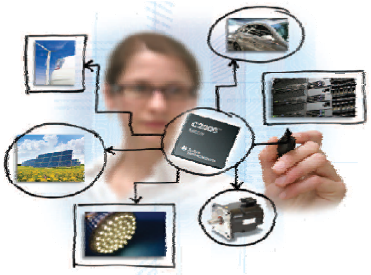
C2000 ™ 32-bit MCU Family



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

MCU Day 2009

Texas Instruments MCU

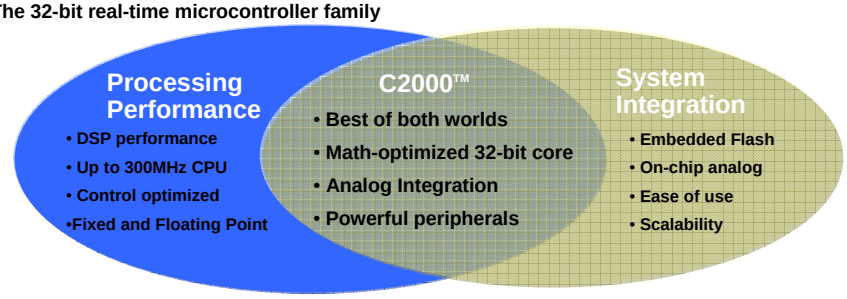
Welcome to MCU Day – One Day, Multiple Solutions

Agenda: C2000

- **C2000 Overview**
  - Value Proposition
  - Target Applications
  - Architecture & Key Features
  - Product Portfolio
    - Piccolo™
    - Delfino™
- **How to Get Started**
  - controlCARD Concept
  - Application Developer's Kits
  - Piccolo controlSTICK
  - Software Libraries & Examples
  - 3rd Party Solutions & Additional Resources

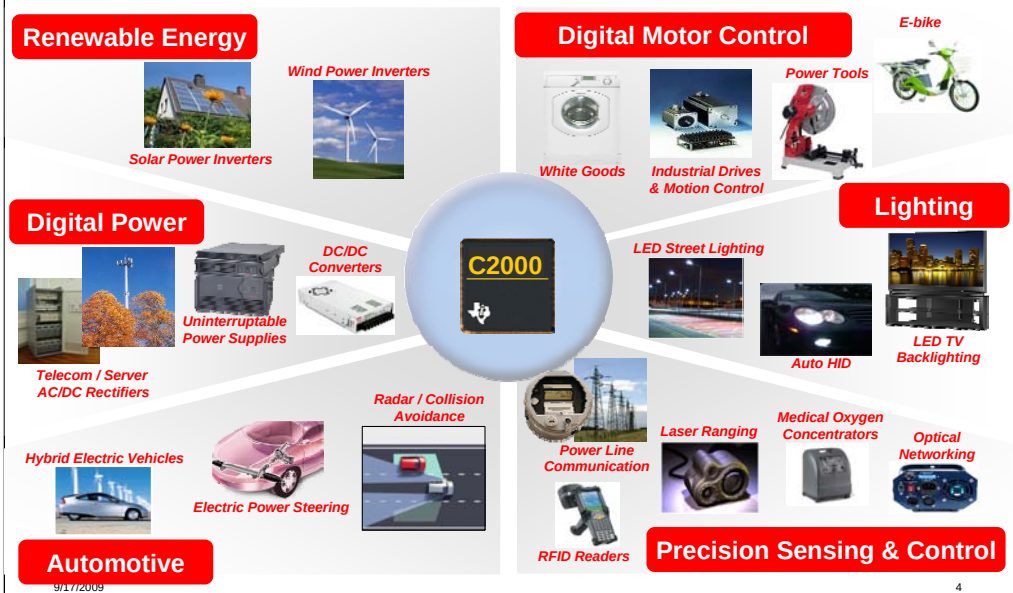
What is C2000?

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

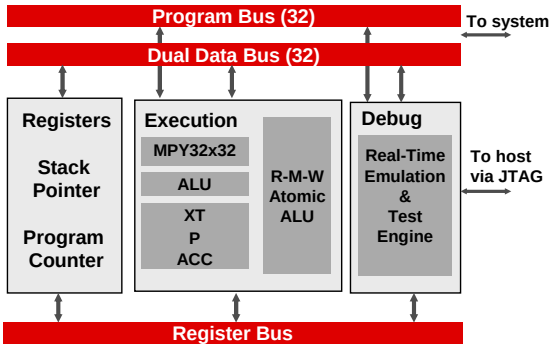


C2000 Architecture & Peripherals

28x Core
Floating Point Unit
Control Law Accelerator
Control Peripherals
- PWM, ADC, Comparator, Capture, Quadrature Encoder

C28x Core

The 32-bit C28x core is at the heart of every C2000 28x 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

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•The 28x CPU is a low-cost 32-bit fixed point processing core

•This device draws from the best features of digital signal processing, reduced instruction set computing (RISC), and microcontroller architectures, firmware, and tool sets

•CPU features a modified Harvard architecture and circular addressing

•RISC features are single-cycle instruction execution, register-to-register operation, and modified Harvard architecture (useable in Von Neumann mode)

•Microcontroller features include ease of use through an intuitive instruction set, byte packing and unpacking, and bit manipulation

•The modified Harvard architecture of the CPU enables instruction and data fetches to be performed in parallel. The CPU can read instructions and data while it writes data simultaneously to maintain the single-cycle instruction operation across the pipeline

•CPU architecture

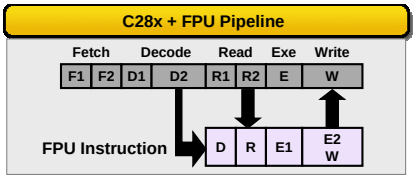
- •Protected pipeline. CPU implements and 8-phase pipeline.
- •Independent register space – system-control, math registers, data pointers
- •ALU – performs 2s complement arithmetic and Boolean logic operations
- •Address register arithmetic unit – generates data memory addresses and increments/decrements points in parallel with ALU operations
- •Barrel shifter – performs all left and right shifts of data
- •Multiplier – performs 32x32 2s complement multiplication w/ a 64-bit result.

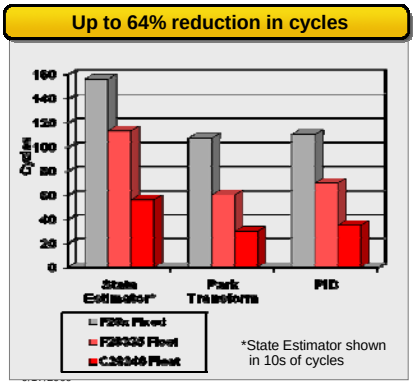
The following debug events can cause a break in program execution and allow more flexibility than software breaks:

- •Breakpoint initiated by ESTOP instructions
- •An access to a specified memory location
- •Request from debug host or other hardware

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

- 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.

Documentation and Software

- TMS320C28x Floating Point Unit Instruction Set Reference Guide
- C28x FPU Primer App Note
- C28x FPU Library and C28x FPU FastRTS Library

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•Native floating point brings many advantages, not only performance-wise.

- •Floating point is more robust, meaning it is less error-prone that fixed point math.
- •It can also do the same math operations or functions as fixed-point with significantly fewer instructions, resulting in easier development and faster time-to-market.
- •Engineers usually start development in floating-point, then translate the code into fixed-point before implementing them in their final designs. Eliminating the need for this conversion reduces development time as well as prevents any possible scaling and saturation issues.

•Through benchmarks against other C28x processors, floating-point instructions can help reduce the cycle count for math functions by 52%.

•C2834x's on-board RAM instead of Flash leads to reduced memory access time, further reducing the cycle count for math loops to a 64% improvement.

•The FPU on Delfino devices adds a secondary pipeline to the C28x core. When the CPU realizes a FPU instruction is being processed (in decode stage 2), it passes the instruction off to the FPU instruction pipeline where the floating-point hardware execution units are used.

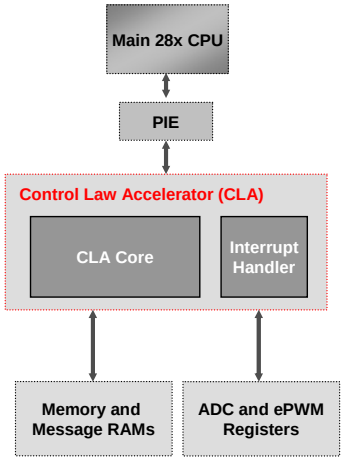
•Floating point instructions are enabled when the programmer sets a compiler switch to fpu mode. Without enabling this switch, the compiler will continue to generate the assembly code using the fixed-point support libraries.

• Another implementation difference between fixed-point and floating point is during function calls. In fixed-point mode, the values to be passed are stored on the stack. In floating-point mode, the values are stored in separate FP registers. Another point of note is that Delfino devices require the floating-point version of libraries to run using the FPU instructions(ex. IQMath, Flash API).

The FPU on Delfino devices (F2833x, C2834x) natively supports IEEE single-precision 754 (double-precision requires support libraries).

Control Law Accelerator (CLA)

The Control Law Accelerator on F2803x devices is an independent math accelerator that can execute algorithms in parallel with the C28x CPU



Control Law Accelerator (CLA)

- Independent, 32-bit floating-point math accelerator
  - Complete bus architecture and 8-state pipeline
  - FP-optimized execution units and registers
- Allows faster system response and higher frequency control loops
  - Simple interrupt handler reduces context switch time
  - No nested interrupts
  - Direct access to ADC and PWMs
- Reduces CPU load, allowing for more system functionality

Memory and Message RAMS

- CPU assigns program memory and data memory blocks to the CLA.
- Dedicated message RAMs to pass data between CPU and CLA.
- If CLA is unused, the CLA program/data memory can be used by CPU as normal memory

ADC and ePWM Registers

- CLA is directly connected to the ADC and ePWM, allowing control loop execution without any main CPU intervention.
- Also capable of using ADC's "just-in-time" interrupts

Main CPU and PIE

- CLA can interrupt the CPU

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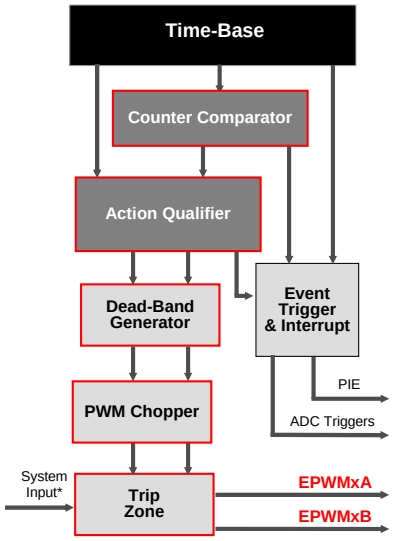
The ADC's just-in-time interrupts are basically early interrupt calls so that the context switch is finished at exactly the same time that the result register is populated, resulting in zero delay.

CLA vs. Floating-Point Unit

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

Enhanced PWM (ePWM)

Each ePWM module has two independently configurable outputs, EPWMxA and EPWMxB, as illustrated below:



Dedicated 16-bit Time Base

- Uses pre-scaled CPU system clock.
- Synchronizes with other ePWM Modules in phase shift and frequency

Counter Comparator (CC)

- Registers and comparators eliminate the need to interrupt the CPU in PWM generation
- Can function as a 16-bit input capture (rising edge only)

Action Qualifier

- Generates actual PWM signal with information from CC and timer.

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 a pre-programmed state.
- One-shot or cycle-by-cycle operation
- Can generate events, filtered events, or trip conditions

Event Trigger and Interrupt

- Two ADC start-of-conversion signals and a PIE interrupt request line

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*Piccolo only

TEXAS INSTRUMENTS

The enhanced pulse width modulator peripheral is a key element in controlling many of the power electronic systems found in both commercial and industrial equipment. The ePWM performs a digital to analog (DAC) function, where the duty cycle is equivalent to a DAC analog value. An effective PWM peripheral must be able to generate complex pulse width waveforms with minimal CPU overhead and intervention. It needs to be highly programmable and very flexible (while being easy to understand and use). The ePWM unit described here addresses these requirements by allocating all needed timing and control resources on a per PWM channel basis. This modular approach results in an orthogonal architecture and provides a more transparent view of the peripheral structure – helping users to understand its operation quickly.

Sub-module Overview

Time Base

•A 16-bit counter is located in the time base module and passes on the time information to the counter Compare (CC) module and the action qualifier (AQ) modules.

•The time base module contains logic for synchronizing with subsequent or preceding ePWM modules.

Counter Compare

•Specify the PWM duty cycle for both PWM outputs -- which can be programmed independently.

•Specify the time at which switching events occur on each output.

•The CC module can also capture the timer value on a rising edge event, functioning as a 16-bit input capture.

Action Qualifier

•The actual PWM signal is generated by the Action Qualifier module based on info from the CC and timer base modules.

•AQ module can be programmed to force the pin to 1, 0, or toggle depending on four different conditions: count = 0, count = max, CompA and CompB.

•The output can also be manually set with software.

•The AQ also can generate interrupt/ADC conversions and pass the event to the Event Trigger and Interrupt module.

Dead Band Generator

•Control of the traditional complementary dead-band relationship between upper and lower switches.

•The first is the original signal, the rising edge of which undergoes a programmable delay in its expansion over time (rising edge delay, RED).

•The second signal is likewise subjected to a freely programmable delay, this time at the falling edge (falling edge delay, FED).

•It is now possible to choose how the two signals are to behave relative to each other, i.e. whether the two signals are “active high”/“active low”or “complementary active high” / “complementary active low”.

•Or Bypass the dead-band module entirely – PWM passed through without modification

PWM Chopper

•The PWM chopper divides up the pulse of a PWM signal – i.e. the logical-1 part – further into single pulses (e.g. in certain transformer applications).

•The chopper frequency may assume certain specific values between 1.6 and 12.5 MHz and have fixed pulse widths of 12.5%, 25%, 37.5%, ..., 87.5%.

•Moreover, the width of the first pulse of a chopper pulse series can be programmed separately from the other pulses, e.g. in order to precharge a capacitor to a certain voltage.

•Or Bypass the PWM chopper module entirely – PWM passed through without modification

Trip Zone Generator

•The Trip Zone module consists of six zones or pins that can be freely assigned to a specific EPWM module.

•The primary function of this module is to react as quickly as possible to a fault or an error in the application and to disable the PWM signals or switch one or more PWM pins to a high-ohm mode (one shot mode).

•This is controlled by the hardware and takes place with minimal delay as soon as an edge has been registered on the trip zone pin. Such circuitry allows a trip zone pin to be offered a rising edge which adjusts itself if, say, the current exceeds a certain threshold at a particular point in the application.

•Alternatively, the trip zone module can also be set such that the length of a single pulse of a PWM is automatically limited by an edge at the trip pin (cycle-by-cycle mode), if the assessed current exceeds a threshold at a certain point. This can take place continuously and without intervention by the software; in contrast, in one shot mode the system is usually disabled in the case of a trip event and the software must evaluate how serious the fault is.

•Channel A can be sent to the High Resolution module for up to 65ps resolution on C2834x, 150ps resolution on others.

•Piccolo devices have an additional digital compare submodule that compares signals external to the ePWM module to directly generate events to trigger trips or events.

High Resolution PWM

C2834x HRPWM Effective Resolution (at 300MHz)

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

Piccolo HRPWM Effective Resolution (at 60MHz)

PWM (kHz)	Standard PWM		HR-PWM	
	bits	%	bits	%
50	11.0	0.05	16.8	0.001
100	10.0	0.10	15.8	0.002
250	8.6	0.25	14.4	0.005
500	7.6	0.50	13.4	0.009
1000	7.1	0.75	12.4	0.018
2000	6.6	1.00	11.4	0.036

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

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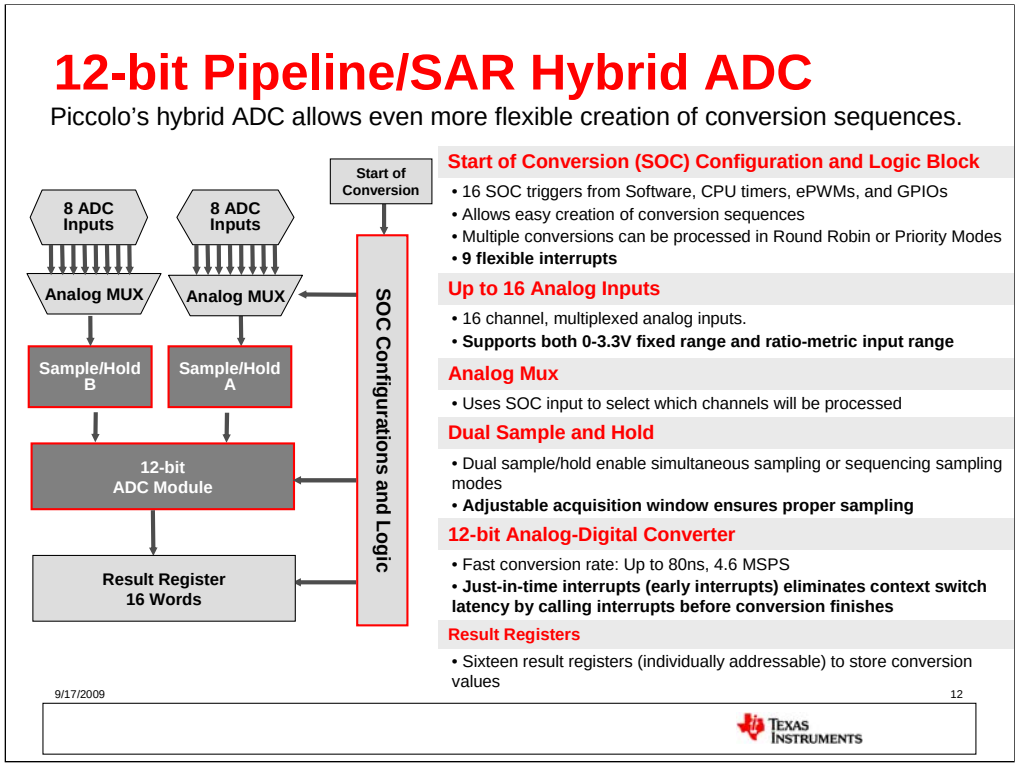
•The High Resolution PWM extends the time resolution capabilities of the conventionally derived digital pulse width modulator (PWM). The HRPWM is typically used with the PWM resolution falls below ~9-10 bits.

•The effective resolution for a conventionally generated PWM is a function of PWM frequency (or period) and system clock frequency.

•As the switching frequency of the PWM increases, the effective resolution decreases.

•The HRPWM is based on micro edge positioner (MEP) technology which is capable of positioning an edge very finely by sub-dividing one coarse system clock of a conventional PWM generator. The time step accuracy is 150ps for Piccolo devices.



•Piccolo uses a part-pipelined, part SAR ADC. The basic structure is similar to the previous, fully pipelined ADC, but the control interface is different. this ADC is not sequencer based. Instead, it is SOC based. *(The term SOC is configuration set defining the single conversion of a single channel. In that set there are three configurations: the trigger source that starts the conversion, the channel to convert, and the acquisition (sample) window size. Each SOC is independently configured and can have any combination of the trigger, channel, and sample window size available. Multiple SOC's can be configured for the same trigger, channel, and/or acquisition window as desired.)*

•This provides a very flexible means of configuring conversions ranging from individual samples of different channels with different triggers, to oversampling the same channel using a single trigger, to creating your own series of conversions of different channels all from a single trigger. Basically, you can program your own auto-sequencer.

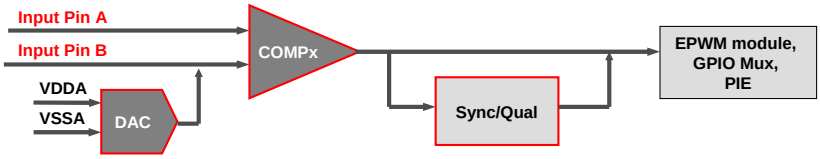
•The Piccolo ADC also brings new features.

- •First, both fixed range and ratio-metric inputs are supported, meaning the input will not always be based on 0-3V. This brings flexibility and more accuracy to the conversions.
- •A second new feature is adjustable acquisition windows. External drivers vary in their ability to drive an analog signal quickly and effectively. Some circuits require longer times to properly transfer the charge into the sampling capacitor of an ADC. To address this, the ADC supports control over the sample window length for each individual SOC configuration.
- •Third, the concept of early interrupts eliminates system latency. The ADC has the ability to call an interrupt before the conversion actually finishes. This way, the CPU can start switching contexts while the ADC finishes the conversion. The early interrupt is timed such that the conversion is ready to be read immediately before the interrupt code starts executing.

•The advantage of having two sample-and-holds is that you can measure two values simultaneously, even if they are converted sequentially by the ADC. This is useful in applications like current and voltage measurements, where a dual sample-and-hold gets the accuracy of two separate ADCs. With the superior speed of the ADC module, such a solution is just as good, if not better, than having two independent ADCs.

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

Comparator Reference Guide

Piccolo: F2802x, F2803x – spruge5

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The comparator module is a true analog voltage comparator in the VDDA domain.

•Can accommodate two external analog inputs or one external analog input using the internal DAC reference for the other input (Each comparator block contains a 10-bit voltage DAC reference that can be used to supply the inverting input of the comparator)

•The output of the comparator can be passed asynchronously or qualified and synchronized to the system clock period

•The comparator output is routed to both the ePWM Trip Zone Modules, as well as the GPIO output multiplexer

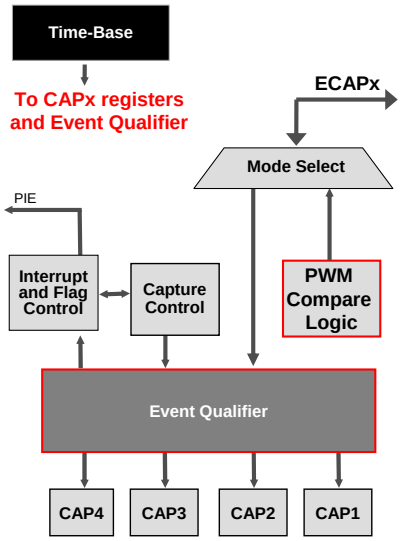
Synchronization can delay the output signal until the next clock cycle.

Qualification can delay the output signal for a pre-programmed duration (in clock cycles).

DAC is not externally available to user.

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 a 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

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•The eCAP module is used in systems where accurate timing of external events is important.

•Uses for eCAP include:

- •Speed measurements of rotating machinery (e.g. toothed sprockets sensed via Hall sensors)
- •Elapsed time measurements between position sensor pulses
- •Period and duty cycle measurements of pulse train signals
- •Decoding current or voltage amplitude derived from duty cycle encoded current/voltage sensors

•The Enhanced Capture unit is also based off of a 32-bit pre-scaled time base.

•The eCAP can be used in two modes: input capture and PWM output

Input Capture:

•Each enhanced capture module has one pin, but it allows discrete times for four events to be recorded.

•This is useful for reading successive inputs, such as signals from a remote control, without having to interrupt the CPU after each trigger.

•Each of the four events can be configured independently as rising or falling edge triggers.

•A 4-state sequencer in the Event Qualifier keeps track of which register to store the timestamp in.

•The Event Qualifier can record the timestamp in one of two modes: delta mode (where the counter is reset after each trigger) or absolute mode (where the counter keeps incrementing as the captures take place).

•The eCAP can operate in one-shot or continuous modes. In one-shot, once all four registers are filled, the contents are frozen until the user finishes reading from them and enables the capture again. In continuous mode, the sequencer automatically resets and cycles back around to put new capture timestamps in the registers as they occur.

•The interrupt is also flexible, as it can be configured to flag an interrupt after any of the four capture events or on counter overflow.

PWM Output:

•The eCAP can also be configured as a basic PWM signal generator.

•Two of the CAPx registers contain the period data and the remaining two serve as shadow registers.

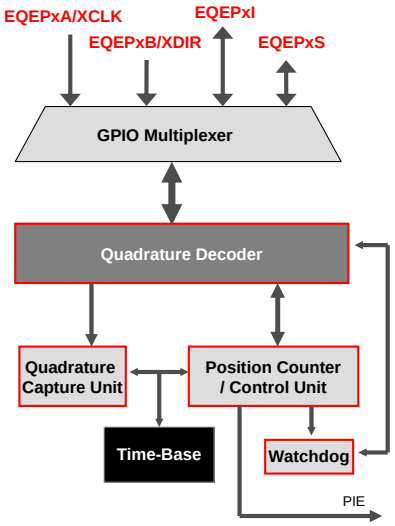
•The eCAP modules can be phase synchronized with each other as well as the ePWM modules.

•The interrupt is can also be flagged by PWM events.

•To obtain advanced functionality like deadband generation or complimentary outputs, the signal can be connected to external logic.

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.

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The enhanced quadrature encode pulse module is used for direct interface with a linear or rotary incremental encoder to get position, directoin, and speed information from a rotating machine for use in a high-performance motion and position-control system.

•The eQEP module supports four inputs:

- •two source pins,
- •an index (or 0 marker) pin,
- •and a strobe input pins.

•A quadrature encoder from a motor typically has a minimum of two signals – A and B.

•In quadrature-clock mode, the eQEP module can use these two signals to determine the direction of rotation and a clock signal (speed).

•Some motors have hardware that decodes A and B internally, and directly outputs a clock and direction signal, which should be used with the eQEP's direction-count mode.

•In both of these modes, a 32-bit register keeps track of the position by incrementing when the motor is spinning in one direction and decrementing when the motor is spinning in the other direction (the polarity is adjustable).

•In the Up-count or down-count modes, the counter direction signal is hard-wired for up count (or down count). In these two modes, the position counter is used to measure the frequency (speed) of the input, which is useful in high-speed motors (it is faster than XCLK)

•The third signal, EQEPxI, is the index signal. Some motors have this output to tell microprocessors when one full revolution has occurred. A pulse is sent through this signal whenever the rotation passes the index point.

•The fourth signal, EQEPxS, is the strobe signal. This is an external signal provided by the system to the microcontroller when the motor has reached a certain physical position, for example, the carriage-return position and home position on a typewriter. The MCU receives the signal and takes the appropriate action.

•The Position Counter and Control Unit (PCCU) initializes the position counter, keeps track of motor position, and triggers interrupts based on position. The position counter can be set to restart in 4 ways – on an index event (after every rotation), on a pre-programmed maximum position, on index event for the very first index only and then by maximum position, and on unit time out. Each of these modes represent different use cases. The PCCU also has a pulse stretcher for easy synchronization with outside signals.

•The Quadrature Capture Unit (or Edge Capture Unit) is used to measure elapsed time between the unit position events, useful for low-speed measurement.

•Each eQEP module contains a 16-bit watchdog timer that monitors the q-clock to indicate proper operation of the system. If no q-clock event is detected until a period match, the watchdog timer will time out and an interrupt flag will be set.

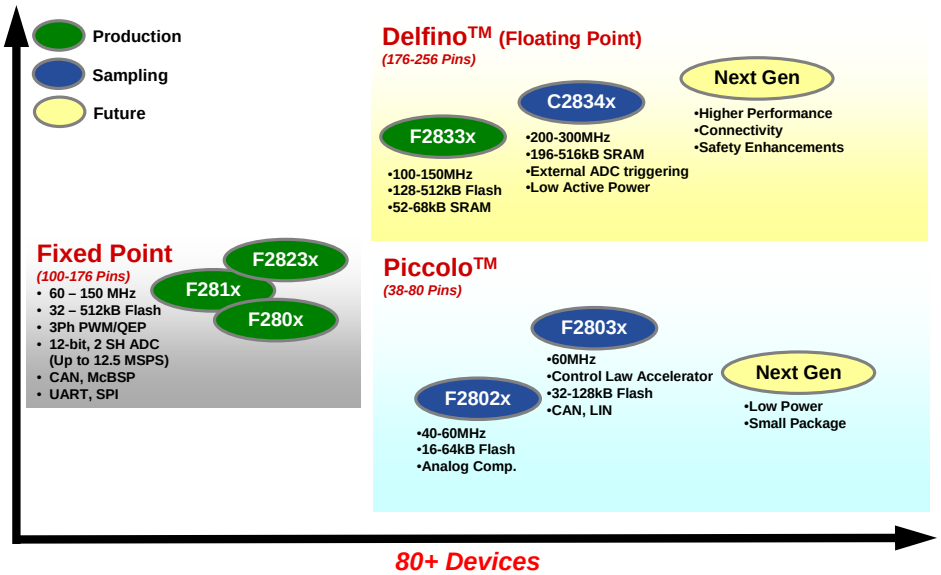
•The time-base in eQEP modules is a 32-bit timer that is used to generate periodic interrupts for velocity calculations.

•The QEP watchdog monitors the quadrature clock and sets an interrupt flag when no event is detected after a programmable time-out value.

C2000 Product Portfolio

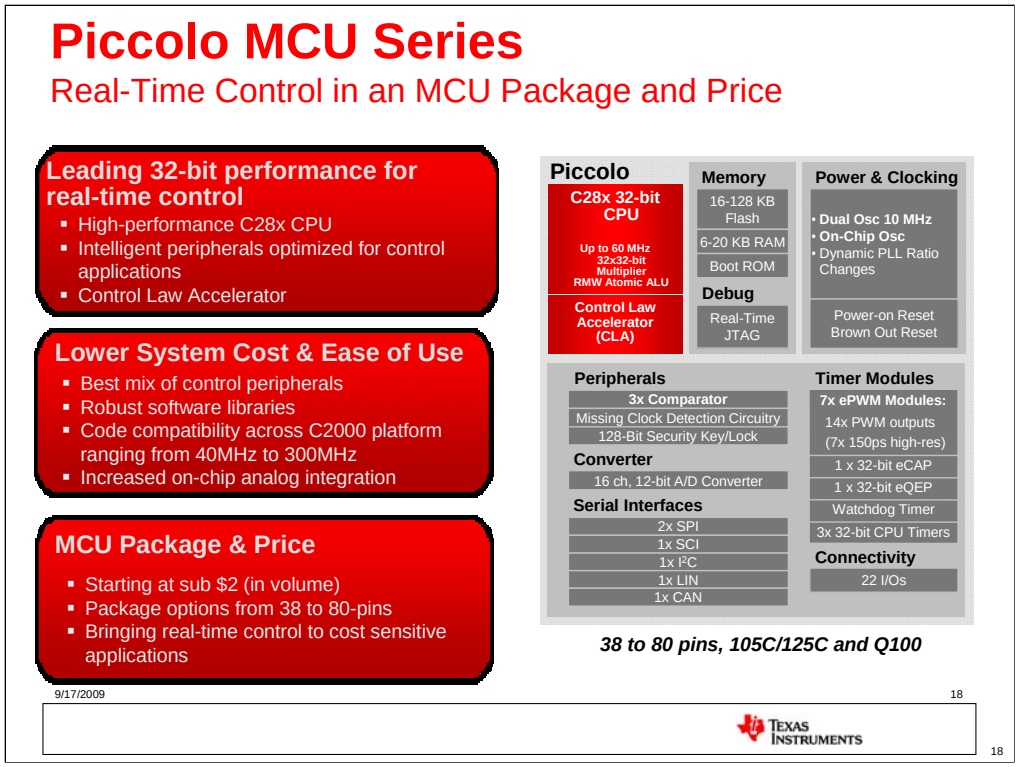
Piccolo™ MCU Series
Delfino™ MCU Series

C2000 32-bit Real-Time Control Portfolio



80+ Devices

Code Compatibility Across Entire Portfolio



On-chip peripherals offer lower system cost

Same high-perf core, throttled performance, same efficiency, code compatible, math algorithms (Alex will provide benchmarks for the core and core + CLA)

PWM ease of use example

(ADC, Sampling and conversion time, PWM, duty cycle and period)

CPU benchmarks for control/math algorithms

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

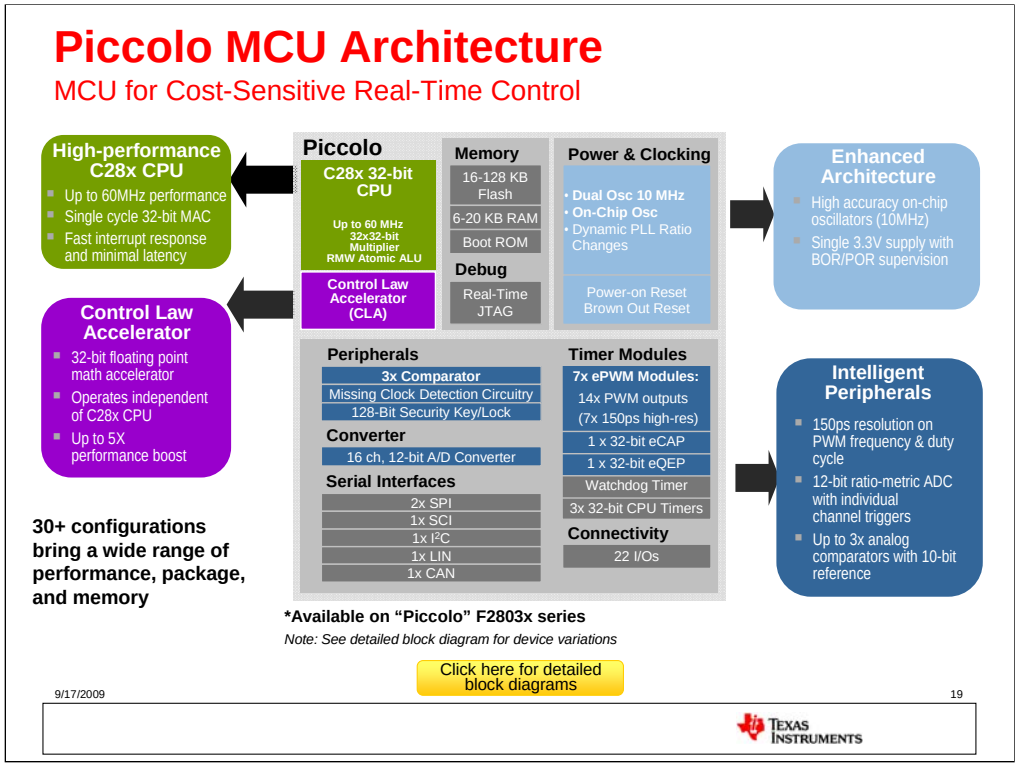
Analog-to-Digital Converter

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



Significantly Lower System Cost
Single Supply
On-Chip Reset
Lower Power Consumption
Minimal Support Pins
More Functional Pins
Smaller Packages
On-Chip Oscillators

Enhanced PWM Capabilities
High Res PWM On **Period**
(i.e. resonant converters)
Enhanced PWM Triggering
(i.e. peak current mode control)

Improved Analog
Ratio-metric ADC
Improved Triggering
Analog Comparators

"Turbo-Charge" Performance
Control Law Accelerator
Improved Power Efficiency

Significantly Reduced **Sample-To-Output** Delay & Jitter
For Improved System Response & Support Higher MHz Control Loops

Control Law Accelerator (CLA)

Turbo Charge Control Systems

Independent 32-bit floating-point math accelerator

Operates independently of the C28x CPU

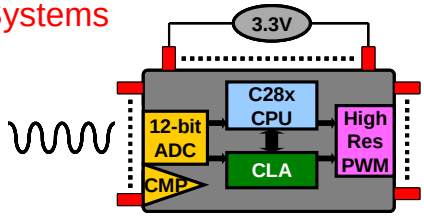
- Independent register set, memory bus structure & processing unit
- Low interrupt response time

Direct access to on-chip peripherals

- Execution of algorithms in parallel with the C28x CPU

Fully programmable: IEEE 32-bit floating

- Removes scaling and saturation burden



Reduced Sample-To-Output Delay

Faster System Response & Higher MHz Control Loops

Improved Support For Multi-Channel (Phase/Freq) Loops

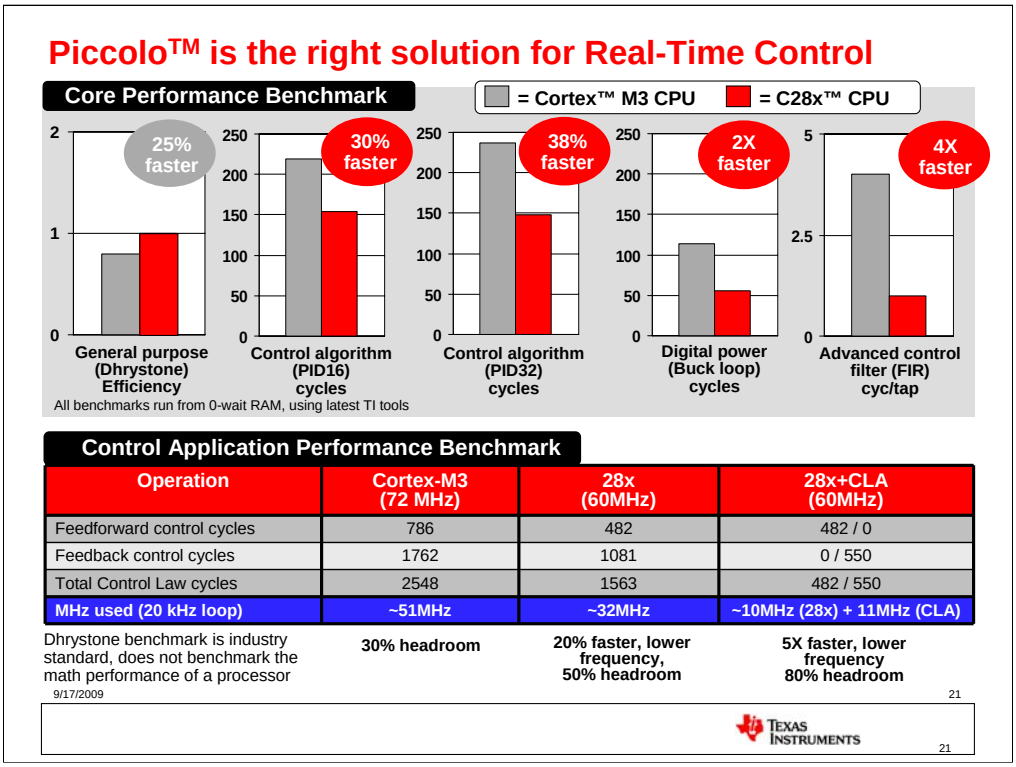
Digital Power Applications

Improved System Robustness

Automotive, White-goods

Free-Up C28x CPU For Other Tasks (communication, diagnostics)

General Purpose MCU Applications



-Dhrystone benchmark is typically understood as an industry standard benchmark for general purpose control apps

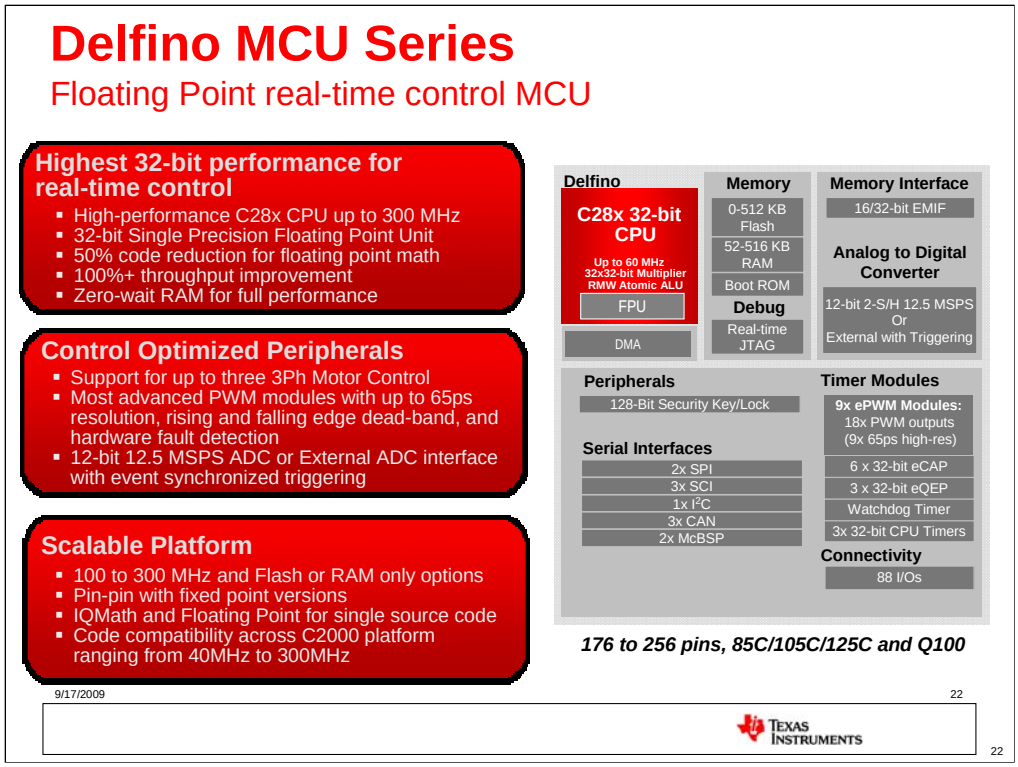
-Real-time control is a mixture of not only general purpose control but also math performance

-TI is the largest licensee of ARM cores, from telecommunication, audio and video apps, and automotive apps

-We understand that the ARM Cortex M3 CPU is a good core for general purpose and host control apps

-When you branch into real-time control apps with math performance we show that the C28x CPU is a much more powerful machine

-The table below shows a standard application – AC induction motor. It shows that the C28x CPU running at a slower clock speed performs these real-time control algorithms faster and has more head room left over to also run the general purpose apps. Thus, the M3 is a good solution for stand-alone general purpose, but the C28x (and the C28x + CLA) prove to be the right solution for real-time control



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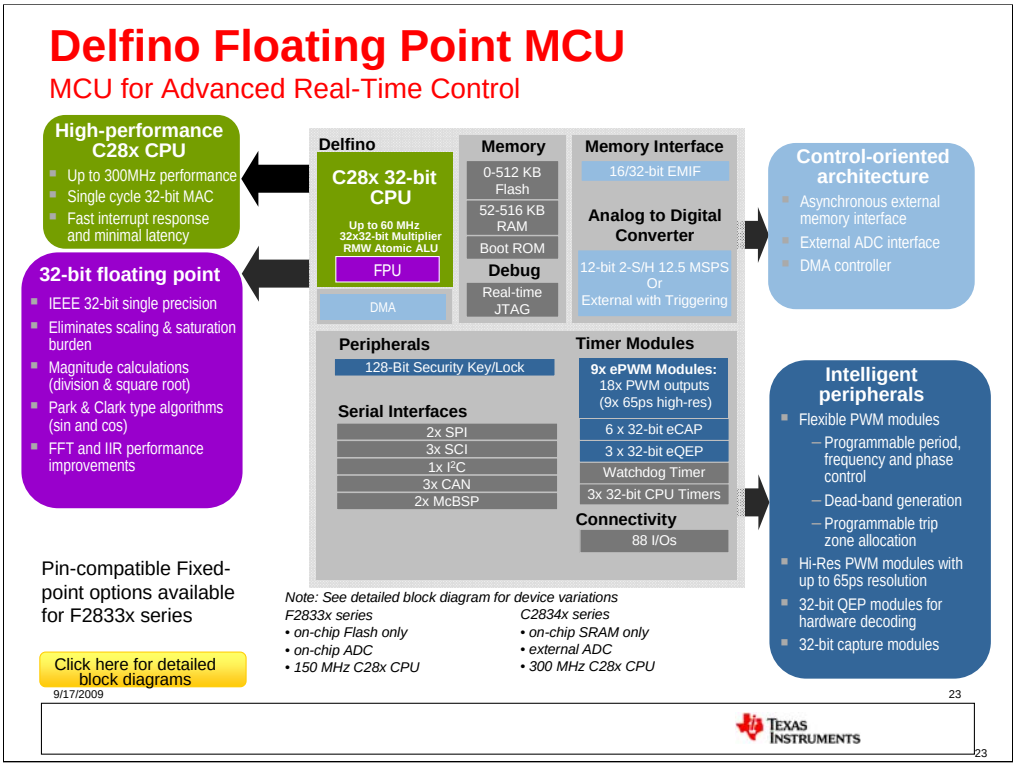
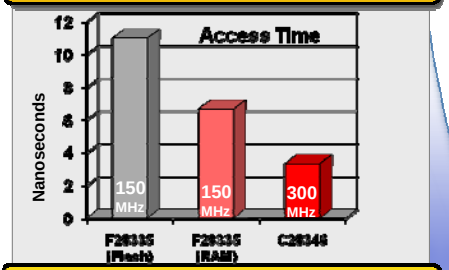


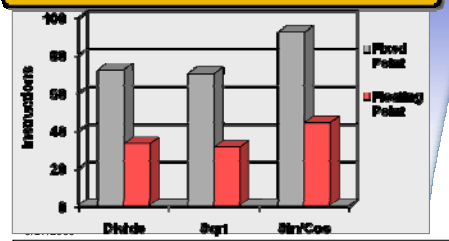
Hit hard on performance boost and floating-point for control (Green and Purple)

Floating-point Performance for Demanding Applications

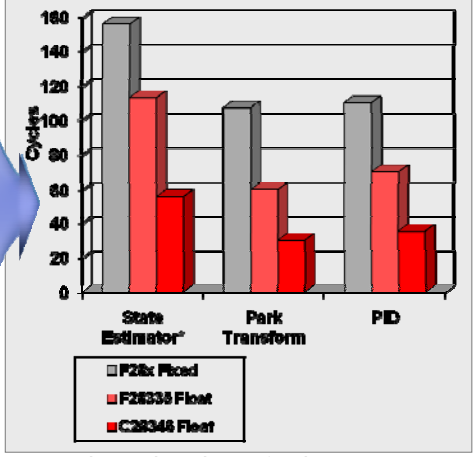
Up to 70% reduction in memory access time



Up to 52% code reduction



Up to 64% reduction in cycles



**State Estimator shown in 10s of cycles*

Texas Instruments

Getting Started

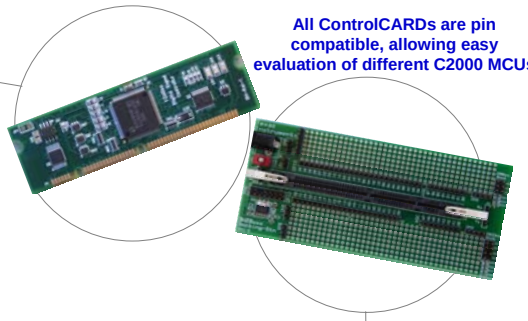
controlCARD Concept
Application Developer's Kits
Piccolo controlSTICK
Software Libraries & Examples
3rd Party Solutions & Additional Resources

C2000 Development Tools – Accelerate the Design Process

ControlCARDs

- **Low cost, small form factor**
- **Standard 100-pin DIMM interface**
  - Includes 28x analog I/O, digital I/O, and JTAG signals available at DIMM interface
- **Robust design**
  - Noise filter at ADC input pins
  - Ground plane
  - Isolated UART communication
  - Supply pin decoupling
- **All life support circuitry (clock, LDO, etc)**
- **Multiple versions available**
  - Piccolo F28027
  - Piccolo F28035
  - Delfino F28335
  - Delfino C28436
  - F2808
  - F28044

Perfect for initial development and small volume system builds



All ControlCARDs are pin compatible, allowing easy evaluation of different C2000 MCUs

Docking Stations

- **Access to all ControlCARD signals**
- **Breadboard area** for rapid prototyping
- **UART communications** header connector
- **On-board USB emulation** or the ability to use an external JTAG emulator
- **Powered by USB's 5V supply** or external power supply
- **Boot jumpers** for all boot modes

Development Tool Offerings

Device Evaluation

Experimenter's Kit
TMDXDOCK28027
TMDXDOCK28035
TMDSDOCK2808
TMDSDOCK28335
TMDXDOCK28343
$79-$159

Experimenter's Kit - 168
TMDXDOCK28346-168
$189

Peripheral Explorer
TMDSPREX28335
$179

Piccolo ControlSTICK
TMDX28027USB
$39

Application Development

Digital Power Experimenter's Kit
TMDSDCDC2KIT
$229

Digital Power Developer's Kit
TMDSDCDC8KIT
$325

AC/DC Developer's Kit
TMDSACDCKIT
$695

Resonant DC/DC Developer's Kit
TMDSRESDCKIT
$229

Renewable Energy Developer's Kit
TMDSENRGYKIT
$349

Dual Motor Control and PFC Developer's Kit
TMDS1MTRPFCKIT/
TMDS2MTRPFC Kit
$369/$399

Open Source Development Platform

Kit Contents

- ControlCARD
- Docking Station
- Code Composer Studio v3.3 with code size limit of 32KB
- Example Software with lab document
- Quick-start demonstration GUI
- Power Supply and Cables
- Developer's Package

Developer's Package

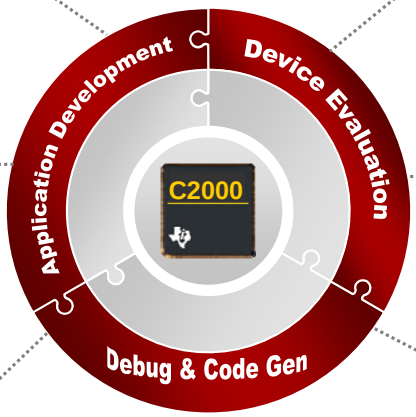
- Schematics (source and .PDF files)
- Bill of materials (BOM)
- Gerber files to freely use or modify
- Pin-out table showing all key signals on the 100-pin connector
- DIMM100 pin/socket mechanical details
- PCB files done in popular Freeware tool for easy modification (Docking Station only)
- Great way to begin a new prototype design

C2000 Comprehensive Software Ecosystem

System Examples
Robust Framework to Enable Rapid Development of Complete Systems
AC/DC Rectifier
Solar Inverter
Power Line Communication
And More…

Application Libraries
Modular Software
Quickly Build or Customize Own System
Fully Documented Usage and Theory
Optimized C Callable
Digital Motor Control
Digital Power

3rd Party Libraries & Simulation
Code Generation
Debug
Software Libraries



Get Started Today
http://www.ti.com/C2000tools

Foundational Libraries
IQ Math
Signal Processing
Math Primitives
Floating Point
Control Law Accelerator
Flash API

Header Files & Example Projects
Initialize Device
Utilize Peripherals
Pre-Defined Functions
Easy User Modification

CCS Integrated Dev Environment
Code Editor
Debugger
Compiler
Real-Time Analysis

Texas Instruments

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

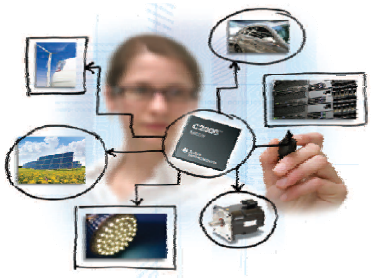
Performance
- 40-300MHz Control Savvy 32-bit 28x CPU
- Control Law Accelerator for high speed control loops
- Floating Point Unit
- Most efficient control techniques
- Hi-res PWM with ***150ps*** resolution
- Up to 12.5 MSPS 12-bit ADC

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

Thank you!



Texas Instruments MCU

Piccolo™ Device Configurations

F2802x Series

TMS320	MHz	Flash (KB)	RAM (KB)	VREG (POR /BOR)	CLA	Analog Comp.	12-bit ADC Chan.	PWM (HRPWM) Outputs	Capture Inputs	QEP	Comm Ports	Package / Temp	SRP (1Ku)
F280200DA/ F280200PT	40	16	4	Yes	-	1/2	7/13 (2 MSPS)	8+1* (0)	0	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to 105^{0}C	$1.85-$1.89
F28020DA/ F28020PT	40	32	6	Yes	-	1/2	7/13 (2 MSPS)	8+1* (0)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to 105^{0}C	$1.99-$2.10
F28021DA/ F28021PT	40	64	10	Yes	-	1/2	7/13 (2 MSPS)	8+1* (0)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to 105^{0}C	$2.20-$2.30
F28022DA/ F28022PT	40	32	12	Yes	-	1/2	7/13 (3 MSPS)	8+1* (4)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to105^{0}C/125^{0}C	$2.25-$2.76
F28023DA/ F28023PT	40	64	12	Yes	-	1/2	7/13 (3 MSPS)	8+1* (4)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to105^{0}C/125^{0}C	$2.45-$3.00
F28026DA/ F28026PT	60	32	12	Yes	-	1/2	7/13 (4.6 MSPS)	8+1* (4)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to105^{0}C/125^{0}C	$2.65-$3.24
F28027DA/ F28027PT	60	64	12	Yes	-	1/2	7/13 (4.6 MSPS)	8+1* (4)	1	-	SPI, SCI, I^2C	TSSOP-38/ LQFP-48 -40^{0}C to105^{0}C/125^{0}C	$2.85-$3.47

** The capture unit can provide one additional PWM output*
Note: Prices are budgetary and subject to change

Piccolo™ Device Configurations

F2803x Series

TMS320	MHz	Flash (KB)	RAM (KB)	VREG (POR /BOR)	CLA	Analog Comp.	12-bit ADC Chan.	PWM (HRPWM) Outputs	Capture Inputs	QEP encoder	Comm Ports	Package / Temp	Pricing (1Ku)
F28030	60	32	12	Yes	-	3	14/16 (2MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$2.79-$3.67
F28031	60	64	16	Yes	-	3	14/16 (2MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$2.97-$3.91
F28032	60	64	20	Yes	-	3	14/16 (4.6MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$3.49-$4.44
F28034	60	128	20	Yes	-	3	14/16 (4.6MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$3.75-$4.77
F28033	60	64	20	Yes	Yes	3	14/16 (4.6MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$4.11-$5.22
F28035	60	128	20	Yes	Yes	3	14/16 (4.6MSPS)	12+1* (6)/ 14+1* (7)	1	1	1/2 SPI, SCI, LIN, I^2C, CAN	TQFP-64/LQFP-80 -40°C to 105°C/125°C	$4.41-$5.62

** The capture unit can provide one additional PWM output*
Note: Prices are budgetary and subject to change

Delfino™ Device Configurations

C2834x Series

TMS320	MHz	Flash (KB)	RAM (KB)	FPU	12-bit ADC Chan.	PWM (HRPWM) Outputs	Capture Inputs	QEP encoder	External Interface	Comm Ports	Supply Voltage	Package / Temp	Pricing (1Ku)
C28346	300	-	516	Yes	-	18+6* (9)	6	3	32-/16-bit	2xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP	3.3V I/O, 1.2V Core, 1.8V PLL	256 BGA 105/125°C	$16.39
C28345	200	-	516		-	18+6* (9)	6	3		2xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP	3.3V I/O, 1.1V Core, 1.8V PLL	256 BGA, 179 uBGA 105/125°C, 105°C	$14.42
C28344	300	-	260		-	18+6* (9)	6	3		2xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP	3.3V I/O, 1.2V Core, 1.8V PLL	256 BGA 105/125°C	$12.78
C28343	200	-	260		-	18+6* (9)	6	3		2xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP	3.3V I/O, 1.1V Core, 1.8V PLL	256 BGA, 179 uBGA 105/125°C, 105°C	$11.25
C28342	300	-	196		-	12+4* (6)	4	2		2xSPI, 3xSCI, I^2C,2xCAN, 1xMcBSP	3.3V I/O, 1.2V Core, 1.8V PLL	256 BGA 105/125°C	$10.17
C28341	200	-	196		-	12+4* (6)	4	2		2xSPI, 3xSCI, I^2C,2xCAN, 1xMcBSP	3.3V I/O, 1.1V Core, 1.8V PLL	256 BGA, 179 uBGA 105/125°C, 105°C	$8.95

** Each capture unit can provide one additional PWM output*

F2833x Series

TMS320	MHz	Flash (KB)	RAM (KB)	FPU	12-bit ADC Chan.	PWM (HRPWM) Outputs	Capture Inputs	QEP encoder	External Interface	Comm Ports	Supply Voltage	Package / Temp	Pricing (1Ku)
F28335	150	512	68	Yes**	16	12+6* (6)	6	2	32-/16-bit	1xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP	3.3V I/0 1.9V Core	176-QFP, 176-BGA., 179-u*BGA -40°C to 85°C/ 125°C (176-BGA)	$15.65
F28334	150	256	68			12+4* (6)	4			1xSPI, 3xSCI, I^2C,2xCAN, 2xMcBSP			$14.75
F28332	100	128	52			12+4* (4)	4			1xSPI, 2xSCI, I^2C,2xCAN, 1xMcBSP			$13.85

*** Fixed point versions available*

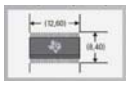
F2802x MCU Series

Up to 60MHz Piccolo Series

Features

- **Core:**
  - C28x 32-bit CPU, single cycle 32-bit MAC
  - Up to 60MHz Performance
- **Memory**
  - 32, 64 KB Flash, 12 KB RAM
- **Highlights**
  - Single 3.3V supply
  - High accuracy on-chip oscillators (10MHz)
  - Best in class PWM and event capture capability
  - High resolution 150 pico-second PWM
  - 12-bit ratio-metric ADC
  - Two analog comparators with 10-bit reference
  - Robust serial communication interfaces
  - Up to 22 General Purpose I/Os
  - Full software compatibility with previous MCUs
- **Packages**

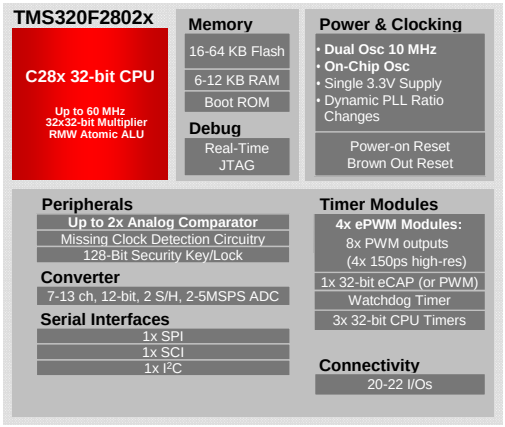
38-pin TSSOP
0.65mm pitch



48-pin LQFP
0.5mm pitch

Applications include:

- Air Conditioners, Washing Machine, Induction Cooking, Compressors, Digital Power, LED Lighting, Audio, Advanced Sensing, AC Drives, DC Drives



Datasheet: http://www.ti.com/lit/gpn/tms320f28027

F2803x MCU Family

60MHz Piccolo Series including CLA

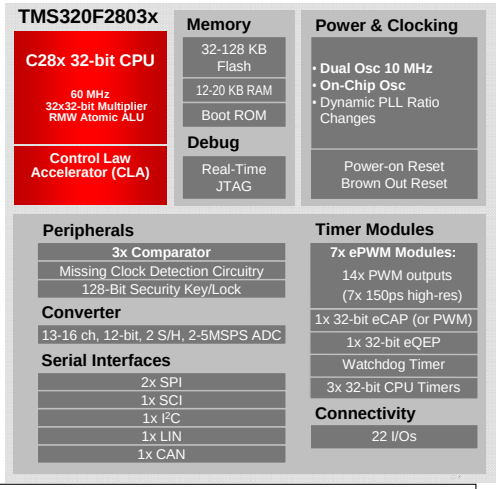
Performance
- 60 MHz C28x 32-bit CPU
- Control Law Hardware Accelerator
- Full software compatibility with previous generations

Features
- **Core**
  - C28x 32-bit CPU
    - Single cycle 32-bit MAC
  - 60MHz Performance
  - **Control Law Accelerator**
- **Memory**
  - Flash: 64, 128 KB
  - RAM: 20 KB

- **Highlights**
  - Single 3.3V supply
  - High accuracy on-chip oscillators (10MHz)
  - Two analog comparators with 10-bit reference
  - 150ps resolution on PWM frequency
  - 12-bit ratio-metric ADC
  - **Quadrature Encoder Pulse (eQEP) Unit**
  - **CAN 2.0B up to 16 mailboxes**
  - **Up to 44 General Purpose I/Os**
    - **More peripherals, channels, memory**

- **Packages: 64-pin TQFP, 80-pin LQFP**

Applications include:
- Air Conditioners, Washing Machine, Induction Cooking, Compressors, Digital Power, LED Lighting, Electric Power Steering, Hybrid Battery Management, Radar Collision Avoidance, Audio, Advanced Sensing



C2834x RAM Based Floating Point MCU

300MHz of 32-bit floating point performance

Performance

- **300 MHz / 600 MFLOPS C28x 32-bit CPU**
- 32-bit Floating Point Unit

Features

- **Core**
  - C28x 32-bit CPU
    - Single cycle 32-bit MAC
  - 600 MFLOPS at 300MHz
  - 6 channel DMA support for EMIF and McBSP
  - Integrated Floating Point Unit
- **Memory**
  - RAM: Up to 516 KB
    - Up to 100KB 0 wait state
    - Up to 416KB 1 wait state
  - Configurable 16- or 32-bit EMIF

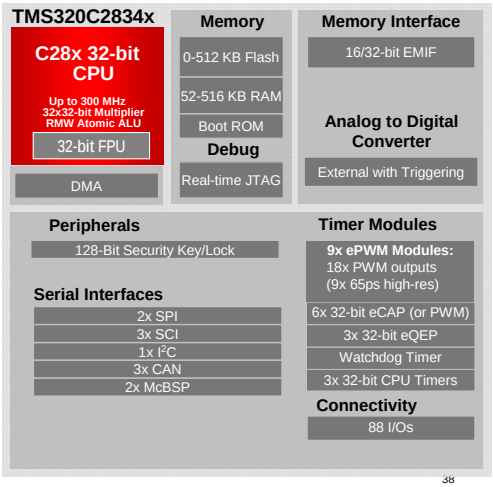
Peripheral Highlights

- Best in class PWM and event capture capability
- PWM outputs for three 3-phase motors
- Robust serial communication interfaces
- External ADC interface
  - Allows external ADC to trigger interrupts and directly trip PWM modules
- Up to 88 General Purpose I/Os

- Packages: 256-ball PBGA; 179-ball u*BGA; -40 to 125°C and Q100 in PBGA

Applications include:

- Advanced Motor Control, Solar Panel Systems, Servo Motor Control, AC Drives, DC Drives, Uninterruptible Power Supplies, Automotive Radar



F2833x Floating Point MCU

MCU for Advanced Real-Time Control

Performance

- 150 MHz / 300 MFLOPS C28x 32-bit CPU
- 32-bit Floating Point Unit

Features

- **Core**
  - C28x 32-bit CPU
    - Single cycle 32-bit MAC
  - 300 MFLOPS at 150MHz
  - 6 channel DMA support for EMIF, ADC, and McBSP
  - Integrated Floating Point Unit
  - F24x/LF240x Source Code Compatible
- **Memory**
  - Flash: 128, 256, 512 KB
  - RAM: 52, 68 KB
  - Configurable 16- or 32-bit EMIF

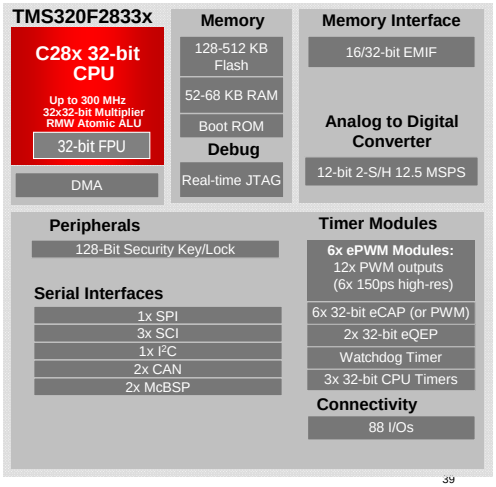
Peripheral Highlights

- Best in class PWM and event capture capability
- PWM outputs for three 3-phase motors
- Highest speed on-chip ADC
- Robust serial communication interfaces
- Up to 88 General Purpose I/Os

- Packages: 176-pin/ball LQFP/PBGA; 179-ball u*BGA; -40 to 125 C and Q100 in PBGA

Applications include:

- Advanced Motor Control, Solar Panel Systems, Servo Motor Control, AC Drives, DC Drives, Uninterruptible Power Supplies, Automotive Radar



F2823x Fixed Point MCU

MCU for Advanced Real-Time Control

Full Pin and Code Compatibility with F2833x Devices

Performance

- 150 MHz / 300 MFLOPS C28x 32-bit CPU

Features

- **Core**
  - C28x 32-bit CPU
    - Single cycle 32-bit MAC
  - 300 MFLOPS at 150MHz
  - 6 channel DMA support for EMIF, ADC, and McBSP
  - F24x/LF240x Source Code Compatible
- **Memory**
  - Flash: 128, 256, 512 KB
  - RAM: 52, 68 KB
  - Configurable 16- or 32-bit EMIF

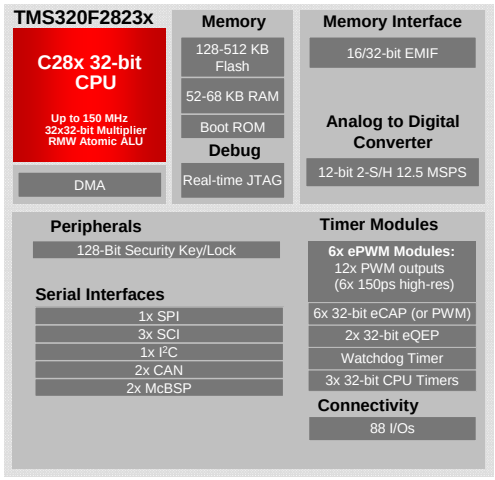
Peripheral Highlights

- PWM outputs for three 3-phase motors
- Highest speed on-chip ADC
- Up to 88 General Purpose I/Os

- Packages: 176-pin/ball LQFP/PBGA; 179-ball u*BGA; -40 to 125 C and Q100 in PBGA

Applications include:

- Advanced Motor Control, Solar Panel Systems, Servo Motor Control, AC Drives, DC Drives, Uninterruptible Power Supplies, Automotive Radar



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

Want to do power factor correction plus run a motor

Delfino Sample Applications

Servo drives & motion control

- Fine tuned motion
- Real-time diagnostics and failure prediction
- Better dynamic and transients control
- Optimize overall system performance

Advanced power line monitoring

- Monitor power delivery systems to detect spikes and failures
- Complex, real-time analysis of incoming data
- Consistent frequency and voltage

Renewable energy

- Maximize power output across varying load conditions
- Increased efficiency reducing cost per kilowatt
- Flexibility to control different turbines types

Driver assistance

- Sophisticated high speed external sensors
- Real time data analysis
- Stringent automotive reliability
- Interface with other automotive systems