New Product Update:
# Latest cost-optimized C2000™ real-time MCU family: F28003x overview, offerings and more

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TEXAS INSTRUMENTS

Agenda

- C2000 real-time MCU identity and portfolio overview

- F28003x real-time MCU family deep-dive
  - Spec
  - Strengths and target application overview
  - Scalability, compatibility, migration options
  - Getting started
  - Newly released content & collaterals

- C2000 + GAN

- Key features and new IPs on F28003x
  - Embedded Pattern Generator (EPG)
  - Configurable Logic Block (CLB)

Where is C2000™ Real-time Control?

Energy Delivery

Charging Infrastructure

Solar Power

Wind Power

Digital Power

DC/DC Converters

Telecom / Server AC/DC Rectifiers

Uninterruptable Power Supplies

C2000™ Real-time Microcontrollers

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Motor Control

Pumps

E-bike

Drones

Appliance

Industrial Drives

AC Drives

Robotics

Automation

Servo Drive

Sensors

Power

Motor

Lighting

On-Board Charging

HV DCDC

Charging Stations

Traction Drive

Compressors

Pumps/ Power-Steering / Fans

Automotive

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# C2000™ Real-Time micro-controllers Overview

Scalable, ultra-low latency, real-time controller platform designed for efficiency in power electronics, such as high power density, high switching frequencies, GaN and SiC technologies

C2000 Real-Time MCUs

Highly accurate sensing
- 12-/16-bit ADCs, up to 24 channels
- Full analog comparators with built in DACs
- Quadrature Encoders and Capture Logic

Sense

Process

High performance processing
Floating-point DSP C28x™ core + parallel multi-core architecture + instructions set optimized for control math, Up to 925 MIPs

Highly flexible, high-resolution PWMs:
- Up to 32 outputs
- Tightly coupled with sensing domain for fast response time
- Buffered Output DACs

Control

Interface

CAN, CAN-FD, LIN, FSI, UART, SPI, I2C, PMBus, USB, 10/100 Ethernet MAC, EtherCAT®, EMIF

Expertise and support:
Software libraries, reference designs, and functional safety-compliant devices.

25 years expertise in real-time control systems

Innovative features:
Configurable Logic Block for peripheral customization, Fast Serial Interface for high-speed communication, ERAD for enhanced diagnostics and profiling

1.2-V core, 3.3-V I/O design	Up to 1.5 MB Flash, 256 kB RAM (ECC protected)	QFN, QFP, BGA packages	-40 to 125C temperature range	Q100 automotive qualified options

Billions of units shipped for industrial and automotive applications with compatible software

Multi-source FAB strategy for safe supply and future expansion

High quality silicon being used by thousands of customers worldwide

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New F28003x: Expanding the C2000 Real-Time Microcontrollers Portfolio
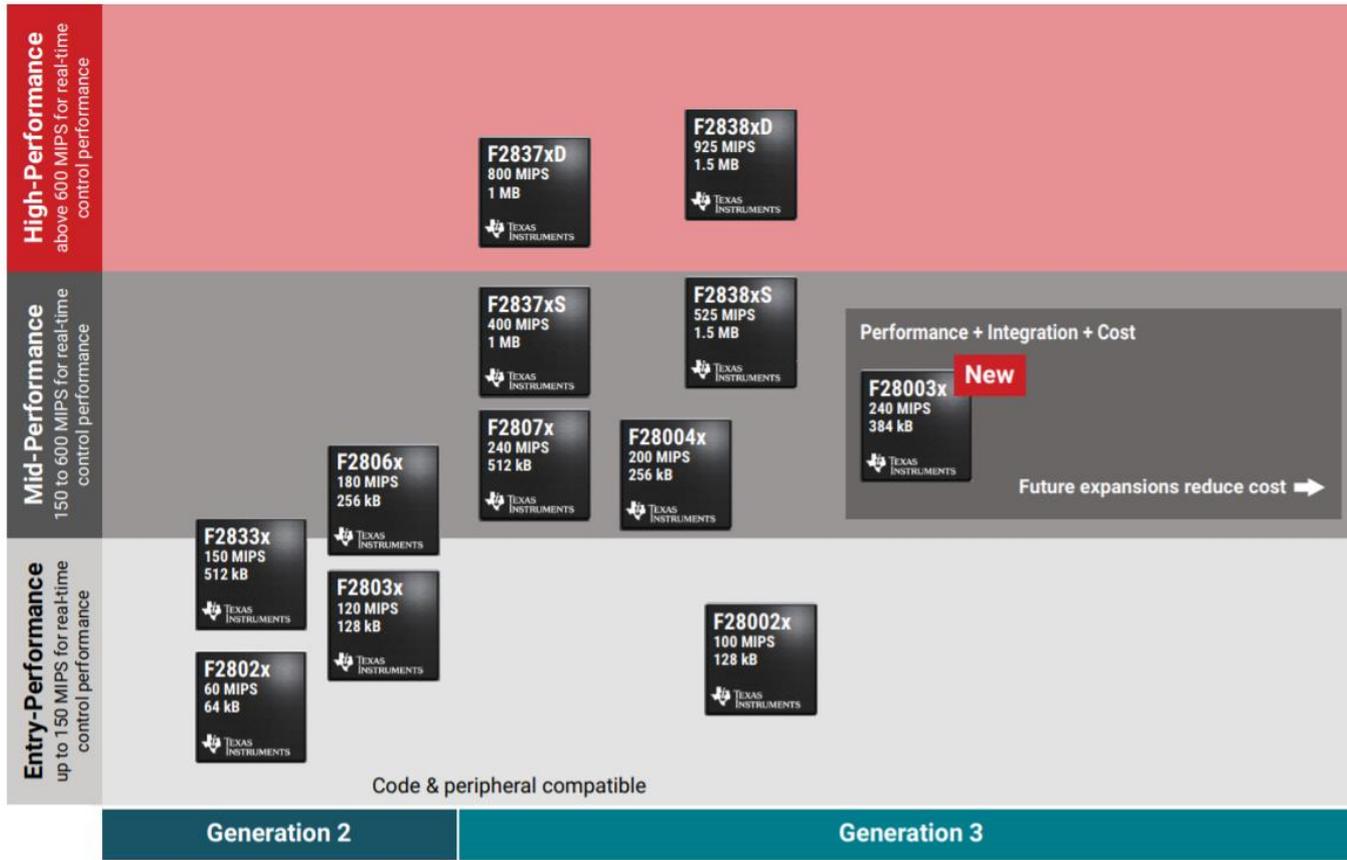
C2000™ F28003x

Differentiation

Cost-Optimized Mid Performance C2000

Improved performance
- 120 MHz with CLA option
- 240 MIPS DSP Processing Power
- 384kB Flash and 69kB RAM
- Better ADC Performance - Effective throughput

Advanced actuation and design flexibility
- Premium Type 4 ePWM modules with more instances and channels

Premium analog
- 8 Sigma Delta Decimation Filters (with separate Data and Comparator filters)
- 2 * Buffered DAC 12-bit , 3* 12 bit ADC @ 4MSPS

Rich digital options
- CAN-FD, 4 * CLB tiles, flexible standard interfaces

Safety
- ASIL-B/ SIL-2 safety enablers

Security
- AES, JTAG Lock & Secure boot

Perfect portfolio
- Pin-pin to F28002x 64-pin (non-Q) and 80-pin(non-Q) and almost compatible to 48-pin and 64-pin (Q)
- 100-pin option

Tools

Experimenter's Kit

Part Number: TMDSCNCD280039C
https://www.ti.com/tool/TMDSCNCD280039C

LaunchPad

Part Number: LAUNCHXL-F280039C, 2Q22

Software

C2000Ware™ Software Package

Application SDKs

F28003x/ F28003x-Q1

Temperatures	125C	Q100

Sensing
- ADC1: 12-bit, 4 MSPS,
- ADC2: 12-bit, 4 MSPS
- ADC3: 12-bit, 4 MSPS
- 4x CMPSS : 12-bit DAC 8 COMP, 8 digital filters
- 8x Sigma Delta Channels (2x Filters per ch)
- Temperature Sensor
- 2x eQEP
- 3x eCAP , 1x HRCAP

Configurable Logic Block
- 4 Tiles

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

Processing

C28x™ DSP core 120 MHz
- FPU, FastDIV, VCRC
- TMU +NLPID

CLA core 120 MHz, FPU
- 6ch DMA
- BGCRC & HWBIST

Memory
- 384 kB FLASH (3 bank) +ECC
- 69 kB SRAM +ECC
- ROM with parity
- Dual Security Zones Secure boot and JTAG lock
- AES
- Host Interface Controller (HIC)

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

Connectivity
- 2x SCI, 2x LIN/SCI
- 2x I2C, 1x PMBus
- 2x SPI, 1x FSI-TX , 1x FSI-RX
- 1x CAN-FD, 1 CAN 2.0B

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

Debug
- cJTAG / Real-time JTAG
- ERAD

Functional Safety Compliant Product

Target Systematic Capability	ASIL-D/SIL-3
Target Diagnostic Coverage (DC)	ASIL-B/SIL-2

Packages

Package	Footprint Dimensions	Temp
48-pin LQFP	9 x 9 mm	S, Q
64-pin LQFP	12 x 12 mm	S, Q
80-pin LQFP	14 x 14 mm	S
100-pin LQFP	16 x 16 mm	S, Q

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F28003x strengths
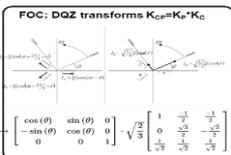
85% Improvement With TMU

- **Quality MIPS Processing**
  - Floating point (32b/64b) DSP math
  - Control Law accelerator (Background loop)
  - Trigonometric Math Unit (TMU)
  - Viterbi Complex math & CRC Unit (VCU)
 - CPU+CLA pairs & multi-loops in parallel
  - Predictable shortest latency

- **Robust Connectivity**
  - Fast Serial interface (FSI), for reliable & high speed connection
  - CAN-FD for automotive and industrial

- **Safety :** ECC memory, Redundancy, ASIL-B, SIL-2 Safety, HWBIST

- **Security:** DCSM, Secure Boot, JTAG Lock, AES256

- **Configurable Logic Block (CLB):** Custom logic building including state-machines, sequencers, counters to replace FPGA

- **Shortest Predictable latency system arch.**
  - Optimal latency architecture for peripherals & memories
  - Highly interconnected trip-trigger circuits
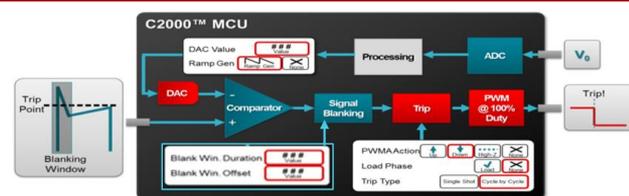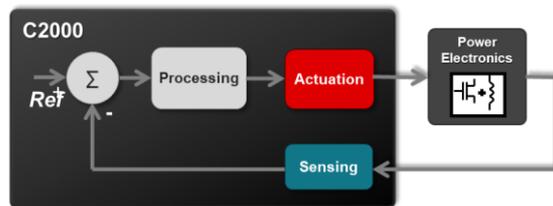
- **Fast & Precise Sensing**
  - 12b ADC, post processing, early interrupt
  - Autonomous triggering & trip operation
  - Fast comparator (< 50ns), Windowed Comp
  - O/P filtering & blanking; Peak Current Mode Control
  - Simultaneous ADC-Comp
  - Fault protection with Comp Trip
  - Integrated Sigma Delta Filters

- **Flexible & high resolution actuation**
  - High resolution duty, phase, dead-band, period control
  - Flexible Action Qual., Trip-zone config.
  - Shadow registers, one shot or global loading
  - PWM phase, timer Synchronization
  - Cycle by cycle trip, One shot trip
  - Advanced protection and control

- **Package and Pin Scalability**
  - More packages and small footprint
  - ~35% more number of GPIOs and analog function vs previous devices

- **More system flexibility**
  - Live Firmware update with no reset
  - Fast 169ms flash bank erase time @ 20k cycles (~10 times better than prior devices)
  - Reliable High-speed comms with ~1.5% internal clock accuracy
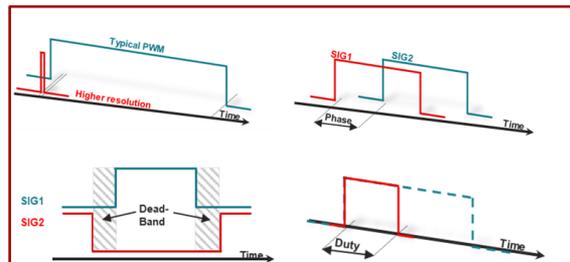
Applications : F28003x + F28003x-Q1 real-time MCUs a good fit
just some key EEs, not limited to this list

INDUSTRIAL

Commercial HVAC

Industrial drives

Server + telecom power

Solar inverters

AUTOMOTIVE

Automotive lighting (headlight, rear light)

Heating & Cooling (eCompressor, HVAC compressor)

EV/HEV on-board charging and DC/DC converters

Traction Inverter

Pumps, blowers, fans

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Feature comparison between closest Generation 3 devices: F28002x/3x/4x

Feature	F28004x	F28002x	F28003x
CPU (MHz)	100	100	120
FPU32	Yes	Yes + FastDIV	YES + FastDIV
TMU32	Type 0	Type 1	Type 1
CLA	Yes	No	Yes
DMA	Yes	Yes	Yes
CLB	4 tiles	2 tiles	4 tiles
Flash (KB)	256	128	384
JTAG Lock	No	No	Yes
RAM (KB)	100.5	24	69
ADC	3 × 12-bit	2 × 12-bit	3 × 12-bit
ADC channels (Max)	21	16	23
CMPSS	7	4	4
CAN (DCAN)-Type 0	2	1	1
CANFD (MCAN)-Type 2	0	0	1
FSI	1 (1 RX and 1 TX)	1 (1 RX and 1 TX)	1 (1 RX and 1 TX)
I²C Type 1	1	2	2
LIN Type 1	1	2	2
HIC	0	Type 0*	Type 1*
SCI	2	1	2
eCAP/HRCAP modules	7 (2 with HRCAP capability) – Type 1*	3 (1 with HRCAP capability) – Type 2*	3 (1 with HRCAP capability) Type 3*
ePWM/HRPWM Type 4	16 (16 with HRPWM)	14 (8 with HRPWM)	16 (8 with HRPWM)

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Easy Hardware and Software migration between the F28002x, F28003x and F28004x device families

Pin-to-pin migration	From F28002x to F28003x	From F28003x to F28002x	From F28002x to F28004x	From F28004x to F28002x	From F28003x to F28004x	From F28004x to F28003x
48-pin	3	3	5	5	5	5
64-pin "S"	1	1	3	3	3	3
64-pin "Q"	2	2	3	3	3	3
80-pin	3	3	5	5	5	5
100-pin	5	5	5	5	4	4

Key

1	Y (software updates)
2	Y (w/ minor migration path)
3	Y (w/ migration path)
4	N (w/ major migration path)
5	NA

For more details about migration, download the migration guides
for F28002x to F28003x and F28004x to F28003x

Pin to pin and SW compatibility across F28002x/ F28003x/ F28004x on the 64-pin package!

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F28003x Getting Started

- F28003x brief (1-pager/brochure) – Brief on the device…. 1 stop shop to immediate F28003x information – what the device offers , block diagram, device configurations, comparisons with prior devices, migration & more….

- How to find on TI.com
  - TMS320F280039C product page – includes access to datasheet, technical reference manual, spec table, etc
  - Order samples:
    - 64,80,100 pin : https://www.ti.com/product/TMS320F280039C#order-quality
    - 48 pin : https://www.ti.com/product/TMS320F280037C#order-quality
  - HW / EVMs – TMS320F28003x controlCARDS product page
  - SW (SDKs include the new device projects + features for new designs)
    - C2000Ware (Version: 4.00.00.00)
    - Digital Power SDK (Planned for Dec 2021)
    - Motor Control SDK (Planned for Dec 2021)

Newly released content & collaterals

- C2000 Academy integrates the rich history of the C2000 hands-on workshops into TI Resource Explorer for an easy to use customer self-paced learning experience
- Speed Up Development With C2000™ Real-Time MCUs Using SysConfig : shows how the SysConfig graphical user interface (GUI) tool is developed to facilitate the development process for designers.
- C2000 SysConfig For developers getting started, having technical questions and needing guidance
- Designing With the C2000™ Embedded Pattern Generator (EPG): New peripheral on F28003x
- Getting Started with the MCAN (CAN FD) Module : Now also on the mid performance F28003x
- Reduce EV cost and improve drive range by integrating powertrain systems : Revamped technical article on how F28003x can help designers achieve various discrete and integrated powertrain topologies
- Bring performance, integration and cost savings to your server power-supply design with a real-time MCU : New technical article showcasing how F28003x can be a good fit for Industrial system applications
- Technical introductory overview video on the C2000 embedded pattern generator or EPG.
- Real-Time Control Pocket Reference Guide : valuable quick guide for often used system-level design formulae and real-time control concepts in order to help facilitate real-time control application design

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GaN + C2000: Maximize Power Density and Efficiency

TI GaN:
- 10x higher switching frequency + reduction of losses
- 5x reduction in magnetics
- Seamless interfacing + design scalability

+

C2000:
- Flexible high-resolution PWM generation and premium analog to digital conversion
- Processing performance for highest possible control loop frequencies: CPU/FPU/TMU + tight coupling of core peripherals
- Quick prototyping with Reference designs + C2000 scalable platform

Silicon PFC
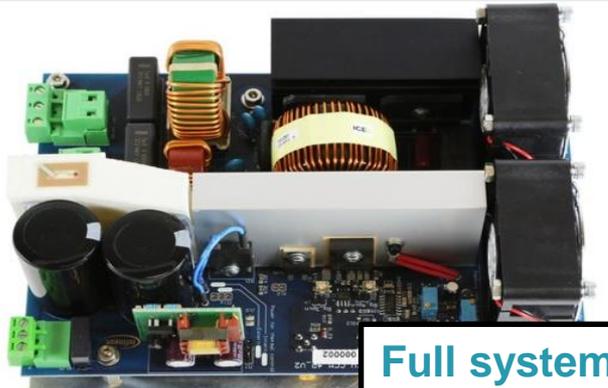
GaN + C2000 PFC

3x Higher Density
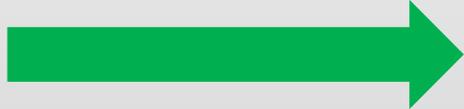
CCM GaN based totem-pole bridgeless PFC stage with > 99% peak efficiency

Full system: 15 W/in³

TIDA-010062 GaN, C2000 Parts*
LMG3410, TMS320F280049
(*TMS320F280039 planned)

Full system: 41 W/in³

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Embedded Pattern Generator (EPG)

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Embedded Pattern Generator

- The Embedded Pattern Generator (EPG) module is a customizable pattern and clock generator

- EPG could serve many test and application scenarios that require:
  - Simple pattern generators
  - Periodic clock generators

- The EPG module can also be used to capture an incoming serial stream of data

EPG

SIGGENx

Pattern Data: 0b001101

CLKGENx

Period: 1 µs, Offset: 0 µs

0 0 1 1 0 1

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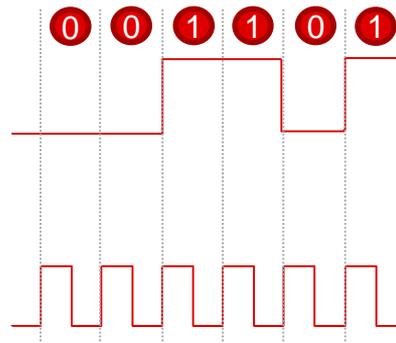
EPG Use-Cases

- Clock generation:
  - Independent clock generation and clock division
  - Synchronous clock generation with programmable offsets

- Pattern generation:
  - Independent serial data stream generation
  - Serial data stream and the associated clock generation
  - Ability to skew clock with respect to serial data
  - Synchronous data stream with programmable offset with respect to one another

Clocks with offset

Serial stream and clock

0 0 1 1 0 1

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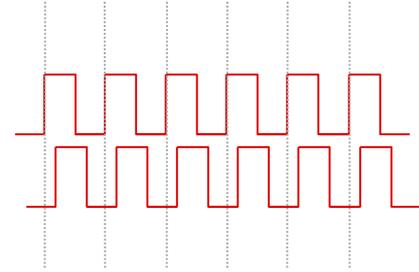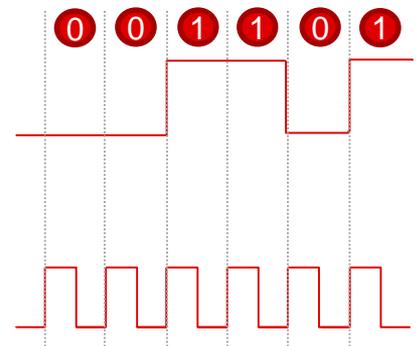
EPG Use-Cases

If needed, EPG can be used to design:

- Additional <u>simple</u> PWM generator

    NOTE: This will not include shadowing, or any other advanced EPWM features

- Additional clock generator
    - Simple periodic clock generation with duty/period control

- Additional serial communication peripheral
    - SPI controllers can be designed using EPG to capture incoming streams, generate output data and serial clock

    NOTE: The controller will not have FIFOs or other advanced SPI features

- Generating test data patterns for internal testing of our peripherals

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EPG Connections

- The following can be used as input signals to the EPG:
  - Input XBARs
  - Signals from the internal connections of other peripheral
    NOTE: Table available in TRM

- The following resources can be used to output the EPG signals:
  - Output XBARs
  - Signals from the output connections of other peripheral
    NOTE: Table available in TRM

TEXAS INSTRUMENTS
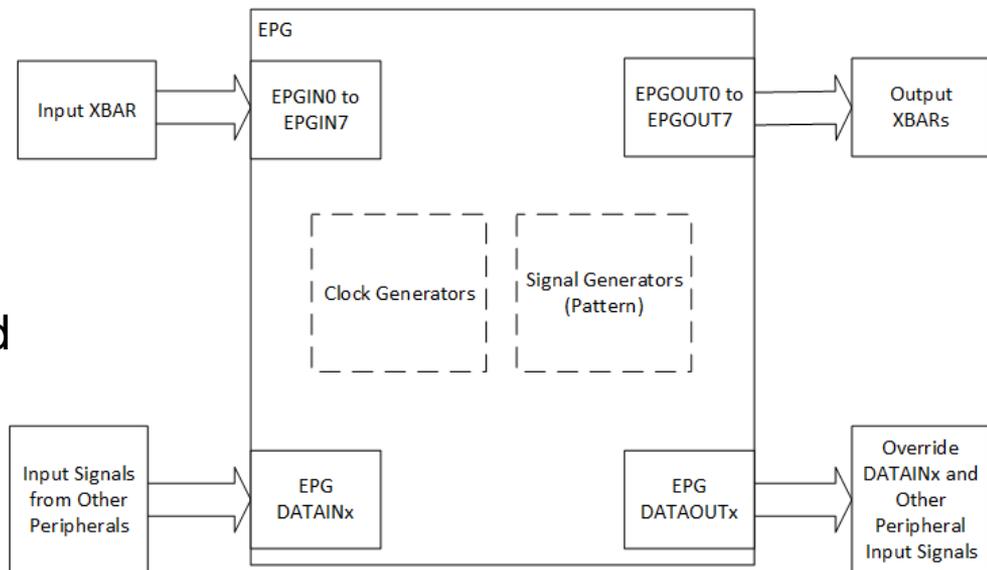
EPG Collateral and Example Release

- Technical Reference Manual (F28003x)

- Driverlib API in C2000Ware

- Video Overview: https://training.ti.com/c2000-embedded-pattern-generator

- Application Report:
  - **Designing With the C2000™ Embedded Pattern Generator (EPG)**
    Step by step guide on how to use the EPG to generate clocks and serial data streams
    This include generating SPI controller data and clock in all 4 SPI modes

- Examples in C2000Ware:
  - Ex1: Very simple periodic clock generator
  - Ex7: Generate two offset clocks (using CLKGEN module)
  - Ex8: Generate two offset clocks (using SIGGEN module)
  - Ex9: Generate SPI transmitter CLK and DATA signals in all 4 POL-PHA modes
  - Ex10: Same as Ex9 but showcasing the design differences between SHIFT and ROTATE modes

Configurable Logic Block (CLB)

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Integrate custom logic and *Augment* peripheral capability in your real-time MCU applications

Customized logic is usually done in a system by adding FPGAs, CPLDs, or external logic. These systems almost always still include a traditional microcontroller as well.
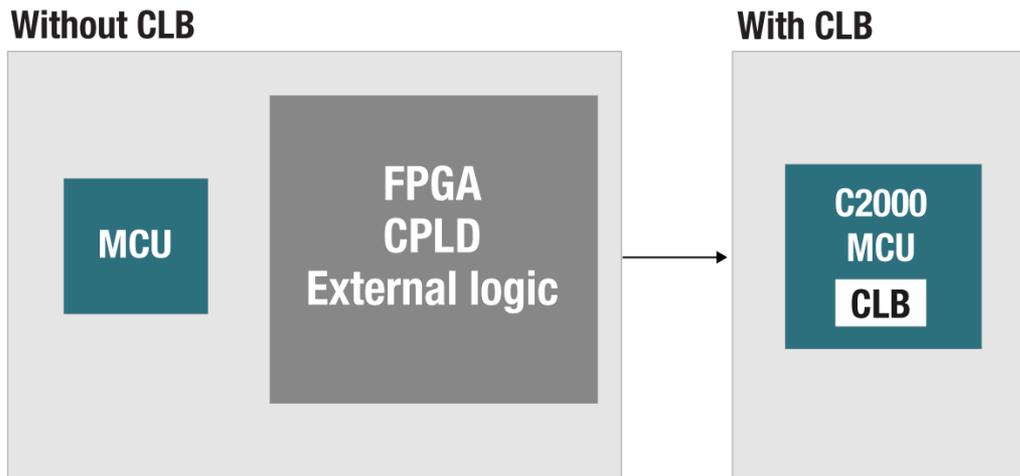
C2000 Configurable Logic Block (CLB) enables customization in a microcontroller based real-time control system while eliminating or reducing the size of the FPGA, CPLD, or external logic

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Common Usages of CLB

- Replace external hardware (CPLD, FPGA, etc.)
- Customize existing peripherals inside the device (EPWM, EQEP, ECAP, etc.)
  - Insert logic before, after, or even inside of a peripheral
- Design new peripherals inside the device

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Replacing CPLD/FPGA, ASICs

Reduces system cost
Improves system performance

- Applications which require external FPGAs/CPLDs along with C2000™ Real-Time Controller→ Potential replacement with CLB

- Reduces feedback latency thus improving control loop time

- Reduces the cost and board area by removing external devices like FPGAs or ASICs
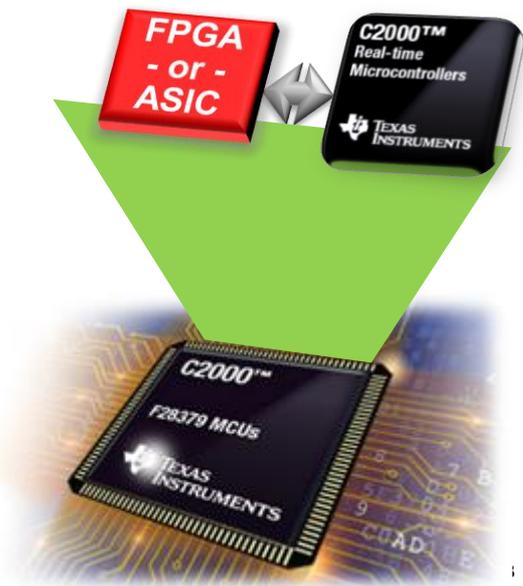
Insert Custom Logic Inside Existing Peripherals
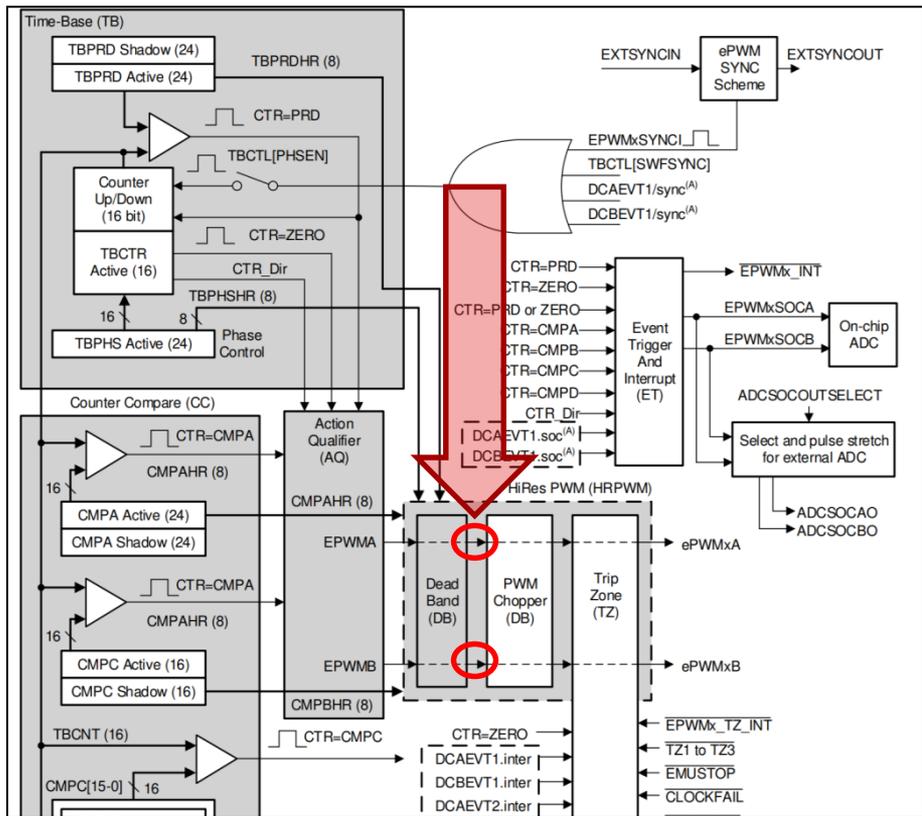
Design New Peripherals

- Insert CLB inside a peripheral
  - Override internal peripheral signals using CLB outputs
- GPIO to CLB to GPIO
  - Design new peripherals inside the Real-Time controller
- Precondition signals before entering a peripheral
- Add logic before sending signals outside of the chip
  - Replace CPLD/FPGA

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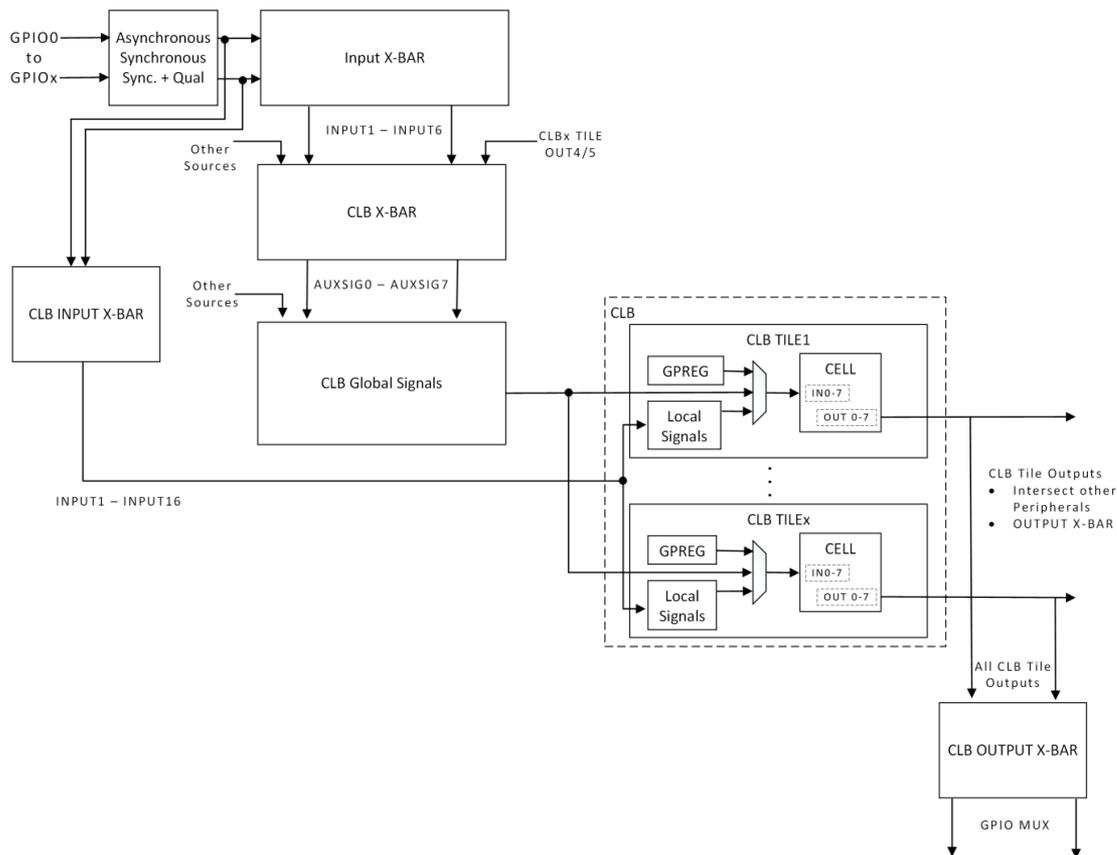
How do you configure the CLB?

- CLB Tool is a Code Composer Studio (CCS) SysConfig plug-in
  – C2000 SysConfig GUI Tool

- GUI based tool to configure and program each CLB tile

- Simulation and Visualization tool to verify logic

- Feature Examples in C2000Ware and System examples in application Software Development Kits

CCS Project
(SysConfig based CLB Project)

C28x Application Code
- main.c
- driverlib.lib
- Other application specific files
- CLB SysConfig tool files
  clb_config.c
  clb_config.h

CLB Tool (SysConfig)
- configured through .syscfg file inside the project)
- Graphical User Interface to configure the CLB Tiles

Generate

Generated Files From CLB Tool (SysConfig)

clb_config.h

clb_config.c   clb_sim.cpp   clb.dot

Application   Simulation   Visualization
Code   Code   Diagram

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CLB Tool

GUI tool to configure the CLB peripheral
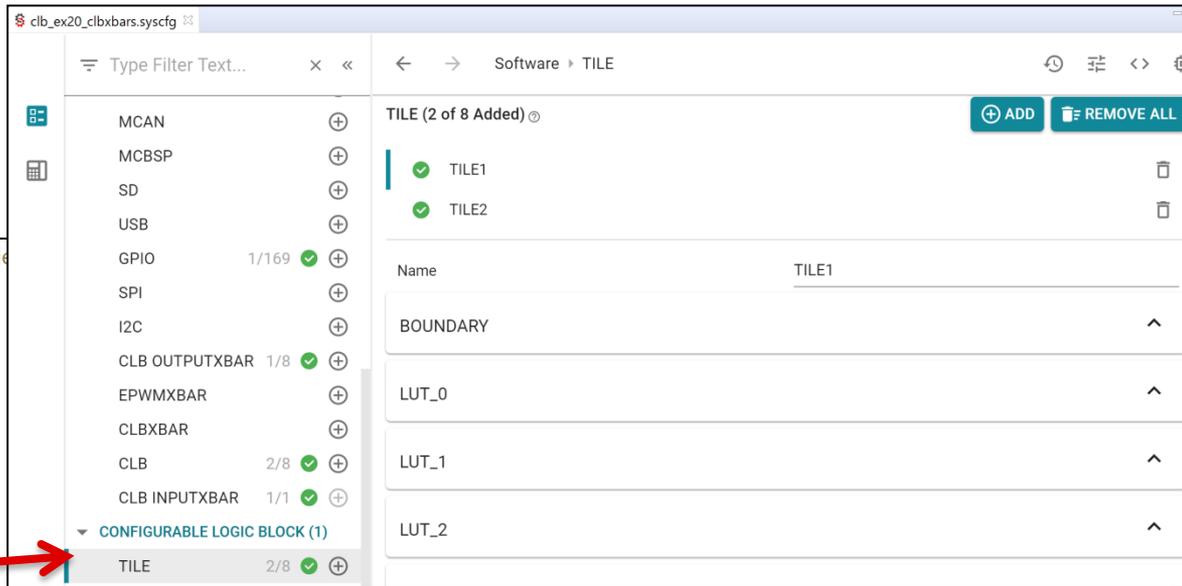
Resources

- [C2000Ware](#) including the [CLB Tool User's Guide](#) [SPRUIR8]

- Application Note: [How to Design with the CLB](#) [SPRACL3]

- Application Note: [How to Migrate from FPGA/CPLD to CLB](#) [SPRACO2]

- Video Training Series
  - Technical CLB Presentation
    - https://training.ti.com/enable-differentiation-configurable-logic-various-automotive-applications
  - Configurable Logic Block (CLB) introduction
    - https://training.ti.com/c2000-configurable-logic-block-clb-introduction
  - CLB architecture
    - https://training.ti.com/c2000-configurable-logic-block-clb-architecture
  - CLB Programming Tool
    - https://training.ti.com/c2000-configurable-logic-block-clb-programming-tool

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Visit www.ti.com/npu

For more information on the New Product Update series, calendar and archived recordings

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