infrastructure: RTOS

BIOS is TI’s royalty/run-time free real-time operating system for processors.

BIOS includes:
- Deterministic kernel with a preemptive scheduler
- Graphical or script-based configuration
- Graphical analysis & debug tools
- Interrupt dispatcher and management macros
- Multiple intertask communication services: semaphores, mailboxes, and queues

Resources: [BIOS 6.x Product Page]
Infrastructure: Real-time Debug

Traditional debugging (Stop Mode)
- stops all threads and prevents interrupts from being handled
- makes debugging real-time systems extremely difficult

C2000 Real-time Mode:
- real-time, non-intrusive, continuous
- Does not require use of target memory, special interrupts, or SW intrusiveness
- Allows time critical interrupts to be marked for special treatment (high priority)
- Allows time-critical interrupts to be serviced while background program execution is suspended
- Included on all C2000 devices and integrated with Code Composer Studio

Resources:
Real-Time Mode on wiki
Chapter 7.4 in the C28x CPU Reference Guide
Infrastructure: Development Network

Graphical Development & Code Gen for C2000

Metatools
Visual Solutions
VisSim
www.vissim.com/c2000

The Mathworks
Embedded Target
www.mathworks.com/products/tic2000/

- DMC and Peripheral Blocks
- Simulation and Modeling
- Auto-Tuning
- Code Generation
- Interface to CCStudio IDE
- Works with controlKITs

Multiple Local Consultants & Design Houses
controlSTICK: Low Cost Evaluation

$39 Kit includes

- Simple USB memory stick form factor evaluation tool
  - Piccolo F28027
  - Onboard USB JTAG emulation
  - Header pins provides access to most Piccolo pins

- 11 example projects explain most Piccolo peripherals

- Fully controlSUITE compatible

- Jumpers and patch cords to easily connect pins together

- USB extension cable

- Code Composer Studio V4

- Complete hardware documentation
  - Gerbers, schematics, etc
Kits: Hardware

Device Evaluation

**controlISTICK**
*JTAG Emulation on-board*
TMDX28027USB
$39

**Experimenter’s Kits - JTAG Emulation on-board**
TMDXDOCK28027
TMDXDOCK28035
TMDSDOCK2808
TMDSDOCK28335
$79-$159

**Experimenter’s Kits**
*Emulator required*
TMDXDOCK28343
TMDXDOCK28346-168
$189

**controlKIT Includes**
- controlCARD + Base Board
- CCStudio IDE v3.3 32KB code size limit
- Example Software with lab document
- Power Supply and Cables

**Developer’s Package**
- Schematics (source and .PDF files)
- Bill of materials (BOM)
- Gerber files to freely use or modify
- Pin-out table showing all key signals
- DIMM100 pin/socket mechanical details

Application Development

**Digital Power Experimenter’s Kit**
TMDSDCDC2KIT
$229

**AC/DC Developer’s Kit**
TMDSACDCKIT
$695

**Resonant DC/DC Developer’s Kit**
TMDSRESDCKIT
$229

**Renewable Energy Developer’s Kit**
TMDSENRGYKIT
$349

**Sensorless FOC DMC + PFC Developer’s Kit**
TMDS1MTRPFCKIT 1 Motor
TMDS2MTRPFCKIT 2 Motor
$369/$399

**High Voltage Sensorless FOC DMC + PFC Developer’s Kit**
TMDSHVMTRPFCKIT - $599

All new kits in controlSUITE. Most existing being ported.
Kits: Hardware

Hardware Developer’s Package

We provide you with all the necessary files to recreate the hardware. The PCB layout and schematics are broken up into modules that can be interconnected or implanted into a new design.

controlCARDs and controlKITS

Hardware Developer’s Package includes:

• Bill of Materials
• PCB layout
• Schematics
• Gerbers
Kits: GUls

- Connects through USB – Serial built in to each kit
- CCStudio (IDE) not required
- Images pre-loaded into flash on-chip for immediate use out of box
- Source code for GUls provided – Roll your own!
# C2000 Community Resources

## 3rd Party Tools
- JTAG Emulators and Adaptors
- Flash Programming
- Development and Evaluation Boards
- Simulators and Code Generation

[More Information](#)

## Workshops & Trainings
- Digital Power Multi-Day Workshop
- Piccolo One-Day Workshop
- 28x Multi-Day Workshop
- Online Training & Videos
- And More...

[More Information](#)

## Academic
- Teaching ROM
- Lab Documents
- Code Examples
- Development Boards

[More Information](#)

## Engineering Services
- Design Services
- System Integration/Reference Designs
- Software Libraries
- Gang Programming

[More Information](#)
The Solution for Real-Time Control

Performance
- 40-300MHz Control Savvy 32-bit 28x CPU
- Control Law Accelerator for high speed control loops
- Floating Point Unit
- Most efficient control techniques
- Hi-res PWM with 150ps resolution
- Up to 12.5 MSPS 12-bit ADC

Integration
- Dual on-chip high precision oscillators
- On-chip voltage regulation
- Analog comparator with DAC reference
- Enhanced PWM, CAP, QEP
- Up to 512kB on-chip Flash
- Up to 516KB on-chip SRAM
- I2C, SPI, UART/LIN, CAN, Buffered Serial Port
- and more…

Roadmap
- 40 MHz Piccolo to 300MHz Delfino controllers
- Starting sub $2
- Embedded Flash, Embedded SRAM, small packages to large I/O
- Floating point or fixed point core
- Future derivatives providing higher performance, additional connectivity, smaller packages, and safety enhancements

Ease of Use
- Low cost, modular dev tools
- Open source developers package
- Flexible software libraries and framework
- Best in class compiler efficiency
- Robust header files and software examples
- Unified memory architecture
- 16 and 32-bit instructions
Demos

• controlSUITE
• Dual Motor Control and PFC Developer’s Kit
controlSUITE Desktop
Easy navigation to all controlSUITE software, as well as C2000 resources

• Launch CCSv4 example projects
• View documentation and online resources
• Access libraries and utilities
• View datasheets and user guides
• See our most useful and popular application notes
• Find all training from live hands-on training to on-demand classes to videos and E2E forum support

Download from www.ti.com/controlSUITE
Low Voltage Dual Axis FOC
Motor Control + PFC Kit

$399 Motor Control and PFC Kit Includes

- Piccolo F28035 controlCARD
- Sensorless Sinusoidal SVPWM based Field Oriented Control
- Single or Dual Axis Operation
- Integrated Digital Power Factor Correction
- Hardware Features
  - 100W 2 phase interleaved power factor correction stage
  - 2 x 60 W motor driver stages based on TI DRV8402 motor driver chips
  - On board isolated XDS100 JTAG emulation
- Software Lab Projects
  - Standalone PFC
  - Dual Axis
  - Single Axis + PFC
  - Dual Axis + PFC (coming soon)
Motor Control GUI

- DC Bus voltage being fed to motor driver stages
- Motor Control Loop
  0: locked rotor
  1: open loop control
  2: sensorless closed loop control
- Target Speed for the motor
- Estimated rotor angle
- Estimated rotor speed
- Board connection status to PC
- Park Algorithm Q and D Outputs
- Measured current draw of leg U
- Motor graph being displayed
- Overall GUI update rate
- Graph Update Rate
- Dlog Prescaler
- Update Rate
Exclusive C2000 Day Discounts

Visit the TI eStore at [http://www.ti-estore.com/](http://www.ti-estore.com/) and take advantage of these limited time discounts!

50% off Piccolo controlSTICK
- Regular price: $39. Discount Price: $19
- Part number: TMDX28027USB
- Discount code: C2000Day1

25% off C2000 tools below:

- Piccolo F28027 Experimenter's Kit
  - Part number: TMDXDOCK28027
  - Code: C2000Day2

- Piccolo F28035 Experimenter's Kit
  - Regular price: $89. C2000 Day Price: $66
  - Part number: TMDXDOCK28035
  - Code: C2000Day3

- F28335 Experimenter Kit
  - Part number: TMDSDOCK28335
  - Code: C2000Day4

  - DC/DC LED Lighting Kit
    - Part number: TMDSDCDCLEDKIT
    - Code: C2000Day5

  - Dual Motor Control and PFC Developer's Kit
    - Regular price: $299
    - Part number: TMDS2MTRPFCKIT
    - Code: C2000Day6

  - High Voltage PFC and Motor Control Developer's Kit
    - Part number: TMDSHVMTRPFCKIT
    - Code: C2000Day7

Discount Terms:
- Each customer can order up to one of each of the 7 tools.
- You can enter multiple discount codes in one order.
- Codes are valid through December 15, 2010.
- You do need to have a my.TI account to place an order, however, if you do not have one signing up will only require you to enter a user name and password. This will allow you to review, track and reorder at a later date.
- If you do not want to enter a user name and password, you call also call the Product Info Center and order the tools with your discount codes at (972) 644-5580.
- For questions or help please email TI_Store@ti.com
Thank you!
C2000: Motor Control

Methodologies

High energy efficiency via Advanced Control
- Variable speed Real-time control
- Better dynamic and transient control

Broadest MCU Architecture
- 40-300MHz Fixed & Floating Point
- Parallel FP CLA for fastest loops
- Single Cycle 32x32-bit MAC
- Fast interrupts
- Flexible & Fast interrupt system
- Real-time debugging
- Best in class ADC performance

Piccolo Family for Lowest System Cost
- High Level of Integration
- Integrated Dual OSC, VREG, Watchdogs
- Limited life support
- No external GPIO filters needed

Application Libraries
- Specialized, application specific software functions
- Modular macros with variable inputs and outputs
- At initialization all variables are defined and outputs of one block are set as inputs to the next
- Complete documentation – including source code, use and technical theory – is provided for every module

Digital Motor Control Library
- Clarke, Park, SMObserver, Phase Voltage, Resolver, Flux
- Speed Calculators and Estimators

Control
- Signal Generation, PID, BEMF Commutation, Space Vector Generators
- Personal Drivers
- Different modes and topology support
- ADC, PWM, Encoders, Sensor Captures

Incremental Build Based Projects
- Incremental section of code built each level
- Verify each portion of their system
- PWMs, feedback, calculations
- Control laws, inner/outer loop, supervision
- Critical in motor control with so many different system variables

Solutions

Low Voltage
- Dual Axis
- DMC + PFC Kit
- TMDS1MTRPFCKIT
- TMDS2MTRPFCKIT
- $369/$399

High Voltage
- DMC + PFC Kit
- TMDSHVMTRPFCKIT
- $599

Quick Start
- GUI with all projects Flashed in MCU

Motor Control 1-day Workshop
- On-Line Self-Paced Coming 2H10

Coming Soon
- DRV83x2 + Piccolo Kit for BLDC/PMSM
- DRV84x2 + Piccolo Kit for Stepper/Brushed
- PFC using new DPSLib (28x and CLA)
- FOC on CLA

www.ti.com/c2000dmc
C2000: Digital Power

Methodologies

Reduces costs
- Tunable platforms
- Calibration across operating range
- Reduced board area and parts count

Higher quality
- Adaptive; efficiency across load range
- Flexibility through programmability
- Calibration at final functional test
- Less drift and better noise immunity
- Monitoring for quality improvement
- Proven concept in digital motor control

Higher reliability
- Built-in supervision
- Diagnostics, failure prediction

Solutions

Digital Power Experimenter Kit
TMDSDCDC2KIT $229

Resonant DC/DC Developer’s Kit
TMDSRESDCKIT $229

AC/DC Developer Kit
TMDSCDCKIT $695

Digital Power 3-day Workshop
sponsored by Biricha Digital Power Ltd

Digital Power 1-day Workshop
On-Line Self-Paced Coming Soon!

Coming in 2010

- New DPSLib in controlSUITE™
- High Voltage PFC Kit
- AC/DC Kit port to Piccolo & controlSUITE™
- High Voltage PSFB Kit
- High Voltage Resonant LLC Kit
- Control Loop Tuning Wizard