基于C2000的数字化电源方案

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Texas Instruments

Agenda

- Introduction to Digital Power Supply
  - What is DPS? Why DPS?
- C2000 Digital Signal Controllers
  - Roadmap
  - Next Generation – Piccolo-A&B
  - CLA and Peripherals
- Digital Power with C2000
  - Application Architecture
- Getting Started
  - Hardware & Software Development Tools

Power Supply System Level Challenges

- Improved Efficiency Across the Load Range:

- 90% From 10% - 100% Load & Pushing For 96% Max Efficiency in AC/DC and DC/DC Systems

- Higher Integration, Lower System Cost w/ Improved Reliability & Density:

- Single Chip Control + Housekeeping w/ Increased Integration of High Speed Analog (Comparators, V-regs, etc…)
- Use of Full Digital Control for More Advanced Fault Prediction Algorithms

- Added Intelligence such as Input Power and RMS Current Measurement / Reporting:

- Better than 2% Accuracy of Input Power From 20% - 100% Load
- Goal is No Added External Components with Minimum Calibration Time

- Ease of Development / Manufacturing

- Best in class development tools & collateral / Expand our GUI Support to wider set of topologies
- Minimize calibration and test times for functions like input power measurement

- Flexibility & Differentiation:

- Support of Advanced Topologies
- Digital Power Solutions Will Enable MP Customers to More Easily Add Value to Their Customers

Complete Power Solutions from TI

UCCxxxx

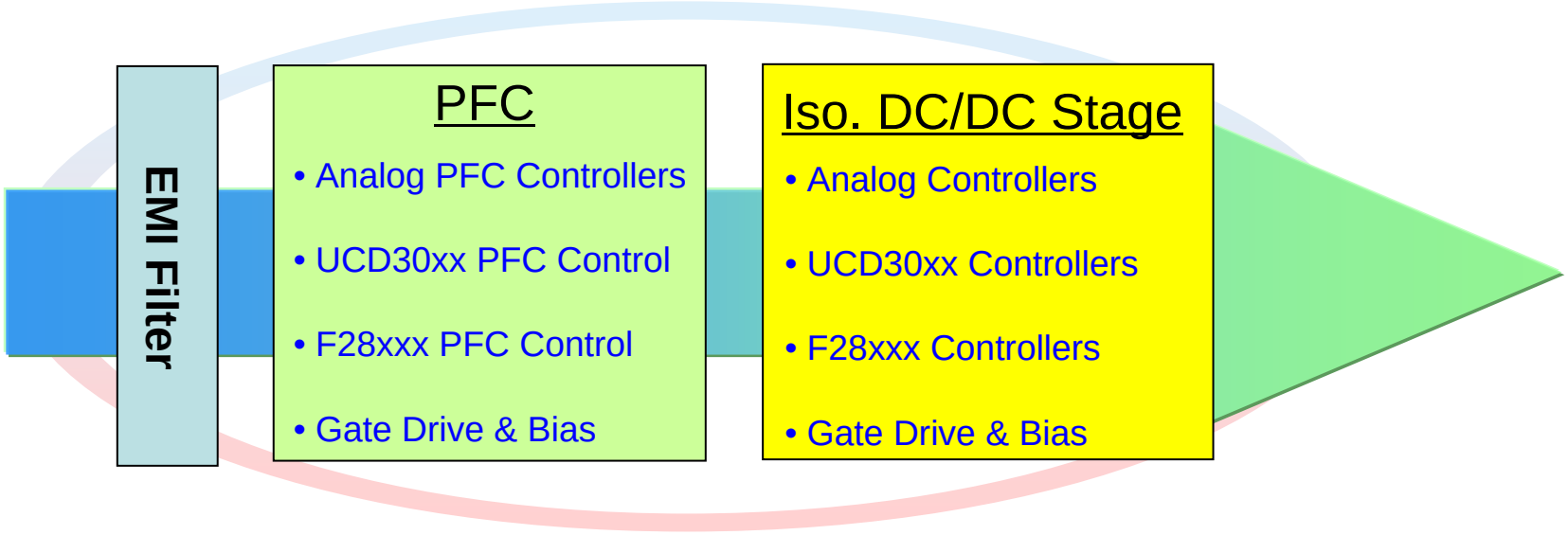
High Performance Analog Solutions

UCD30xx

Power-Optimized Digital Controllers

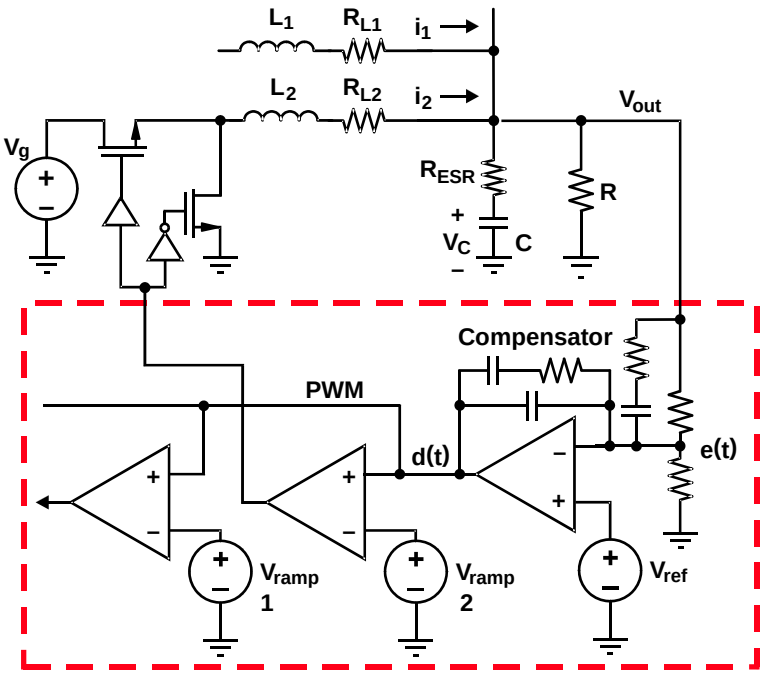
F28xxx

Fully Programmable Digital Controllers

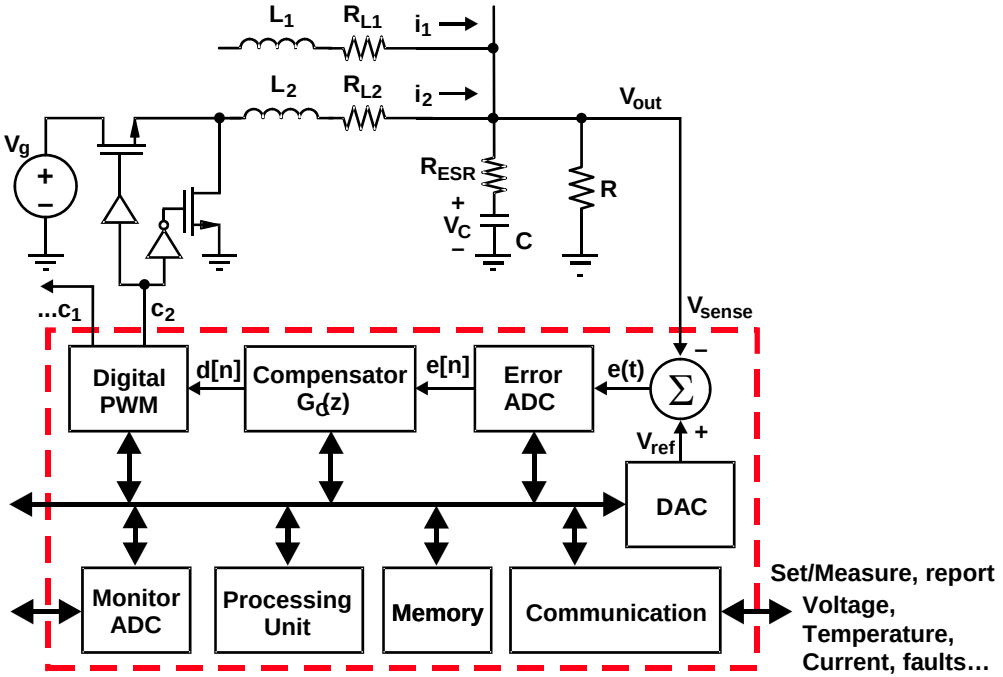


TI Solutions Cover the Spectrum of Power Applications

Analog & Digital Voltage Regulators - A example



Analog Controller



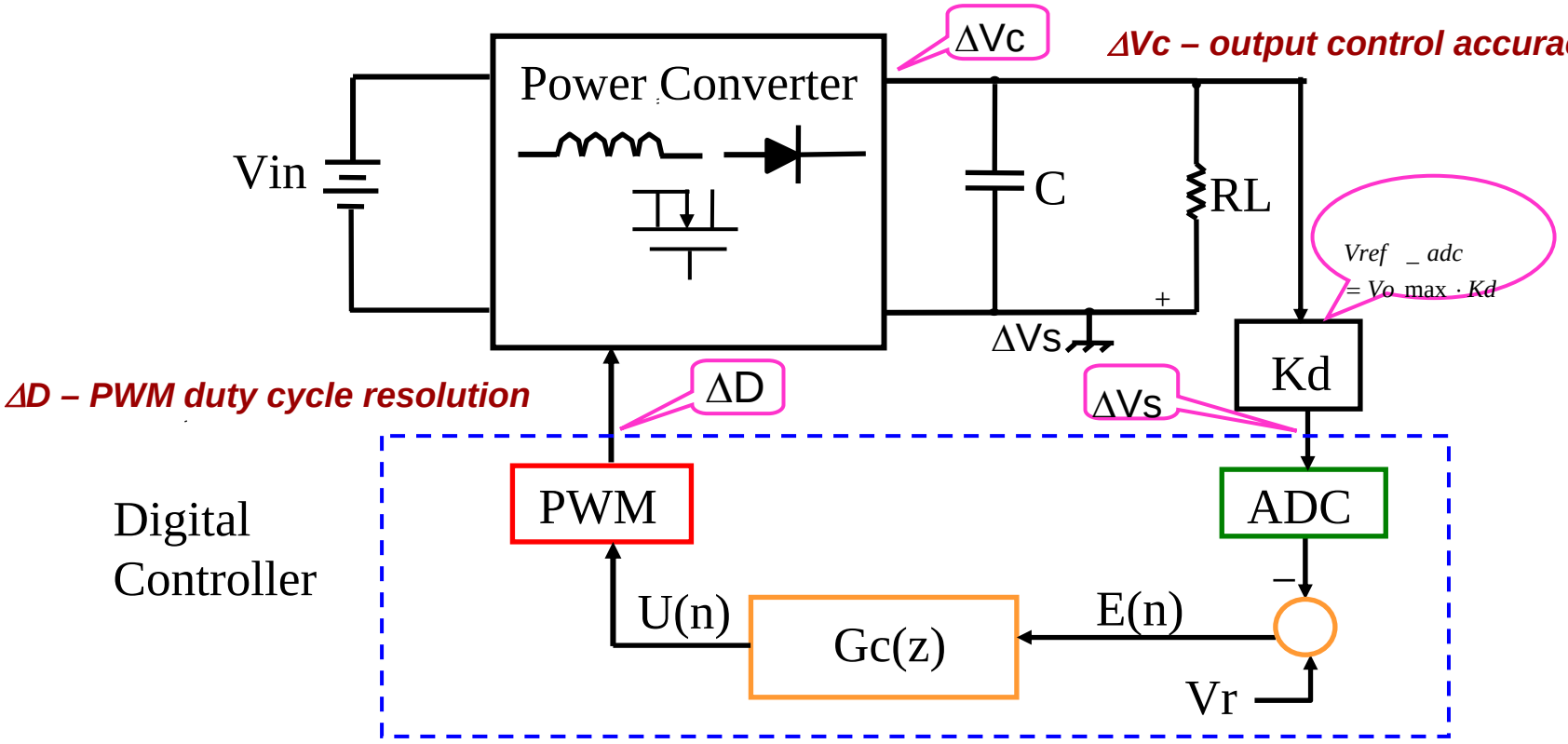
Digital Controller

- "Digital Control" means sampling feedback information using ADC and closing the loop numerically

  Compensator uses digital signal processing techniques to construct the control effort in form of PWM duty rario(s)

- Enables ‘inherent’ monitoring and management of the converter(s)

Digitally Controlled Power Converter - Conceptual Block Diagram



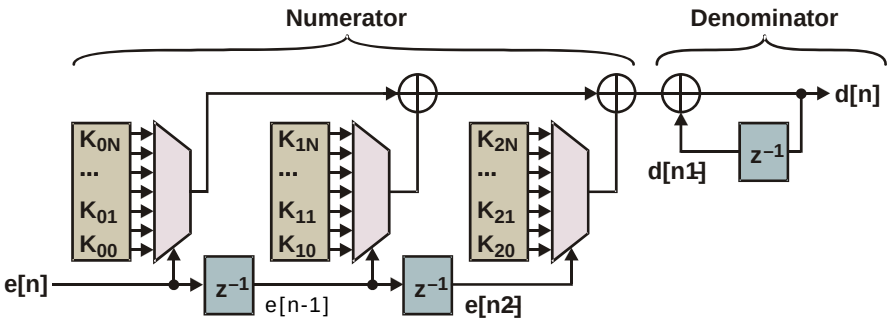
$$G_c(z) = \frac{U(z)}{E(z)} = \frac{B_0 + B_1 z^{-1} + B_2 z^{-2}}{1 - A_1 z^{-1} - A_2 z^{-2}}$$

$$U(n) = B_0 E(n) + B_1 E(n-1) + B_2 E(n-2) + A_1 U(n-1) + A_2 U(n-2)$$

Compensator Realizations

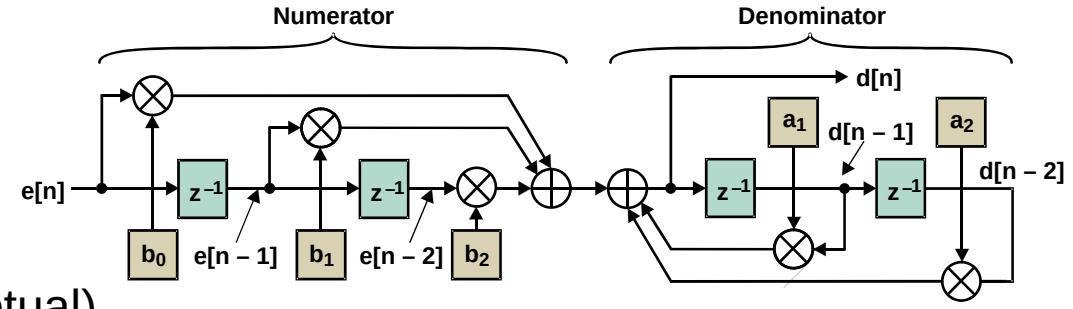
- 2nd-order table look-up (UCD9112)

$$\frac{d(z)}{e(z)} = \frac{K_0 + K_1 z^{-1} + K_2 z^{-2}}{1 - z^{-1}}$$



- Direct-form digital filter (UCD9240)

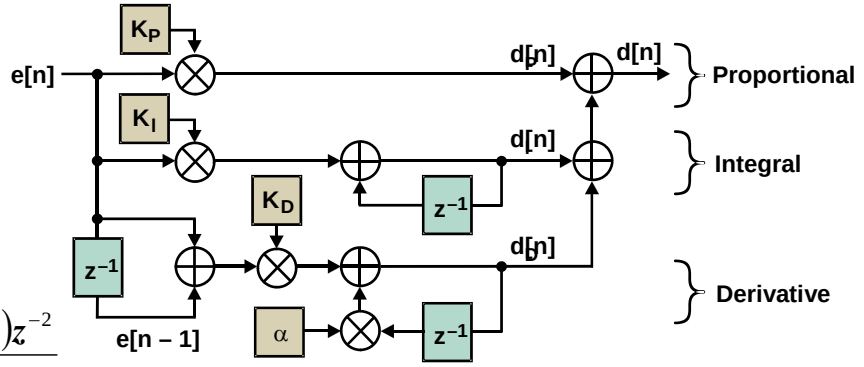
$$\frac{d(z)}{e(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 - a_1 z^{-1} - a_2 z^{-2}}$$



- PID-form digital filter (conceptual)

$$\frac{d(z)}{e(z)} = K_P + K_I \frac{1}{1 - z^{-1}} + K_D \frac{1 - z^{-1}}{1 - \alpha z^{-1}}$$

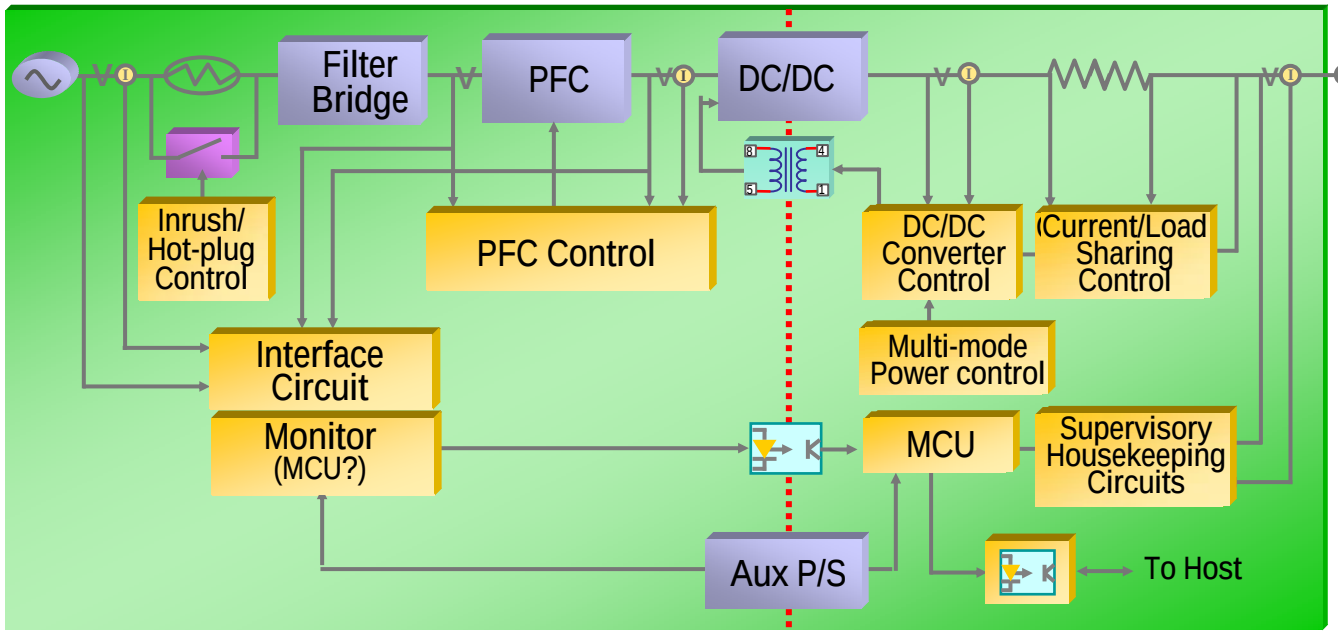
$$= \frac{(K_P + K_I + K_D) - (K_P(1+\alpha) + K_I\alpha + 2K_D)z^{-1} + (K_P\alpha + K_D)z^{-2}}{1 - (1+\alpha)z^{-1} + \alpha z^{-2}}$$



Analog vs. Digital Solution Tradeoffs

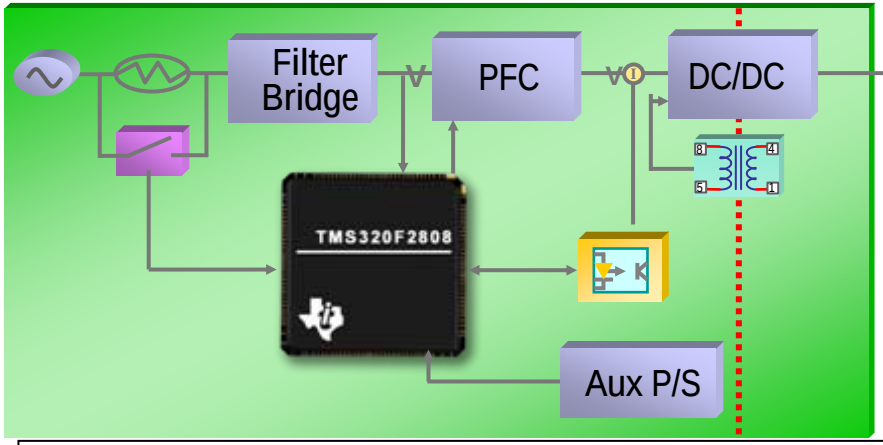
	Strengths	Weaknesses
ANALOG	• Continuous operation (infinite sample rate) • Low power consumption • Single chip solutions available (integrated driver)	• Hardwired design • Separate “signal” lines for every converter • No communication with controllers • Need separate system manager
DIGITAL	• GUI, programmable parameters • Adaptive and nonlinear compensation • Flexibility, easier board development • Features integration • Multiphase reliability Phase shedding N+1 redundancy • Easier PWM synchronization • Fault logging • Up to 32 devices on single PMBus	• Discrete PWM operation • Higher quiescent current • Dual chip solution (controller + driver) even for low power apps

Digital Power: Greener Approach that Saves Money



Traditional Analog Power Supply

- Multiple chips for control
- Micro-controller for supervisory
- Dedicated design

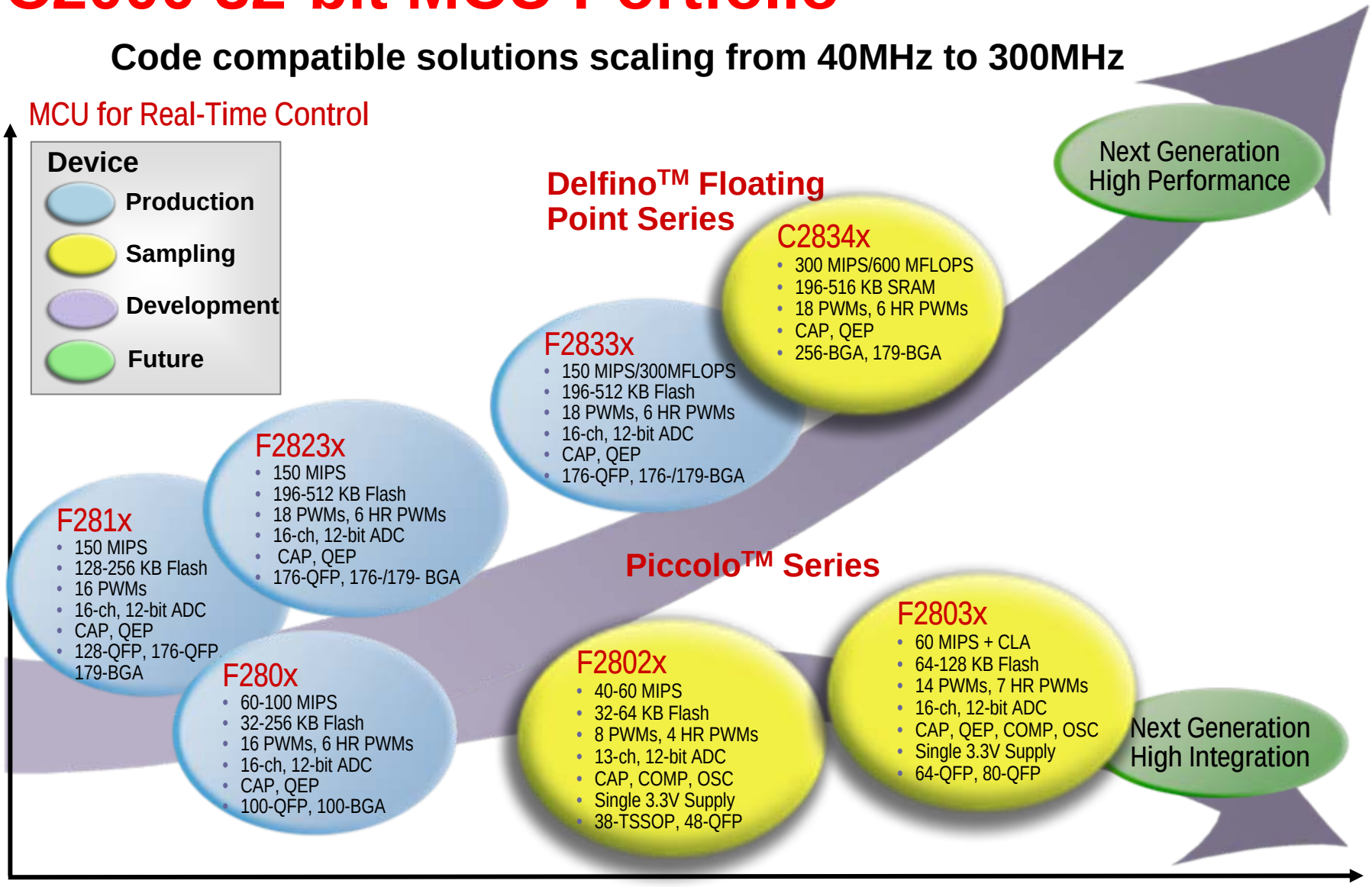


Digital Power Supply

- Eliminate Components
- Reduce Manufacturing Cost
- Better Performance Across Corners
- One Design, Multiple Supplies
- Failure Prediction

C2000 32-bit MCU Portfolio

Code compatible solutions scaling from 40MHz to 300MHz



C2000 - Real-time Control in an MCU Package & Price

Leading 32-bit performance for real-time control

- High-performance C28x CPU
- Intelligent peripherals optimized for control applications
- Control Law Accelerator

Lower System Cost & Ease of Use

- Best mix of control peripherals
- Robust software libraries
- Code compatibility across family and with previous generations
- Increased on-chip analog integration

MCU Package & Price

- Starting at sub $2 (in volume)
- Package options starting from 38-pins
- Bringing real-time control to cost sensitive applications

F2802x MCU Series

Back

Performance

- 40-60 MHz C28x 32-bit CPU
- Full software compatibility with previous generations

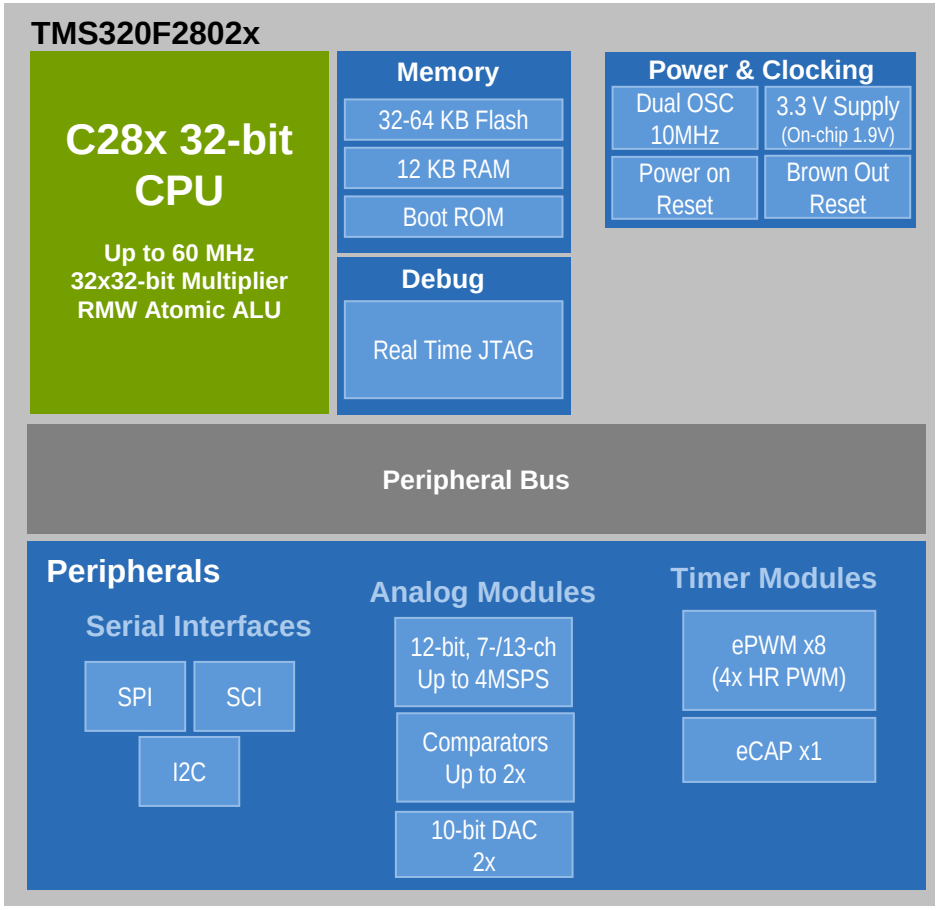
Features

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

- Packages: 38-pin TSSOP, 48-pin LQFP

Applications include:

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



F2803x MCU Series

Back

Performance

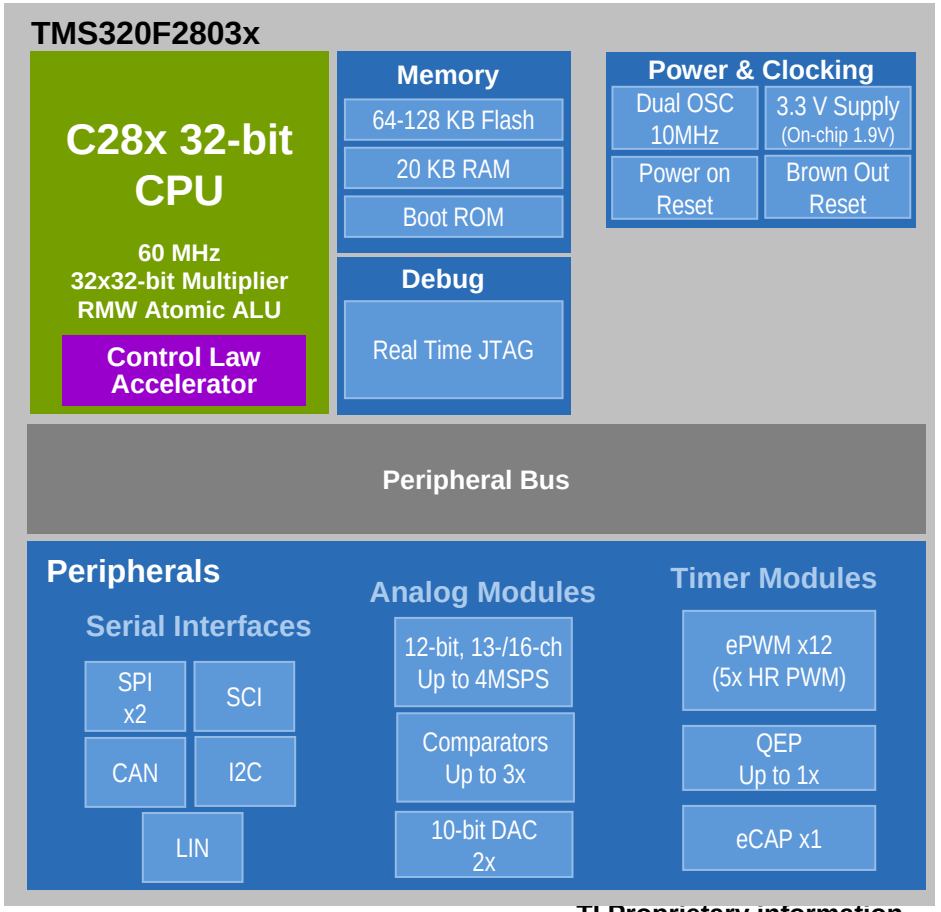
- 60 MHz C28x 32-bit CPU
- Control Law Hardware Accelerator
- Full software compatibility with previous generations

Features

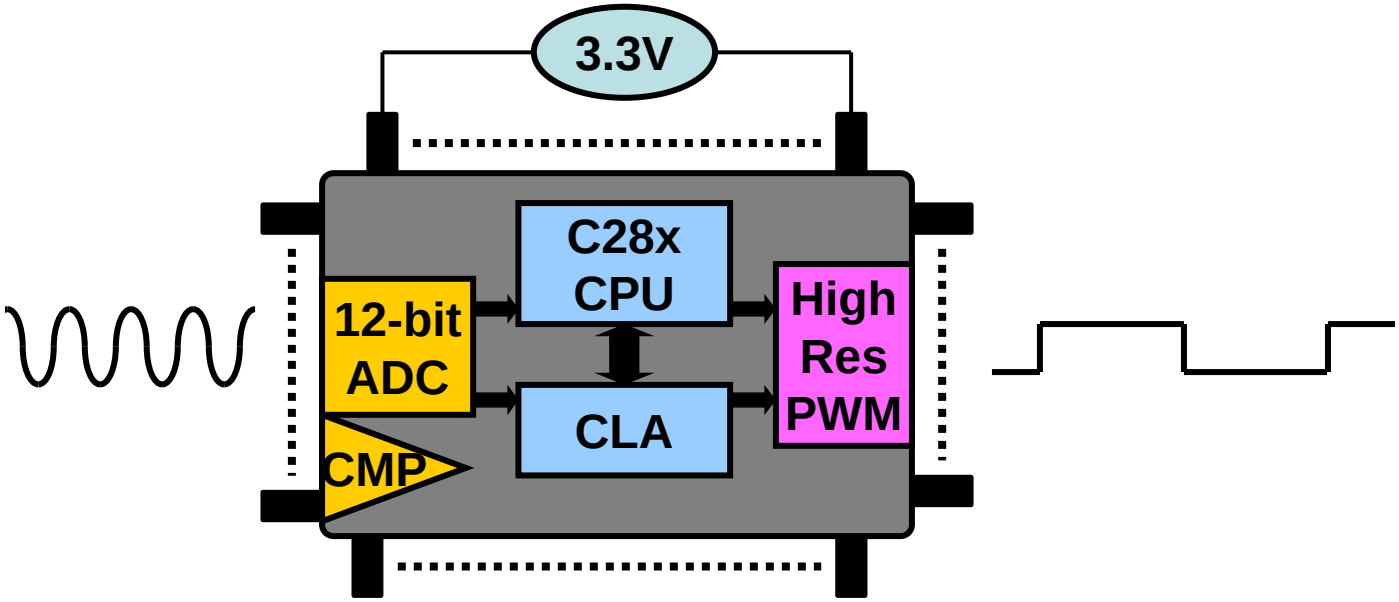
- **Core**
  - C28x 32-bit CPU
    - Single cycle 32-bit MAC
  - 60MHz Performance
  - Control Law Accelerator
- **Memory**
  - Flash: 64, 128 KB
  - RAM: 20 KB
- **Highlights**
  - Single 3.3V supply
  - High accuracy on-chip oscillators (10MHz)
  - Best in class PWM and event capture capability
  - 150ps resolution on PWM frequency
  - 12-bit ratio-metric ADC with individual channel triggers
  - Three analog comparators with 10-bit reference
  - CAN 2.0B up to 16 mailboxes
  - Up to 44 General Purpose I/Os
- 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



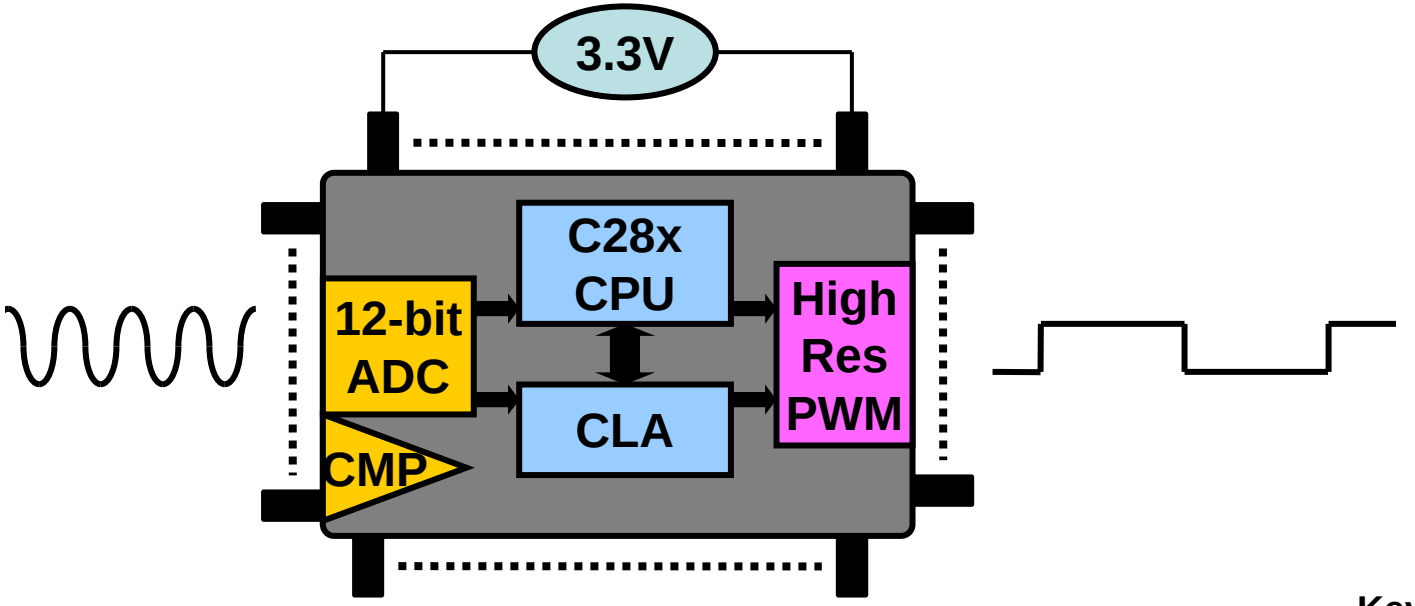
What Is the Control Law Accelerator?



An Independent, 32-bit Floating-Point Math Accelerator

- ✓ Executes algorithms in parallel with the C28x CPU
- ✓ Has direct access to ADC result, ePWM+HRPWM and comparator registers
- ✓ Responds to interrupts independent of the C28x CPU
- ✓ Fully programmable: IEEE 32-bit floating-point

CLA System Benefits



	Key Driver(s)
Reduced **Sample-To-Output** Delay (& Jitter)	Digital Power Applications
Faster System Response & Higher MHz Control Loops	
Improved Support For Multi-Channel (Phase/Freq) Loops	
Improved System Robustness (IEC60730, SIL-3)	Automotive, White-goods
Free-Up C28x CPU For Other Tasks (comms, diagnostics)	All Applications

CLA Summary

CLA Features:

- ✓ A programmable 32-bit floating-point math accelerator.
- ✓ Independent of the main CPU
- ✓ 32-bit floating-point format – easy to code and robust!
- ✓ Supports 8 tasks (interrupts)
- ✓ Interrupt sources: ADC, EPWM, CPU Timer 0
  Main CPU Software

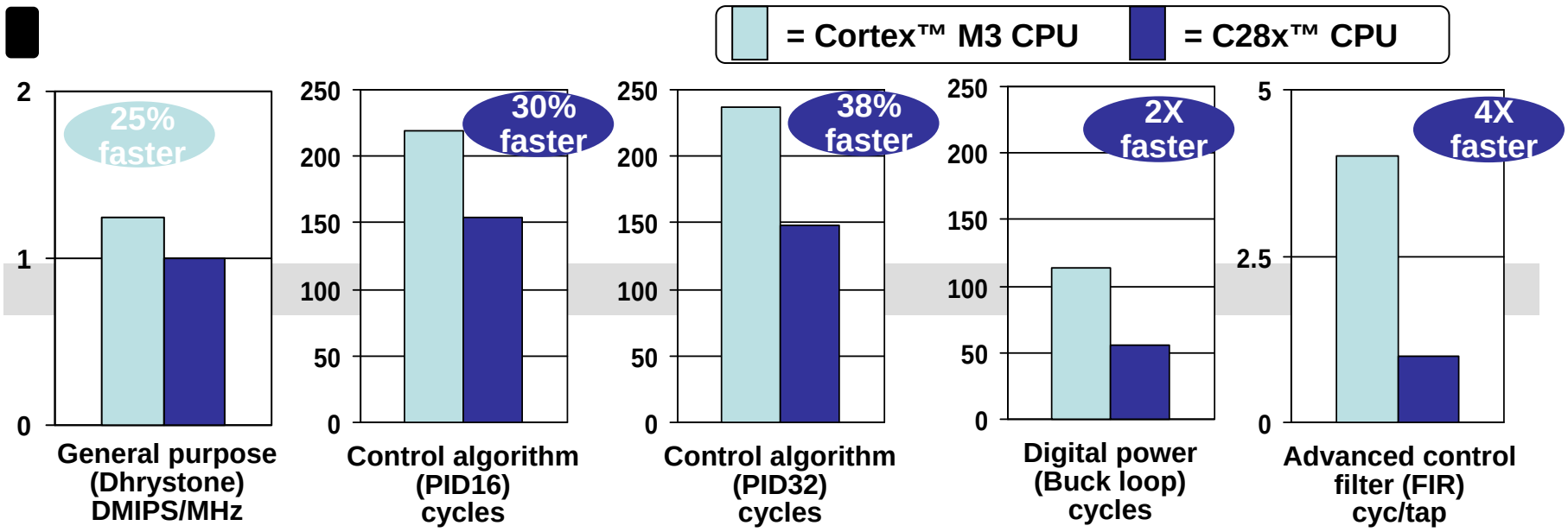
Direct access to:

- ✓ Program RAM, 2 Data RAMs, 2 Message RAMs,
- ✓ ePWM+HRPWM, Comparator and ADC result registers

CLA in your system can:

- ✓ Improve robustness
- ✓ Sample ADC “just-in-time” to reduce sample to output delay
- ✓ Increase system response, enable higher MHz control loops
- ✓ Perform filtering, math, or trig functions
- ✓ Free the main CPU for other operations
- ✓ And more!

“Piccolo” Boosts Performance by up to 5X



All benchmarks run from 0-wait RAM, using latest TI tools

Operation	Cortex-M3 (72 MHz)	C28 (60MHz)	C28/CLA (60MHz)
Feedforward control cycles	786	482	482 / 0
Feedback control cycles	1762	1081	0 / 550
Total Control Law cycles	2548	1563	482 / 550
MHz used (20 kHz loop)	**~51MHz**	**~32MHz**	**~10/11MHz**
	< 1/3 headroom	**20% faster, lower frequency, 50% headroom**	**5X faster, lower frequency 80% headroom**

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

Piccolo Serial Ports

SPI Port: Limited I2S Emulation Mode Using 2 SPI Ports (PICCOLO-B):

- One SPI Port Processes Left Data, Other SPI Port Processes Right Data
- Typically Used In Audio Applications

3-Wire SPI Mode:

- Can Transmit And Receive Data On One Data Line
- Reduces Pin Usage On Low Pin Count Devices Such As Piccolo

Reduced FIFOs On SCI/SPI/I2C Ports To 4 Levels:

- FIFO's Help To Reduce Interrupt Overhead When Streaming Data
- 4 Levels Is OK For This Class Of Product

LIN Port (PICCOLO-B):

- Supports SCI Operating Mode
- Typically Used In Automotive Applications

CAN Port (PICCOLO-B):

- Same CAN Port Used On All Other 28x Devices (32 mailboxes)

Piccolo VREG + POR + BOR

PICCOLO Devices Are Single Supply Devices (3.3V +/-10%)

VREG:

- Piccolo devices support on-chip regulator to generate core voltage
- VREG can be disabled and core voltage sourced externally (~1.8V)
- Short circuit current protection is provided on core supply

POR:

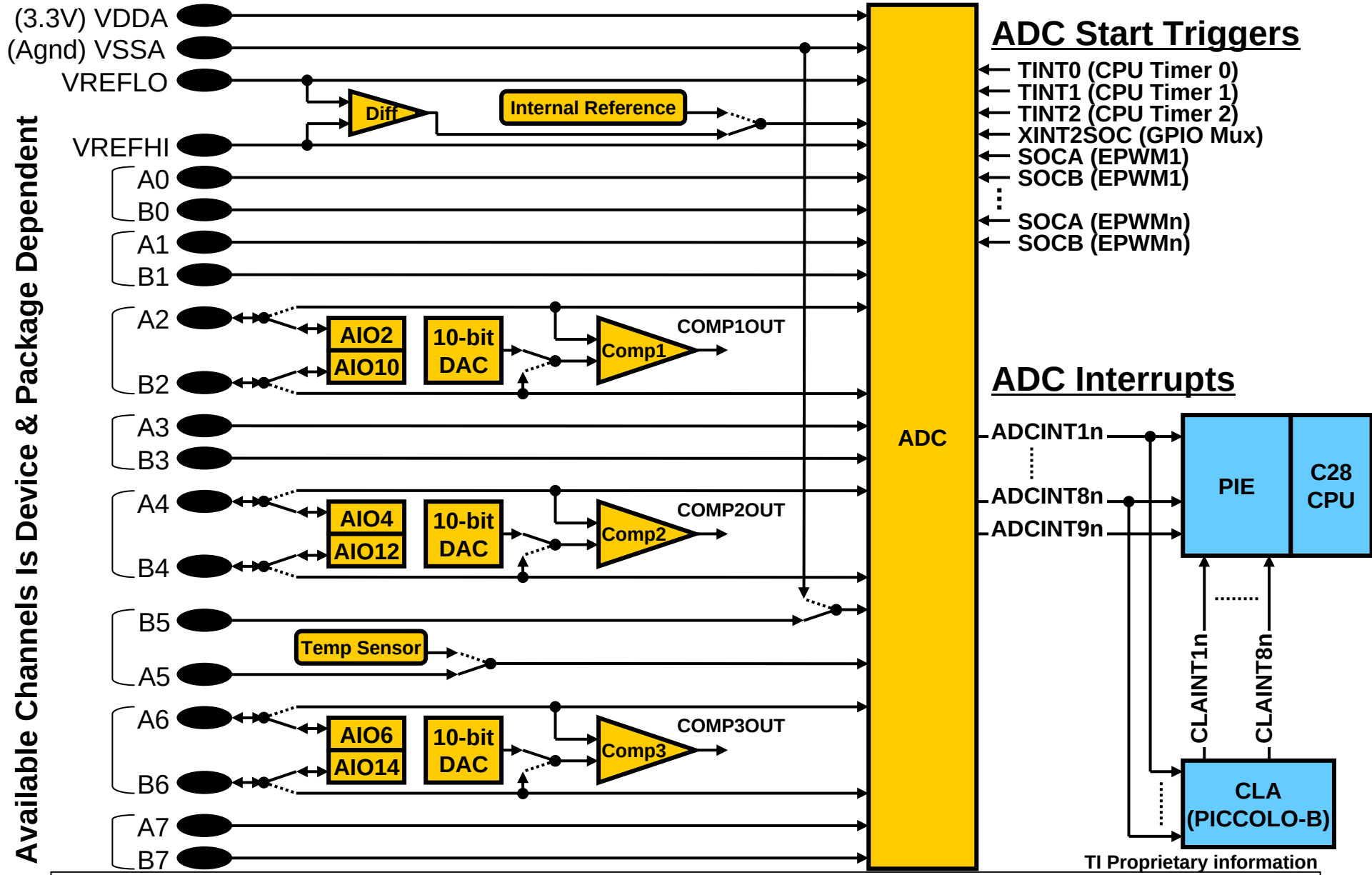
- Power-On Reset generates a device reset during power-up conditions
- POR reset is visible on external reset pin (XRSn)
- POR is enabled even when VREG is disabled

BOR:

- Brown-Out Reset generates a device reset on power supply dropping below ~3.0V (below 3.3V - 10% supply spec for device)
- BOR reset is visible on external reset pin (XRSn)
- BOR can be re-enabled when VREG is disabled

Note: **No Power Sequencing Requirements On PICCOLO**
No I/O Glitches On PICCOLO

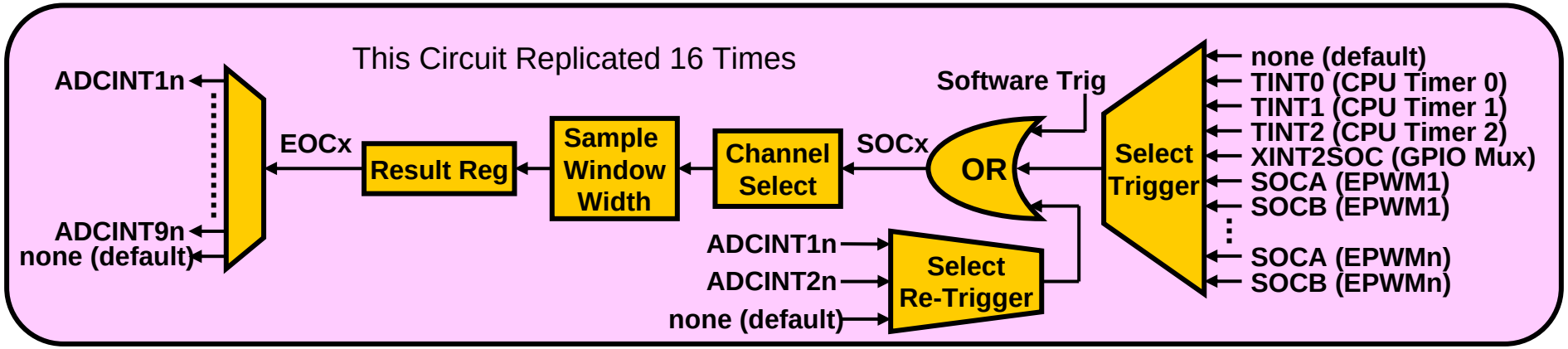
Piccolo ADC



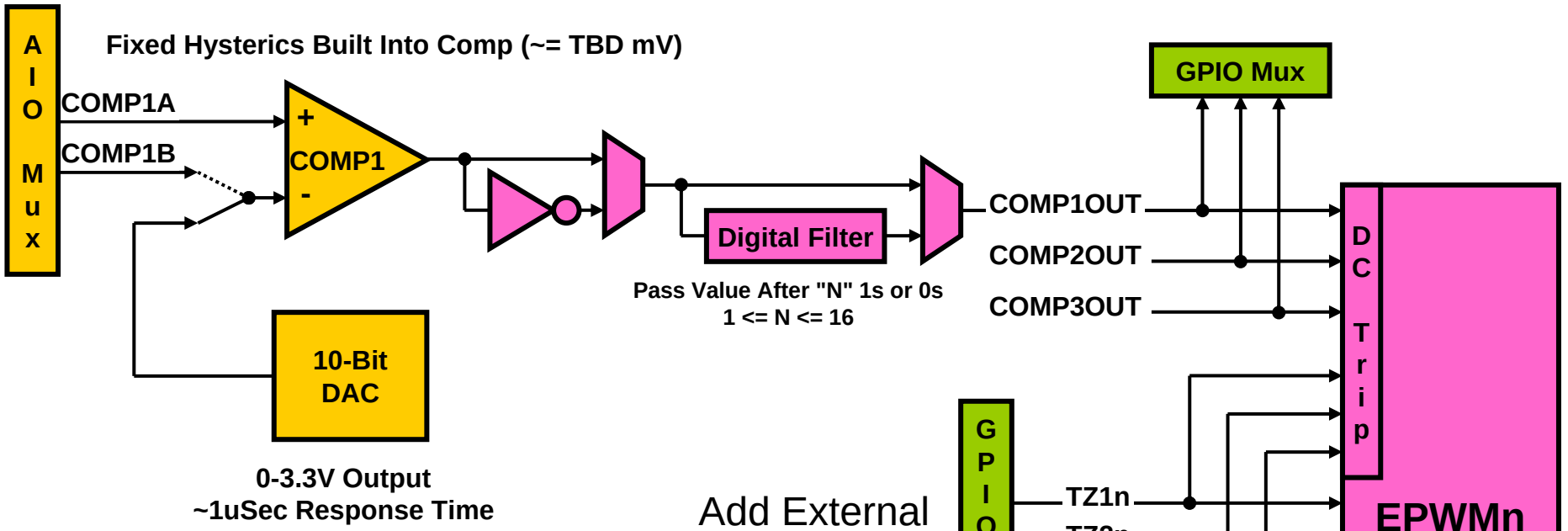
ADC Improvements

Performance	Characteristics
12-bit 4.6/3.1 MSPS up to 16 Channels 2 S/H	Re-cyclic Architecture (hybrid of SAR + pipeline) Design 4 Support Pins Much Lower Power Consumption (~11mA @ 3.3V) Ratiometric (differential and unipolar) Gain & Offset Trim Registers (with internal AGND select) Rail To Rail Range (0-3.3V) Sampling Window Can Vary Between Channels Internal Temp Sensor Connection Internal Or External Reference Selection Early Interrupt Generation

Improved Triggering Mechanisms Enables Easier Support For Multi-Frequency & Phase Sampling



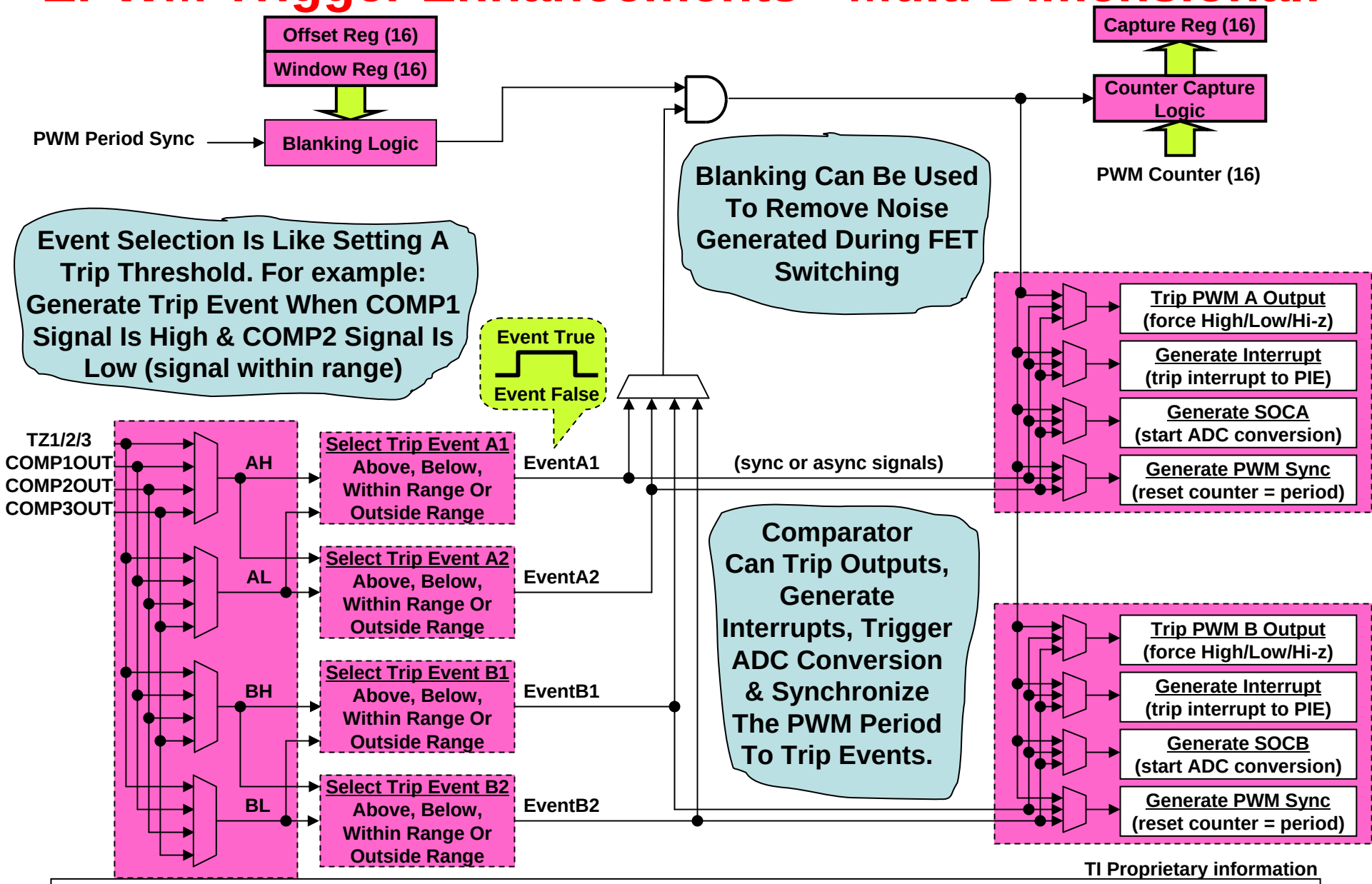
EPWM Comparator Support - Trip Inputs



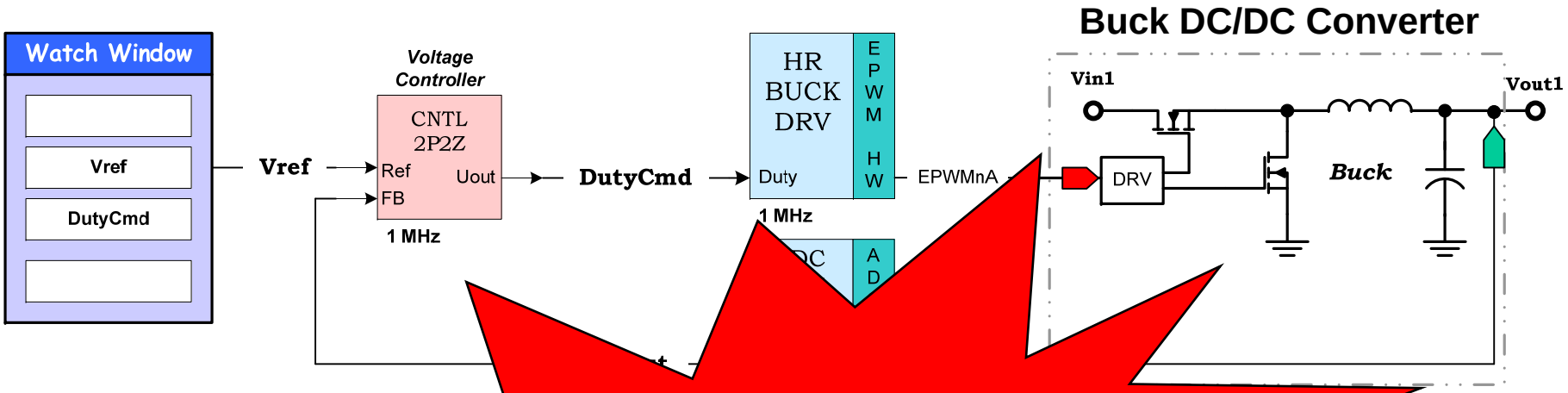
Response Time

Comp Input To Output
PWM Trip < 50nSec
(asynchronous mode)

EPWM Trigger Enhancements - Multi Dimensional!

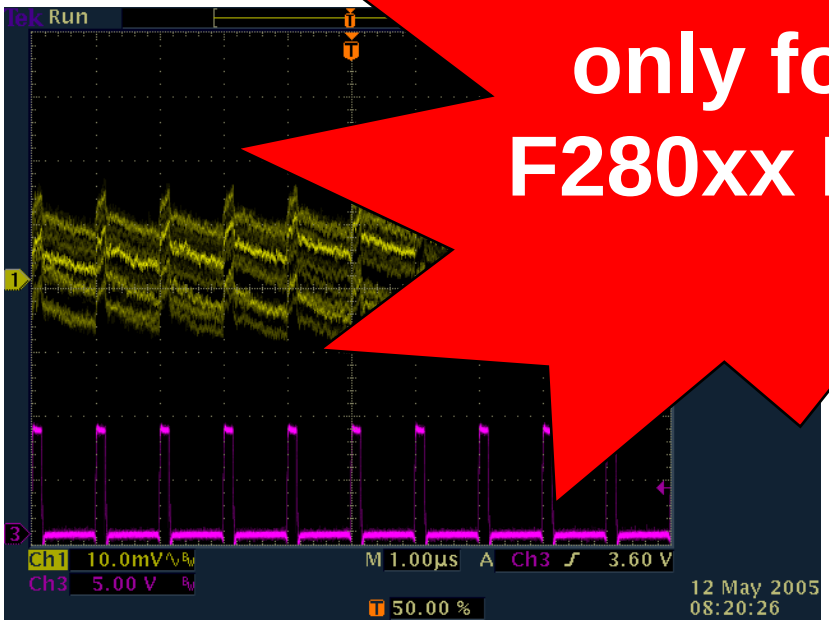


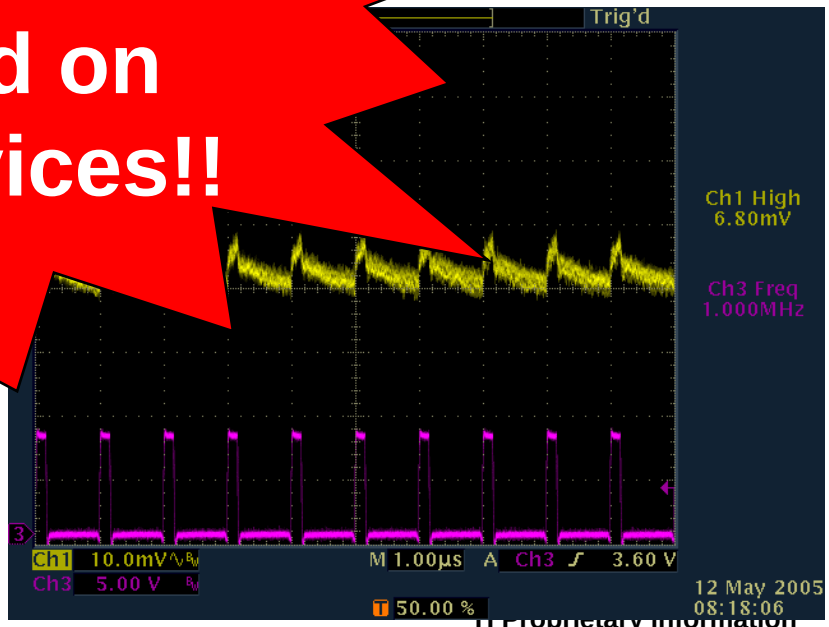
HRPWM: Enabler For Digital Power Supplies



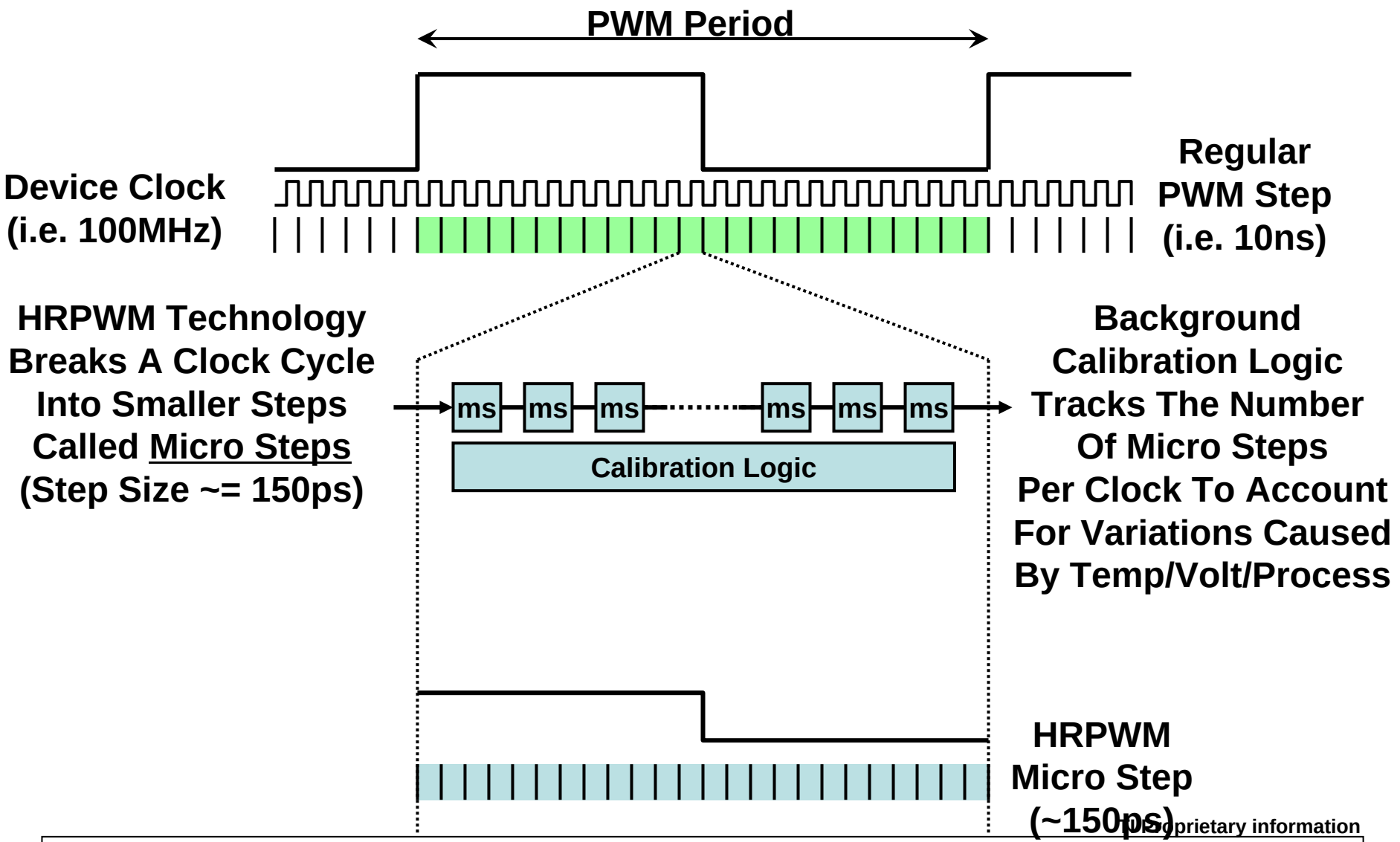
HRPWM only found on F280xx Devices!!

Regular (10nS) PWM — Stable Output

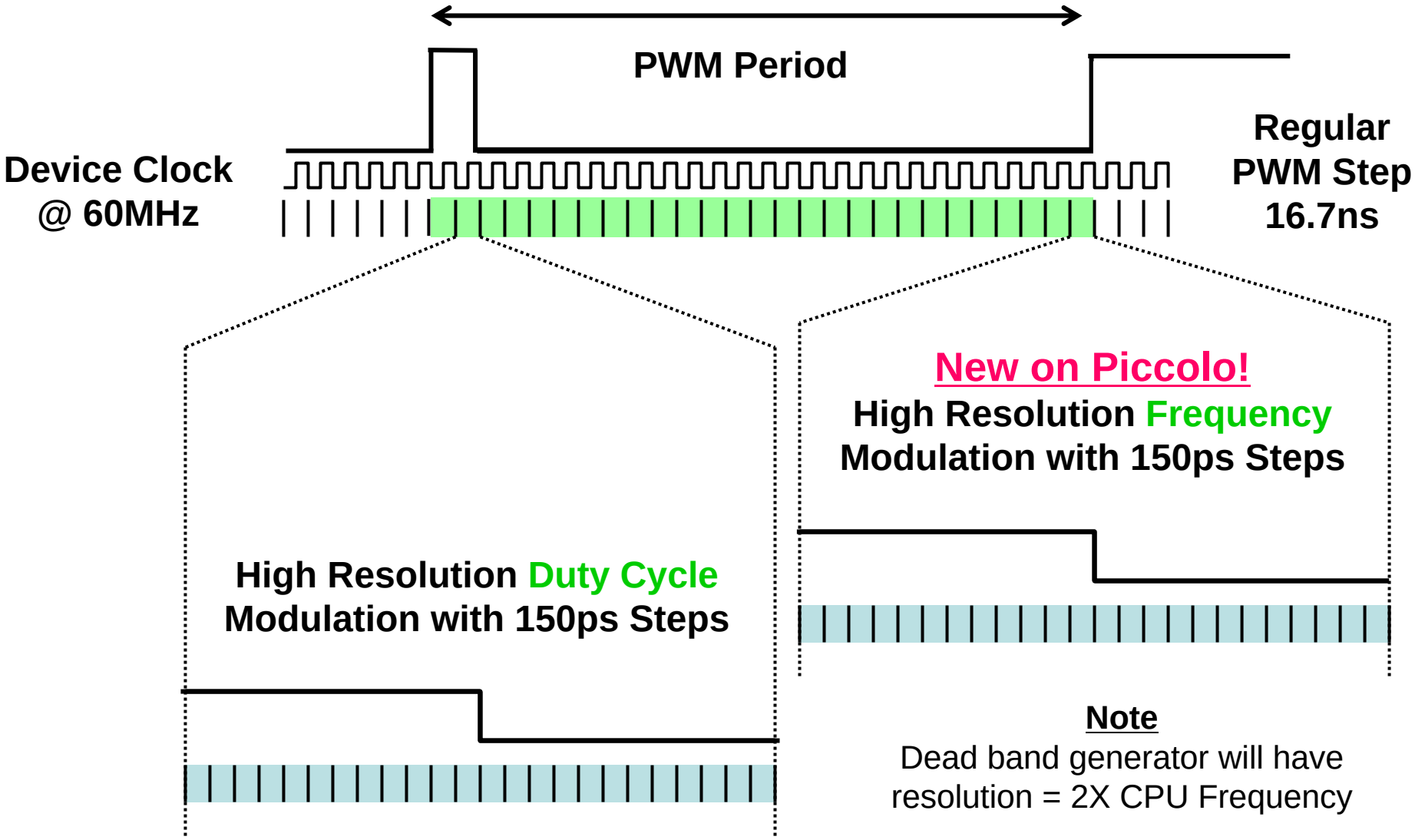




280xx High Resolution PWM (HRPWM)

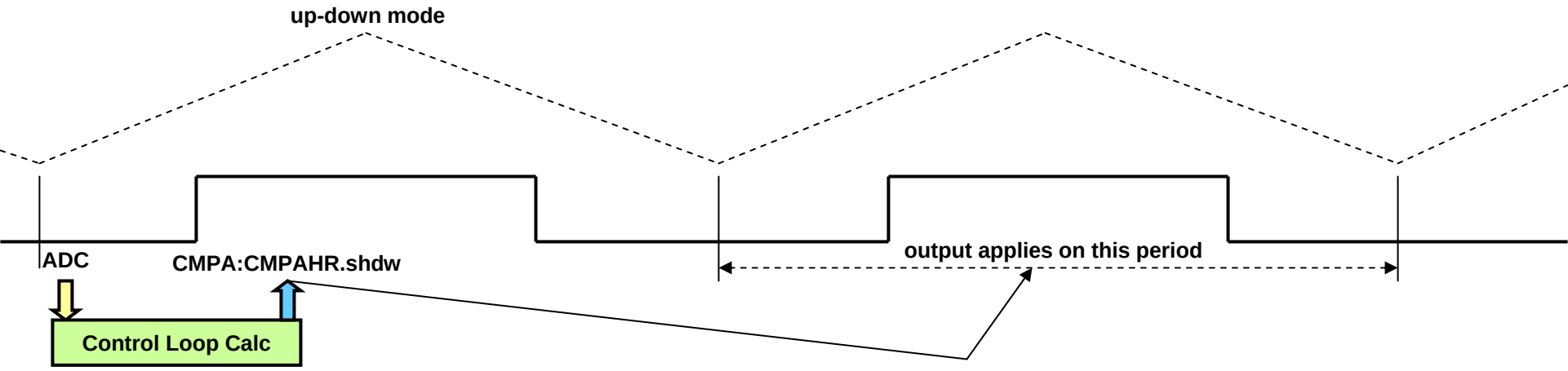


High Resolution PWM

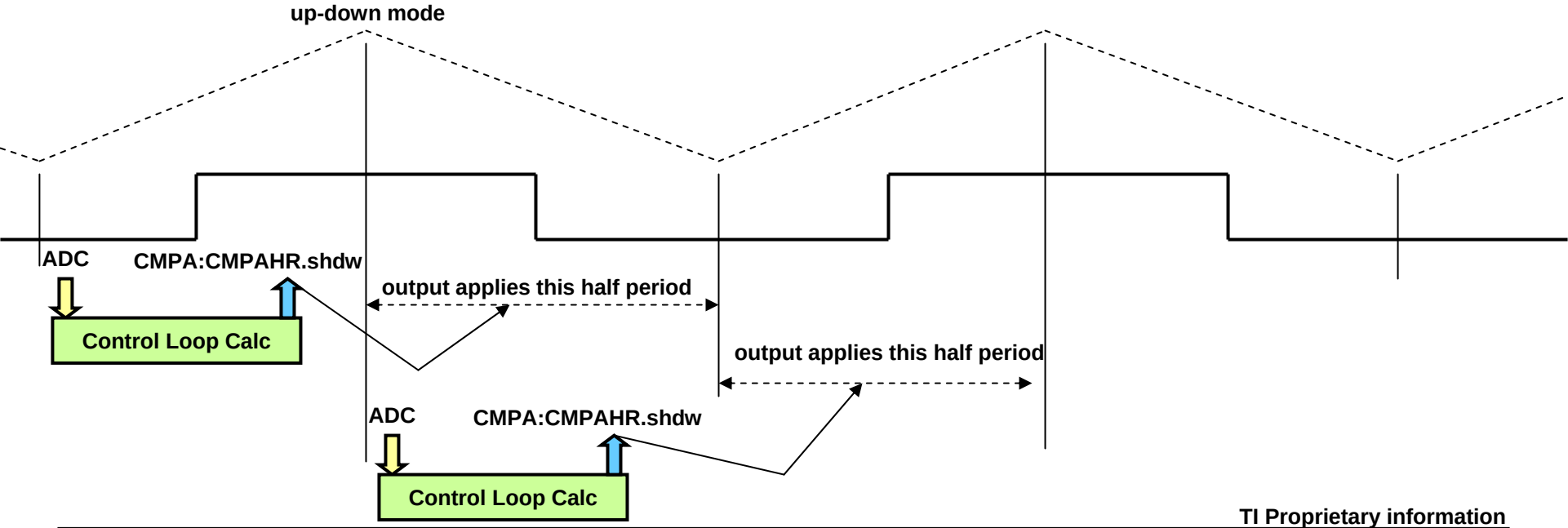


EPWM - Dual Edge Control

Traditional Single Edge Control: Output Is Updated Once Per PWM Period And There Is A Full Period Output Delay



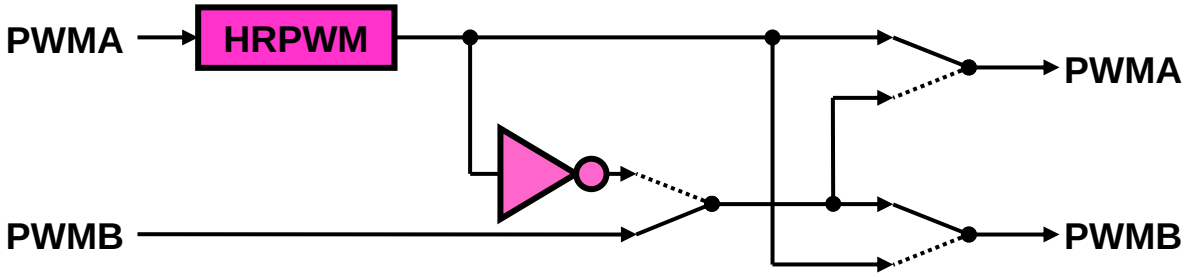
Dual Edge Control: For The Same PWM Frequency, Output Is Updated Twice In A PWM Period And Output Delay Is Reduced To Half A Period



EPWM Enhancements + High Res Compatibility

EPWM Enhancements:

- Swap A & B Outputs
- B Output = Inverted A Output



HRPWM Compatibility:

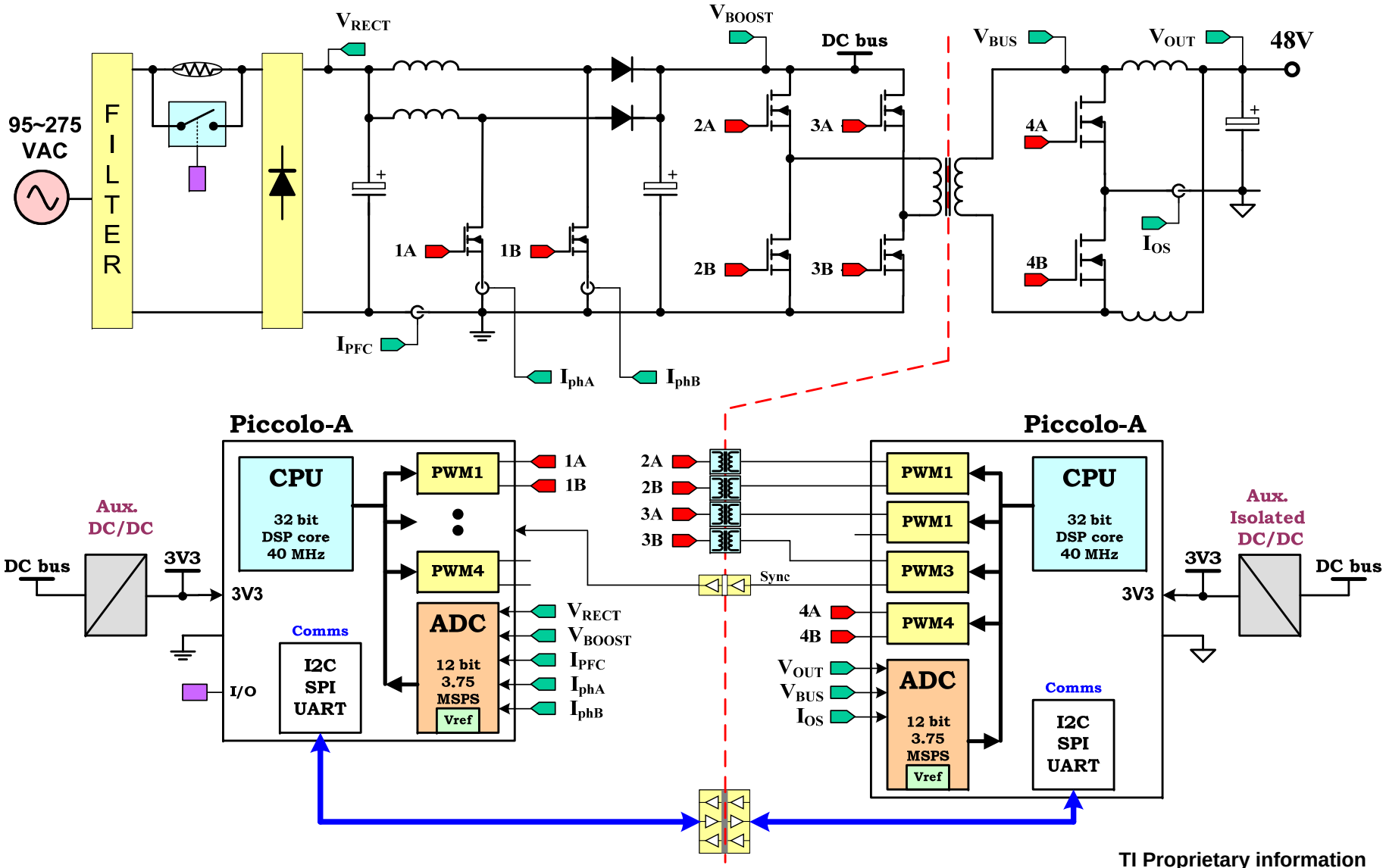
- Users Will Have To Update Micro-STEP Calibration Drivers For Piccolo
- All Other Code Remains The Same
- Some Small Differences In High-Res Exclusion Zone Timings:

Differences In High Res Exclusion Zone Timing		
Module & Mode	**Cycles From Start Of Period**	**Cycles From End Of Period**
EPWM Type 0 (used on all other devices)	3 or 6	1
EPWM Type 1 - Duty (PICCOLO)	3	0
EPWM Type 1 - Period (PICCOLO)	3	3

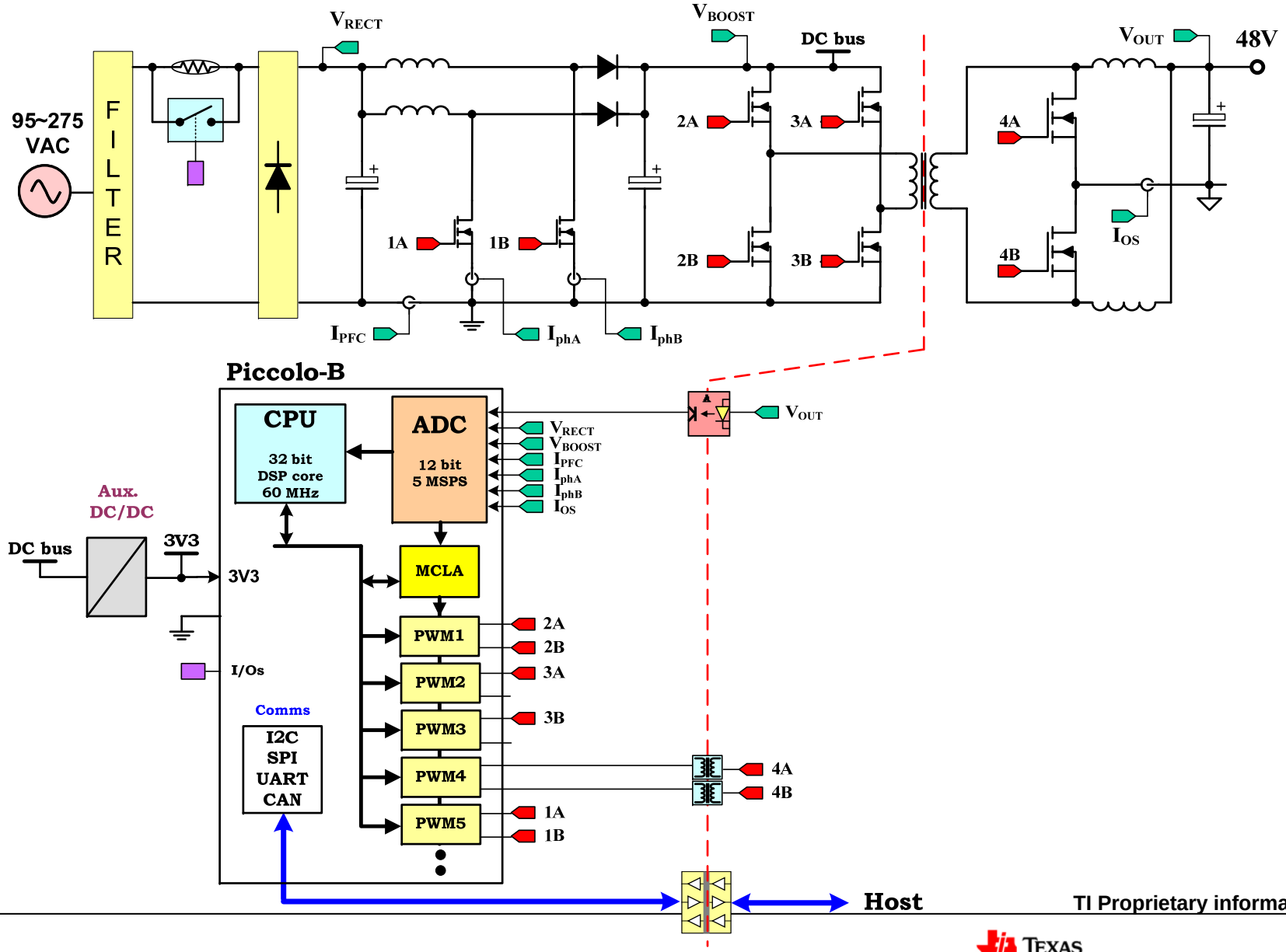
Key Goals of Piccolo Platform

- **Minimize external chip "life support"**
  - → Single 3.3V, On-chip - Osc, POR, BOR, & 1.8V vreg
- **Low pin count packages**
  - → 38, 48, 64, 80 and 100 pin
- **More Analog performance while reducing power**
  - → 5 MSPS ADC with 50% pwr reduction
- **More Analog integration**
  - → High-speed Comparators, 10 bit DACs, dual OSC
- **Algorithm Acceleration (with MCLA)**
  - → Companion 32 bit math engine
- **Reduce Sample to PWM update delay**
  - → MCLA direct connect to ADC, PWM, Memory,...etc
- **Reduce Sample jitter**
  - → New ADC sequencer with "On demand" conversion
- **Support for high frequency Resonant topologies**

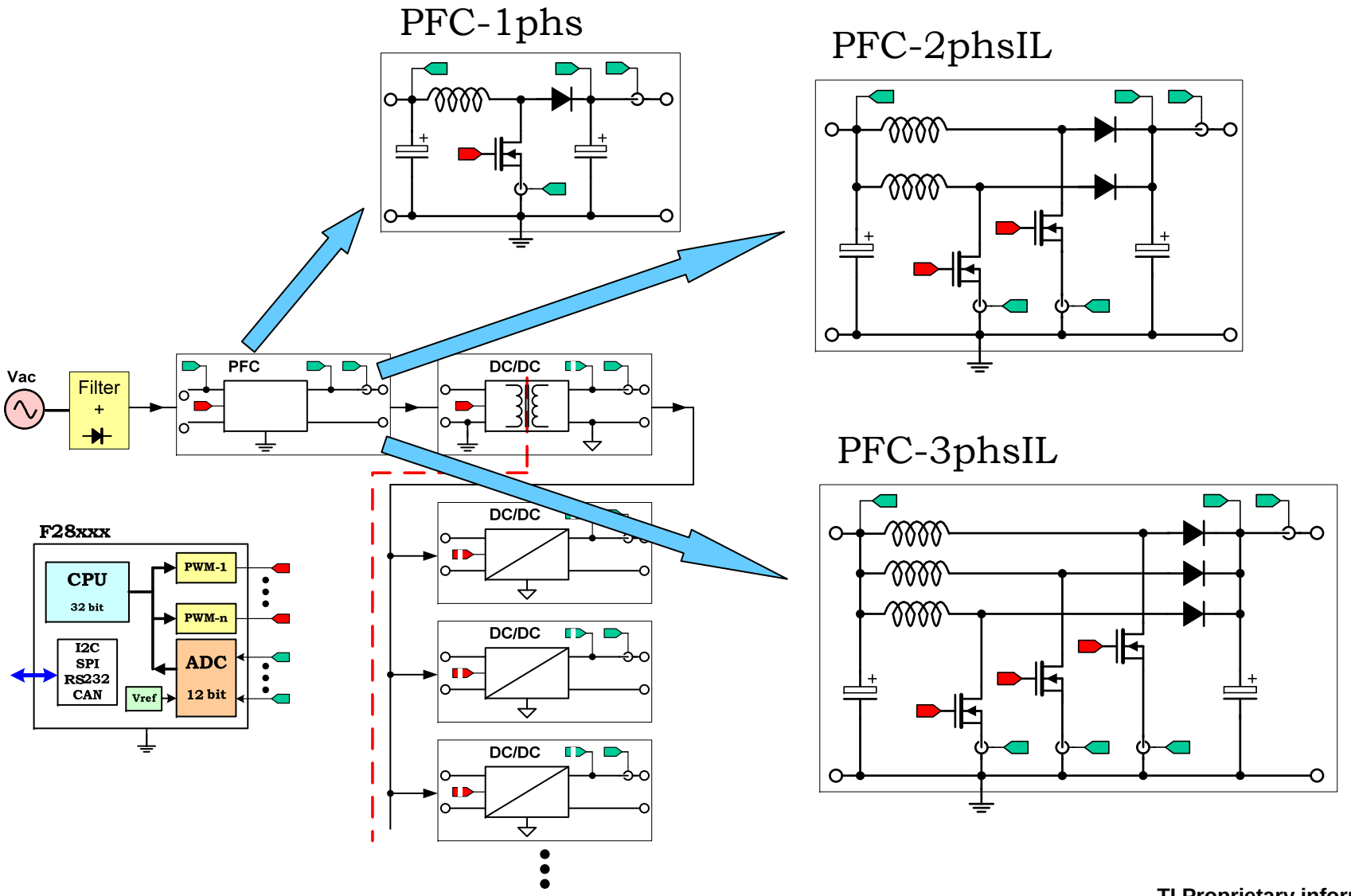
Digital Power Dual Controller Arch.



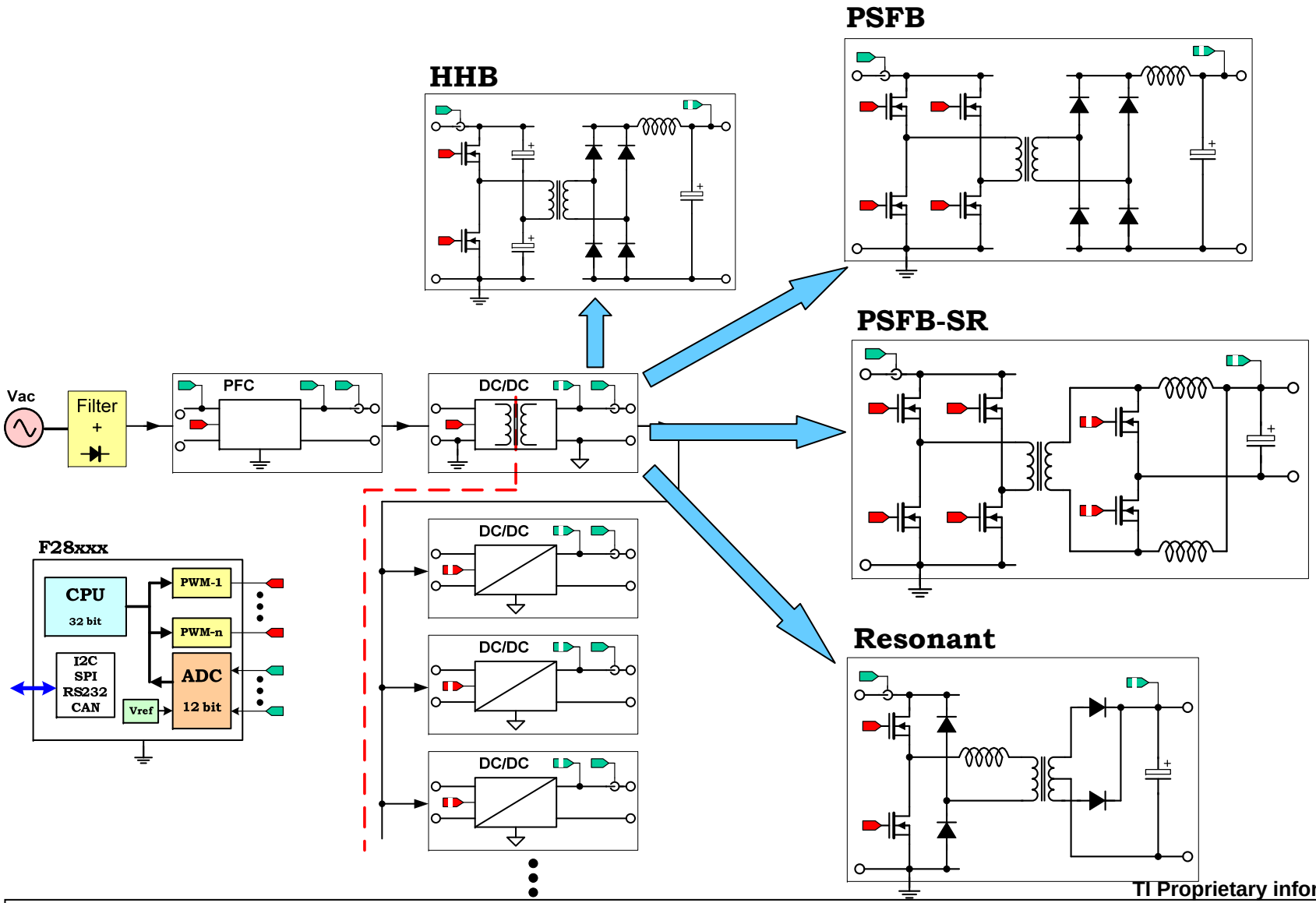
Digital Power Single Primary Controller Arch.



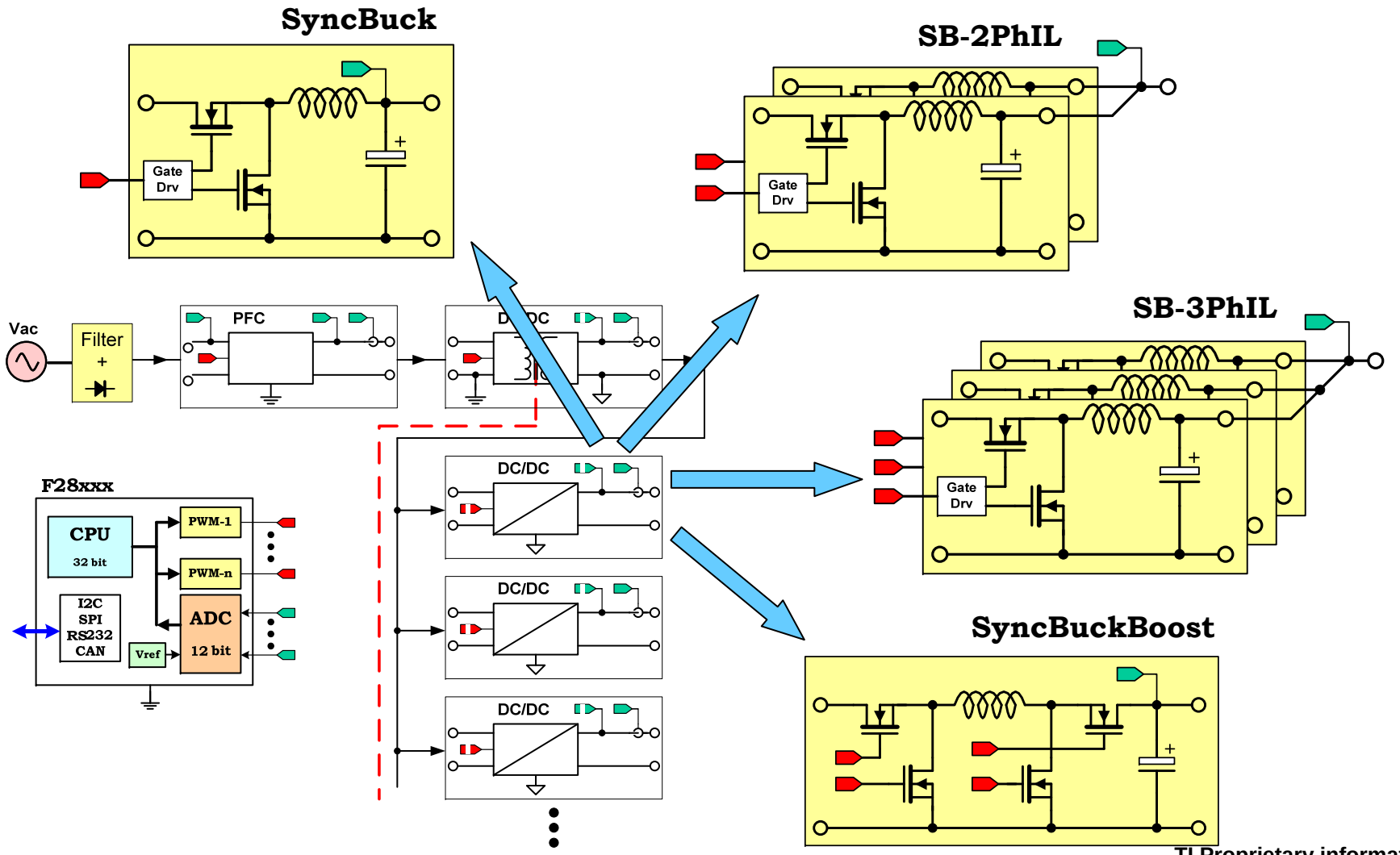
Power Stage Topology Support - PFC



Power Stage Topology – Iso. DC/DC

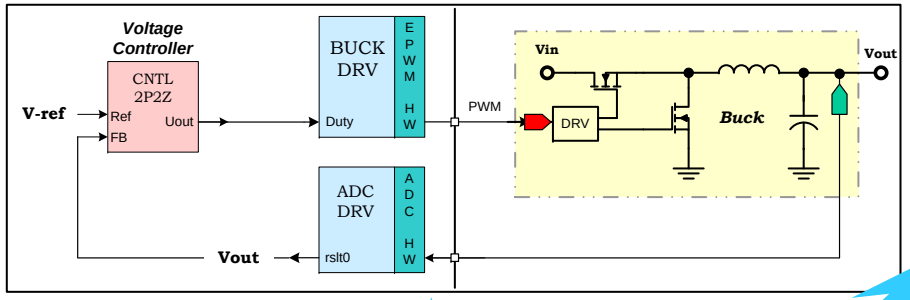


Power Stage Topology – NonIso DC/DC

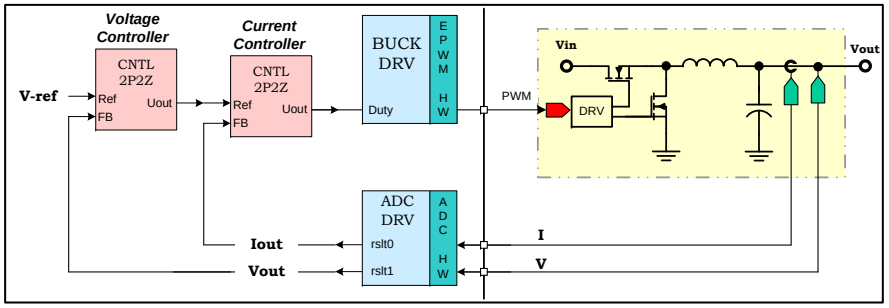


Power Stage – Loop Control

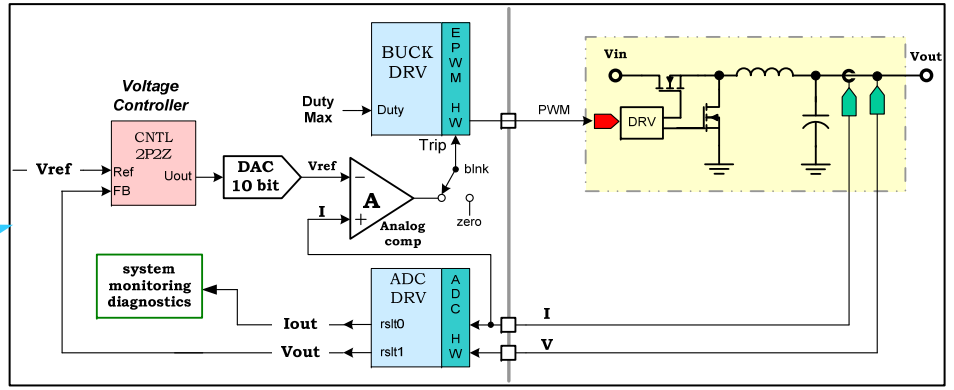
Voltage Mode

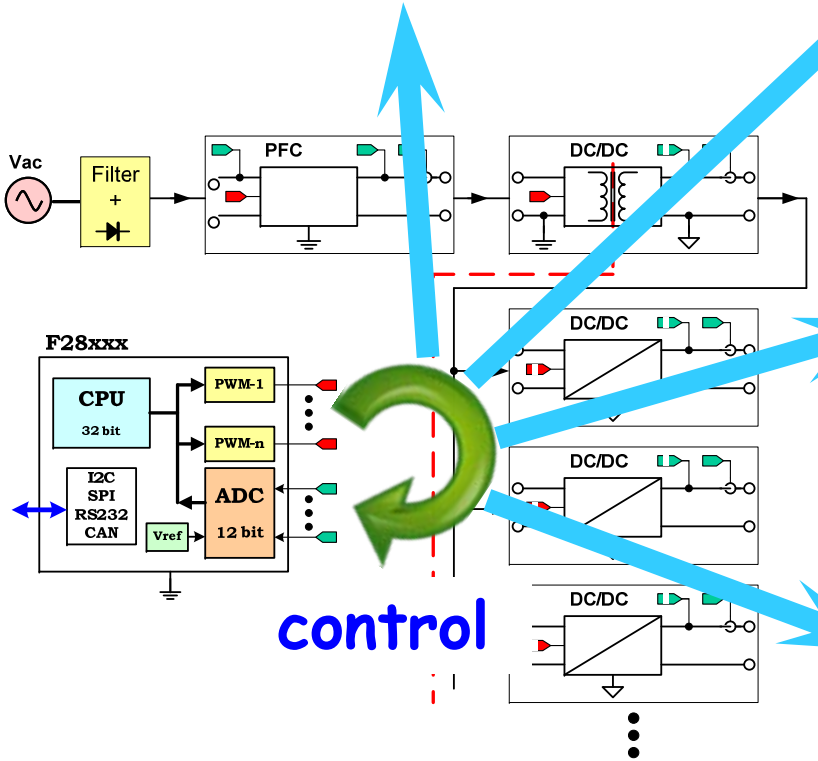


Avg Current Mode

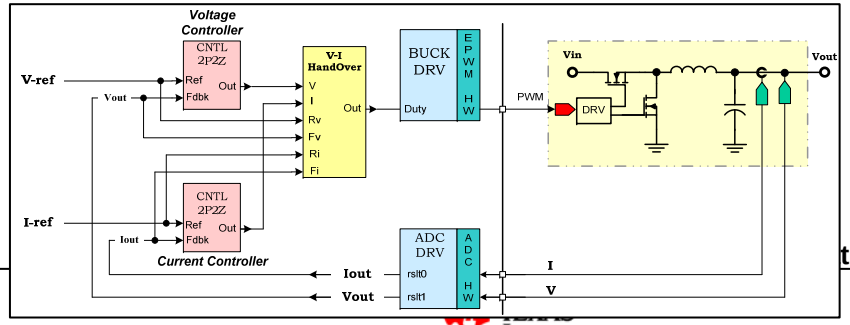


Peak Current Mode

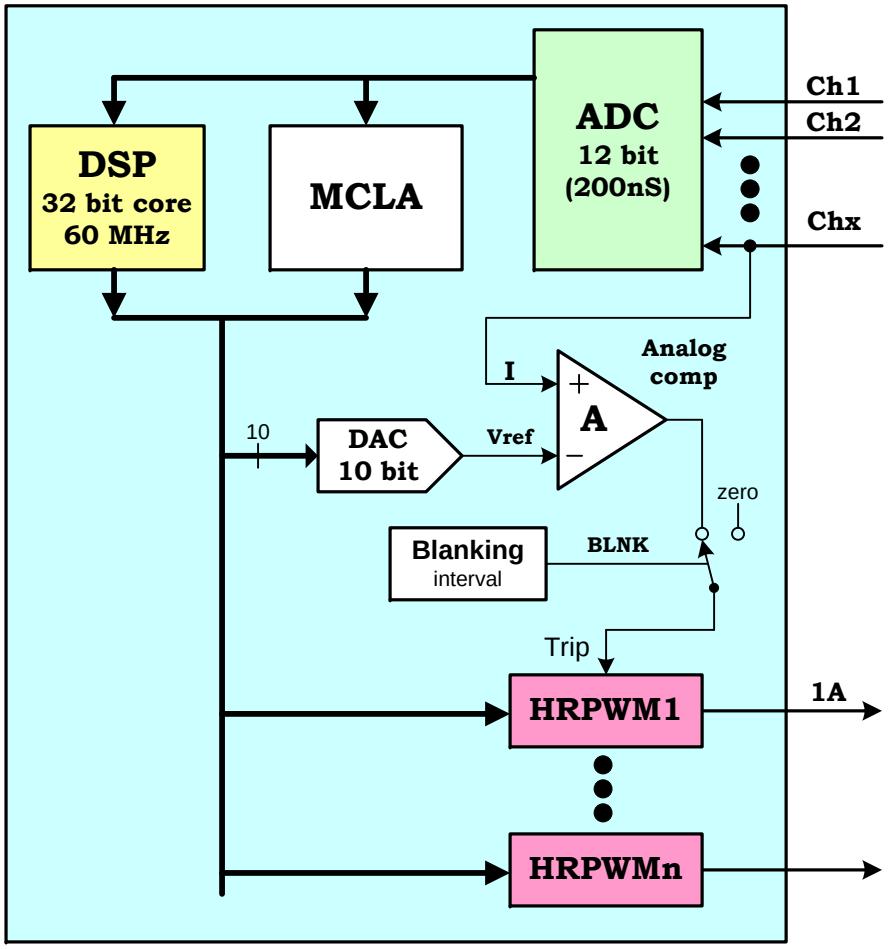


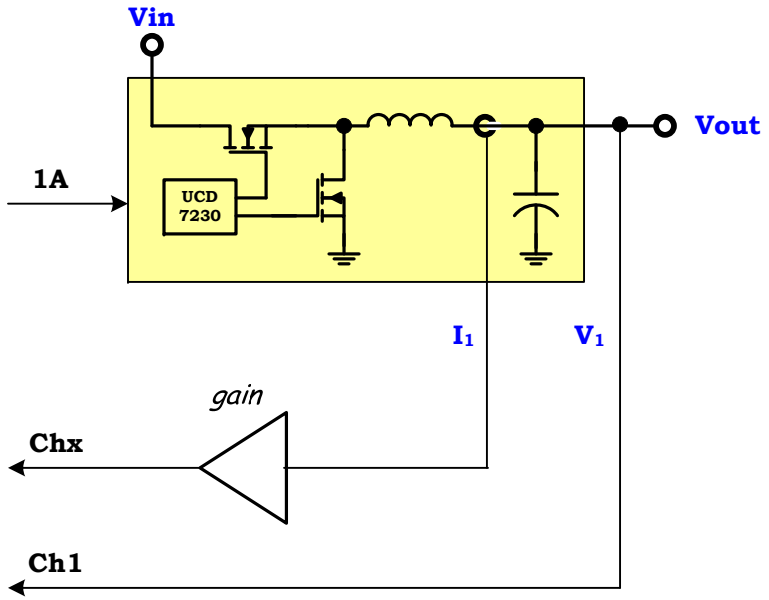


Constant Power

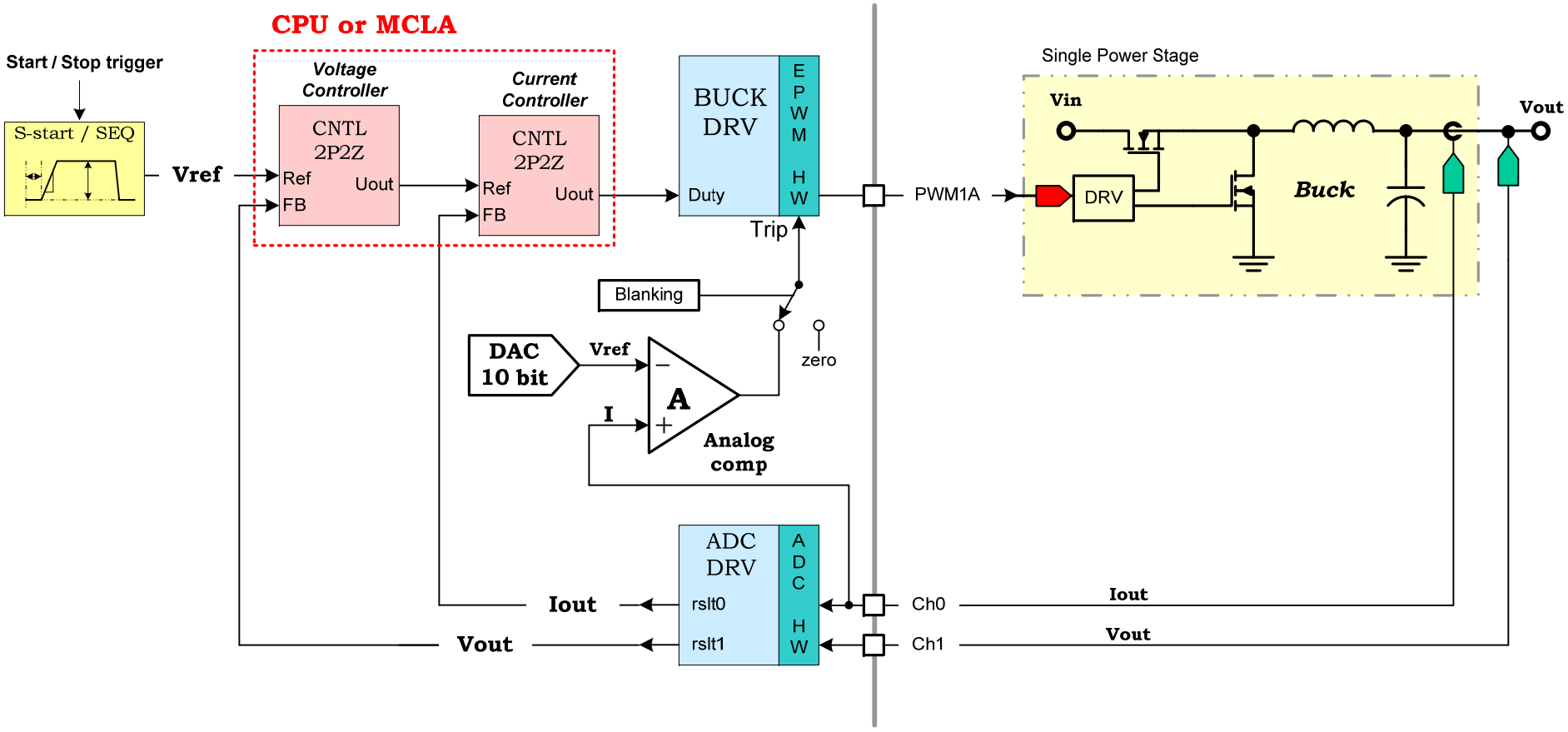


Piccolo – Peak or Avg Current Mode

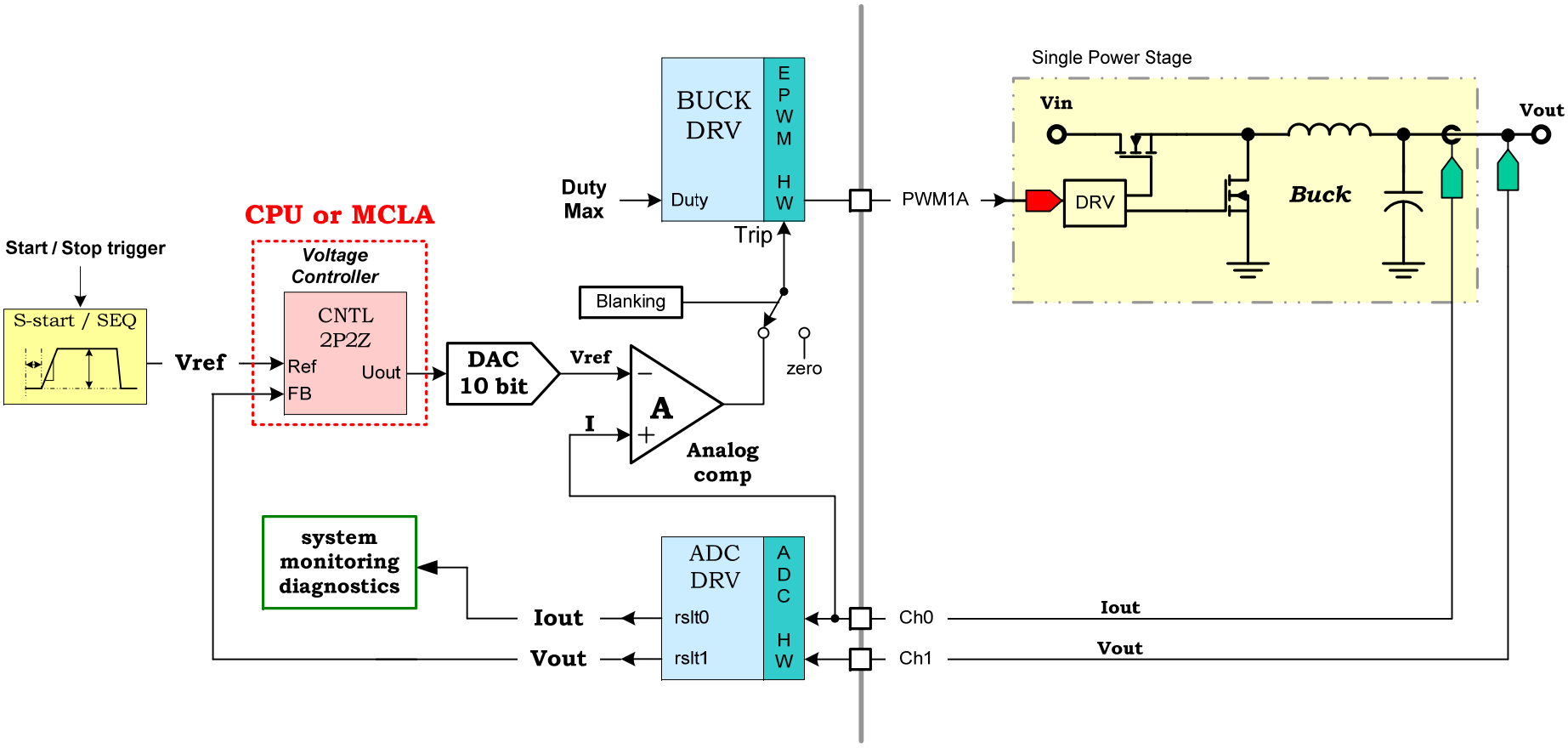




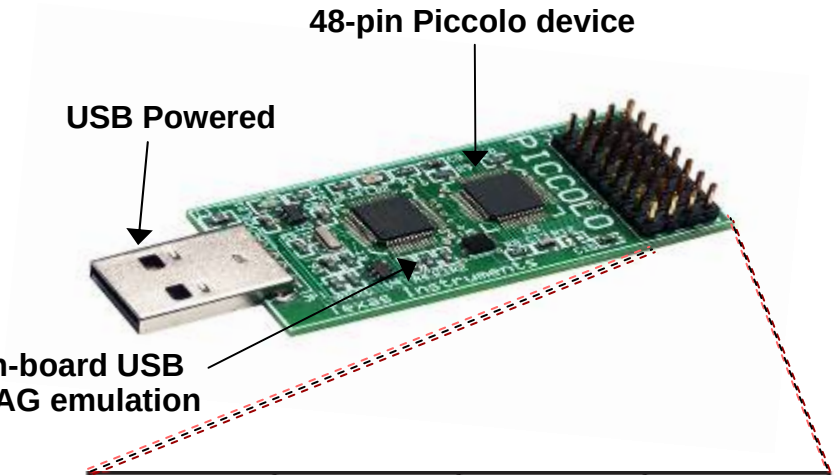
Piccolo – Avg Current Mode with Over-current trip



Piccolo – Peak Current Mode control (cycle-by-cycle)



$39 Piccolo MCU controlSTICK



1 ADC-A7	2 ADC-A2 COMP1 (+VE)	3 ADC-A0 Vref-HI	4 3V3
5 ADC-A4 COMP2 (+VE)	6 ADC-B1	7 EPWM-4B GPIO-07	8 TZ1 GPIO-12
9 SCL GPIO-33	10 ADC-B6	11 EPWM-4A GPIO-06	12 ADC-A1
13 SDA GPIO-32	14 ADC-B7	15 EPWM-3B GPIO-05	16 5V0
17 EPWM-1A GPIO-00	18 ADC-B4 COMP2 (-VE)	19 EPWM-3A GPIO-04	20 SPISOMI GPIO-17
21 EPWM 1B GPIO-01	22 ADC B3	23 EPWM 2B GPIO-03	24 SPISIMO GPIO-16
25 SPISTE GPIO-19	26 ADC-B2 COMP1 (-VE)	27 EPWM-2A GPIO-02	28 GND
29 SPICLK GPIO-18	30 GPIO-34 (LED)	31 PWM1A-DAC (Filtered)	32 GND

Access to all Piccolo control peripherals through header pins

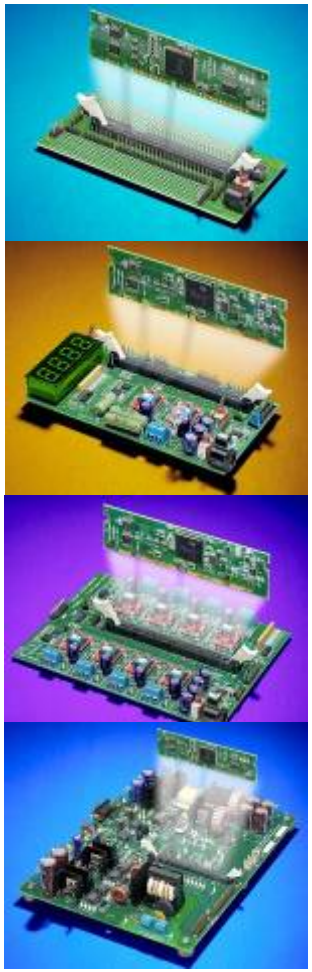
Allows designers to evaluate Piccolo MCUs quickly, easily and for only $39

Kit Includes:

- Piccolo™ controlSTICK USB evaluation tool
- USB extension cable
- Jumpers and patch cords necessary for example projects
- Full version of Code Composer Studio with 32kB code size limit
- Example projects showcasing Piccolo MCU features
- Full hardware documentation, including bill of materials, schematics and Gerber files

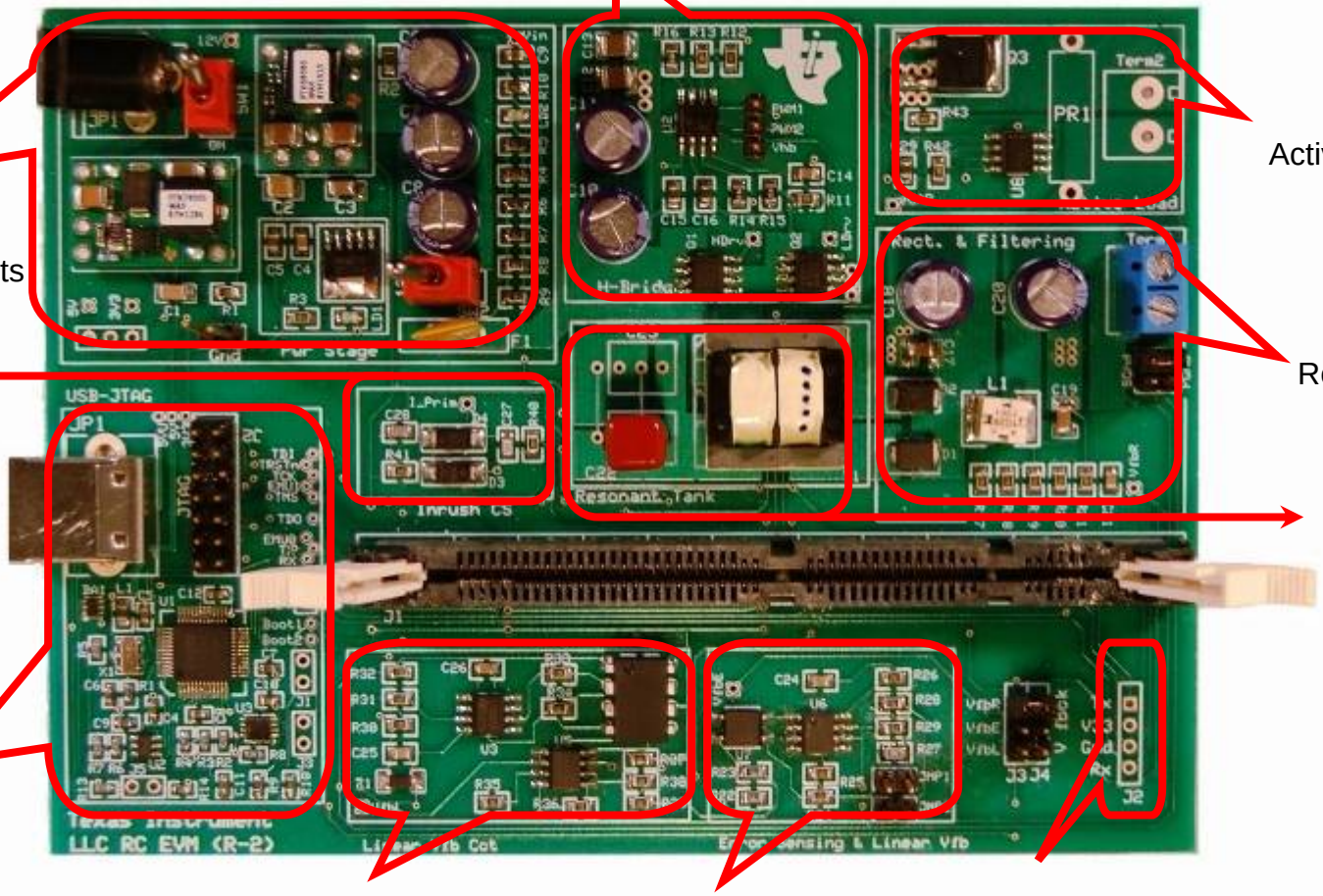
New Kits Jump-start 32-bit Based Designs

Kits include free applications software with code examples and full hardware details

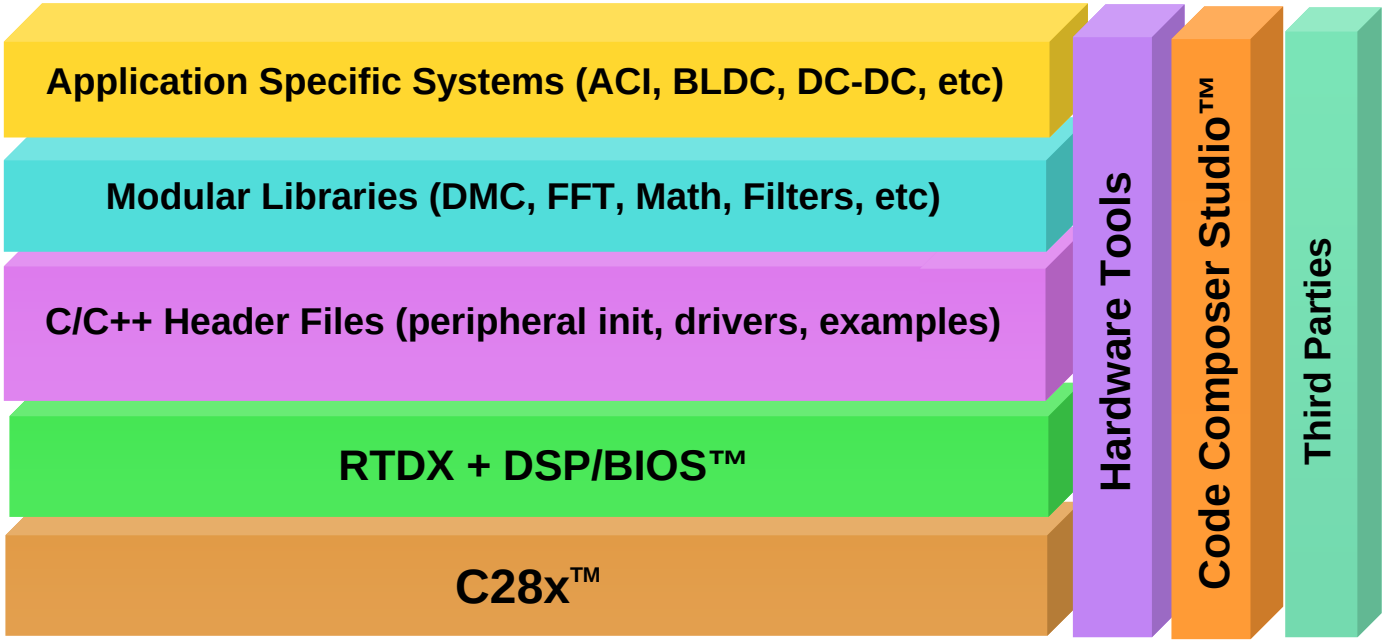


- **controlCARDS (From $59)**
  - Low cost single-board controllers
  - Perfect for initial development and small volume system builds
  - F28x analog I/O, digital I/O, and JTAG signals available at DIMM interface
- **C2000 Experimenter's kits ($89)**
  - Includes controlCARD
  - Access to controlCARD signals, breadboard areas, RS-232 an JTAG connectors
- **Digital power experimenter's kit ($229)**
  - 2-rail DC/DC EVM using TI PowerTrain™ modules (10A), F2808 controlCARD
  - On-board digital multi-meter and active load for transient response tuning
- **DC/DC Developer's kit ($325)**
  - 8-rail DC/DC EVM using TI PowerTrain™ modules (10A)
  - Applications software with example code and full hardware details
- **AC/DC Developer's kit ($695)**
  - AC/DC EVM with interleaved PFC and phase-shifted full-bridge
  - Primary side control, synchronous rectification, peak current mode control, Two-phase PFC with current balancing

LLC Resonant Converter



Modular Software Development for Control Systems



- Reduces time to market
- Provides reusable software

Gets you there quickly

http://www.ti.com/c2000getstarted

DPS Software Library & Header Files

Today's DPSLib components:

ePWM Demonstration	SPRC228
HRPWM Demonstration	SPRC227
DC/DC Buck Converter	SPRC229
DC/AC Single Phase Inverter	SPRC303
Two-phase PFC	SPRC307
DC/DC Phase-shifted Full-Bridge	SPRC311

Visit www.ti.com/dpslib for above library s/w and link to the h/w platforms

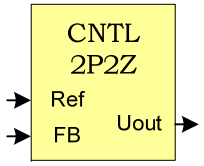
C2000 header files Simplify peripheral init. and other functions, takes care of register defs

- **Header file package consists of:**
  - **\DSP280x_headers\include → .h files**
  - **\DSP280x_common\src → .c source files**
  - **\DSP280x_headers\cmd → linker command files**
  - **\DSP280x_headers\gel → .gel files for CCS**
  - **\DSP280x_examples → example programs**
  - **\doc → documentation**
  - **Visit www.ti.com/c2000getstarted**

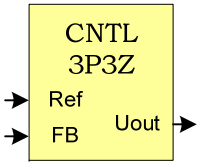
Free On-line Training

- **Using Multi-Phase DC/DC Power Supply Control**
  http://training.ti.com/courses/CourseDescription.asp?iCSID=53935
- **Enabling High-Freq Power Conversion Applications**
  http://training.ti.com/courses/CourseDescription.asp?iCSID=54032
- **Implementing High-BW, Low-Cycle Count Controllers**
  http://training.ti.com/courses/CourseDescription.asp?iCSID=54259

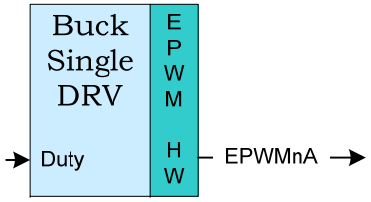
Software Library Approach



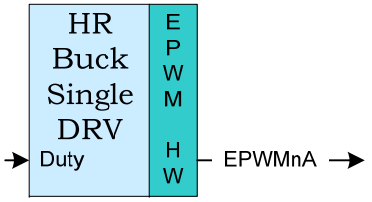
Control 2-pole / 2-zero



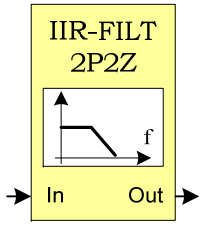
Control 3-pole / 3-zero



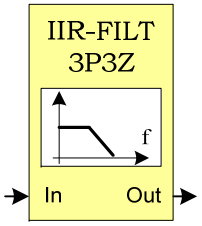
Buck Single Output



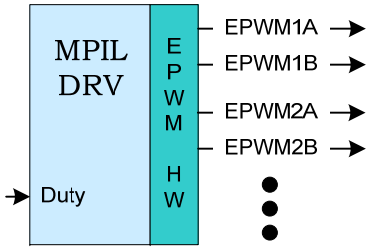
High Resolution Buck



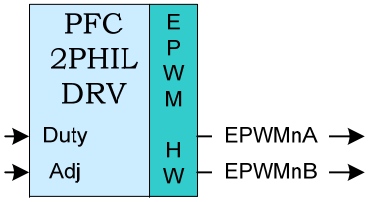
2nd order IIR filter



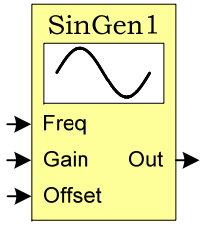
3rd order IIR filter



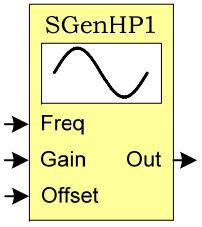
Multi-Phase Interleaved



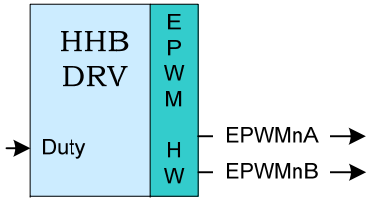
Power Factor 2-phase
Interleaved



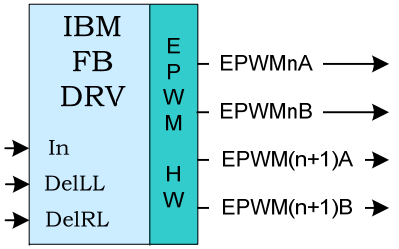
Sine Wave generator



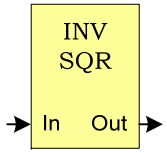
High precision Sine Gen



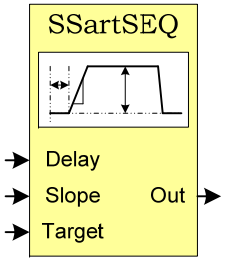
Half H-Bridge



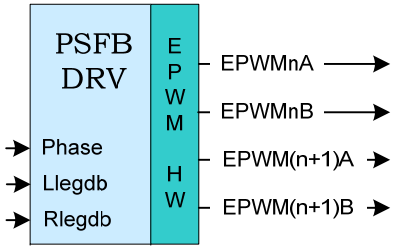
IBM method Full Bridge



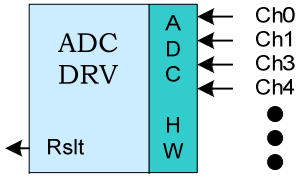
Inverse Square function



Soft Start and Sequencing

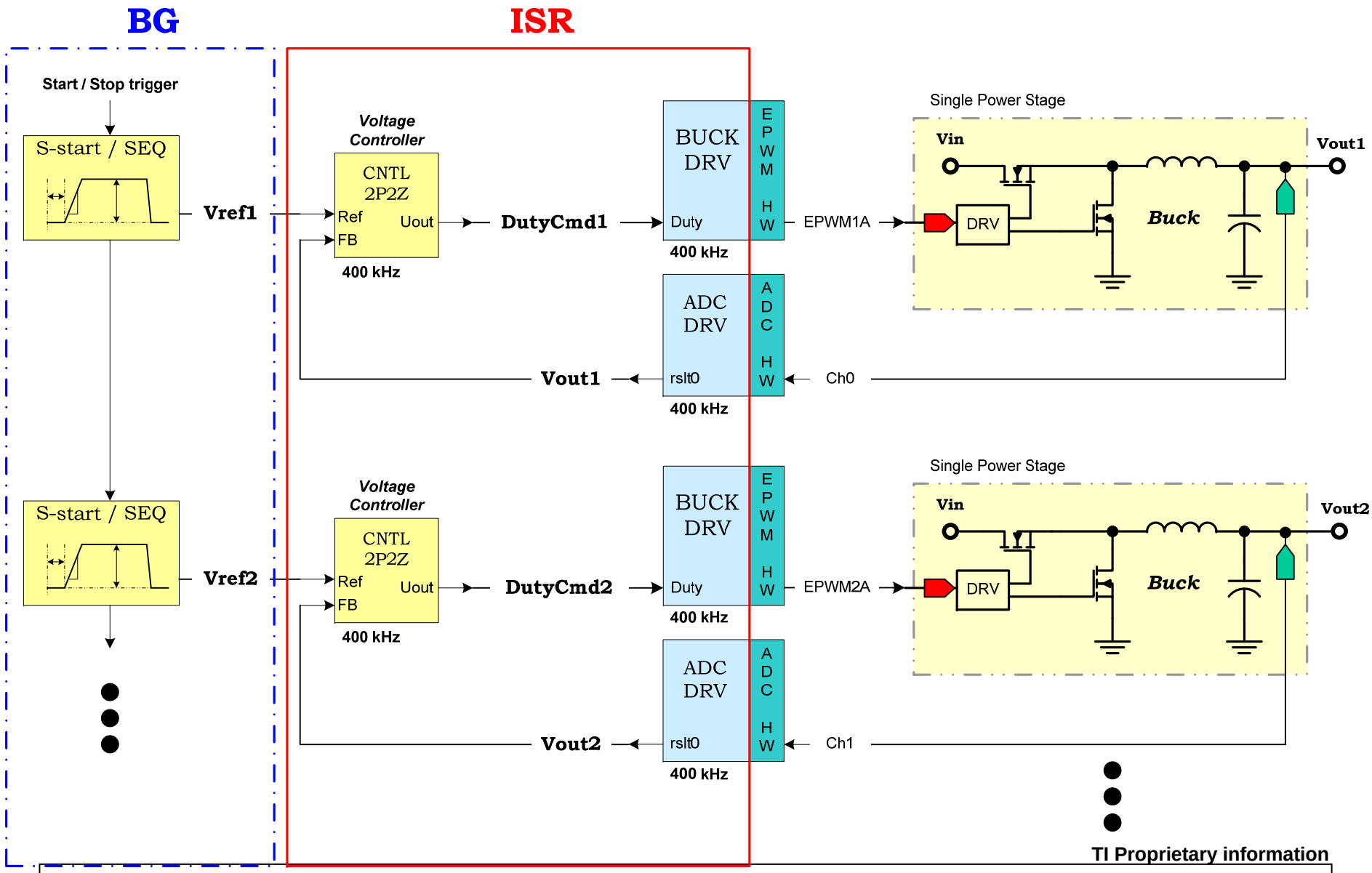


Phase Shifted Full Bridge

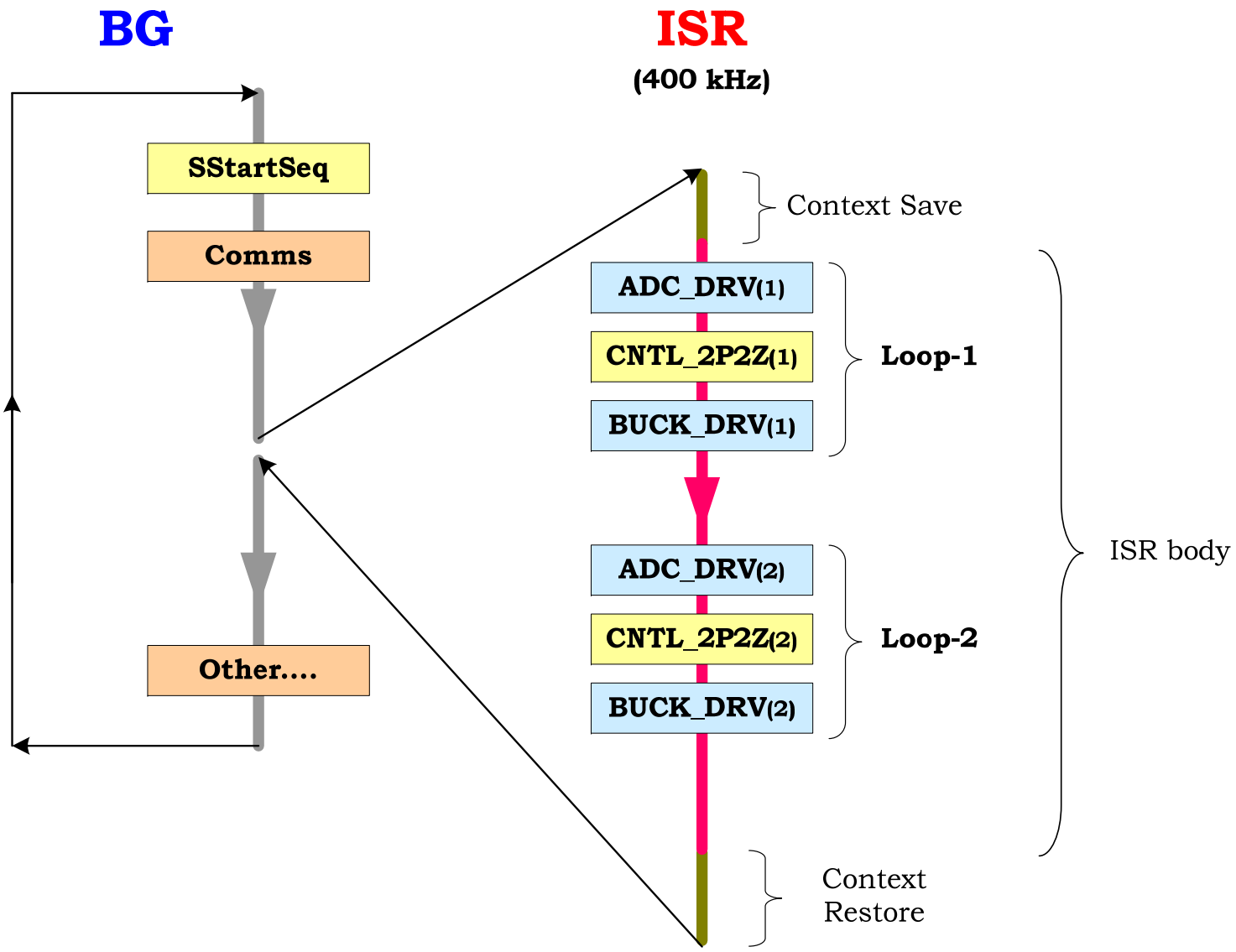


Analog-Digital Converter driver

Dual Buck Example



Software Block Execution



Code Composer Studio Components:

Fully Integrated, Easy to Use, Supporting R/T Debugging

Flash Memory Plug-In
- **Easy Set-Up and Programming**

Menus or Icons

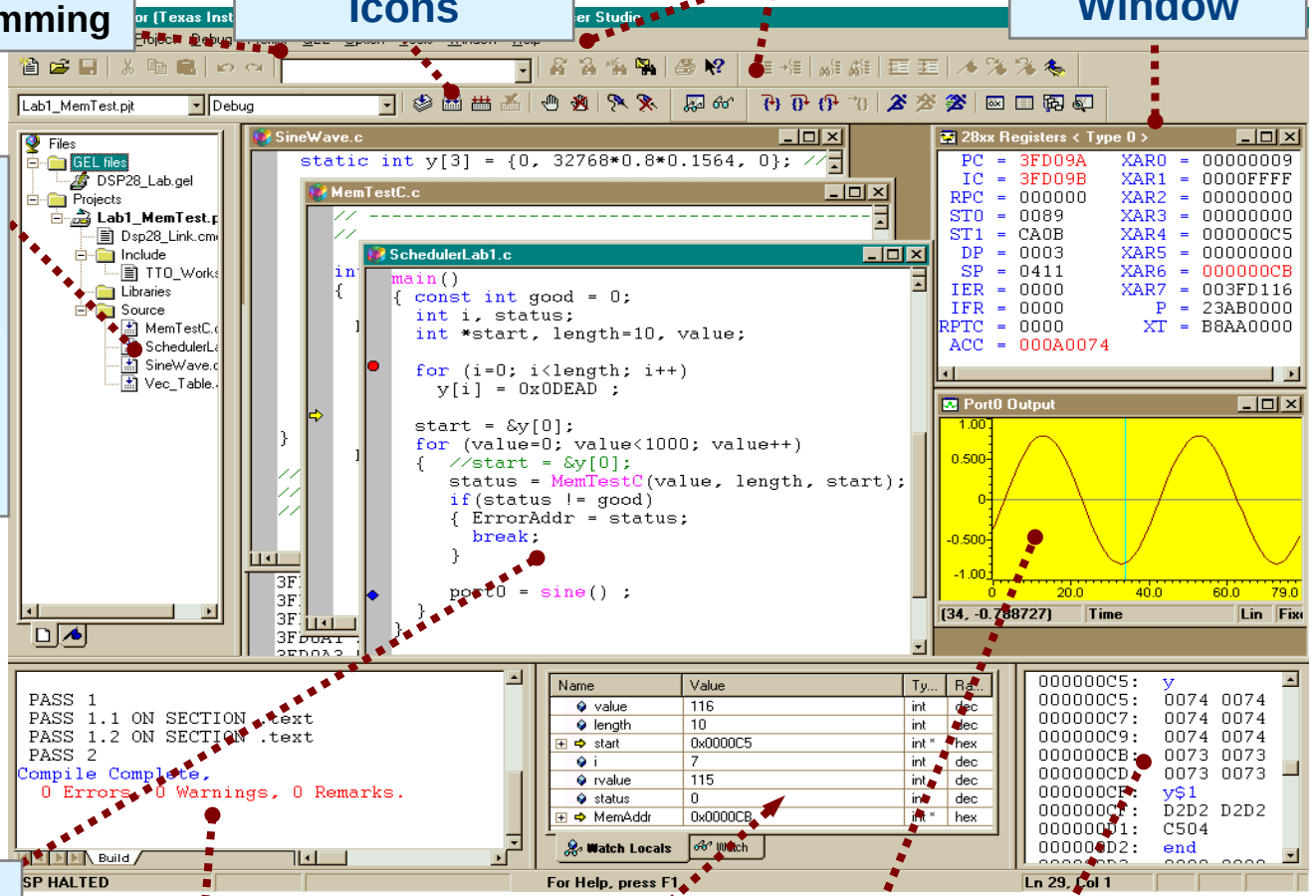
Help

CPU Window

Project Manager
- **Source & object files**
- **File dependencies**
- **Compiler, assembler & linker build options**

Included with eZdsps
$495 for full license

Productive Editor:
- **Structure expansion**



Status Window

Watch Window

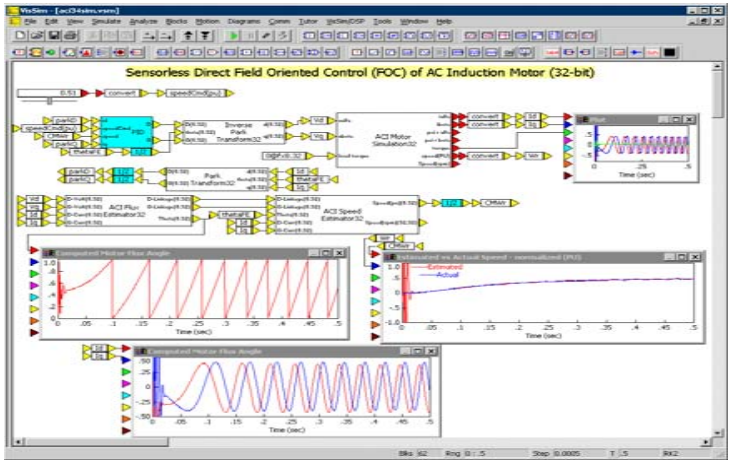
Graph Window

Memory Window

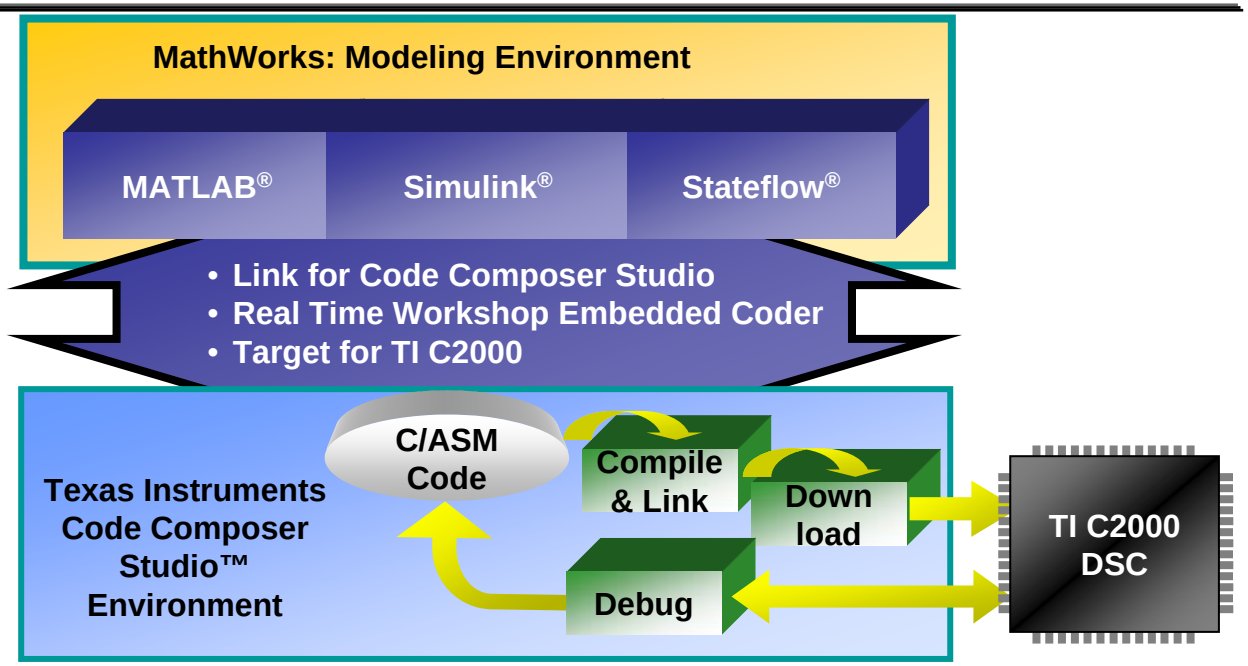
C2000 Modeling & Code Generation

VisSim/Embedded Controls Developer:
Model Based Development for TI C2000

www.vissim.com



The Mathworks Support for C2000



Why C2000 for Digital Power Supply

- ✓ Single or dual chip solution meets static/dynamic performance specs
  - Highest (32bit) CPU performance
  - Fastest ADC, Highest PWM Duty and Frequency Resolution
- ✓ Reduced parts count and system cost
  - Highest integation vs cost
- ✓ Increase efficiency (especially at load condition) and power density
  - 100% s/w approach making load adaptation easy
- ✓ Increased functionality and intelligence
  - Intelligent fault management, monitoring and reporting
  - Power stage sequencing
  - Active in-rush control, ORing MOSFET control.
  - Advanced control (non-linear, multi-variable), multiple control loops.
  - Centralized supervisory / system management.
  - Under-voltage lockout, over-voltage & over-current protection.
  - Constant volt, constant current, constant power operation
  - Programmable PFC boost voltage (efficient operation)
  - Programmable output voltage (margining) and current limit
- ✓ Reliability of digital design and no drift
- ✓ Faster time to market because of s/w flexibility and reduced manufacturing and R&D cost
- ✓ Large and scalable product portfolio that is 100% s/w compatible, perfect for platform choice

Benefits of C2000™ Controllers Over Competition

- Highest Performance: 32-bit Controllers (40 MIPS-300MIPS)
- CLA for Tight Control Loop and Increased Processing Power or Reduced Power Consumption
- 9 32-bit Timers (more than competition)
- Larger amount of Flash & RAM memory (One Time Programming Flash Available)
- Lowest Cost/Performance Starting at sub $2.0 1Ku. On-Chip Integration of Vreg, BOR/POR, Analog Comparators, and Dual Oscillators
- 150ps PWM resolution (up to 16ch)
- Fastest 12-bit ADC starting from 3.75 MSPS (up to 12.5 MSPS)
- Devices available with CAN & SPI
- External Interrupt Capability and fast interrupt response overall
- Plenty of I/O pins
- Large family of compatible devices for performance scalability
- Advanced code development and debug tools, rich library, large third party network

Thank You!

www.ti.com.cn/processors