C2000 for Digital Power Solutions and Digital Controlled LED Lighting System

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- What is Digital Power
- Value of Digital Power
- Digital Controller Key Considerations
- What is Digital Controlled LED Lighting System
- LED Lighting and Communications
- Why C2000 for Digital Power
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- LED Control Techniques
- Software Examples and Digital Power Libraries
- LV Development Kits and Solutions
- HV Power Supply Kits
- LED Lighting Kits
- Development Support

C2000 Applications & Digital Power / LED Lighting Market

Digital Power Is a Technology Applicable to Many Markets

Renewable Energy

Solar Power Inverters

Wind Power Inverters

Digital Motor Control

Variable-Frequency Air-Conditioner

Industrial Drives & Motion Control

White Goods

Power Supply

Telecom / Server AC/DC Rectifiers

DC/DC Converters

Lighting

LED Street Lighting

Auto HID

LED TV Backlighting

Hybrid Electric Vehicles

DC/DC Converters

AC/DC Chargers

Automotive

DC/DC Converters

Uninterruptable Power Supplies

DC/AC Inverters

Battery Charger / Boost

UPS and Inverter

Digital power impacts broad applications

Servers/ telecom rectifiers

Hybrid electric vehicles

Street/building lighting

Power grid management

Solar energy products

Wind energy products

Challenges

What developers need

Challenges	What developers need
Programming	Easy-to-use modular software
Digital design learning curve	Training for all experience levels
Redesigning for varying power supply models	Scalable, programmable MCU platform
Efficiently managing multiple load points	Performance
Minimizing component count	Integrated hardware

Texas Instruments

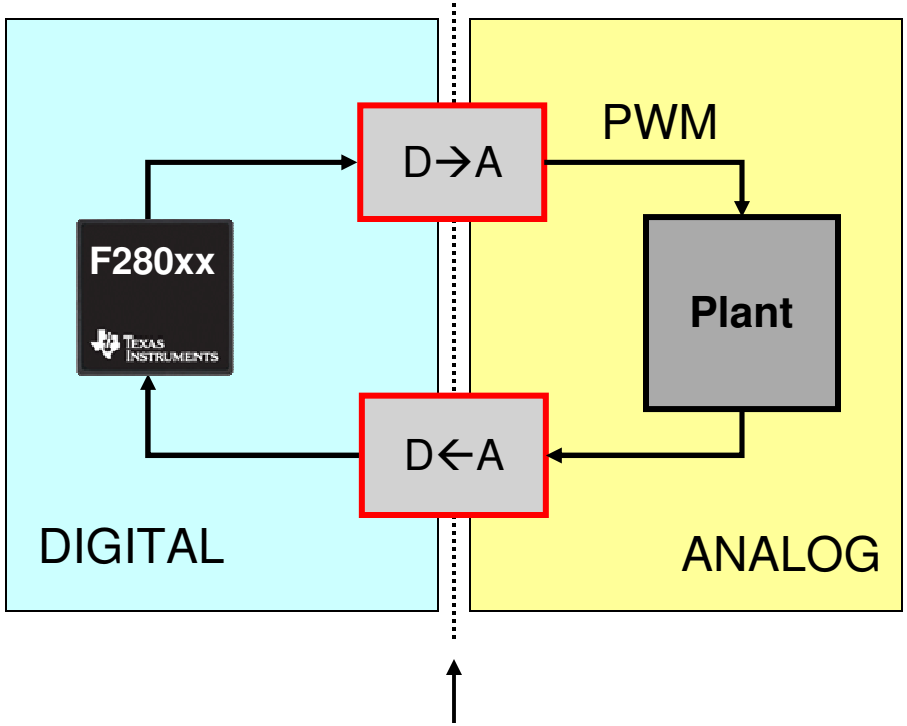
What is Digital Power

What is Digital Power?

Simply put, using a real time MCU to control the output of a power supply.

WHY?

- **FLEXIBILITY!!!**
- **EFFICIENCY!!!**
- Power Factor Correction
- Phase Tuning
- Power Supply Margining
- DC/DC Converter Control
- Multi-Mode Power Control
- Housekeeping Functions
- POR/BOR
- Inrush / Hot-Plug Control
- Failure Prediction
- Communication with Host

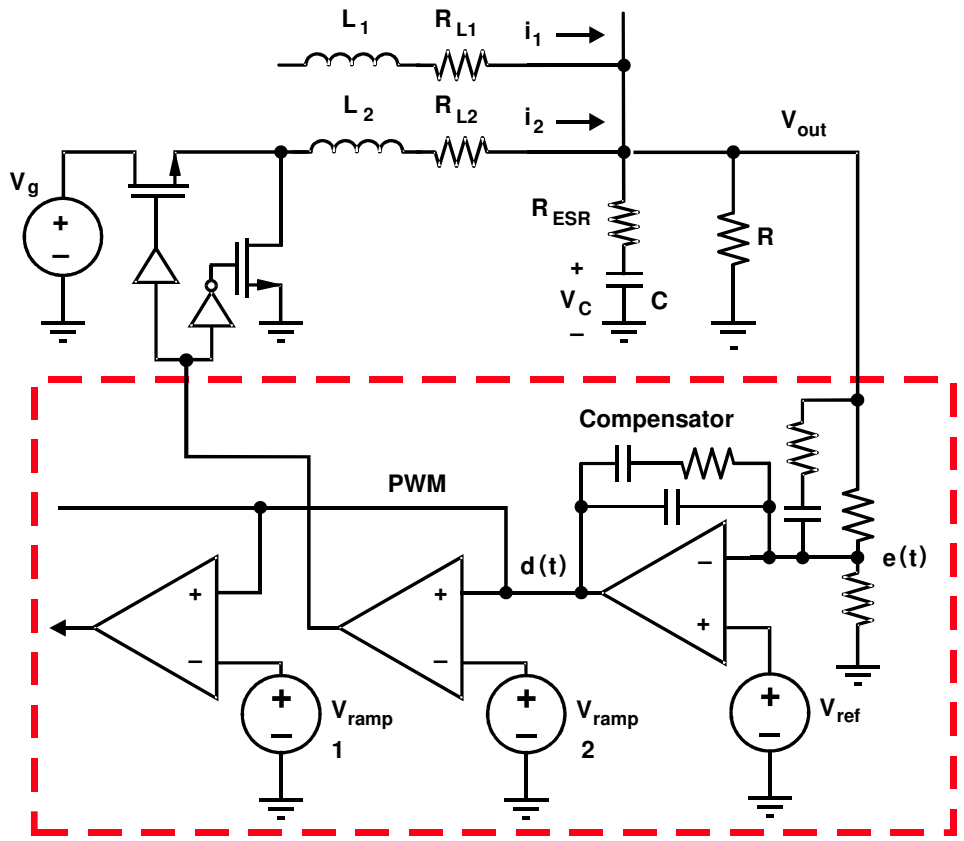


This can also represent an Isolation Barrier!

WHERE?

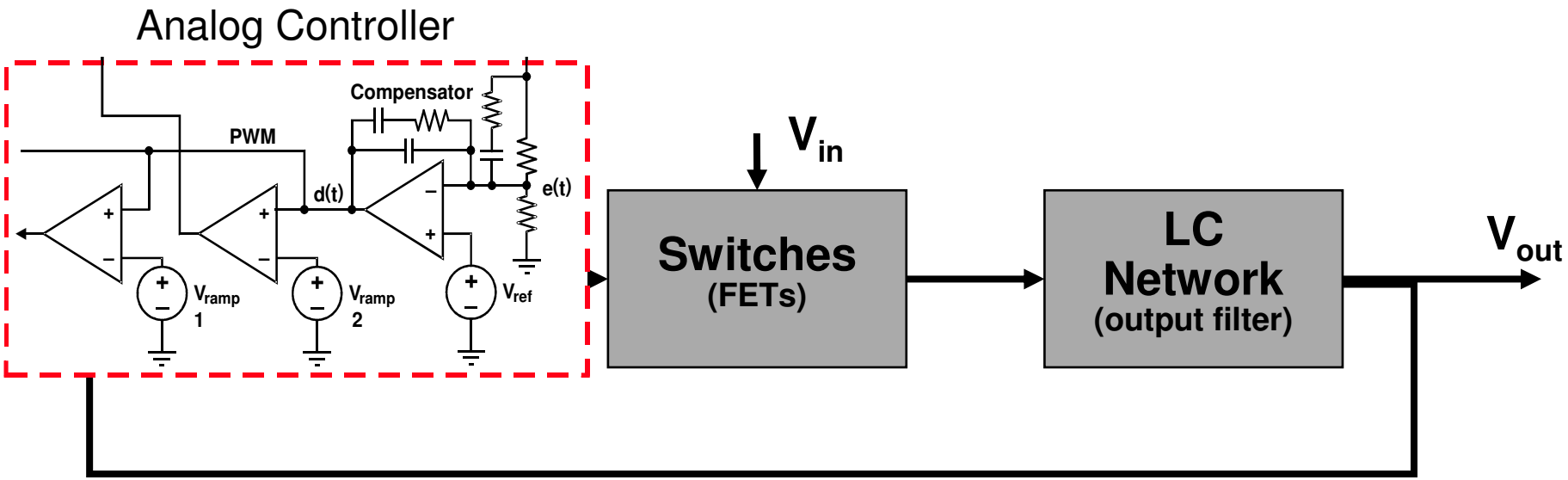
- Rectifiers (AC/DC)
  - White Goods
  - Server / Telecom
  - "Silver Box" PS
- DC/DC Modules / POL
  - Buck/Boost
  - Half Bridge
  - Full Bridge
  - Multiphase
- Switch Mode PS
- Inverters(DC/AC)
  - Solar & Hydro
  - Generators
  - SINE Output Inverters

An Example Switch-Mode Power Converter



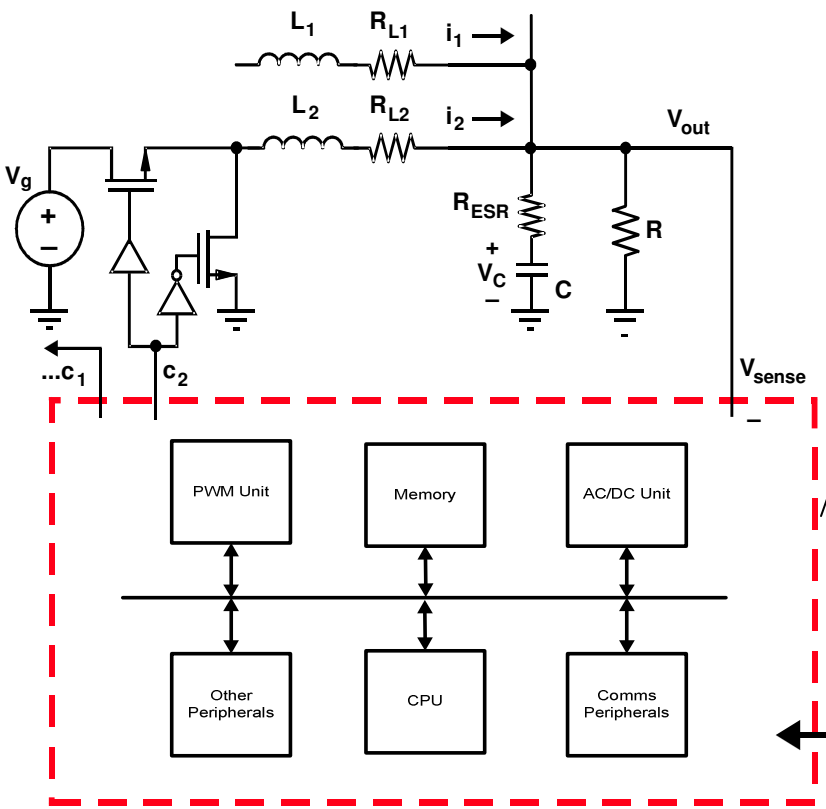
- It's a discrete control system
- It uses analog compensator/controller
- The controller is both a PWM generator and compensator/controller

The Block Diagram of the Example Switch-Mode Power Converter

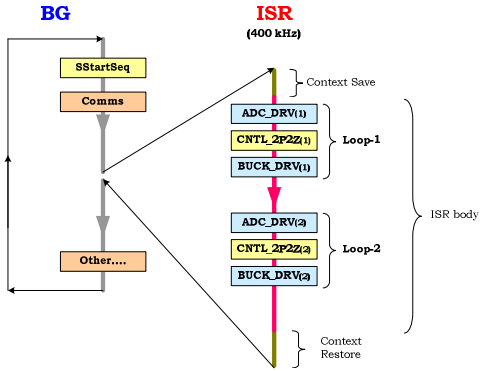


Goal: maintain constant Vout regardless of change in Vin or load, within spec.

Example Digitally Controlled Switch-Mode Power Converter



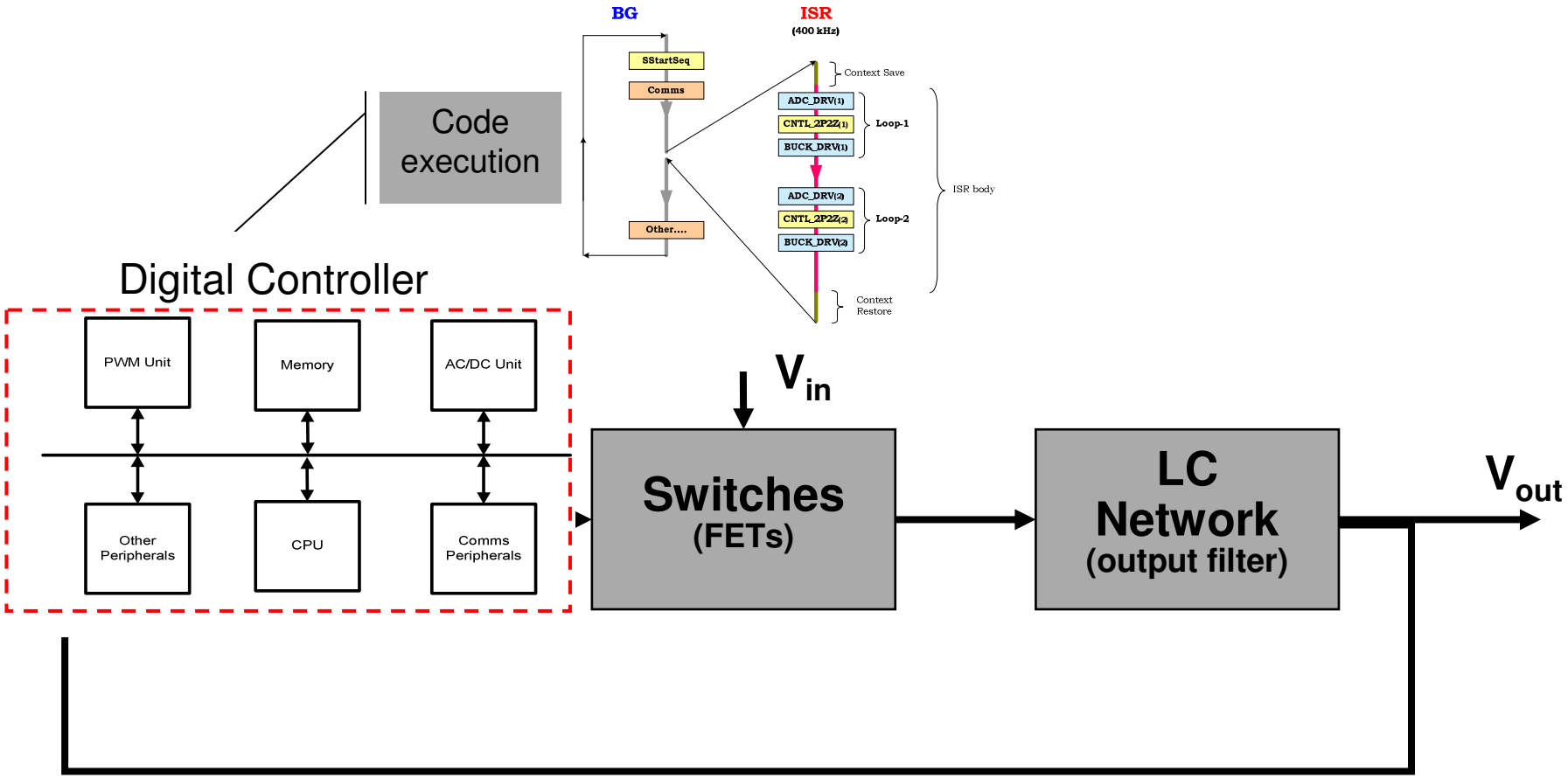
Code execution



Set/Measure, report
Voltage, Temperature, Current, faults…

Controller is replaced with a digital controller/MCU (and drivers and OpAmps)

Block Diagram of Digitally Controlled Power Converter



Goal: maintain constant Vout regardless of change in Vin or load, within spec.

- **The controller block is what differentiates between a digital power system and a conventional analog power system**

Value of Digital Power

Value of Digital Power

Increased Peak & Light Load Efficiency

- PFC Stage
  - Support for Interleaved Topologies
  - Active Phase Management (Shedding phases for light load efficiency improvement)
  - Dynamic Boost Voltage Adjustment
  - Dynamic Switching Frequency Adjustment
  - Support for New Advanced High Efficient PFC Topologies
    - (ZVS/ZCS) Bridgeless PFC
- DC/DC Stage
  - Adaptive Deadband Adjustment & Dynamic Switching Frequency Adjustment
  - Ideal Diode Emulation
  - Dynamic SyncFET Control (Soft On/Off Control)
  - Burst Mode Support
  - Support for New Advanced High Efficiency Topologies
    - Resonant LLC with Direct SyncFET Control
    - Dual Bridge DC/DC

Value of Digital Power - Continued

Integration, Reduced System Cost with Improved Reliability & Increased Power Density

- PFC Stage
  - Support for Interleaved and Bridgeless Topologies
  - Integrated Input Power Measurement
  - Integrated Protection (Analog and Digital Comparators)
  - Integrated AC Drop Detection & Recovery
  - Integrated Monitoring w/ Fault Prediction Capabilities to Improved Reliability
  - Primary to Secondary Communication & Frequency Synchronization
- DC/DC Stage
  - Integrated Protection (Analog and Digital Comparators)
  - Integrated Current Sharing / Support for Redundant Systems
  - Constant Current and Power Support
  - Direct SR Control Including Pre-Bias Startup Support
  - Integrated Monitoring and Communication Capabilities w/ Fault Prediction Capabilities
  - Integrated Copper Trace Current Sensing with Calibration Support
  - Non-Linear Control For Improved Transient Response

Value of Digital Power - Continued

Support for Accurate Measurement, Reporting, Data Logging & Calibration:

- Direct & Indirect Techniques for Input Power & I_RMS Current Measurement & Reporting
- Integrated Memory for Data Logging (Data-flash, FRAM, etc…)
- Support for Direct Temperature Monitoring & Calibration
- etc…

Increased Flexibility & Configurability:

- Reduced Time to Market; Feature-Set Adjustments with Simple Firmware Updates vs. Complete Hardware Redesigns…
- Increased Configurability with Possible GUI Support
- Controller Standardization; Will simplify control design over time as engineering teams become comfortable with a standard controller with Flexibility to Support a Wide Set of Topologies

Value of Digital Power - Continued

Other Performance Enhancements:

- Improved Power Factor / THD Across the Load Range: High Performance ADC with up to 8x Oversampling Capabilities

- Improved Transient Response with Non-Linear Control Capabilities across range

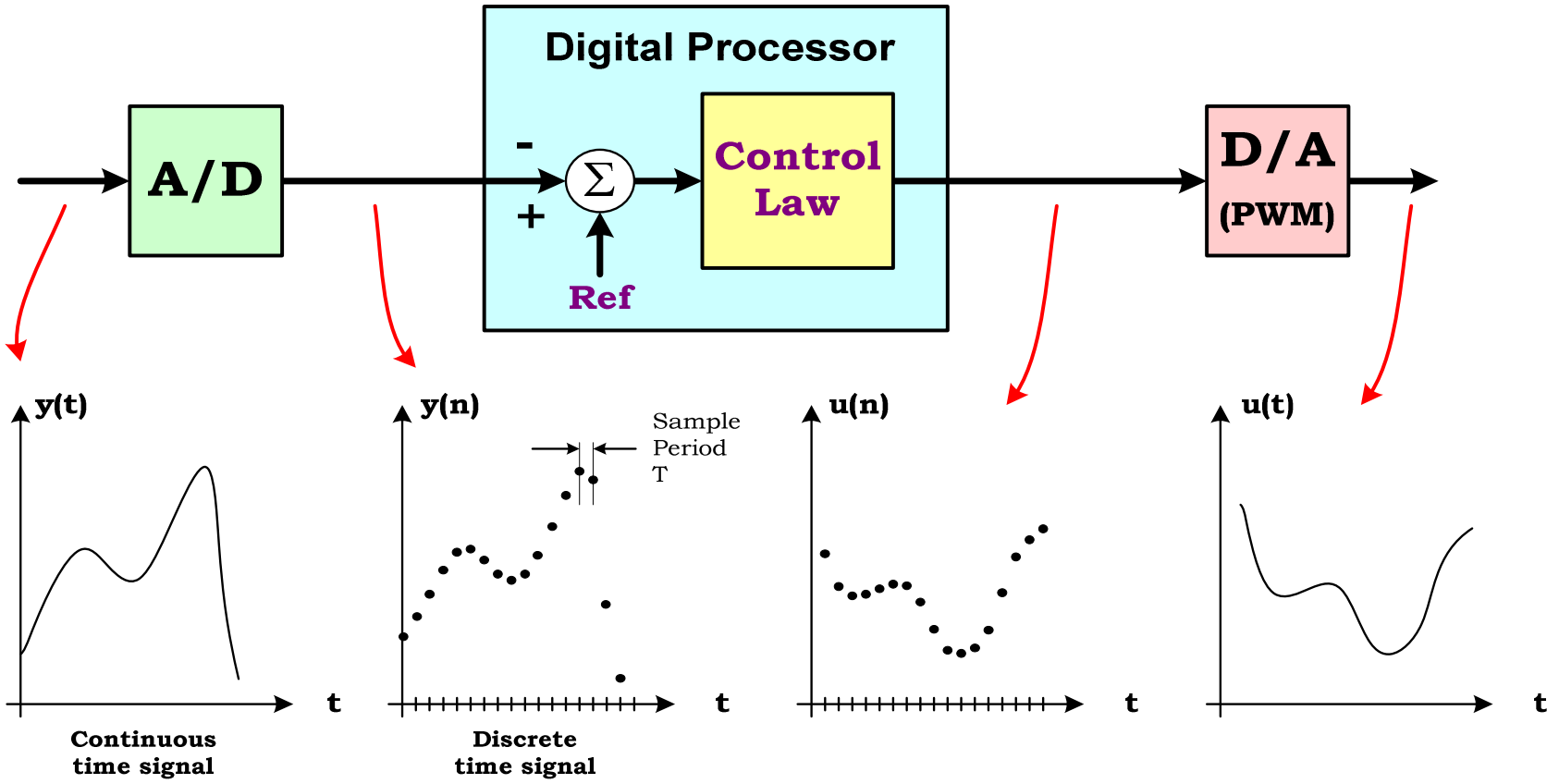
- Reduced EMI with Frequency Dithering

- Flexible Power Up-Down Sequencing

- etc…

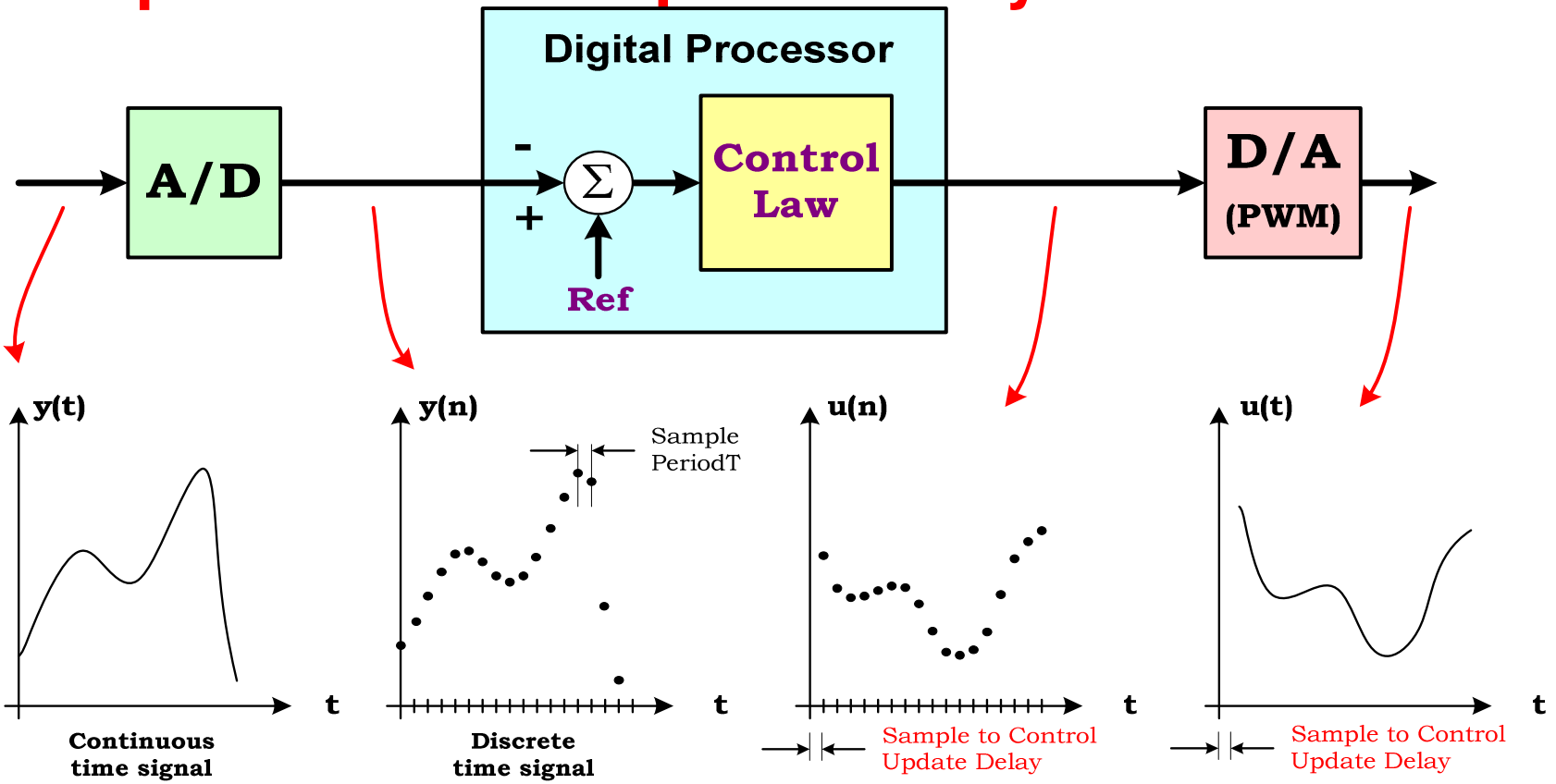
Digital Controller Key Considerations

Digital Power Is a Time Sampled Control System



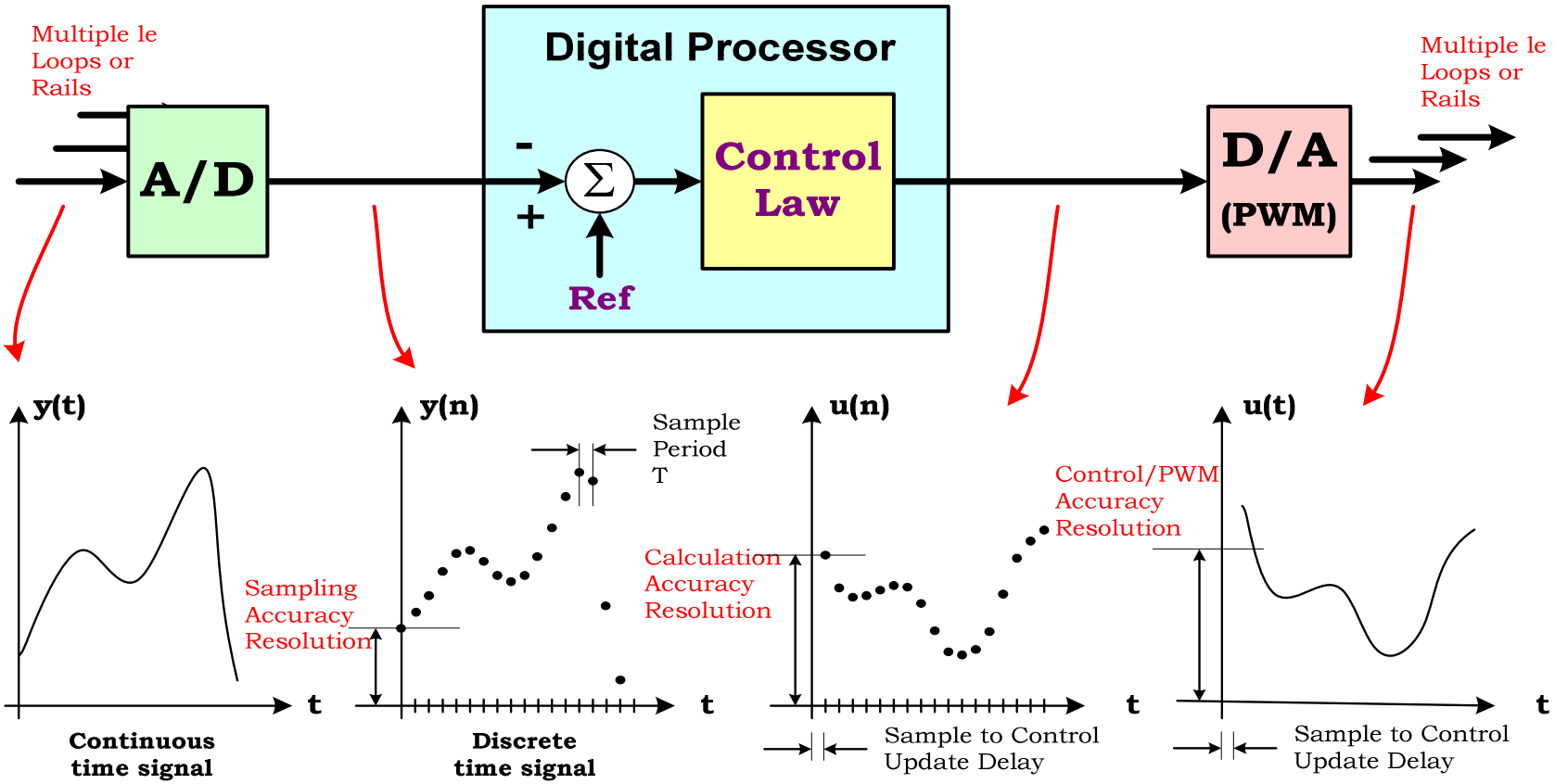
- Output sampling and control update happen on periodical basis – same as switching mode power supply
- Key difference is control update is not affected by current output, rather output of certain time period before – sample to control update delay

Sample to Control Update Delay Critical



- **Sample to control update delay may or may not be the same as sampling period**
- Minimizing this delay is critical to performance of digital power. This delay directly erodes into control loop phase margin.
- **Key contributors to the delay are**
  - **A/D conversion delay ->** Fast A/D conversion time, advanced A/D interrupt, flexible sequencing control
  - **Time it take to execute the compensation ->** Fast CPU speed and high processing power, CLA, on-chip analog comparators for peak mode current control or c-b-c current limiting

Other Key Considerations

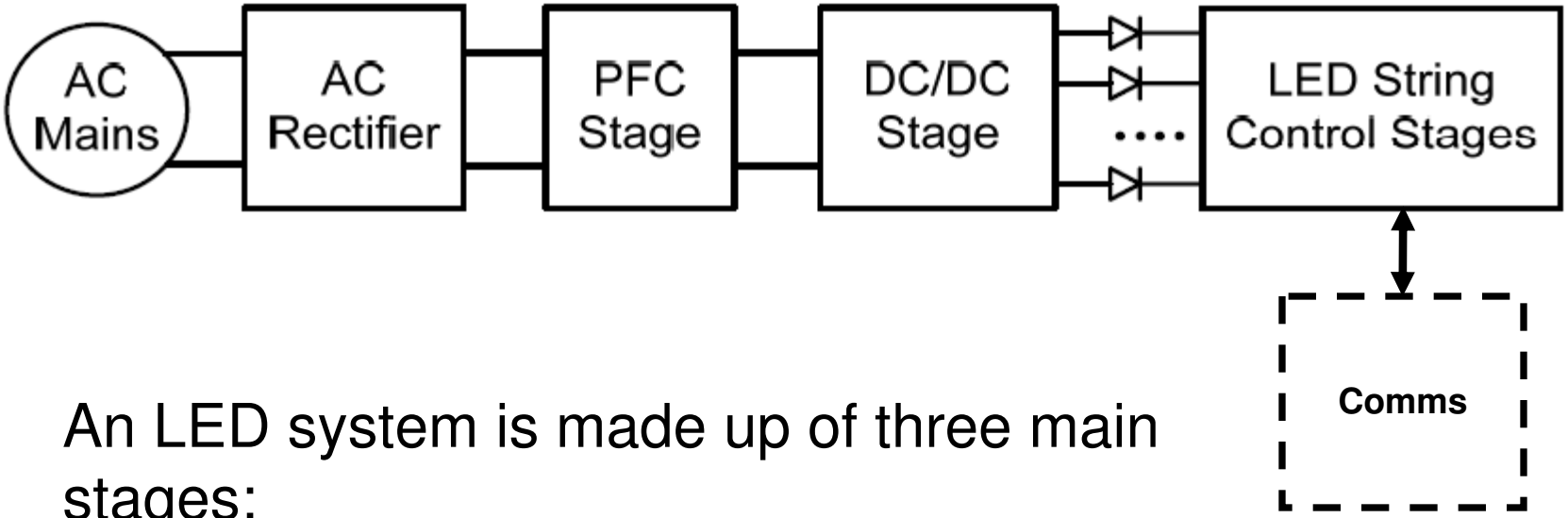


- **Sample accuracy and resolution –** ADC resolution
- **Calculation accuracy and resolution –** CPU word length and computing power
- **Control/PWM accuracy and resolution –** PWM resolution

- **Multiple loops, multiple tasks (monitoring and supervision, communication, etc.), multiple rails –** ADC speed, CPU speed and processing power

What is Digital Controlled LED Lighting System

An efficient LED system

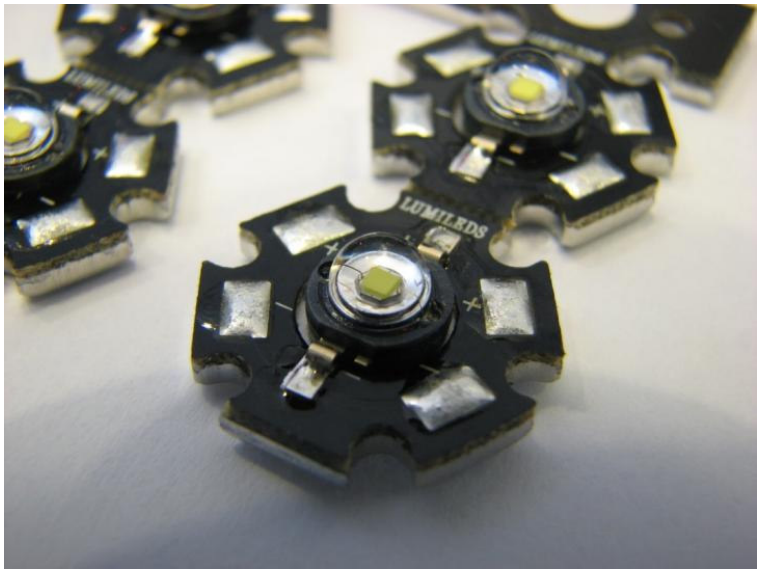


An LED system is made up of three main stages:

1. Power supply
2. LED control
3. Communications (PLC and others)

MCUs can play a role in all three stages

Benefits of MCUs in LED lighting



- Higher efficiency
- High dimming ratio
- Very high PWM frame clock possible for no strobing effects
- Interleaving
- PWM or constant current dimming
- Performs all power management functions needed
- Adds flexibility in design and in manufacturing
- Communications/control
- Accuracy, precision and flexibility
- LED temperature sensing for increased reliability
- Adaptive dimming based on usage, aging, or ambient lighting conditions
- No separate housekeeping MCU required

TI MCUs are shipping today in…

- Light bulb replacements
  - PAR30, MR16, etc.
- LED lighting ballasts
- FL ballasts
- LCD backlights
- Wireless lighting control
  - ZigBee, KNX
- Wired lighting control
  - DALI, Triac dimming, DMX-512,
- Power line

C2000 LED Target Markets

Street Lighting

Outdoor/ Industrial Lighting

Smart Lighting

Stage Lighting/Color Lighting

Market Needs:

- AC/DC conversion + PFC
- DC/DC conversion
- LED lighting control
- Communications (PLC, DALI, DMX, KNX, …)
- Advanced monitoring functions
- High efficiency power conversion

❑ Typical analog designs could use 5 or more controllers plus related circuitry!
❑ Competitive digital designs do not have the MIPS to implement all of these functions and implement them well!

US high-brightness LED market projected to triple in size by 2014 ($350 million)
The market is growing!

C2000 LED Lighting Value Proposition

C2000 MCUs bring high levels of integration and advanced functionality to LED lighting applications

Integration:

Control with a single C2000 MCU:

- Power supply (AC/DC, PFC, DC/DC)
- LED driver stages
- Communications (PLC, RF, DALI, DMX, etc.)

- Reduce BOM cost
- Reduce system complexity
- Reduce board size
- Digital power efficiency
- Dynamic response to changes at the system level

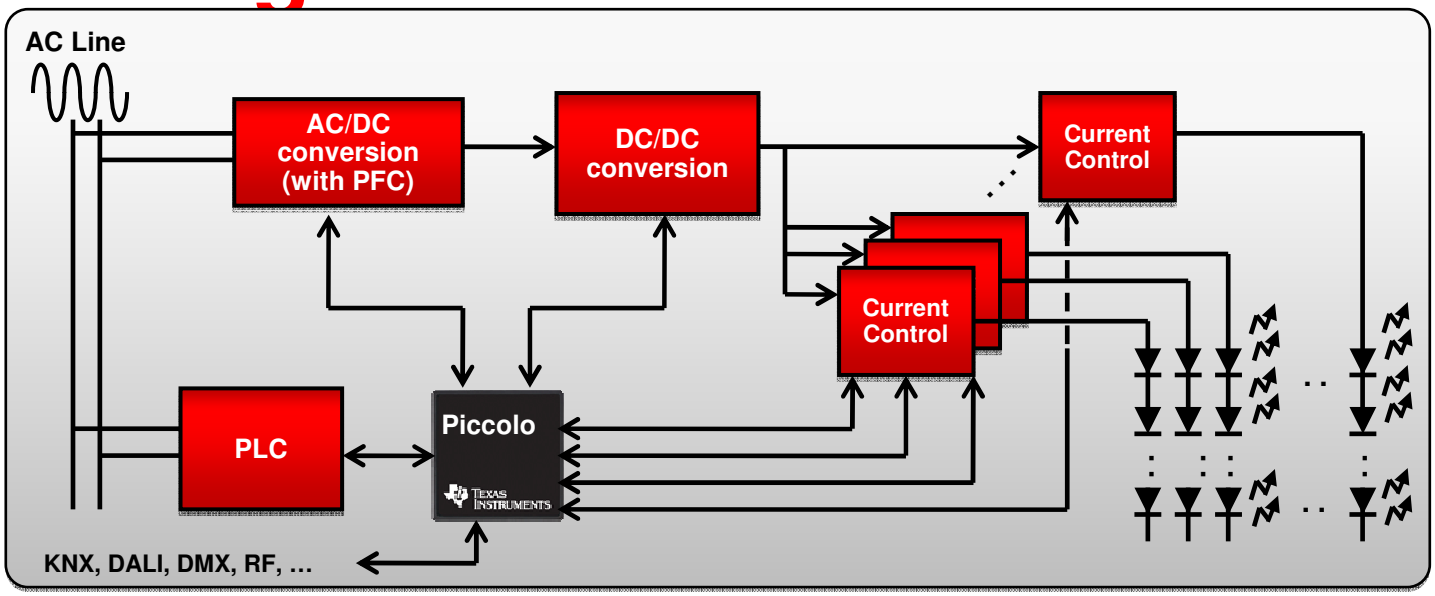
Advanced Functionality:

Digital control brings flexibility to implement advanced functions:

- Temperature monitoring and correction
- Failure monitoring and correction
- Ambient Lighting adjustment
- Safety Functions
- LED aging color/brightness correction
- Color mixing and precise color tone adjustment

- Easy field upgrades
- Add differentiation
- Easy to implement with a digital system

C2000 Integration Picture



1. **Integration of the power conversion from AC input through DC output**
2. **Integration of current control for dimming and brightness adjustment**
3. **Integration of PLC and advanced communications**

Device Specific:

- Optimized DSP-based core provides headroom to implement all functions
- Integrated ePWM and ADC channels allow precise control of multiple LED strings
- Fast and high-resolution ADC and ePWMs allow greater dynamic response leading to increased power efficiency and reduced side-effects on the output such as flickering
- Unique IP such as the VCU on F2806x devices allow implementation of advanced communications applications such as power line communications
  - Unheard of on a low-cost MCU!

LED Lighting and Communications

Why LEDs and communications?

- Greater system intelligence
  - Coordinated lighting for applications such as stage lighting or traffic signals
- Remote control
  - For example, one could remotely disable/enable the lighting in large industrial system
  - Emergency or safety controlled lighting
- Failure reporting
  - Instant knowledge and corrective action if a lighting module fails
- Monitoring of the environment
  - Could feedback environmental conditions to a central hub whom could then increase or decrease brightness levels or change color levels depending on conditions
  - PLC is popular due to easy installation and low cost

TI Lighting Communications and Control

- TI solutions solve issue of lighting comms and control without expensive re-wiring
- Control via wireless
  - 2.4GHz, <1GHz
  - ZigBee, 802.15.4, DALI over SimpliciTI, proprietary
  - 6loWPAN
- Control via “wired”
  - DALI, DMX-512, KNX, etc.
  - Power line communications (PLC)
    - DALI over PLC
    - PLC lighting control
      - Streetlight control

Intelligent lighting tools

Protocol	MCU	Initial code dev platform	Certification/standard	Demo platform	Status/ Comments
DALI	MSP430	F2619	DALI—complete	TPS62660EVM-338	Demo code and reference design available http://focus.ti.com/general/docs/litabsmultiplefilelist.tsp?literatureNumber=slaa422
DMX512	MSP430	F2012	DMX-512—complete	Wall washer reference design	Demo code and reference design available upon request
PLC (SFSK)	C2000	F2803x	EN50065--Complete	TMDSPLCKIT-V1	Available http://focus.ti.com/docs/toolsw/folders/print/tmdsplckit-v1.html
PLC (OFDM)	C2000	F2803x	EN50065(Cenelec) IEC 6100-3	TMDSPLCKIT-V2	Up to 76.8KBPS, 24-94.5kHz Released http://focus.ti.com/docs/toolsw/folders/print/tmdsplckit-v2.html
KNX	MSP430	MSP430F2	EN 50090 ISO/IEC 14543-3-x	Wienzierl / Tapko	Available through 3P
KNX-RF	MSP430/ CC25xx	MSP430F2/ CC1101	EN 50090 ISO/IEC 14543-3-x	Wienzierl	Available through 3P
6loWPAN	CC430/ CC25xx	CC430 or CC25xx			Available through 3P
802.15.4	MSP430/ CC25xx	F541x/5x CC25xx	802.15.4—complete	Multiple	Released http://focus.ti.com/analog/docs/gencontent.tsp?familyId=367&genContentId=24198
ZigBee	MSP430/ CC25xx	F5438 CC25xx	ZigBee—complete	Multiple	Released http://focus.ti.com/analog/docs/gencontent.tsp?familyId=367&genContentId=24198

Communications - DALI

- DALI stands for Digital Addressable Lighting Interface and is a worldwide standard protocol set out in IEC62386.
- Bidirectional digital protocol used to control electronic lighting ballasts.
- 0-16V (nominal) twisted pair is the standard physical layer.
- Can control up to 64 devices with each device being able to take part in a maximum of 16 “scenes”.
- DALI over PLC also has had some interest from customers

Communications – Power Line Communication

PLC is a robust means of communicating over power lines.

Applications

- E-Metering
- Lighting
- Solar
- Industrial
- EVSE (Electric Vehicle charging)

Technologies (modulation schemes)

- FSK
- S-FSK
- OFDM

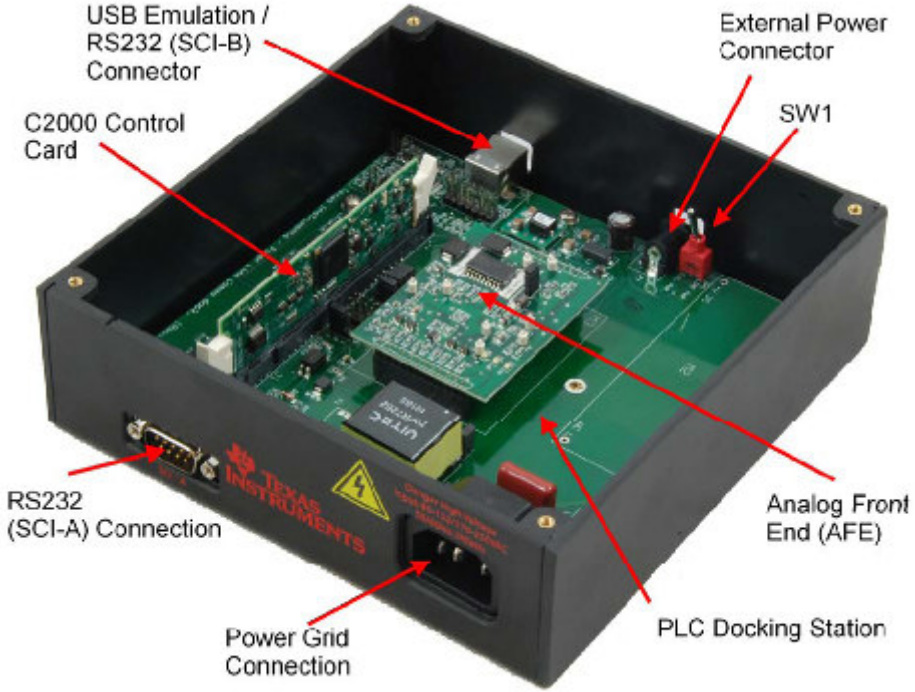
Standards

- Prime
- G3
- IEC 61334

Regulations

- CENELEC
- FCC
- ARIB

TI PLC Modem Development Kit (TI PLC DK)



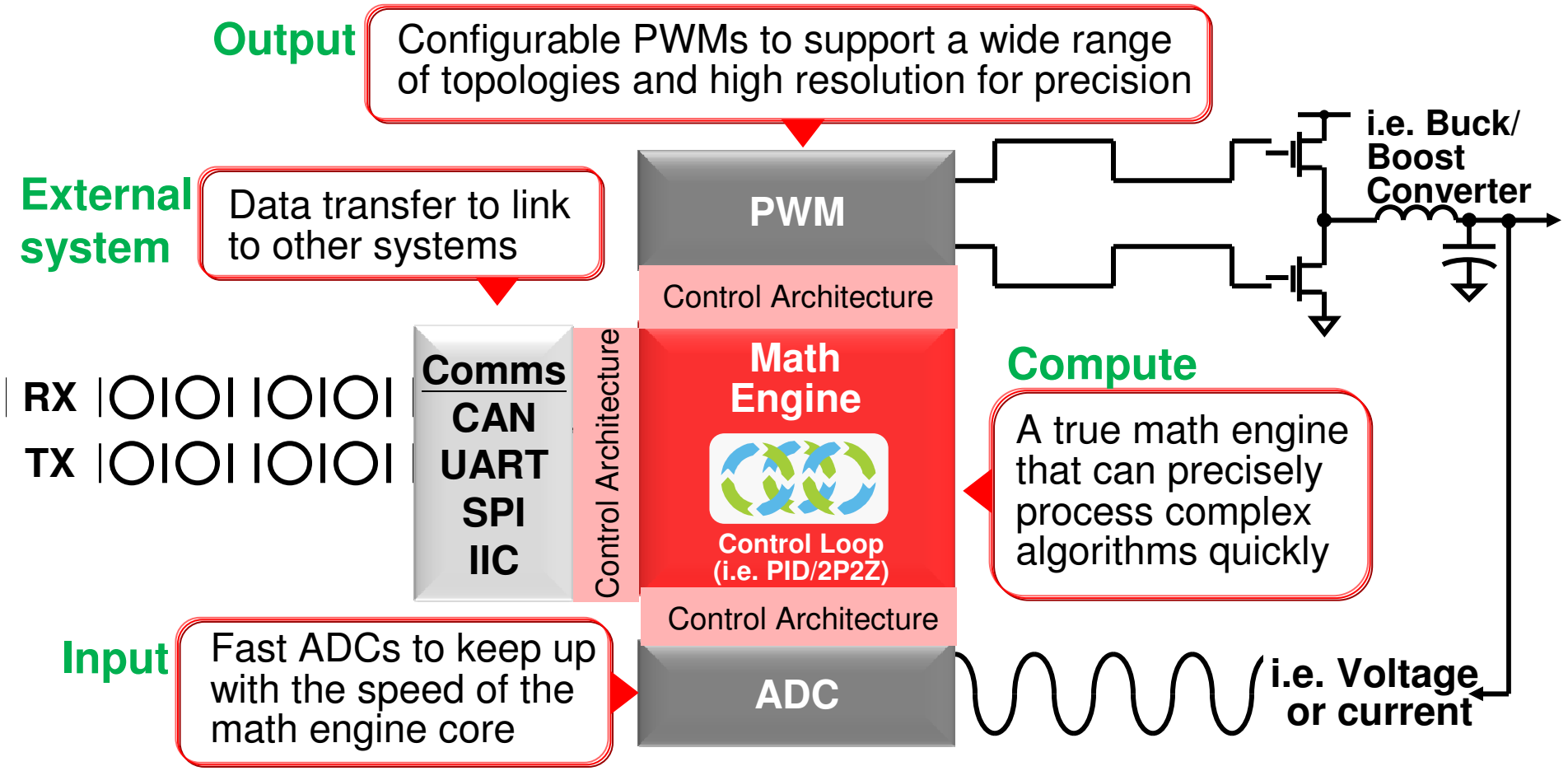
TI PLC DK contains:

- 2 PLC modems
- Power supply and cables
- GUI and documentations
- Run any IP applications through PC host
- **Part#: TMDSPLCKIT-V2**
- **Price: $599 USD**
- **Distribution and TI eStore**
- **plcSUITE™ Software available via download**

- Robust narrowband PLC modem over low-voltage/medium-voltage power line
- PLC standards/modulation supported
  - PRIME
  - G3
  - FlexOFDM™
  - IEC61334 S-FSK
- Scalable data rates up to 128 kbps for single phase
- Software reference design package: **plcSUITE** APIs, Libs, source codes
- AFE operating frequency range 9–500 kHz (**usage of different filters**)
- Easy integration into end-point or network devices of AMR/AMI systems
- NRE and royalties FREE

Why C2000 for Digital Power

The C2000 Advantage for Digital Power Supplies

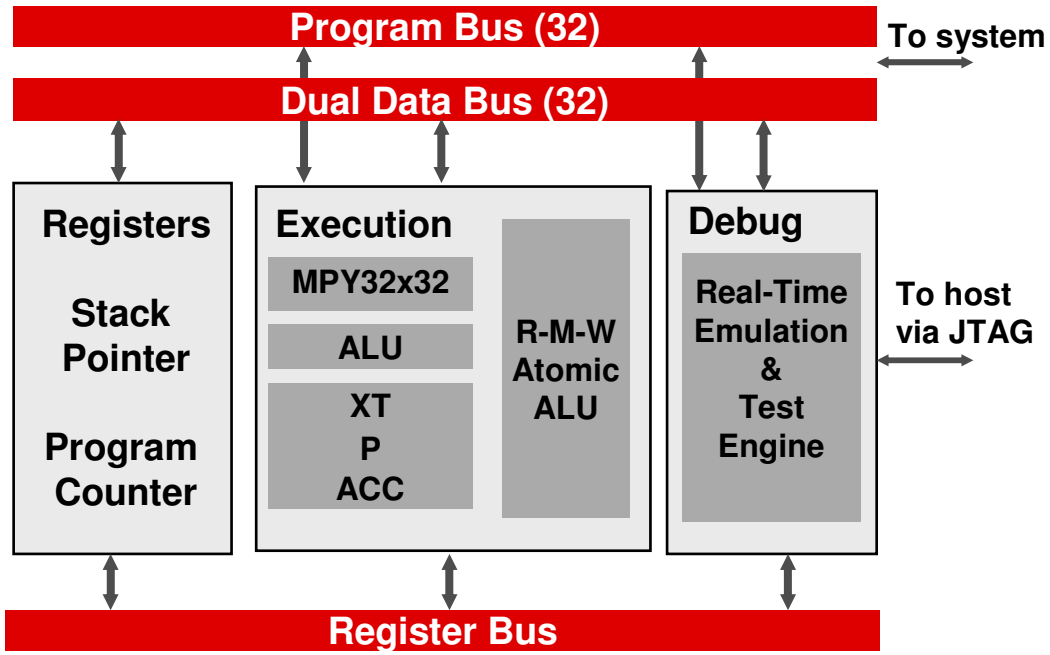


Real-world application software and kits

Fixed- and floating-point math libraries, application-specific frameworks, optimized control blocks, model based software

C28x Core

The 32-bit C28x core is at the heart of every C2000 28x microcontroller. Based on a DSP architecture, the core is optimized to quickly execute math-based operations, but can also handily process general-purpose code.



C28x CPU

- 32-bit fixed-point DSP
- RISC instruction set
- 8-stage protected pipeline
- 32x32 bit fixed-point MAC for single-cycle 32-bit multiplys
- Dual 16x16 bit fixed-point MACs
- Single-cycle instruction execution

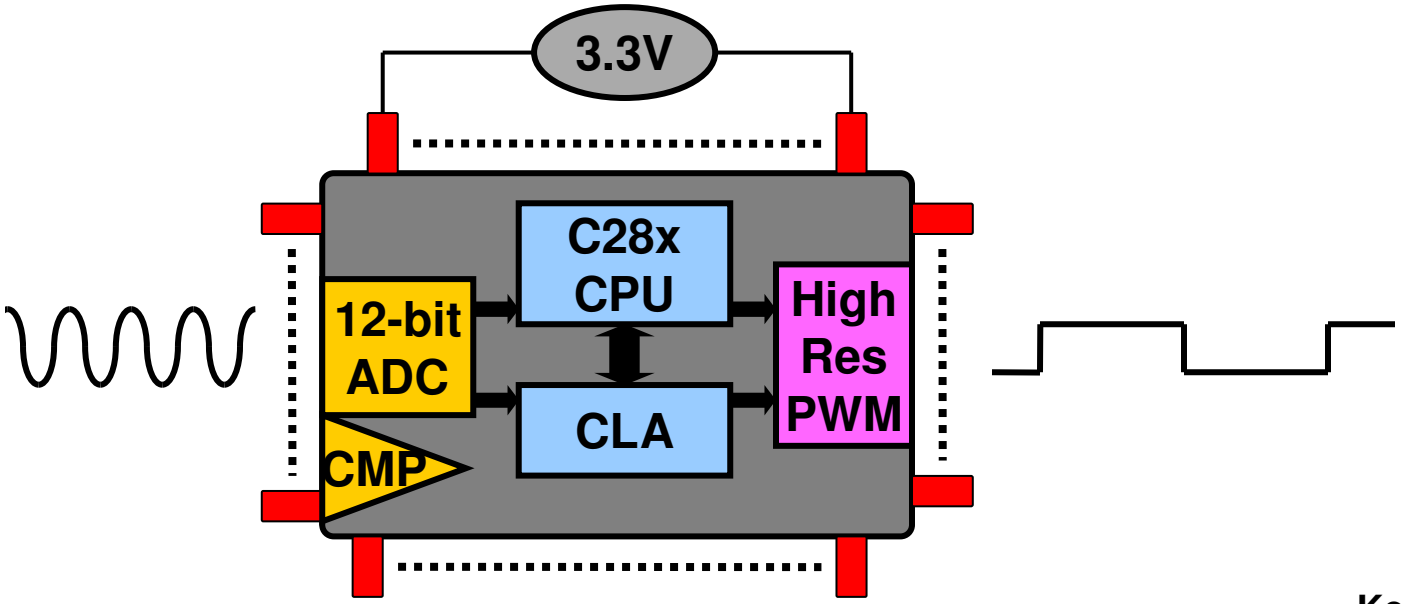
Modified Harvard Bus Architecture

- Separate data and instruction buss
- Two data buses – one for read, one for write
- Enables fetch, read, and write in a single cycle

Emulation Logic

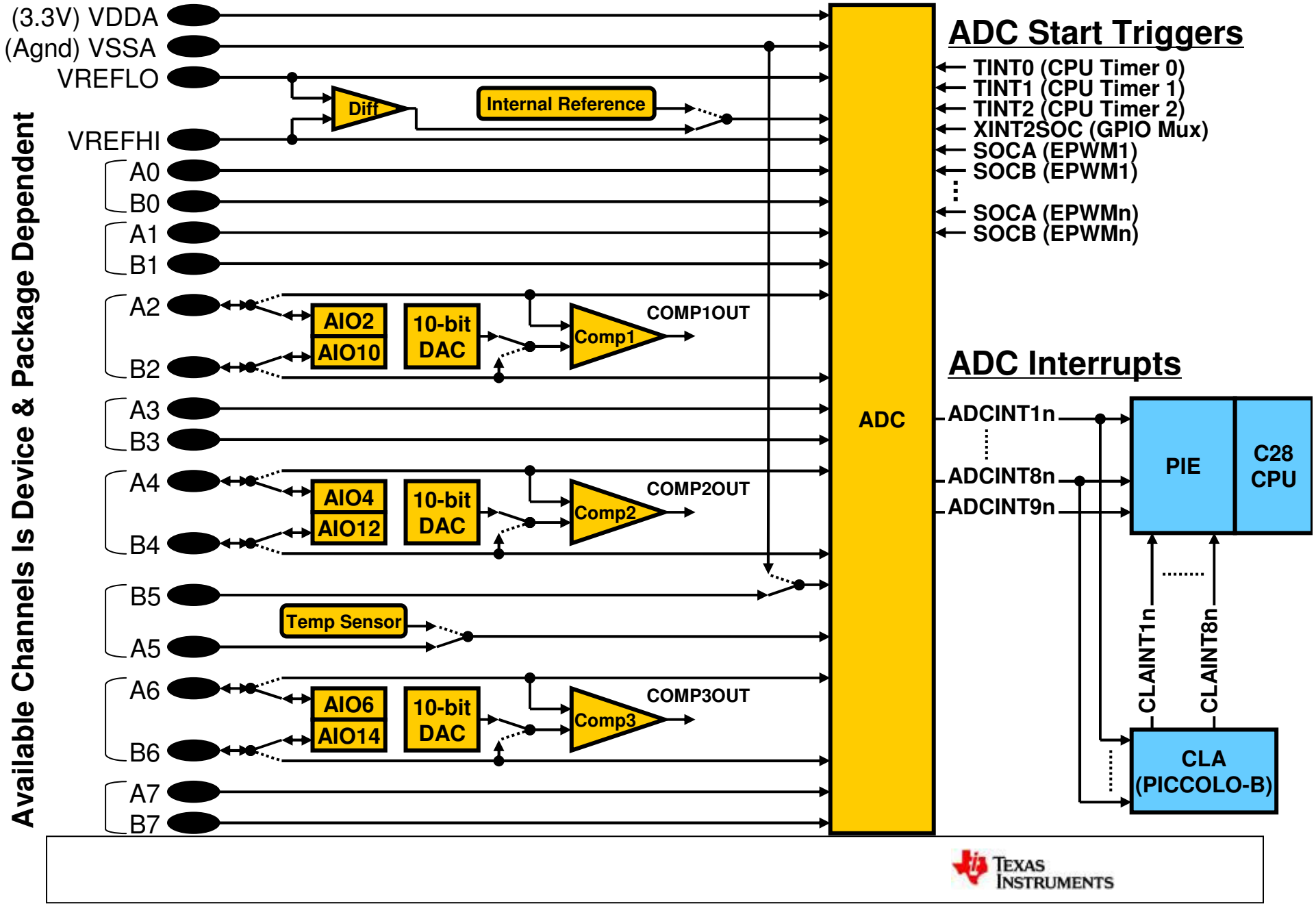
- Real-time emulation allows interrupt servicing even when main program is halted
- Debug host has direct access to registers and memory
- Enables data logging to the debug host
- Multiple hardware debug events and breakpoints

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

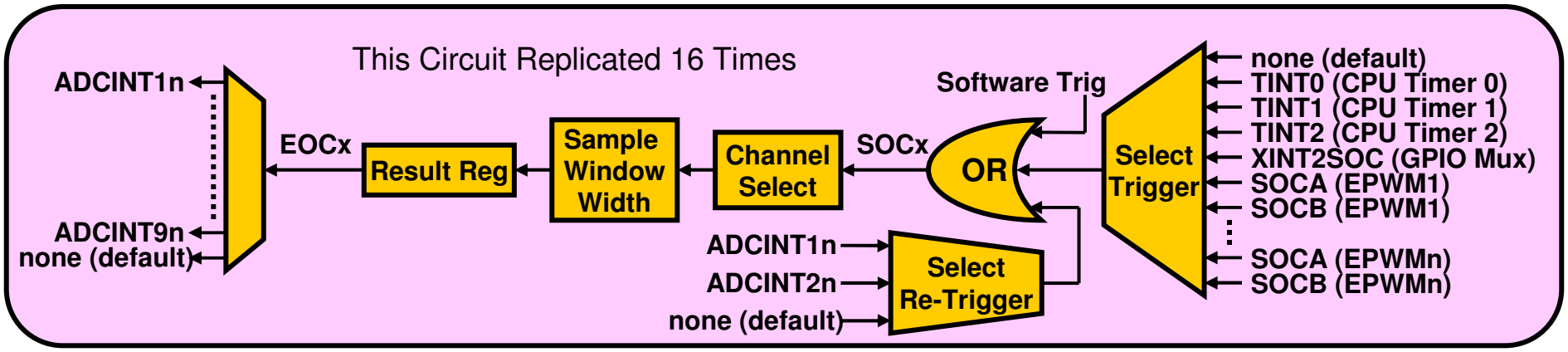
Piccolo ADC


(3.3V) VDDA
(Agnd) VSSA
VREFLO
VREFHI
A0
B0
A1
B1
A2
B2
A3
B3
A4
B4
B5
A5
A6
B6
A7
B7
Available Channels Is Device & Package Dependent
Diff
Internal Reference
AIO2
AIO10
10-bit DAC
Comp1
COMP1OUT
AIO4
AIO12
10-bit DAC
Comp2
COMP2OUT
Temp Sensor
AIO6
AIO14
10-bit DAC
Comp3
COMP3OUT
ADC
ADC Start Triggers
TINT0 (CPU Timer 0)
TINT1 (CPU Timer 1)
TINT2 (CPU Timer 2)
XINT2SOC (GPIO Mux)
SOCA (EPWM1)
SOCB (EPWM1)
SOCA (EPWMn)
SOCB (EPWMn)
ADC Interrupts
ADCINT1n
ADCINT8n
ADCINT9n
PIE
C28 CPU
CLAINT1n
CLAINT8n
CLA (PICCOLO-B)

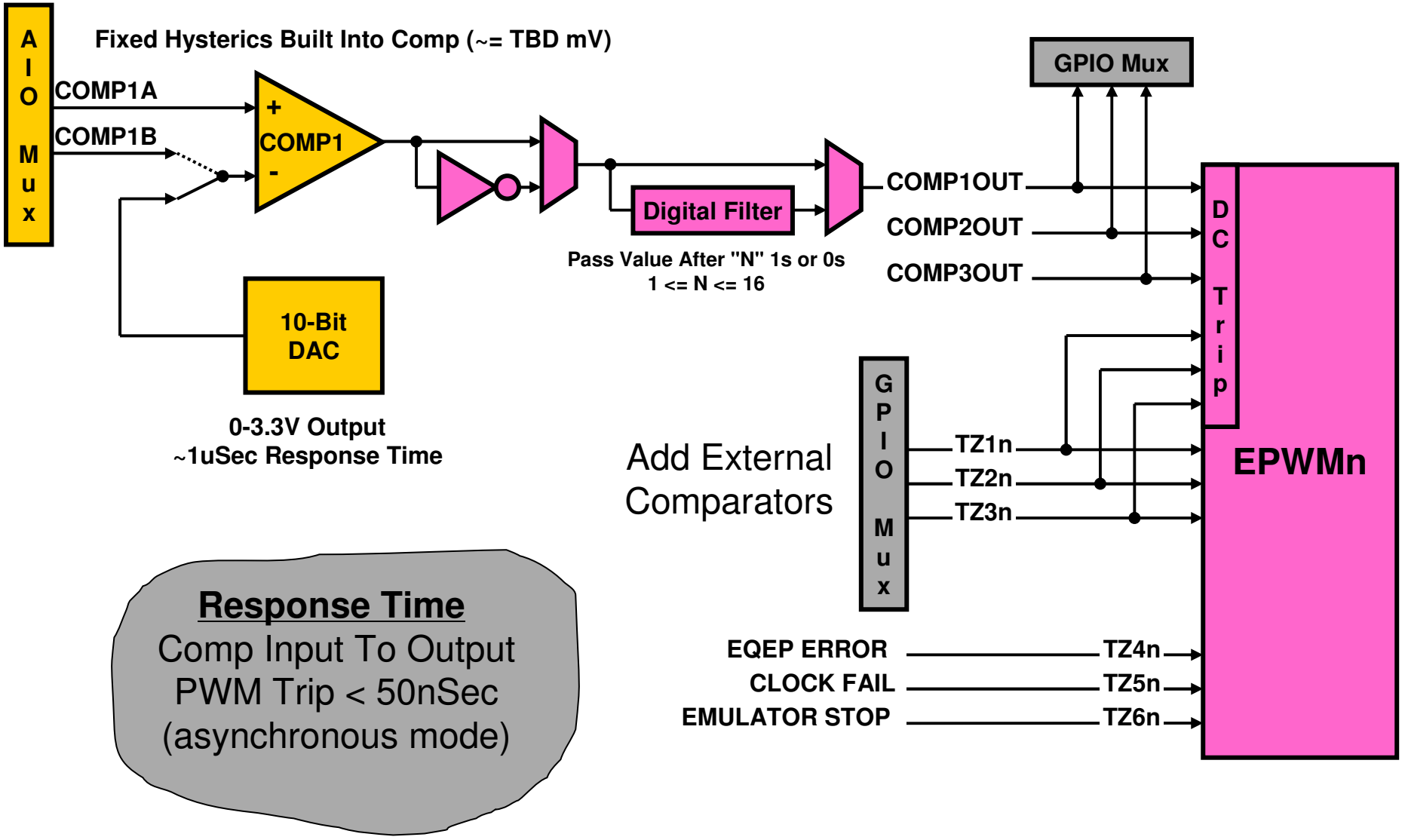
ADC Improvements

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

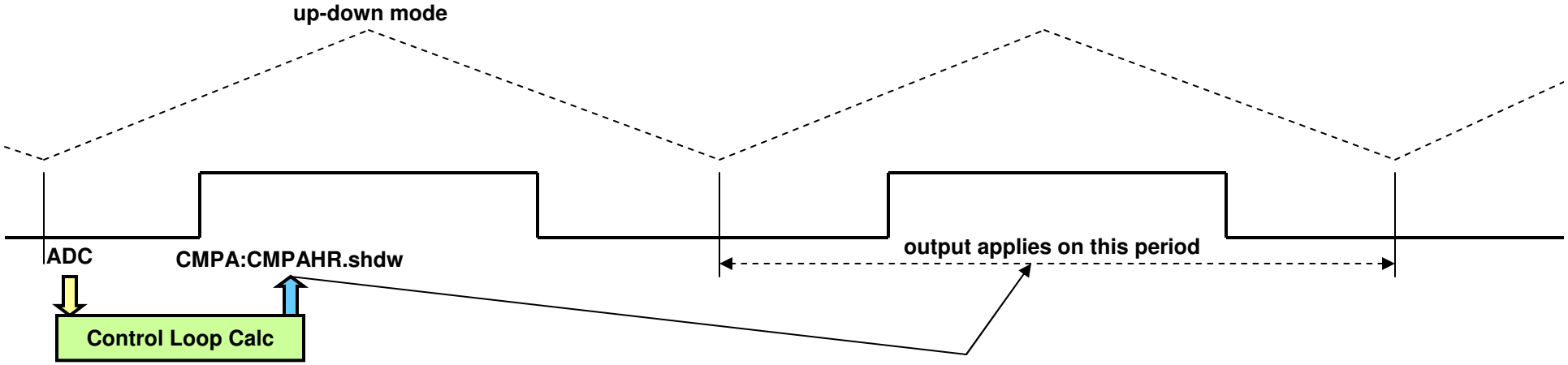


Response Time

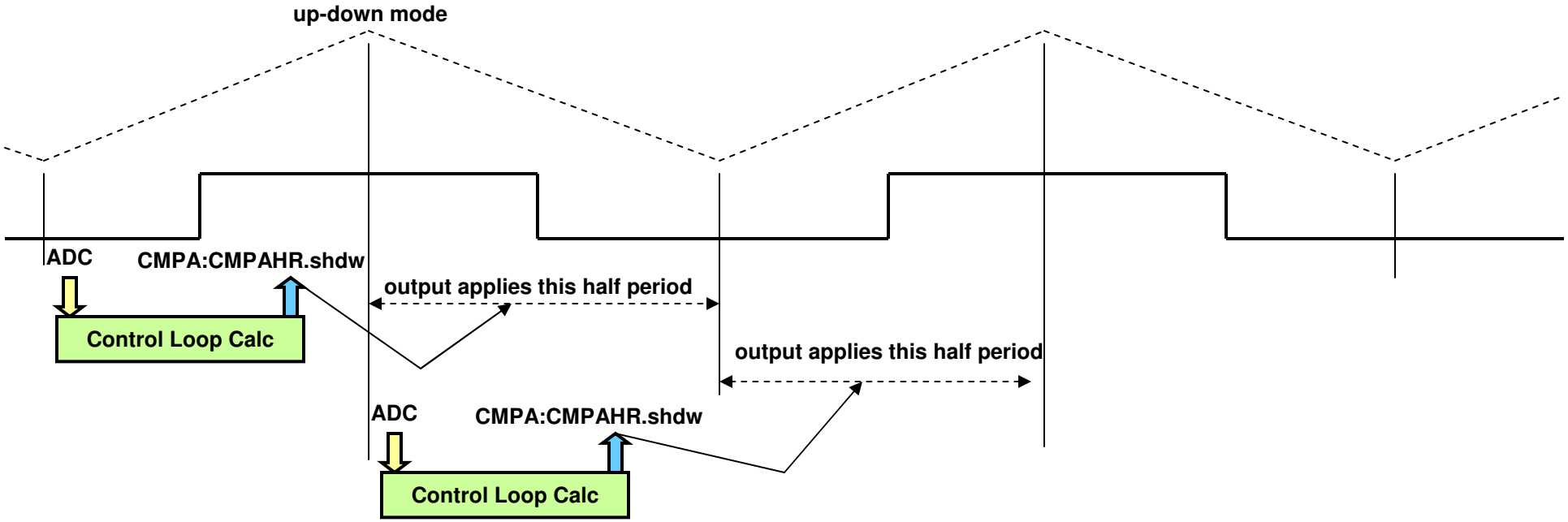
Comp Input To Output
PWM Trip < 50nSec
(asynchronous mode)

EPWM - Dual Edge Control

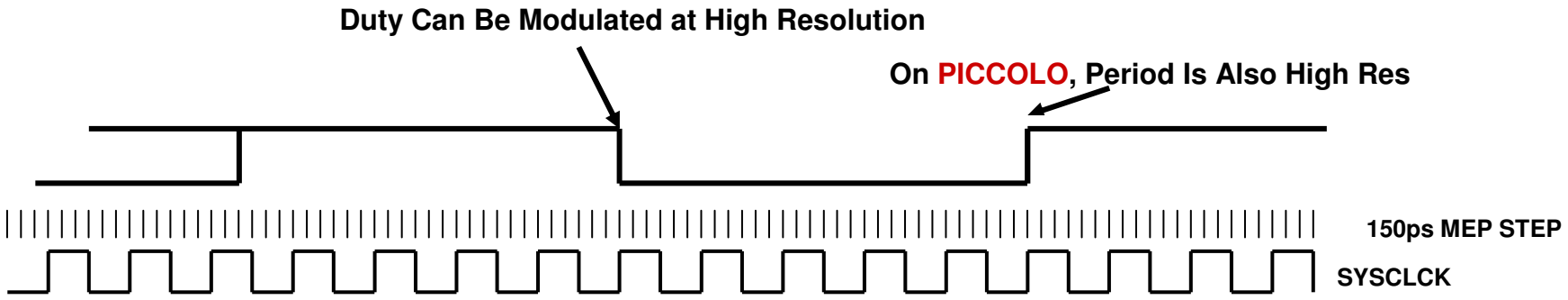
Traditional Single Edge Control: Output Is Updated Once Per PWM Period And There Is A Full Period Output Delay



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



High Resolution PWM



EX:
Target PWM f = 189.753KHz
50% Duty Cycle
40MHz SYSCLK

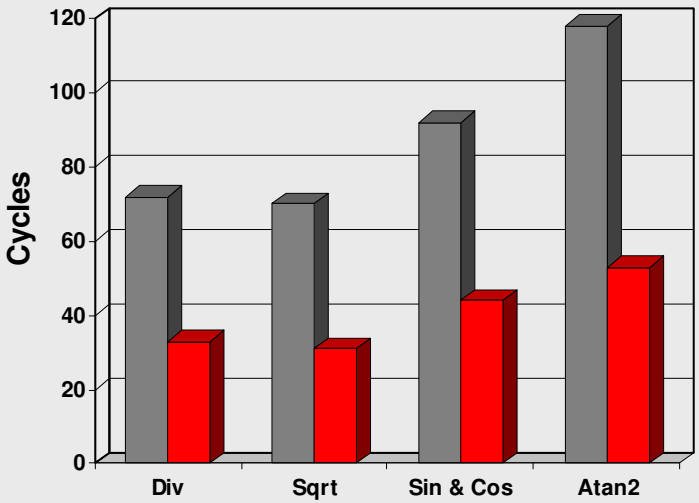
Hi-Res
189.755KHz, error = 2Hz = 0.001%

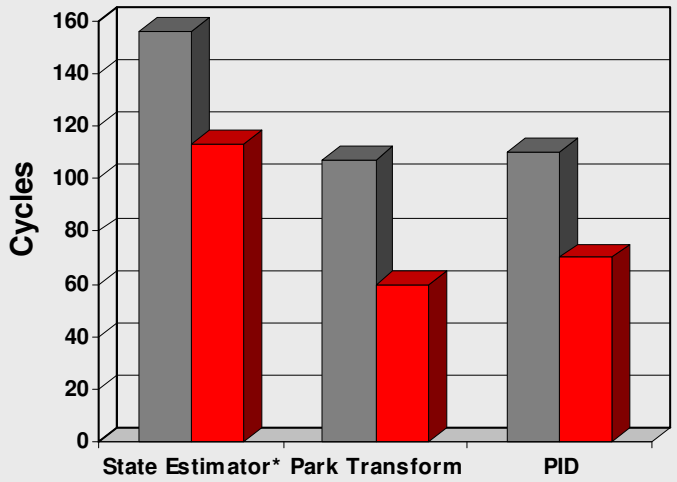
No Hi-Res
190.476KHz, error = 721Hz = 0.38%

Update Period	PWM Step		
(kHz)	25 ns (bits)	10 ns (bits)	150 ps (bits)
20	11.0	12.3	18.3
50	9.6	11.0	17.0
100	8.6	10.0	16.0
150	8.1	9.4	15.4
250	7.3	8.6	14.7
500	6.3	7.6	13.7
750	5.7	7.1	13.1
1000	5.3	6.6	12.7
1500	4.7	6.1	12.1
2000	4.3	5.6	11.7

Math Engine: FPU + CLA + VCU

Floating point: Up to 40% fewer cycles





F28x Fixed F2806x Float

*State Estimator shown in 10s of cycles

Floating-point at the core delivers:

- **Performance boost**
- **Ease of use/time to market**
  - **Eliminate scaling and saturation**
  - **Better support for meta-language tools**
- **Better Code Efficiency**

Control Law Accelerator adds:

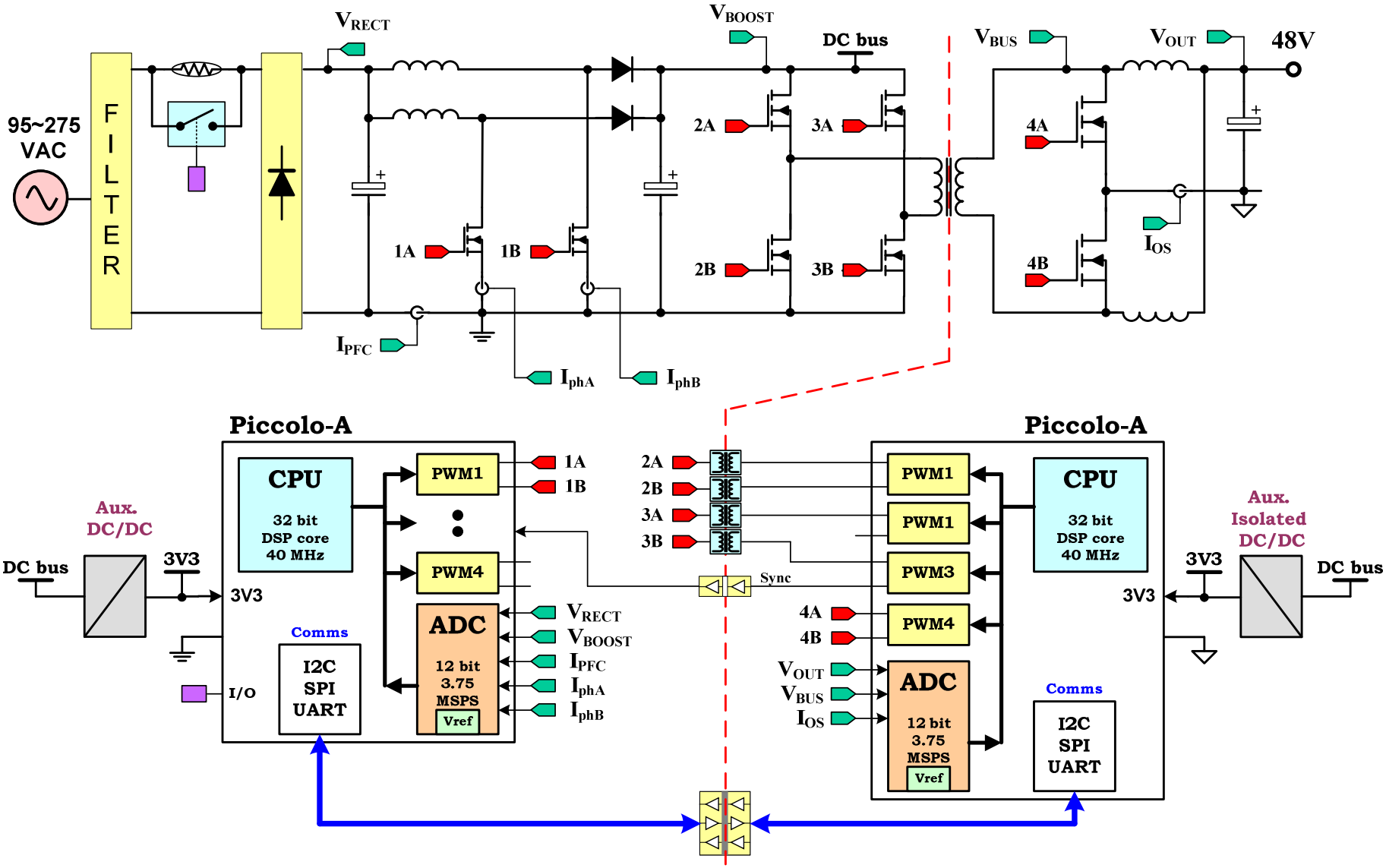
- Extra 80 MIPS performance
- Parallel control loops

New VCU adds:

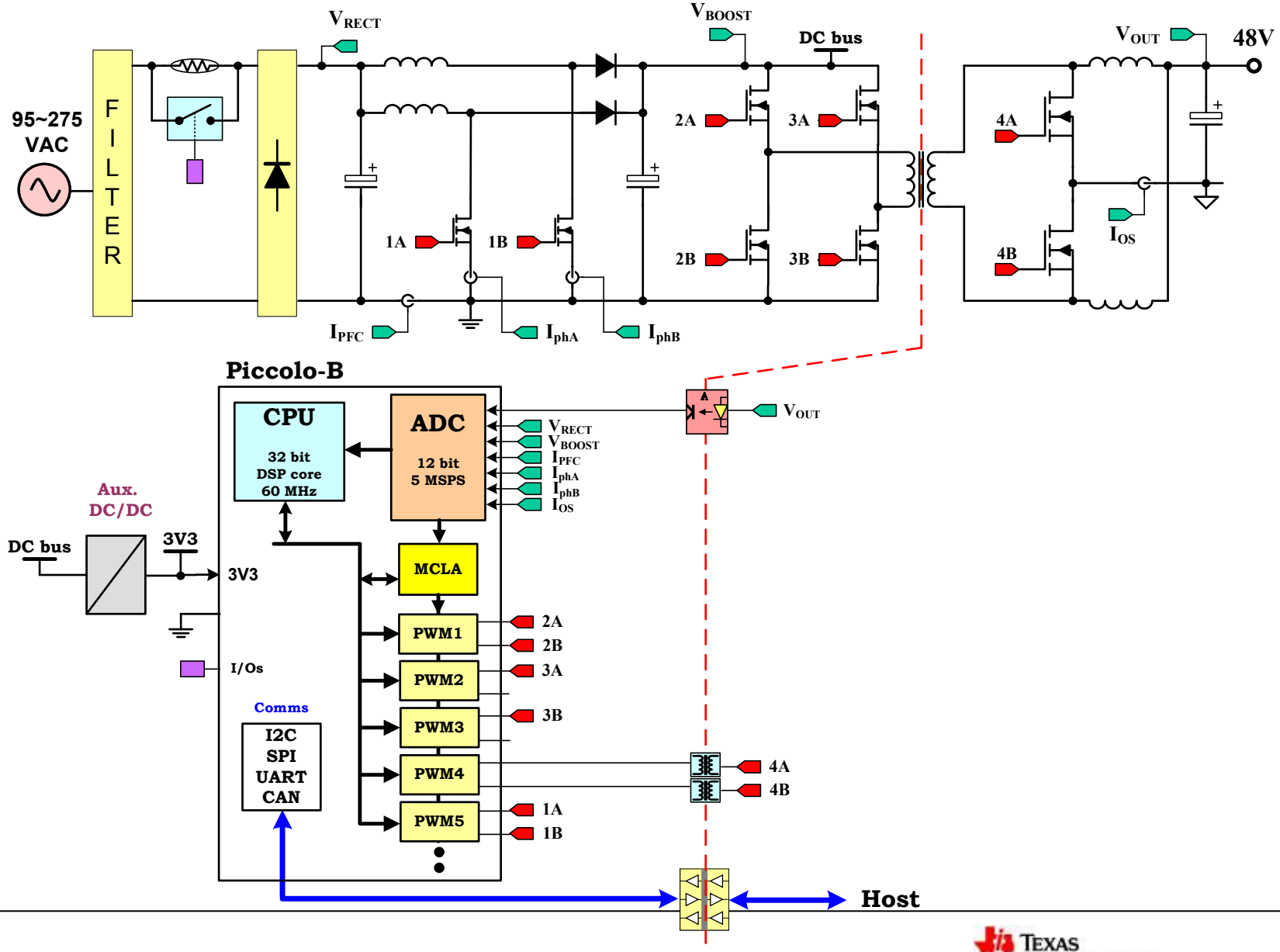
- Viterbi, Complex Math, CRC
- 75 added math instructions

Power Supply Topologies & Control Mode

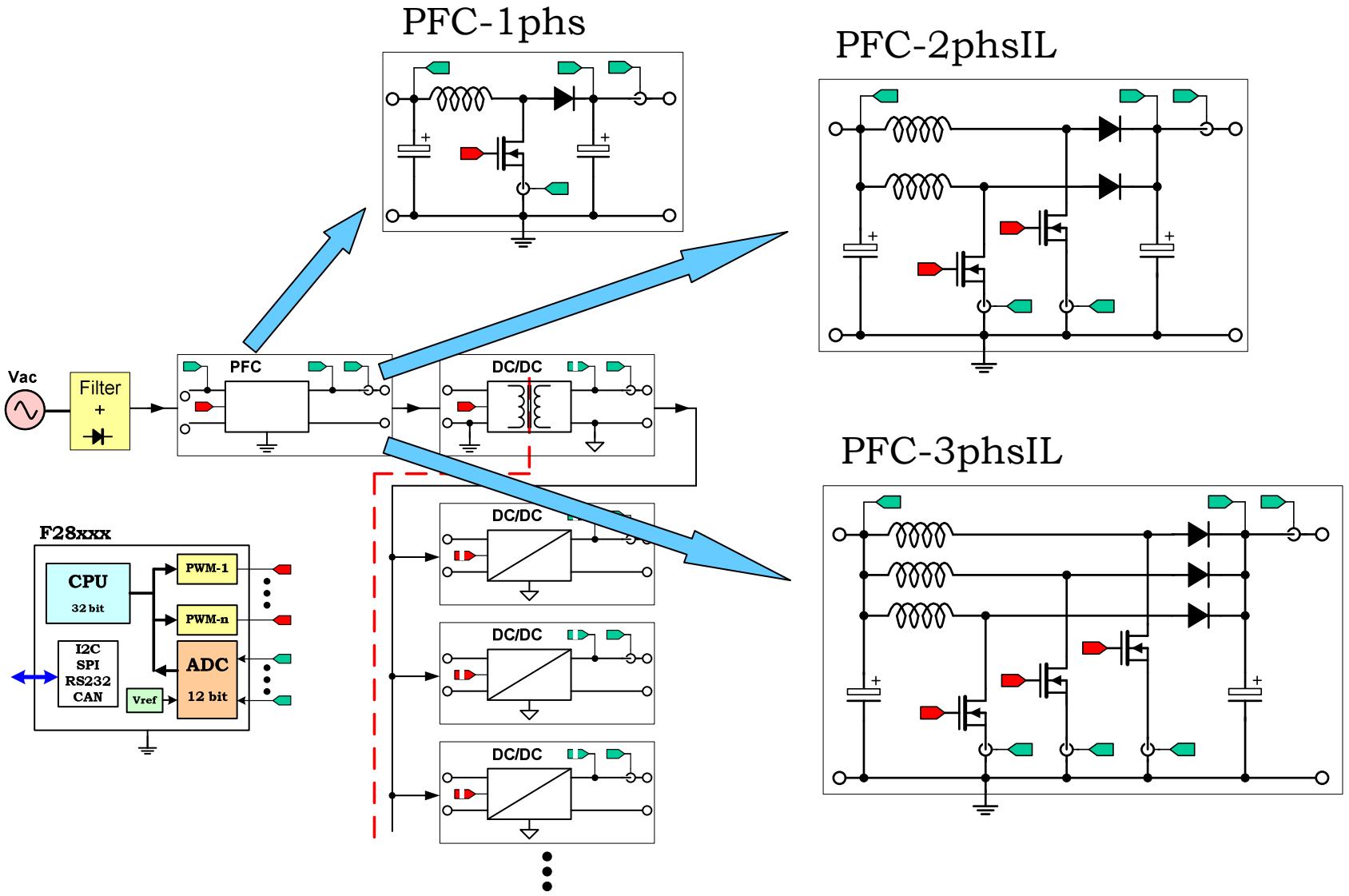
Dual Controller Arch



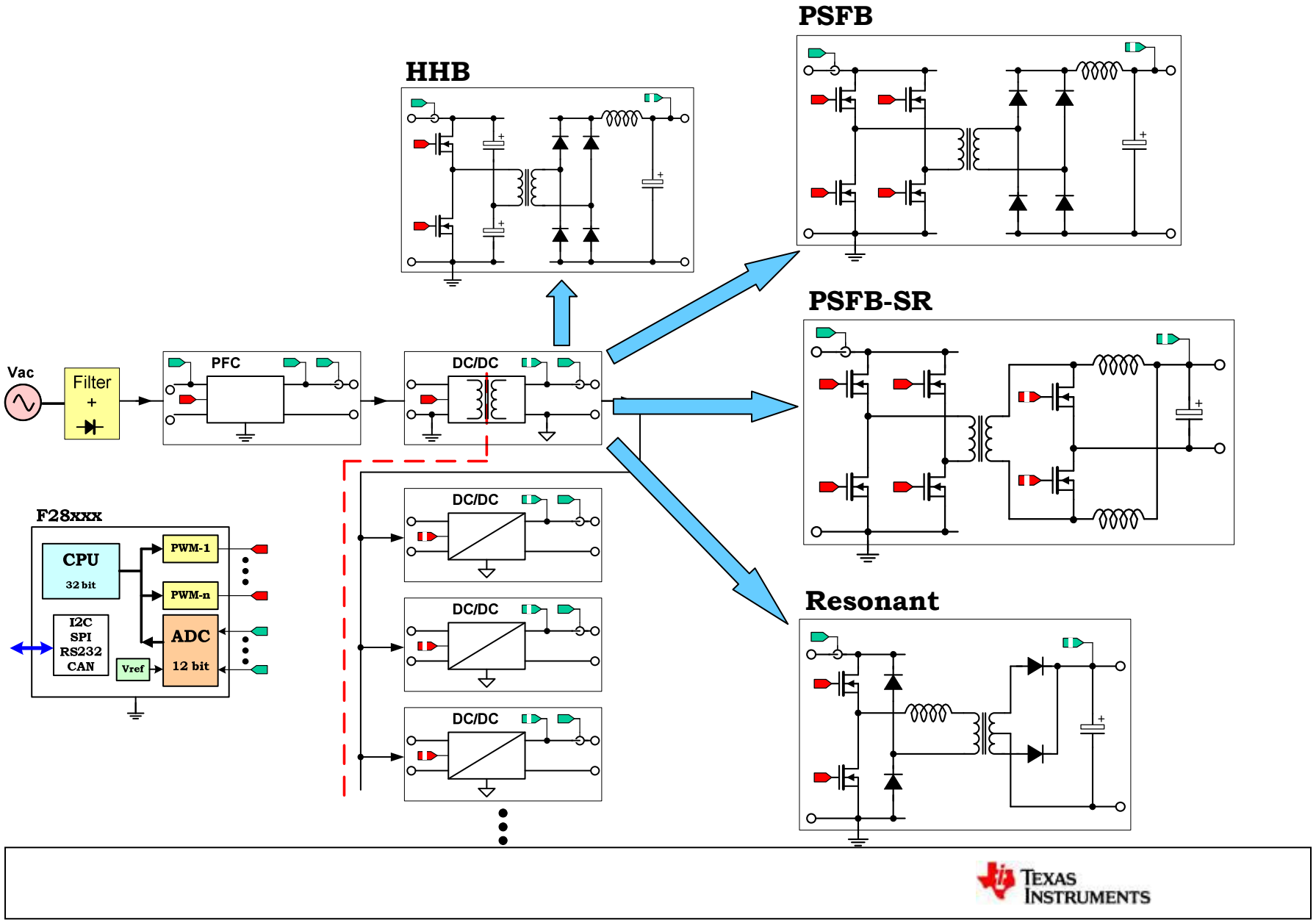
Single Primary Controller Arch



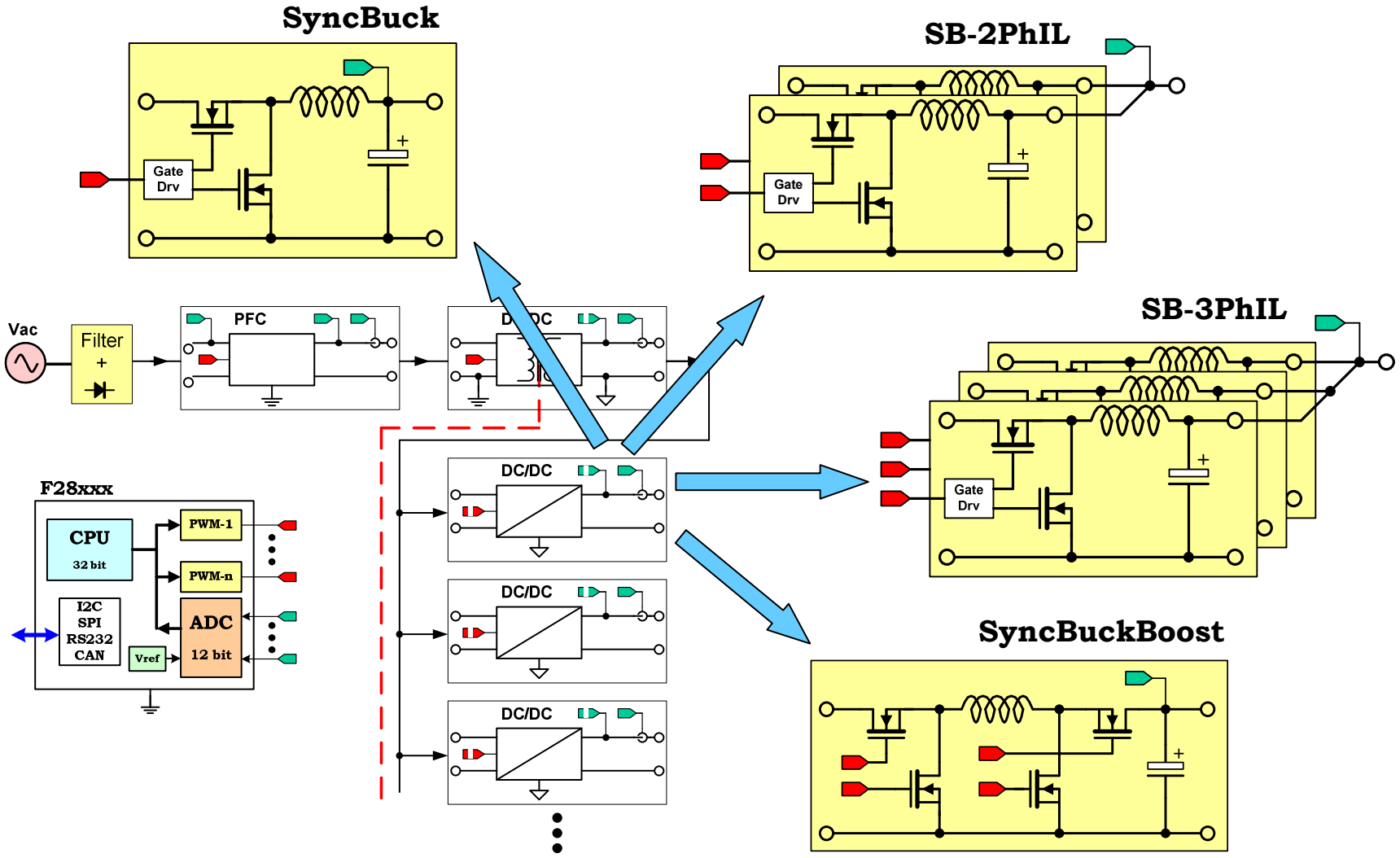
Power Stage Topology Support - PFC



Power Stage Topology – Iso. DC/DC

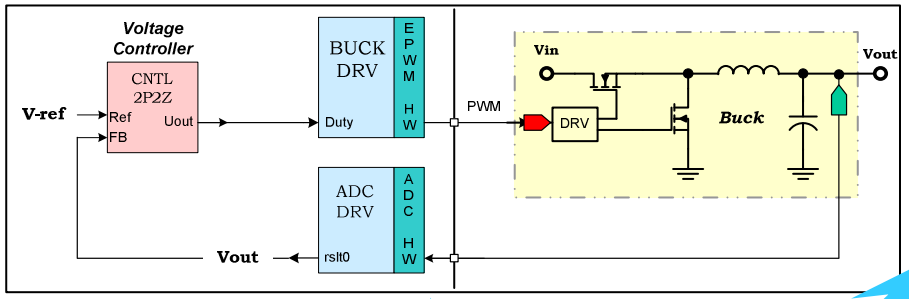


Power Stage Topology – Non-Iso DC/DC

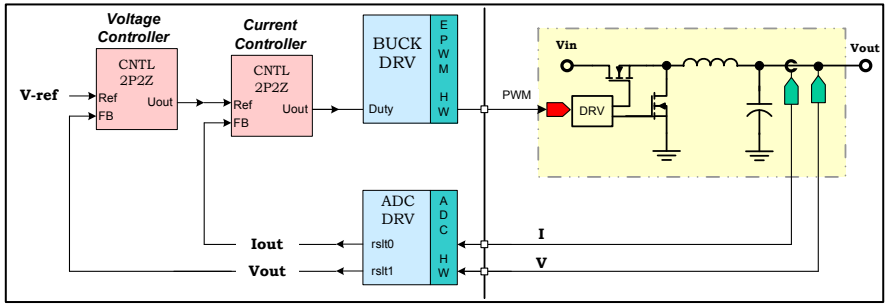


Power Stage in the Loop

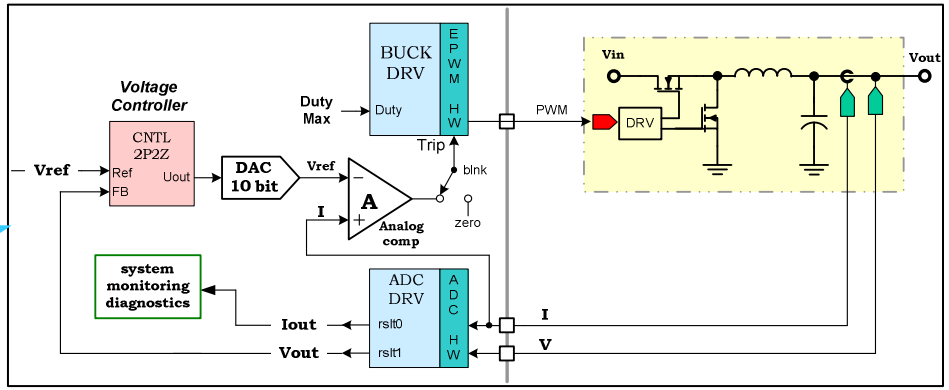
Voltage Mode

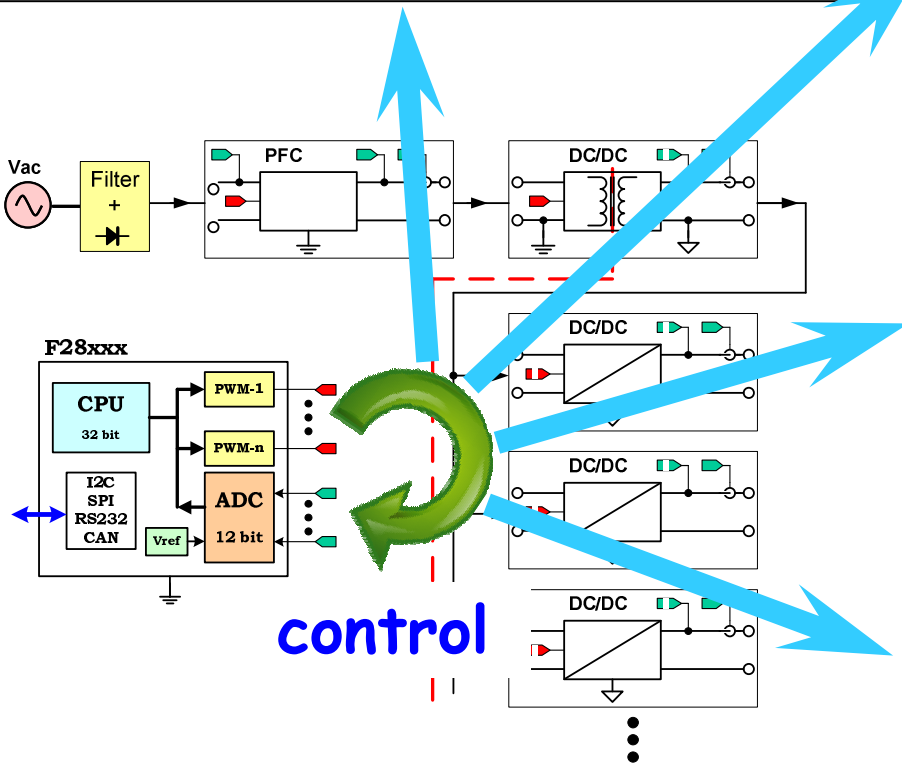


Avg Current Mode

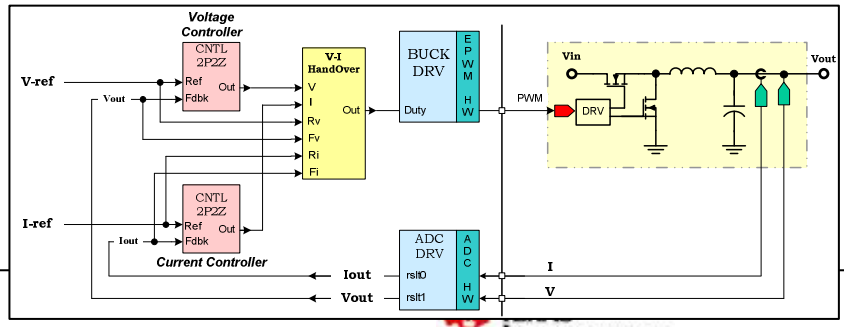


Peak Current Mode

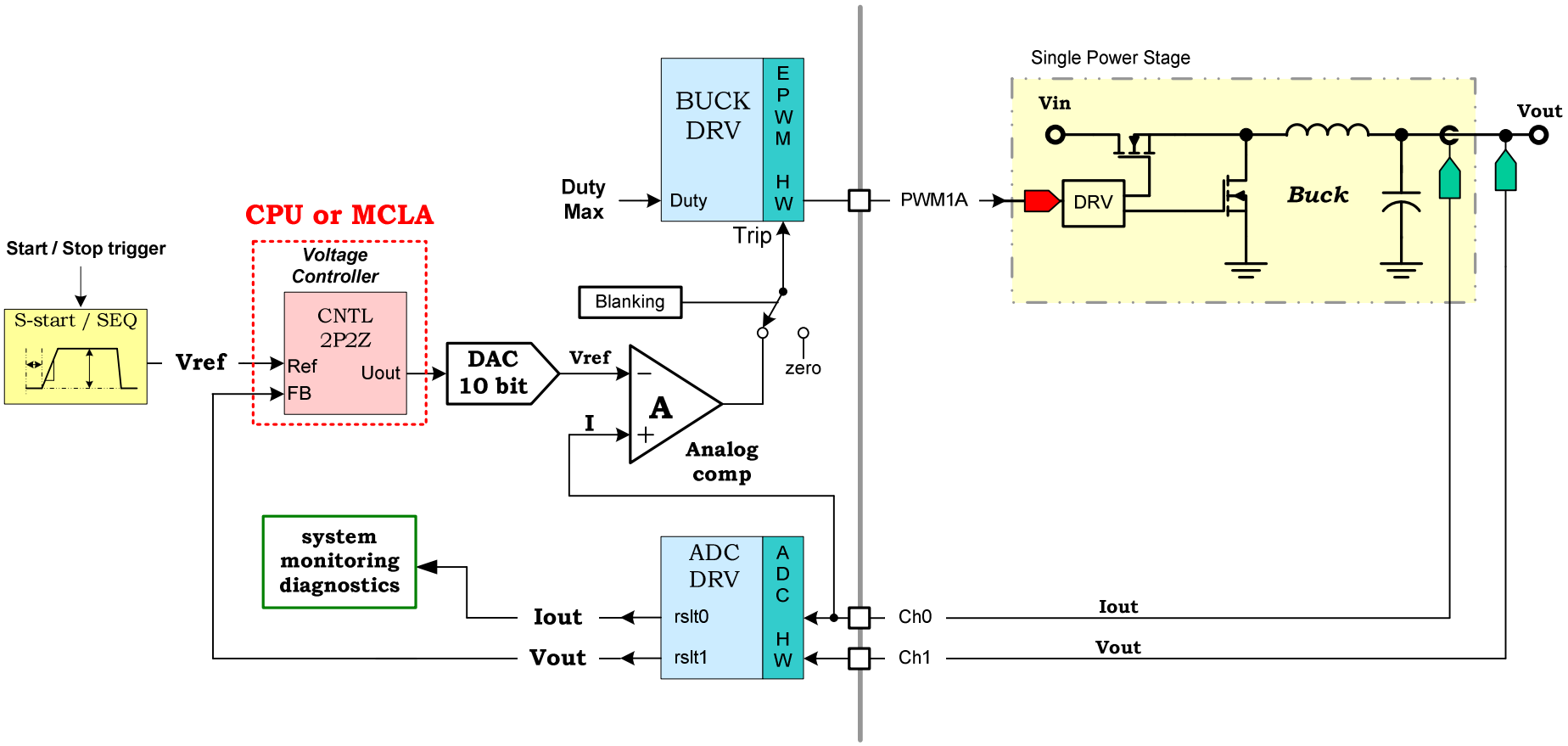




Constant Power

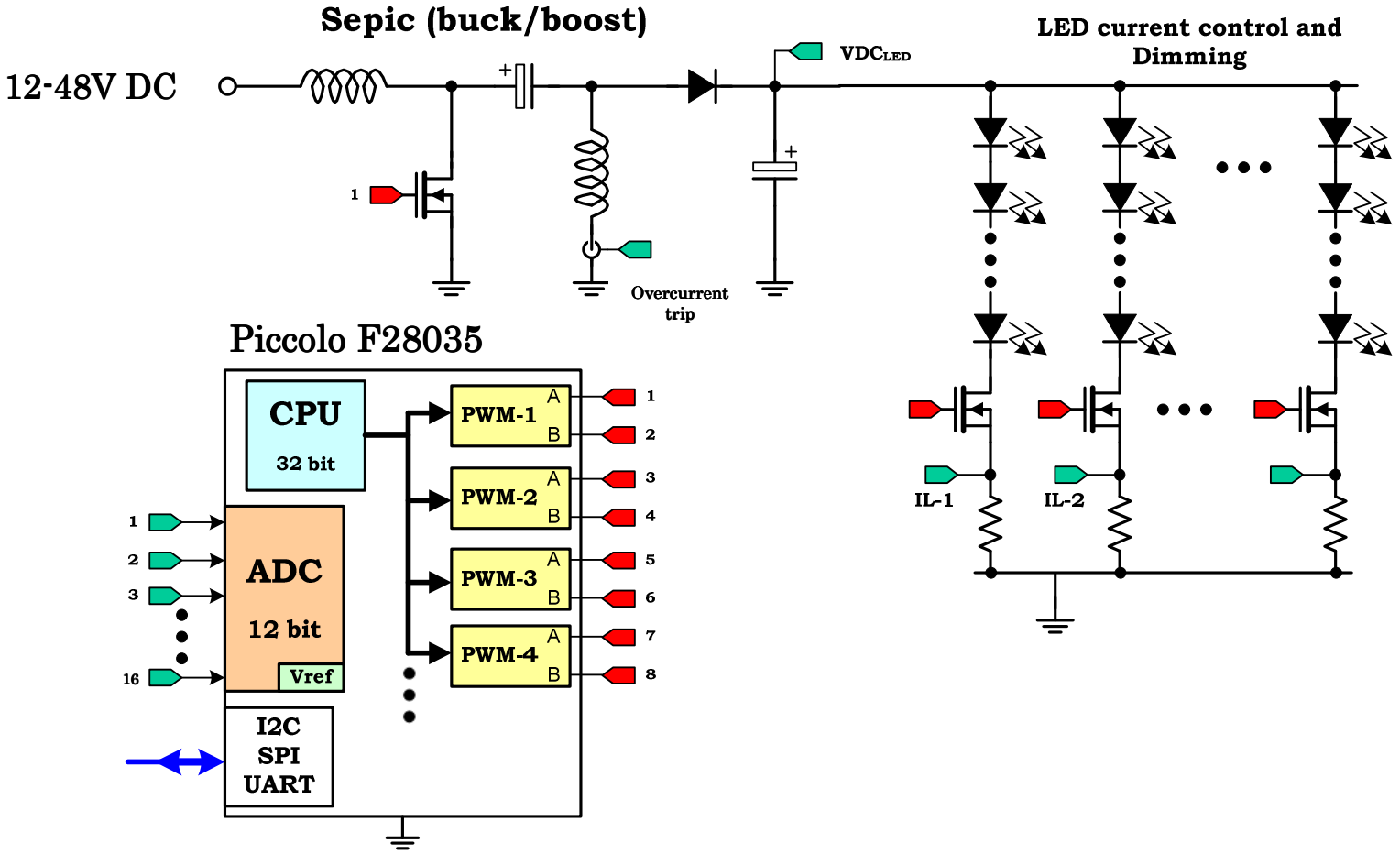


Peak Mode Current Control



LED Control Techniques

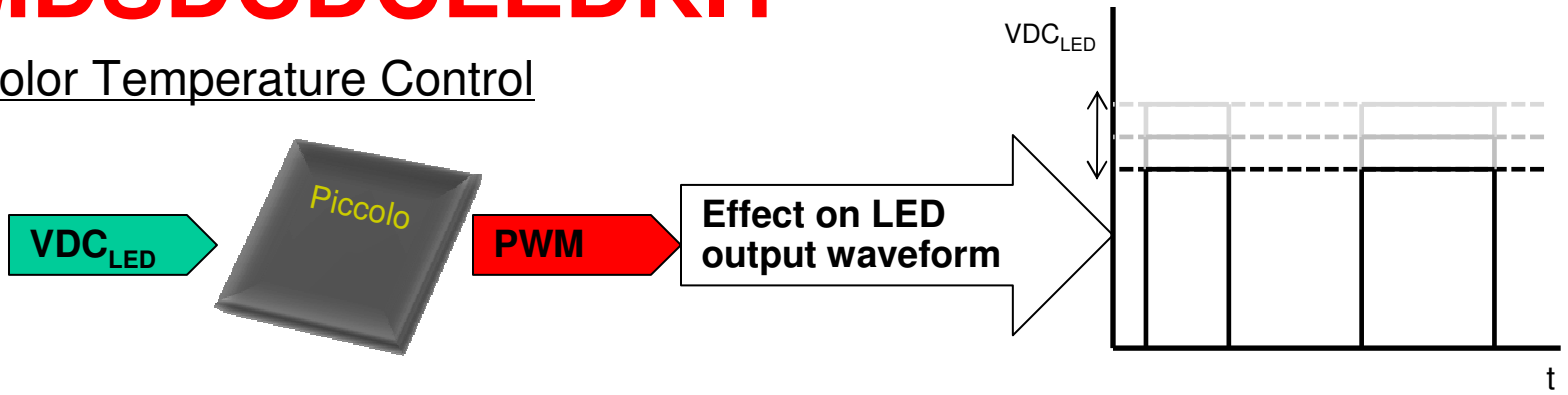
Power Topology - TMDSDCDCLEDKIT



Voltage bias level control and duty cycle dimming

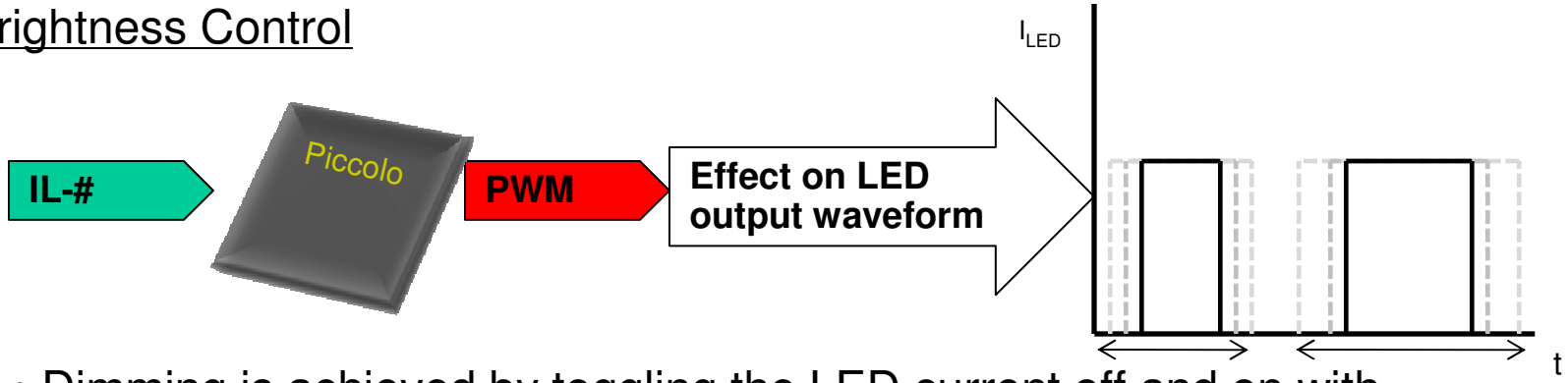
Control Explained… - TMDSDCDCLEDKIT

Color Temperature Control



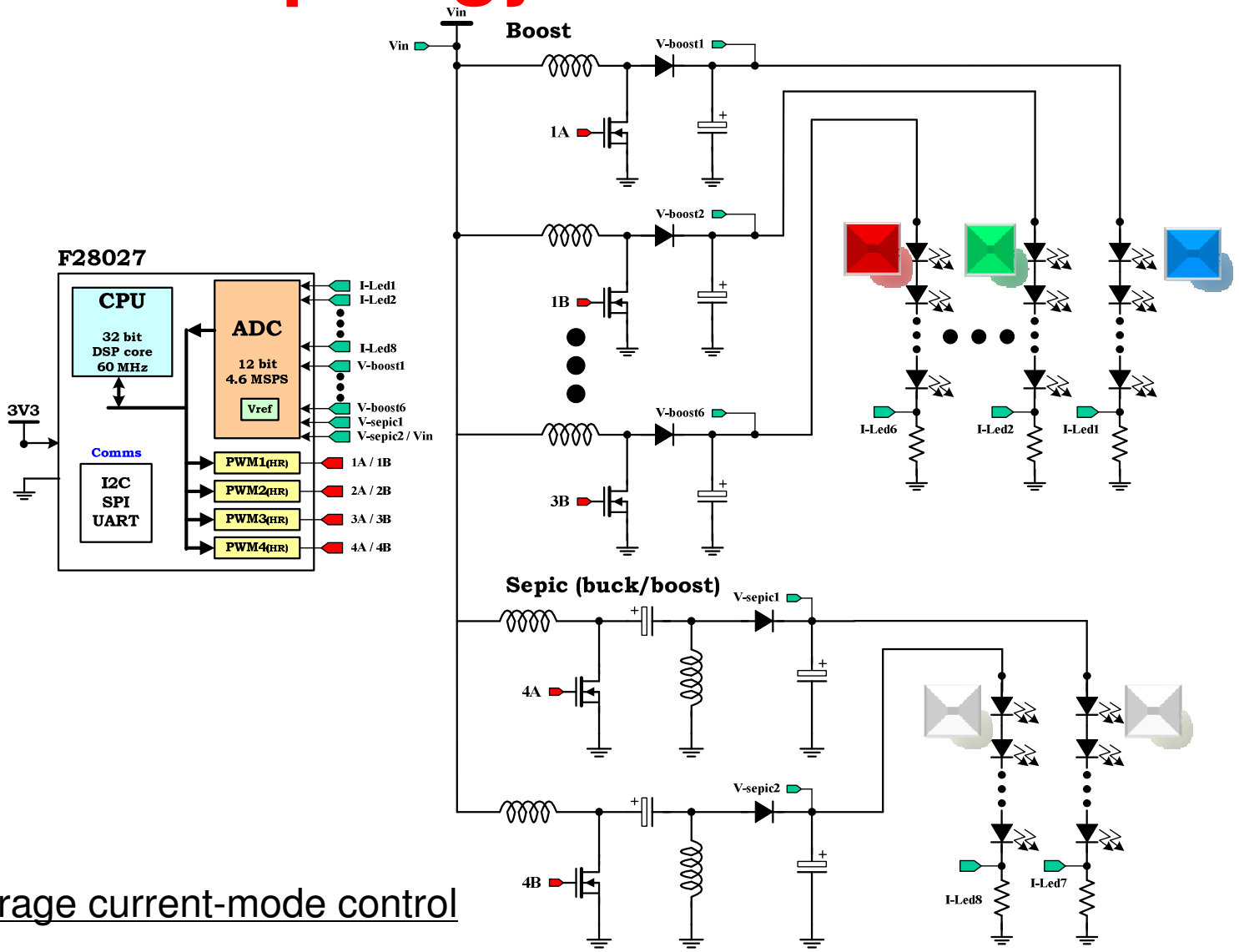
• The LED “on” voltage bias is varied through the SEPIC power stage to achieve desired color hue and LED efficiency

Brightness Control



• Dimming is achieved by toggling the LED current off and on with variable duty cycles

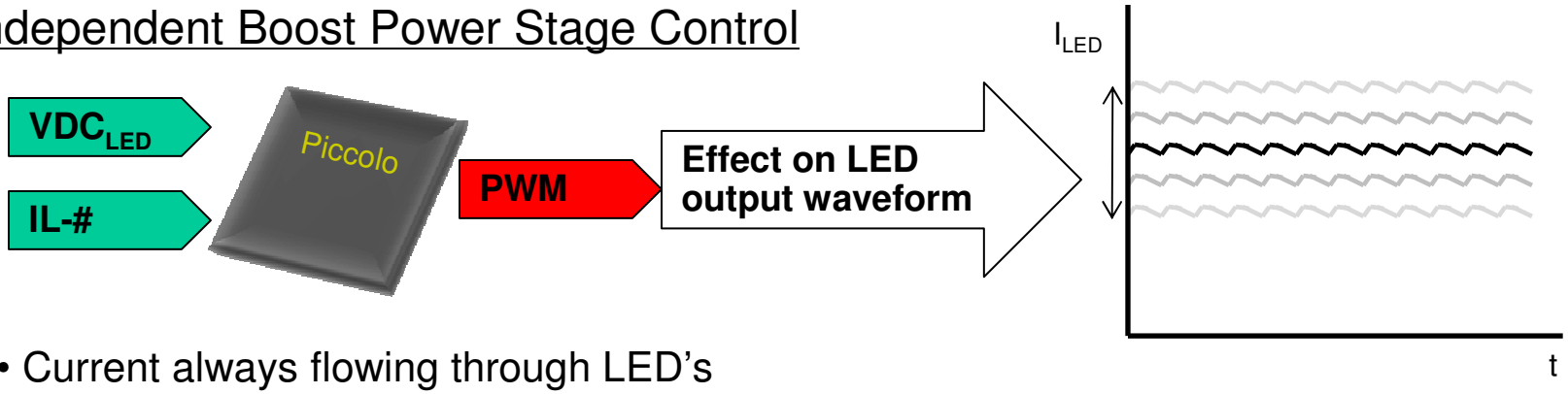
Power Topology - TMDSRGBLEDKIT



Average current-mode control

Control Explained… - TMDSRGBLEDKIT

Independent Boost Power Stage Control

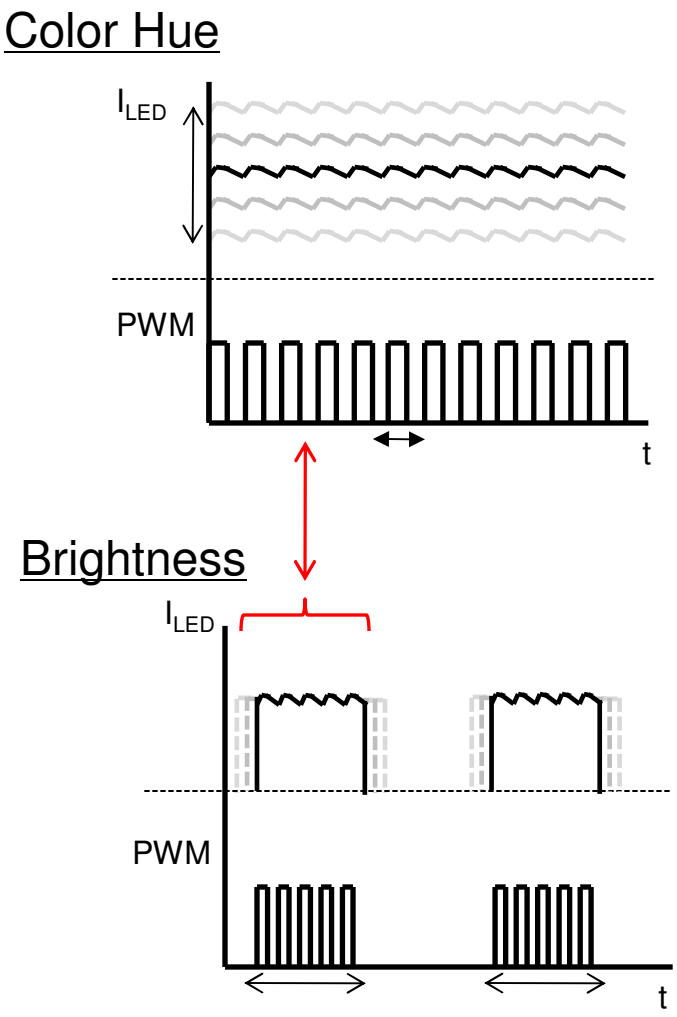


- Current always flowing through LED's
- Average current through LED's is adjusted by PWM duty cycle toggling
- Dimming is achieved by lowering and raising the average current flowing through the LED's
- Color levels are achieved by controlling the current levels through red, green, and blue LED strings. These LED light outputs mix to create the desired color output.
- By dimming red, green, and blue strings simultaneously, precise color control can be maintained while varying the brightness

TMDSRGBLEDKIT – More Advanced Control

With more advanced PWM generation, color hue could be precisely maintained while dimming an individual string:

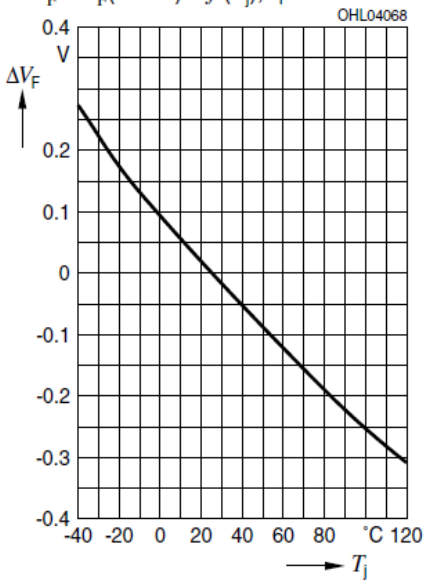
- Varying the period of the PWM chopper waveforms controls the color hue
- Varying the period of the overall PWM on/off periods control the brightness and dimming
- While dimming, color hue can be precisely maintained as long as the PWM chopper frequencies are unaltered during the overall “on” periods



Temperature Issues

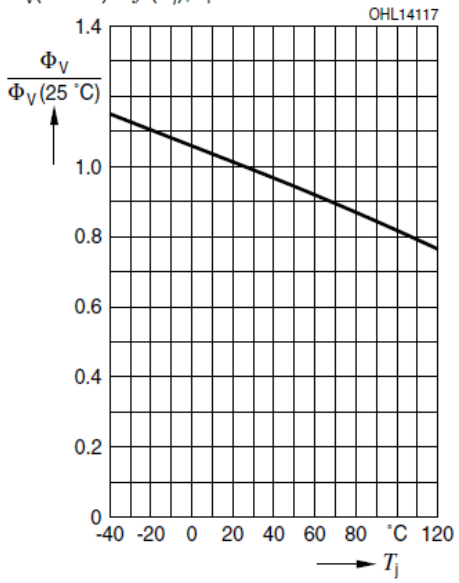
Relative Forward Voltage[2)4) *page 17*]

$\Delta V_F = V_F - V_F(25\ °C) = f(T_j)$; $I_F = 350$ mA



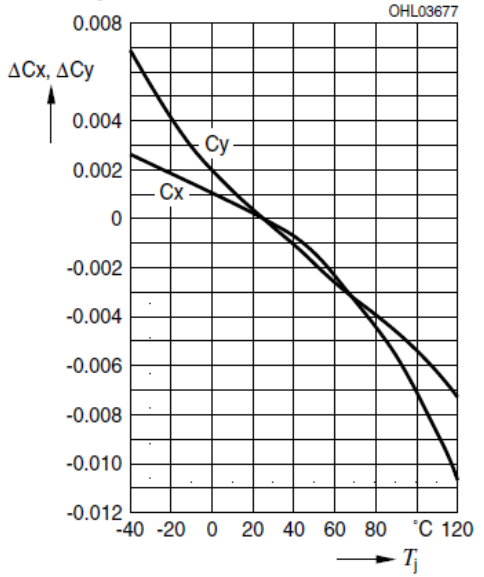
Relative Luminous Flux[2) page 22]

$\Phi_V/\Phi_V(25\ °C) = f(T_j)$; $I_F = 350$ mA



Chromaticity Coordinate Shift[2) page 22]

x, y = $f(T_j)$; $I_F = 350$ mA



- Average lifetime is based on assumptions of temperature. The average LED lifetime can be 50K hours or greater. With higher temperature this number becomes lower.
- As the LED junction temperature increases, luminous flux decreases.
- Other LED characteristics change with temperature
- A heatsink is required to maintain good thermal characteristics.
- If an temperature sensor is mounted to the LED panel, a microcontroller could compensate light output and/or provide overheating warnings to the system

Aging Compensation

- Like other light sources, LEDs age with time. This aging decreases the lumen output with respect to current. (see below)
- A digital controller could gradually increase the amount of current necessary to keep light output constant through the lifetime of the LED.
  - This could be done via a lookup table

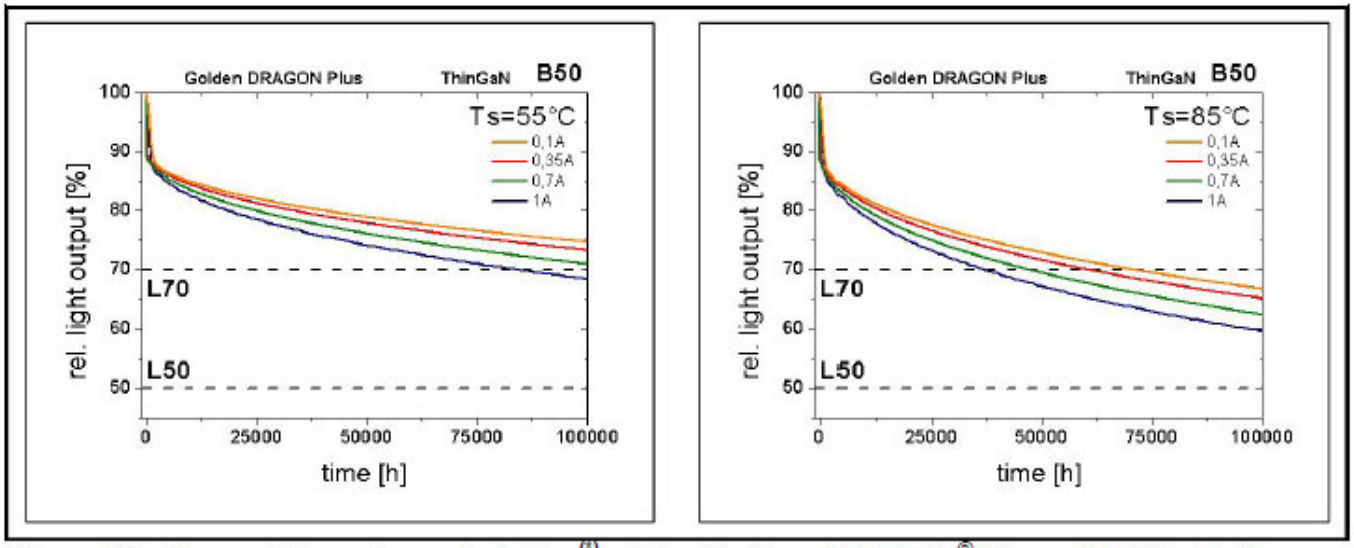


Figure 6b: Degradation characteristics(*) of the Golden DRAGON® Plus with ThinGaN technology for T_S = 55°C and T_S = 85°C (grouping current I_F = 0.35 A)

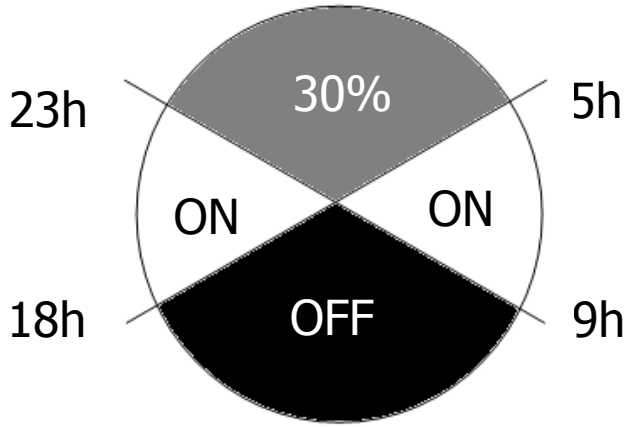
Ambient Light Compensation

- LEDs should light an area to a specific room brightness.
- Sense the current ambient light via a luminosity sensor
- A microcontroller could then use this sensor's input to control the current reference for the LED strings.

- Applications:
  - Streetlighting: Use LED power only during dawn/dusk/eclipses when ambient light is not high enough.
  - Commercial/Industrial Lighting: Maintain light levels in a room to a regulated safe level given by the company.

Dimming scheduler

- When full brightness is not always required LED lights could be dimmed (outdoor, office, architectural)
- Additional function maybe to vary Dimming profile depending on outdoor light sensor

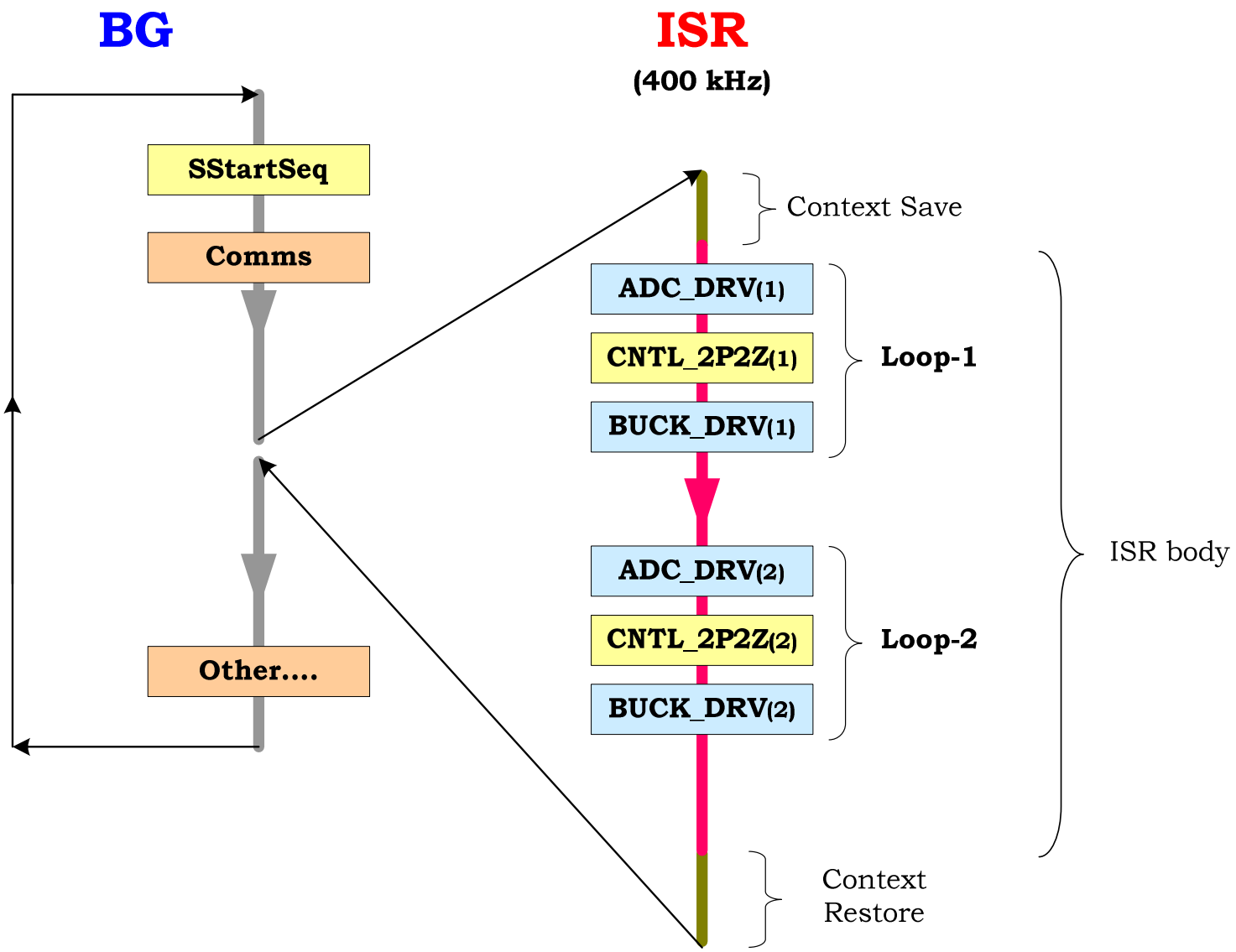


Software Examples and Digital Power Libraries

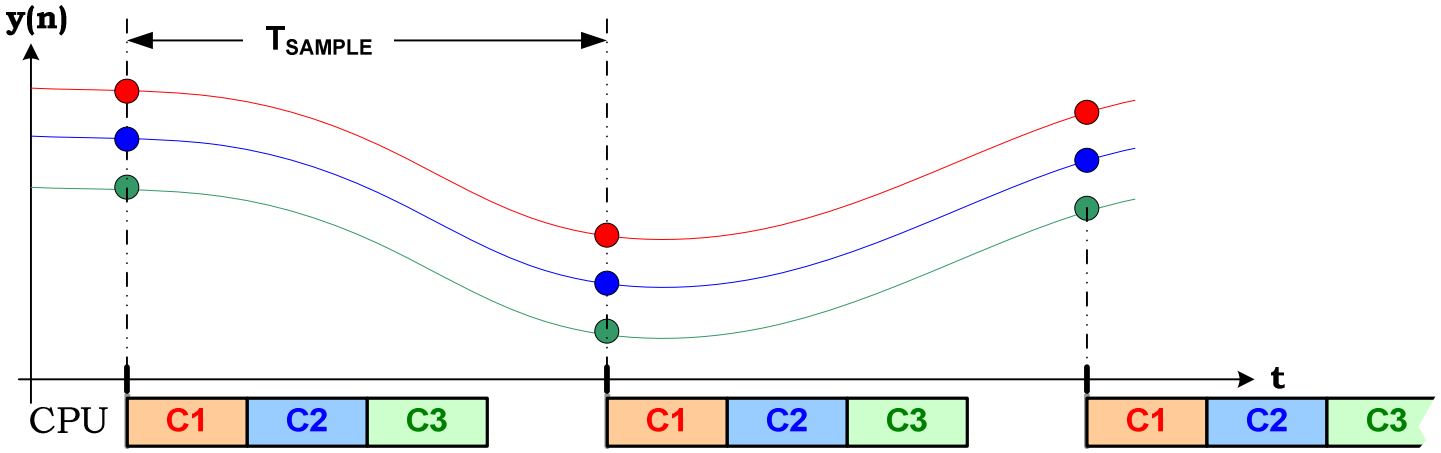
Control Software Basics

- Typically want to have one control loop interrupt and multiple background tasks
  - Single control loop interrupt runs all control loops
  - Enables software to be simple and loop execution time to be very deterministic
- For multiple control loop, the control loop interrupt runs at the speed of the fastest loop and the other loops are divided into sections
- Background loop runs all other tasks and services non-control (lower priority) interrupts
- This is TI's method for control software, some customers use and RTOS or other control schemes. The key is that the control loops must execute at a precise rate.

Software Structure

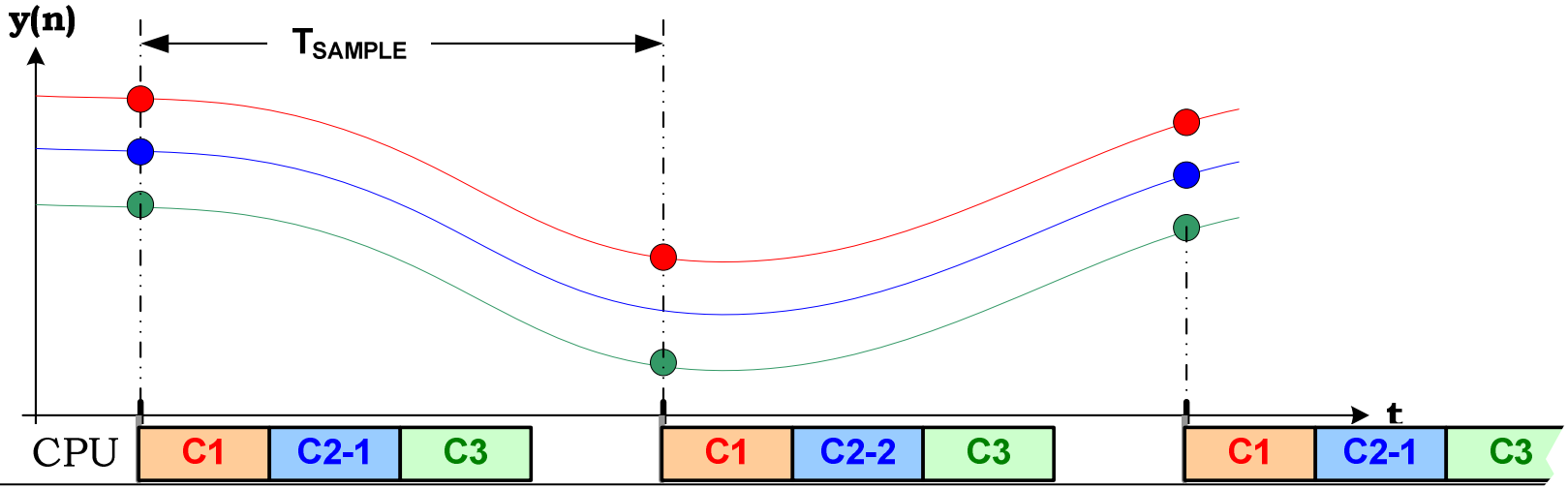


Running Multiple Loops

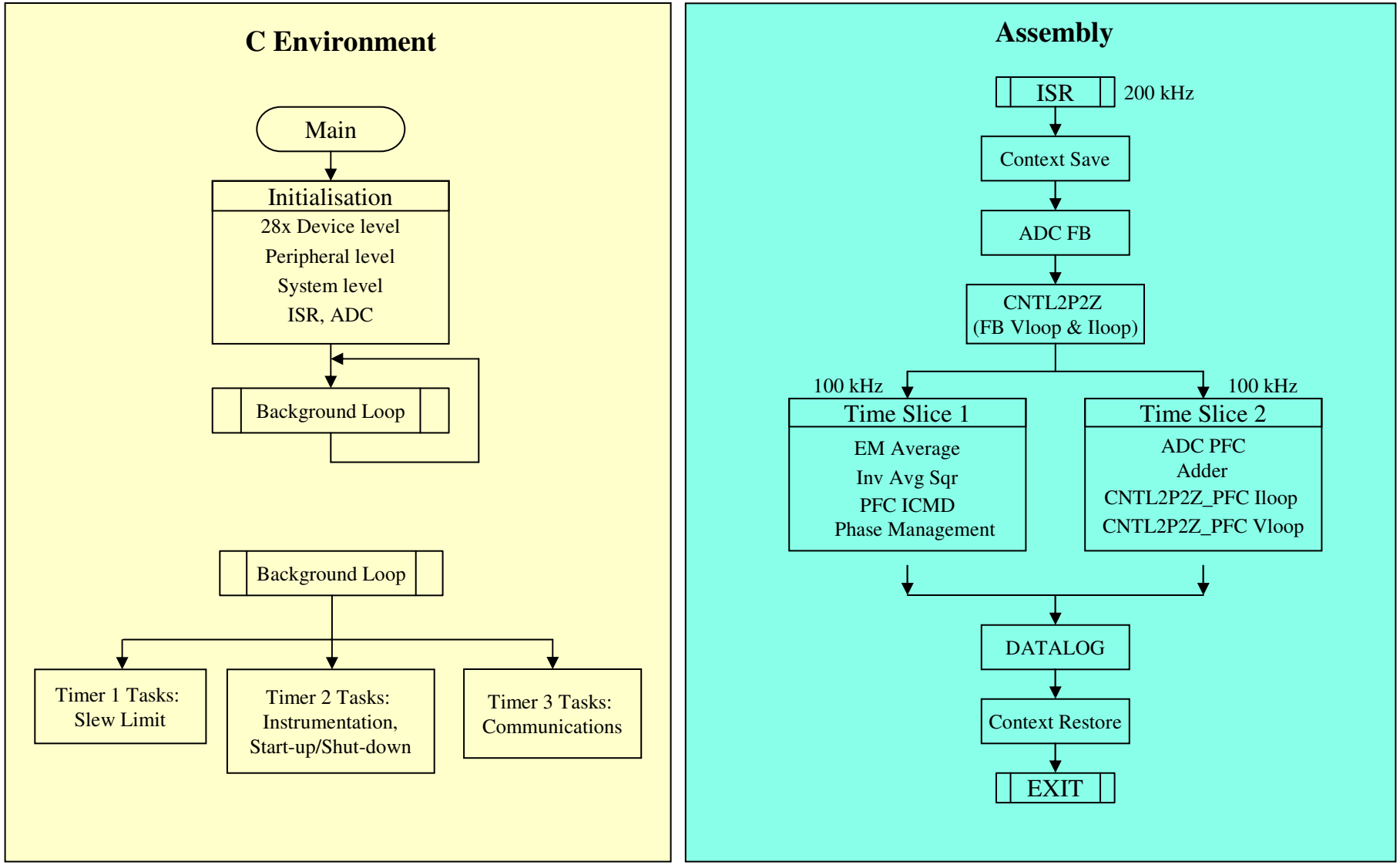


If you can close all the loops in a single Sample Time, GREAT!

If you can't, consider multiple Sample/Update Rates. Slower loops as a divisor of your fastest loop.
Time Division Multiplexing



Example: Rectifier Software



Software Examples and Libraries

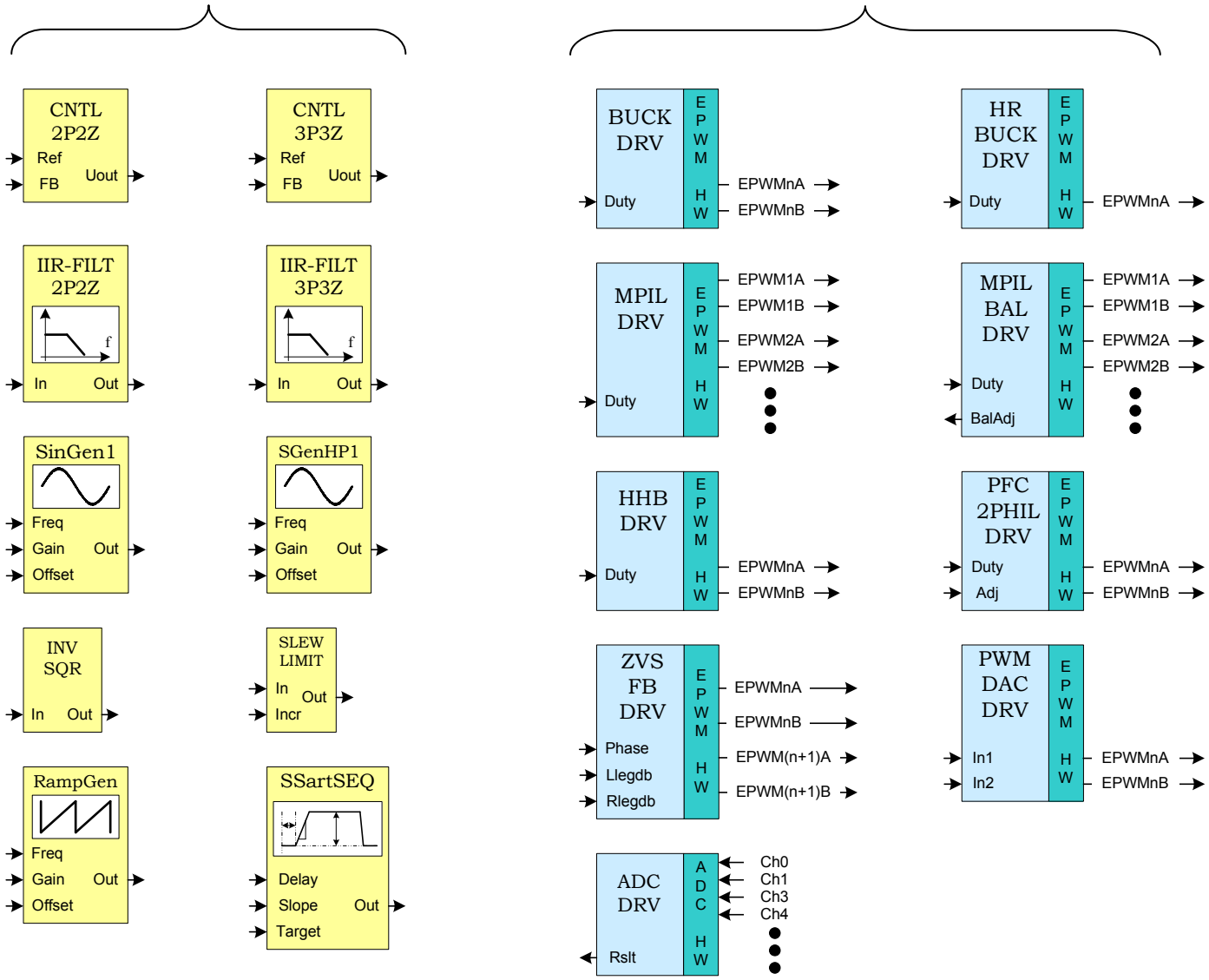
- TI's controlSUITE software platform includes examples and modular software libraries
  - With one download controlSUITE provides all digital power software and libraries for C2000 MCUs

- Digital power library uses a modular software approach, with each part of the system being an easy to use software block
  - Over 20 blocks for the C2000 CPU and the CLA
  - Digital power library includes detailed documentation for each block
  - Modular approach enables easy software development

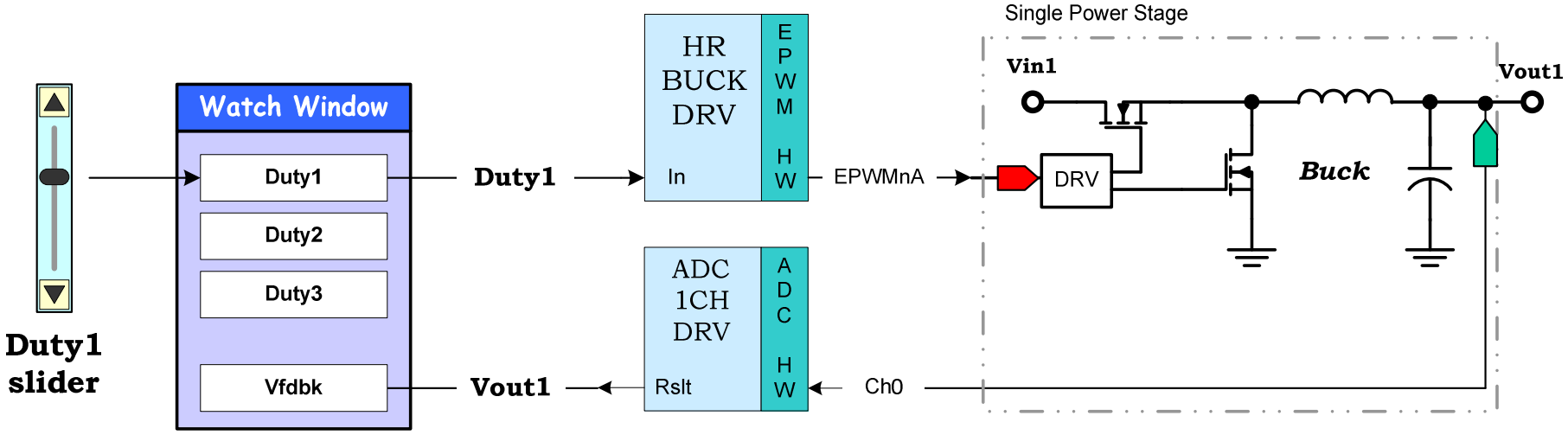
Digital Power Software Library

CPU dependency only:
- **Math / algorithms**
- **Multiple instanciation**

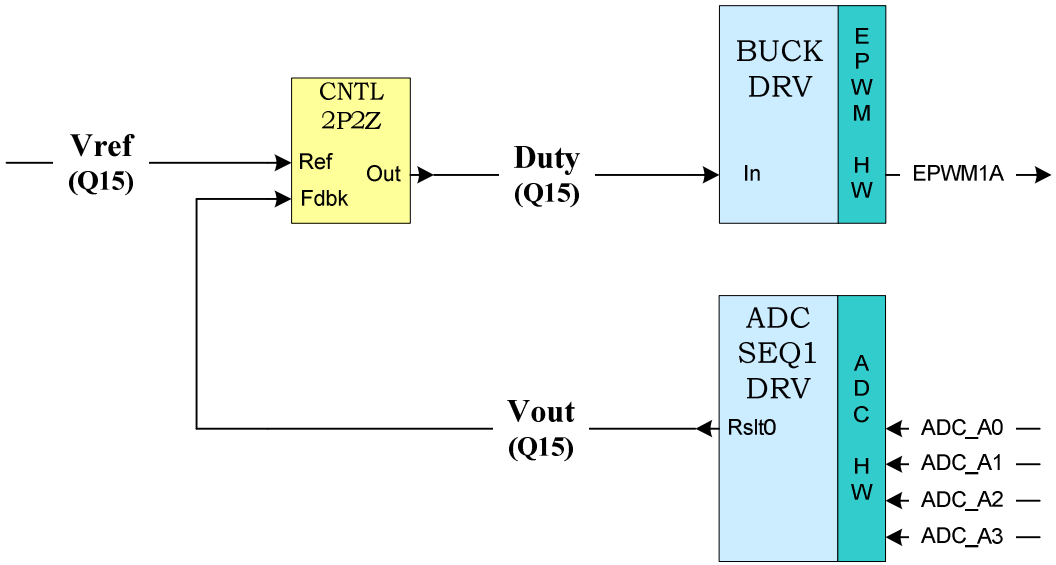
Hardware dependent:
- **Configuration required**
- **Limited instanciation**



Simple Open-Loop Diagram



Macro Module Connection



Initialisation in C:

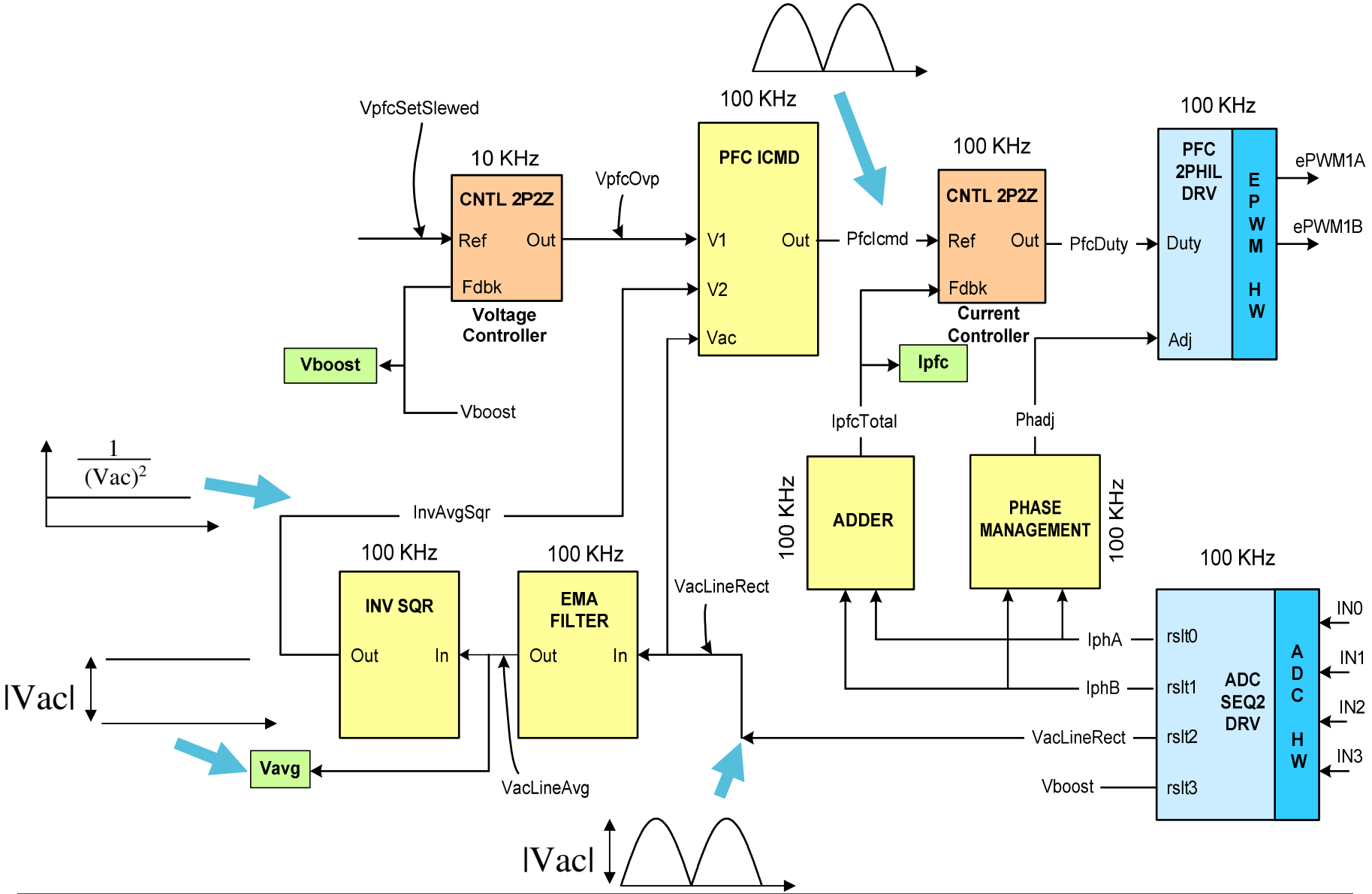
```
// pointer & Net declarations
int *CNTL_Ref1, *CNTL_Fdbk1, *CNTL_Out1;
int *BUCK_In1, *ADC_Rslt1;
int Vref, Duty, Vout;

// "connect" the modules
CNTL_Ref1 = &Vref;
CNTL_Out1 = &Duty; BUCK_In1 = &Duty;
CNTL_Fdbk1 = &Vout; ADC_Rslt1 = &Vout;
```

Run-time macro execution:

```
; execute run-time macros
ADC_SEQ1_DRV   1
CNTL_2P2Z 1
BUCK_DRV  1
```

Example: Example PFC + PSFB



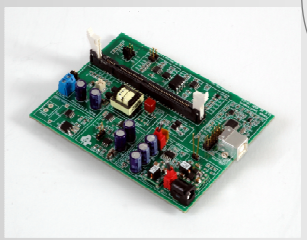
LV Development Kits and Solutions

Digital Power and Inverter Kits

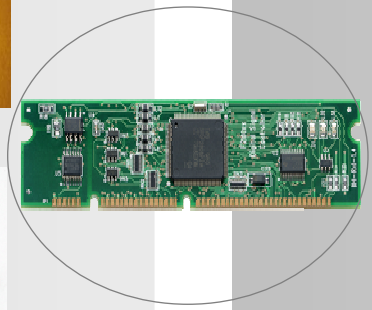
DC/DC Kits

Digital Power Experimenter's Kit
TMDSDCDC2KIT
$229

Resonant DC/DC Developer's Kit
TMDSRESDCKIT
$229



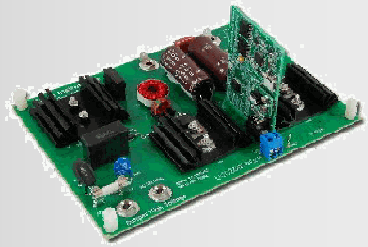
Digital Power Developer's Kit
TMDSDCDC8KIT
$325



AC/DC Kits

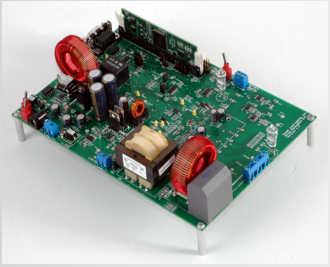
AC/DC Developer's Kit
TMDSACDCKIT
$695

High Voltage PFC Developer's Kit
TMDSHVPFCKIT
$249



DC/AC Kit

Renewable Energy Developer's Kit
TMDSENRGYKIT
$349



Texas Instruments

Digital Power Experimenter's Kit
Application Development

$229 Kit Includes

- F2808 controlCARD
- 2-rail DC/DC EVM using TI PowerTrain™ modules (10A)
- On-board digital multi-meter and active load for transient response tuning
- Code Composer Studio v3.3 with code size limit of 32KB
- C2000 Applications software with example code
- Full hardware details
- Quick Start Guide
- 9V power supply
- Digital Power Supply workshop teaching material and lab software

Stand alone JTAG emulator required.
Recommended emulators.

Part number: TMDSDCDC2KIT

Digital Power Developer's Kit
Application Development

$325 Kit Includes

- F28044 controlCARD
- 8-rail DC/DC EVM using TI PowerTrain™ modules (10A)
- Code Composer Studio v3.3 with code size limit of 32KB
- C2000 Applications software with example code
- Full hardware details
- Quick Start Guide
- 9V power supply

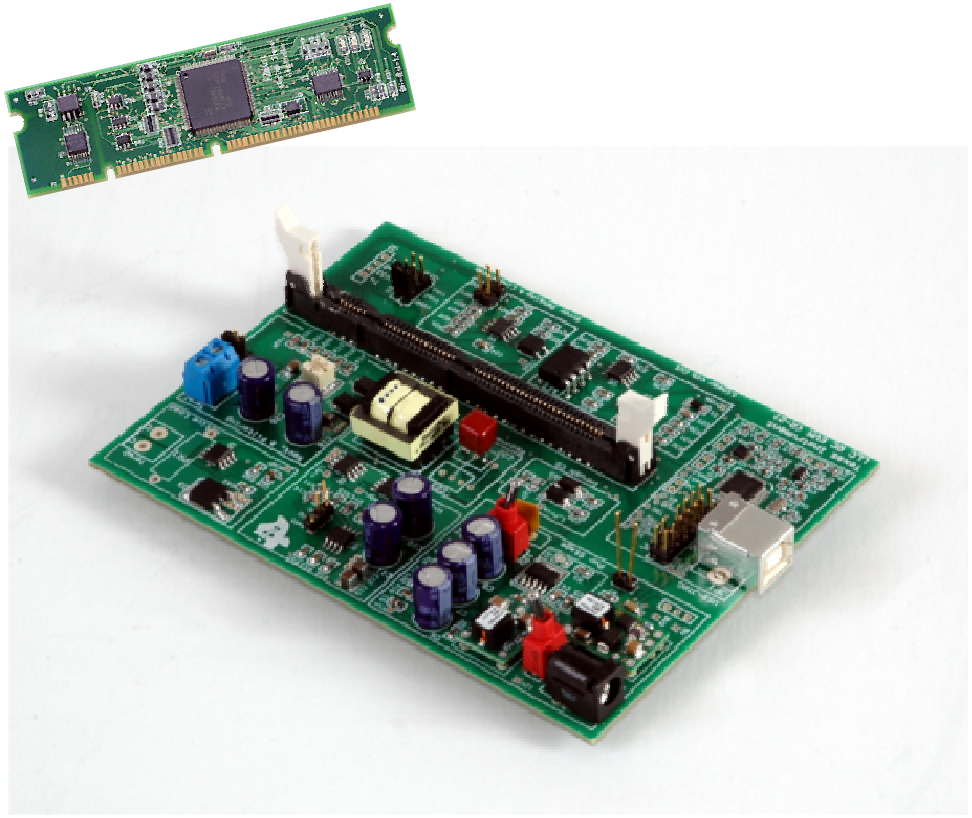
Stand alone JTAG emulator required.
Recommended emulators.

Part number: TMDSDCDC8KIT

Resonant DC/DC Developer's Kit
Application Development

$229 Resonant DC/DC Kit Includes

- F2808 controlCARD
- Single transformer LLC type resonant DC/DC EVM
  - 16-22V DC input, 15 watt 12V regulated DC output, with 50mV ripple under full load
  - Four different feedback methods
  - In-rush current sensing
  - Active load for transient response tuning
  - **Onboard USB JTAG emulation**
- Code Composer Studio v3.3 with code size limit of 32KB
- C2000 Applications software with example code



No external emulator required!

Part number: TMDSDCRESKIT

Renewable Energy Developer's Kit
Application Development

$349 Renewable Energy Kit Includes

- F2808 controlCARD
- ~45 Watts DC/AC Inverter
  - 15-20V DC input, 30V AC output, ~45 Watts
  - Front end single phase boost
  - Single phase inverter output implemented; board designed for single or three phase
  - Battery charging and management
  - Relay to switch between battery & solar panel.
  - AC line sensing and synchronization
  - All necessary voltage and current measurements for advanced development
- Code Composer Studio v3.3 with code size limit of 32KB
- C2000 Applications software with example code

Stand alone JTAG emulator required.
Recommended emulators.

Part number: TMDSENERGYKIT

AC/DC Developer's Kit
Application Development

$695 AC/DC Developer's Kit

- F2808 controlCARD
- AC/DC EVM with interleaved PFC and phase-shifted full-bridge
  - 12VAC in, 80W/10A output
  - Primary side control
  - Synchronous rectification
  - Peak current mode control
  - Two-phase PFC with current balancing
- Code Composer Studio v3.3 with code size limit of 32KB
- C2000 Applications software with example code
- Full hardware details
- Quick Start Guide

Stand alone JTAG emulator required.
Recommended emulators.

Part number: TMDSACDCKIT

HV Power Supply Kits

C2000 Fits in all Power Applications

Typical “Offline” Power Supply Stages for >~600W Power Supplies

AC Input
85 – 265VAC

→ • Rectifier Bridge PFC
• Bridgeless PFC

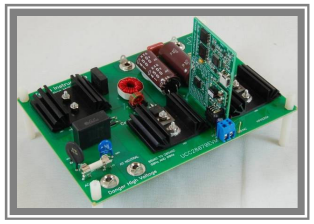
→ DC Output
350 – 410 VDC

→ • Resonant LLC
• Phase Shifted Full Bridge

→ DC Output
12 – 48VDC

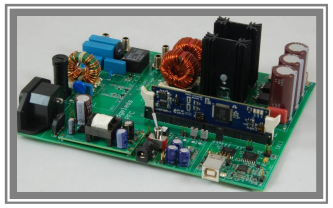
→ • Multiple Buck, SEPIC, Flyback, Cuk, etc.
• Boost / Buck

→ Board level voltages
1.5V, 3.3V, 5V, etc.



Rectifier Bridged PFC
- Traditional Design
- PF >0.9
- Efficiency >90%
- Lower Inductor Cost but less efficient due to loss in rectifier bridge

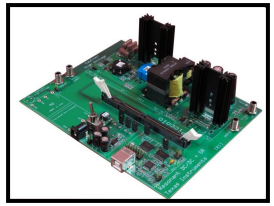
TMDSHVPFCKIT



Bridgeless PFC
- Emerging Topology
- Higher Efficiency
- PF >0.99
- Efficiency ~95%
- Higher Inductor Cost but no rectifier diodes

TMDSHVBLPFCKIT

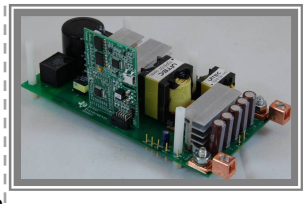
Resonant LLC, ZVS



- 200 - > 1500W
- Zero Voltage Switching control

TMDSHVRESLLCKIT

Phase Shifted Full Bridge



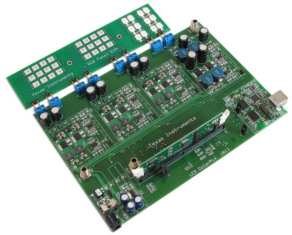
- 400-5000W+
- Peak Current Mode Control

TMDSHVPSFBKIT

8 Channel DC/DC Buck

- Control of 8 independent 10A Power Stages
- Control Phase, Voltage and / or Current on each channel

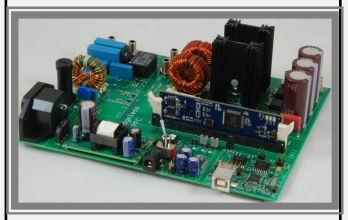
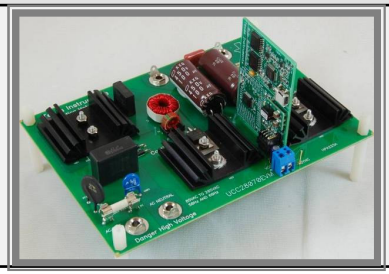
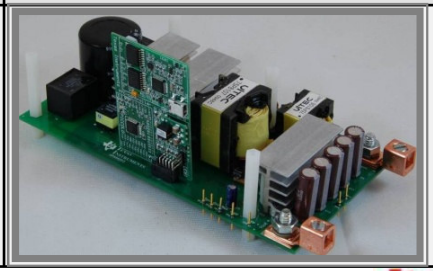
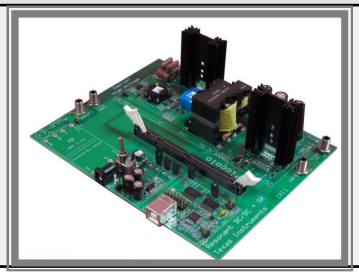
Multi-String / Multi-Color LED Drive



- 6x boost stages driving RGB LEDs
- 2x SEPIC stages driving white LEDs
- Control Brightness, Color, etc

TMDSRGBLEDKIT

High Voltage Reference SOLUTIONS

	TMDSHVBLPFCKIT	TMDSHVPFCKIT	TMDSHVPSFBKIT	TMDSHVRESLLCKIT
Topology	High Efficiency Bridgeless PFC AC/DC Developers Kit	High Voltage PFC Developers Kit AC/DC	Phase Shifted Isolated Full Bridge DC/DC Developers Kit	Resonant LLC Isolated Half Bridge DC/DC Developers Kit
Control Method	• Half Cycle RMS Feed Forward • Auto Compensate • Pgain, Igain, Dgain Loop Control	• Auto Compensate • Pgain, Igain, Dgain Loop Control	• Peak Current Mode Control with Slope Compensation • Voltage Mode • Soft Start / Ramp • OVP, OCP, UVP	• Zero Voltage Switching Mode • Zero Current Switching •Frequency Modulation Voltage Mode Control • Burst Mode Control • Soft Start / Ramp • OVP, OCP, UVP
Device	F28035*	F28027	F28027	F28027
Input / Output Voltage	•Universal 90– 260VAC Input •400VDC Output	•Universal 90-260VAC Input •400VDC Output	•400VDC Input •12V regulated Output	•400VDC Input •12V Regulated Output
Cost	$450	$249	$550	$375
				

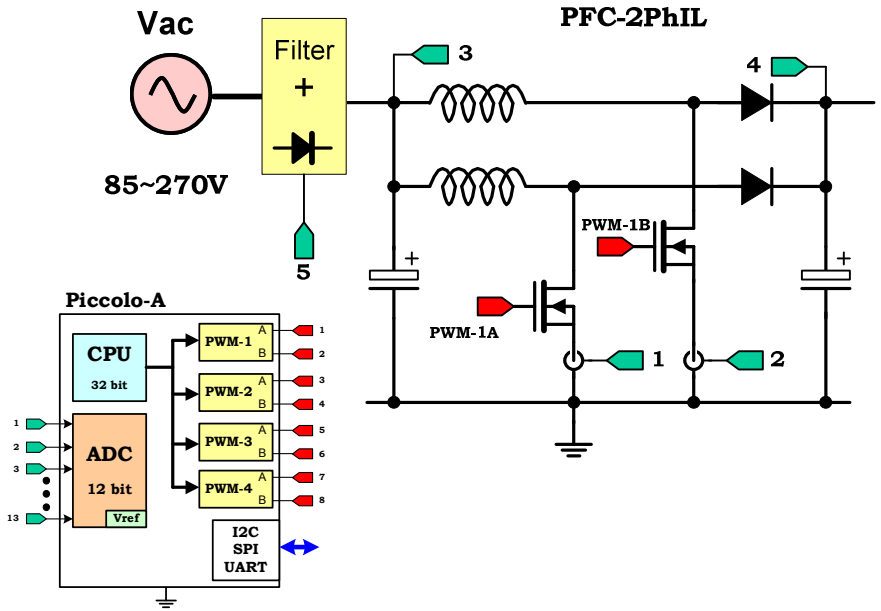
HV PFC (2 phase-Interleaved)

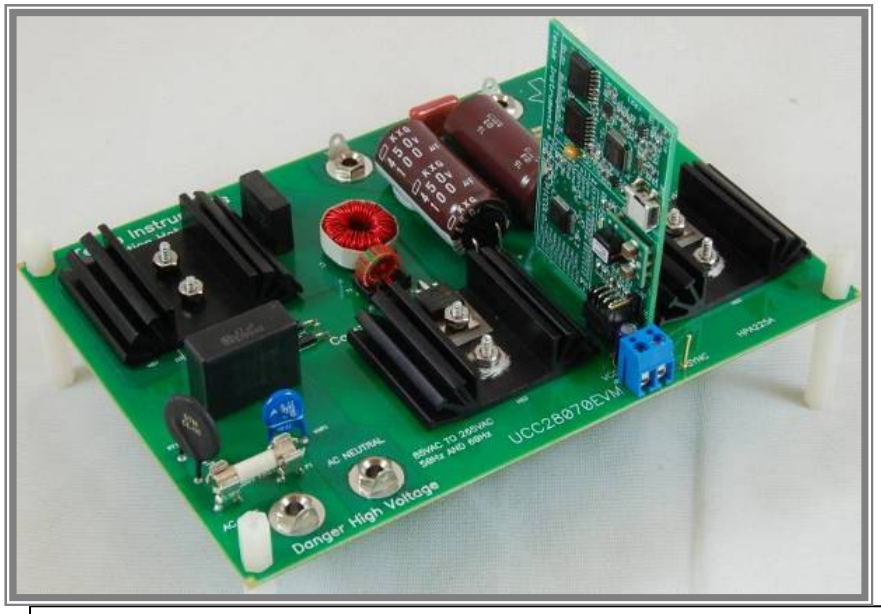
Description

- 85~285V AC input (universal)
- 2 phase interleaved
- PFC boost – 400V
- 300W
- Isolated JTAG

Markets / EEs

- Telecom and Server ACDC power
- Industrial, UPS
- EV battery charging





HW status

Proto ☑ TE ☑ EVM ☑

SW deliverables

- PFC with 2 Phase IL Boost (I+V loop)

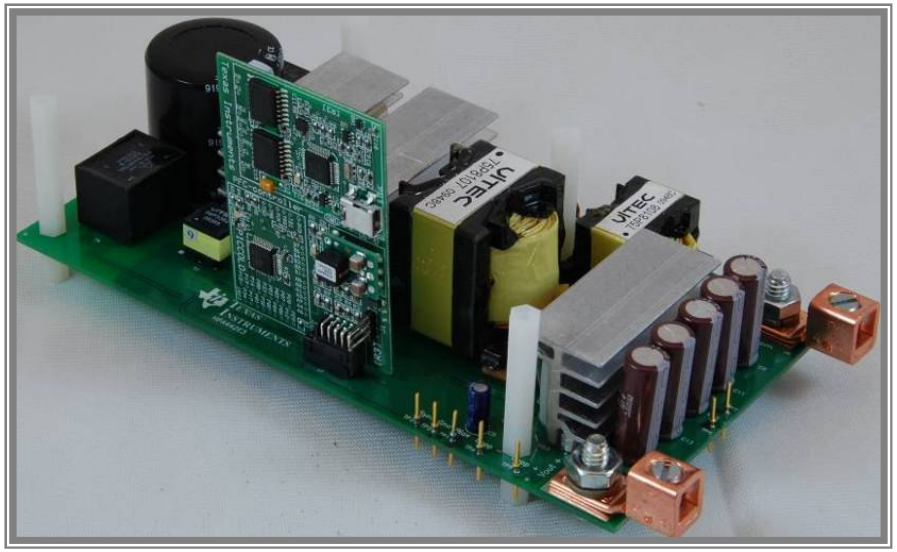
HV PSFB + SR

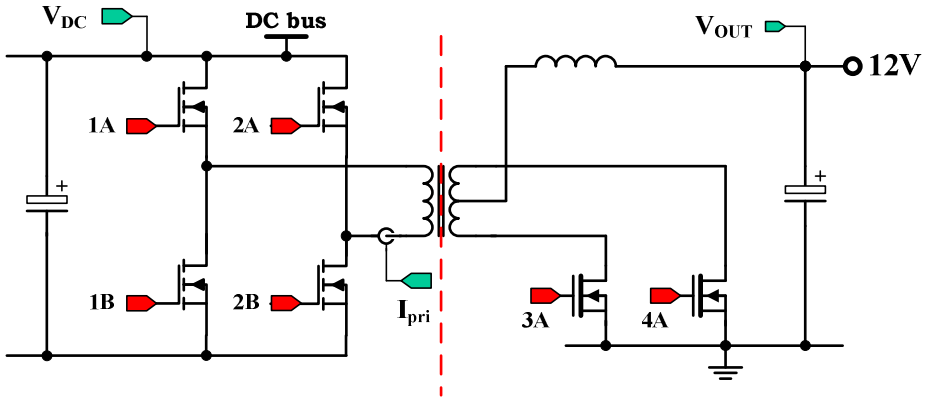
Description

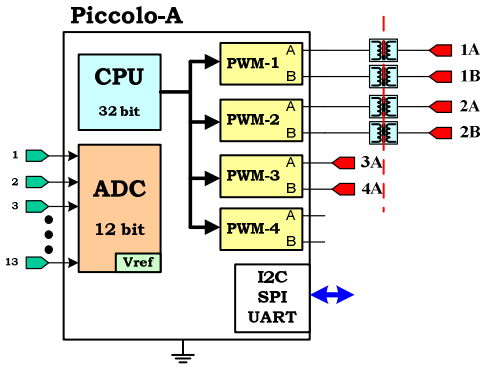
- 300~400V DC input / 12V output
- Phase Shifted Full Bridge
- Synchronous Rectifiers on output
- 600W
- Isolated JTAG

Markets / EEs

- Telecom and Server ACDC power
- Industrial, Solar DCDC
- EV battery charging







HW status

Proto ☑ TE ☑ EVM ☑

SW deliverables

- ZVS with V + Avg loop + simple SR
- ZVS with V + PCM loop + adaptive SR

Texas Instruments

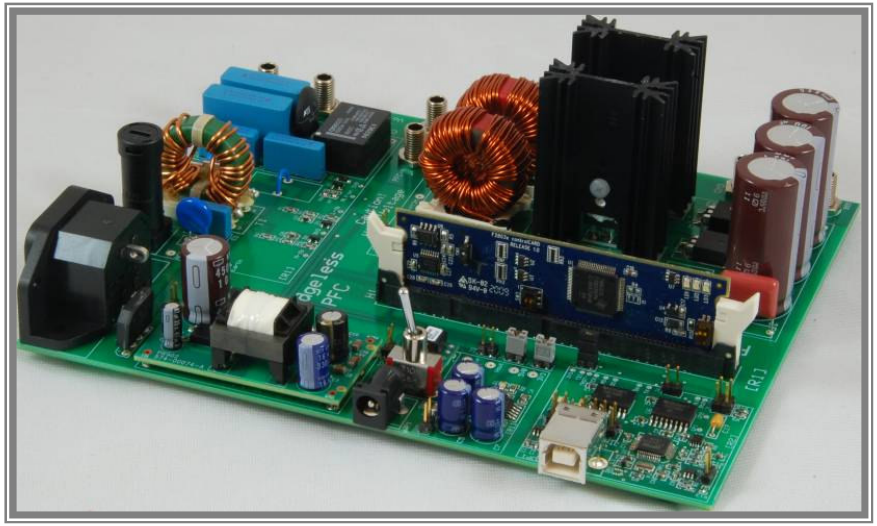
HV PFC Bridgeless

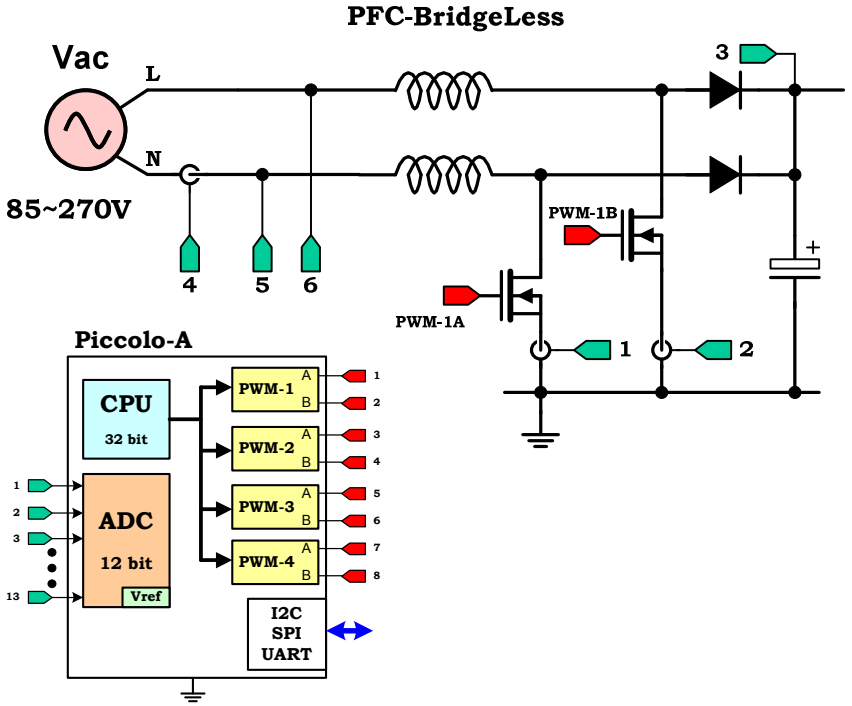
Description

- 85~285V AC input (universal)
- PFC boost – 400V
- Higher Efficiency
- 300W
- Isolated JTAG

Markets / EEs

- Telecom and Server ACDC power
- Industrial, UPS
- EV battery charging





HW status

Proto ☑ TE ☑ EVM ☑

SW deliverables

- PFC with Bridgeless Boost (I+V loop)
- Input Power measurement

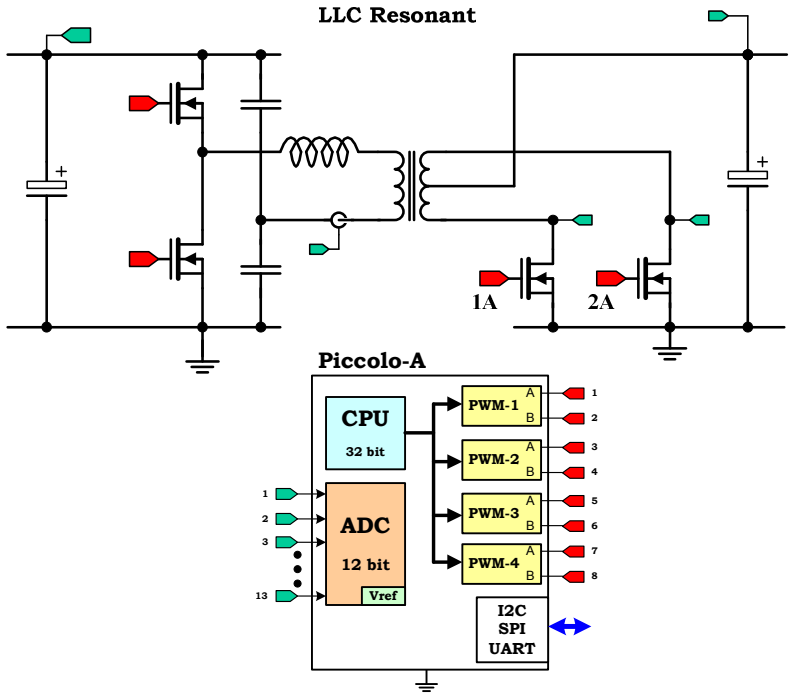
HV Resonant LLC

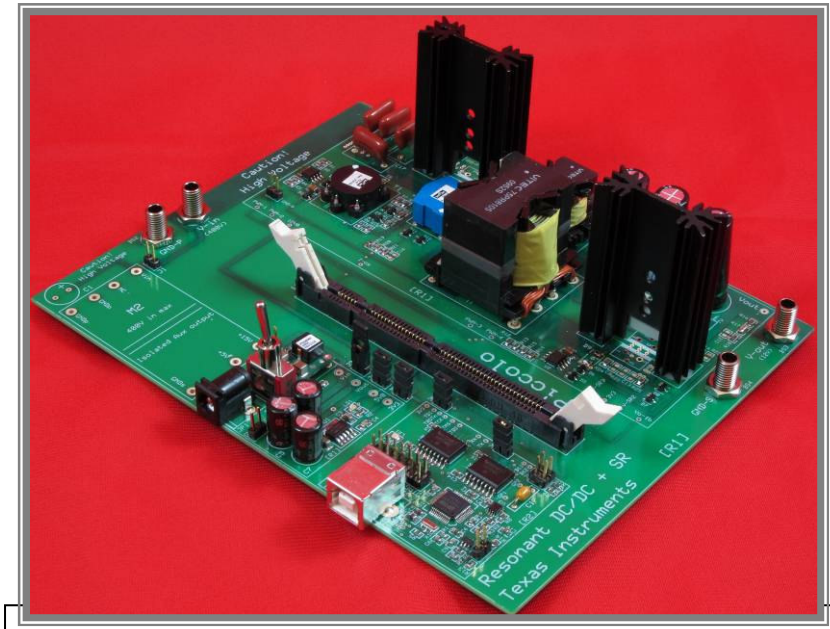
Description

- 300~400V DC in / 12V DC out
- Half Bridge + SR / 300W
- Frequency controlled (150~500KHz)
- Higher Efficiency DCDC
- Isolated JTAG

Markets / EEs

- Telecom and Server ACDC power
- Industrial, Solar,
- EV battery charging





HW status

Proto ☑ TE ☑ EVM ☑

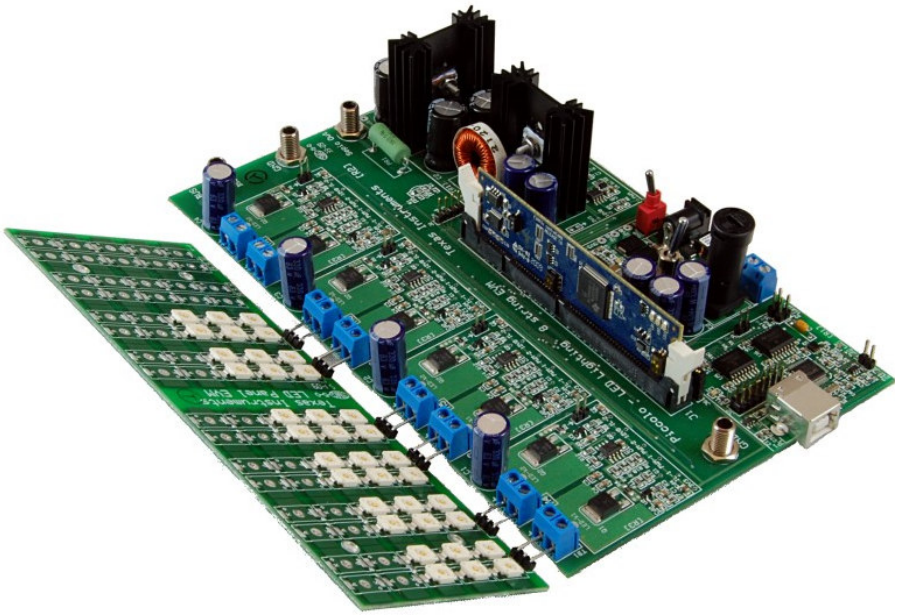
SW deliverables

- Frequency controlled V-loop with SR timing
-

LED Lighting Kits

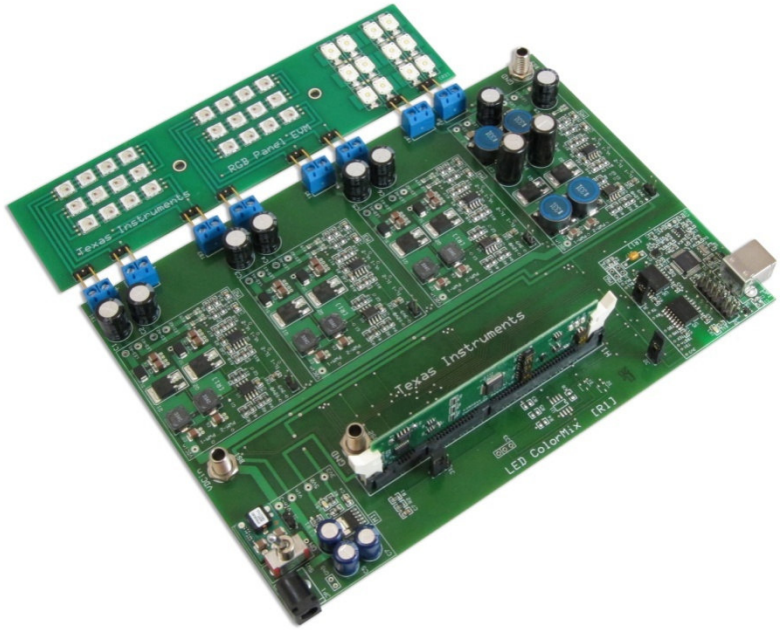
C2000 LED Lighting Developer's Kits

DC/DC LED Lighting Developer's Kit



TMDSDCDCLEDKIT

Multi-DC/DC Color LED Kit

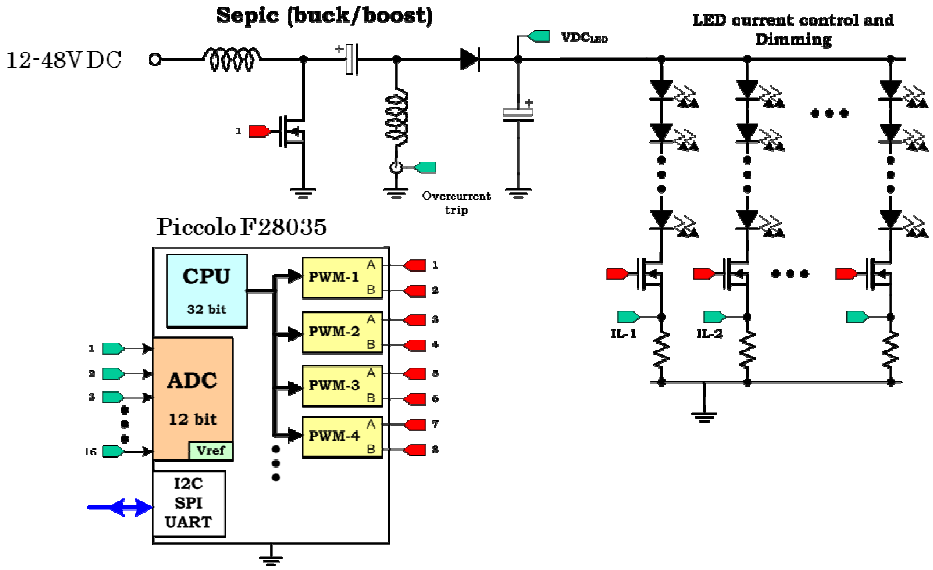


TMDSRGBLEDKIT

DC/DC LED Lighting Developer's Kit

Hardware

- **Piccolo F28035 controlCARD based platform**
- **Common SEPIC DC/DC power conversion stage**
  - 12-20V input, 24V output
- **8 independent 10 watt LED string driver stages**
  - Current sensing for each string
  - Each driver stage's power from common SEPIC DC/DC
- **Onboard isolated XDS100 USB JTAG emulation**



No external emulator required!

Price: $379
Part number: TMDSDCDCLEDKIT
Available now!

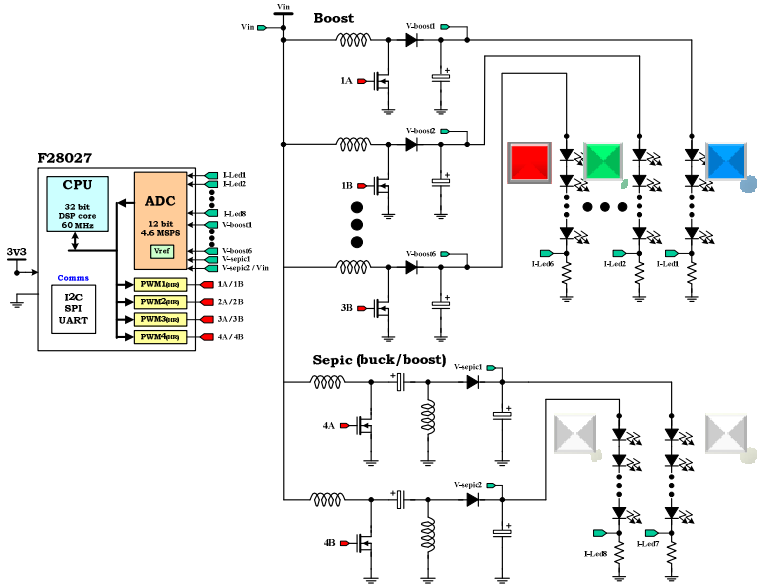
Software

- **Included in controlSUITE**
- Digital DC/DC SEPIC closed loop regulated control
- Digital independent brightness control of each string based on current
- Incremental builds walk developers through the design process
- Includes CCS v4

Multi-DC/DC Color LED Kit

Hardware

- **Supports up to eight LED strings of variable length and variable type LEDs**
- **Eight independent DC/DC power stages:**
  - 6x Boost, driving RGB LED strings
  - 2x SEPIC, driving white LED strings
- **36V (max) DC input, 50V (max) DC output**
- **400mA/string max current**
- **Piccolo F28027 controlCARD**
- **Onboard isolated XDS100 JTAG Emulation**
- **Detachable diffusion panel diffuses light output for demonstration of real-world lighting applications**



Software

- **Digital DC/DC SEPIC and Boost closed-loop, regulated control**
- **Digital brightness and color control of each string based on average current-mode control**
- **Simple GUI interface for out of the box experimentation with color mixing**
- **Incremental builds walk developers through the design process**
- **Includes CCS v4**

Price: $499
Part number: TMDSRGBLEDKIT
Availability: Now

Available in controlSUITE™ and on the web at www.ti.com/c2000tools

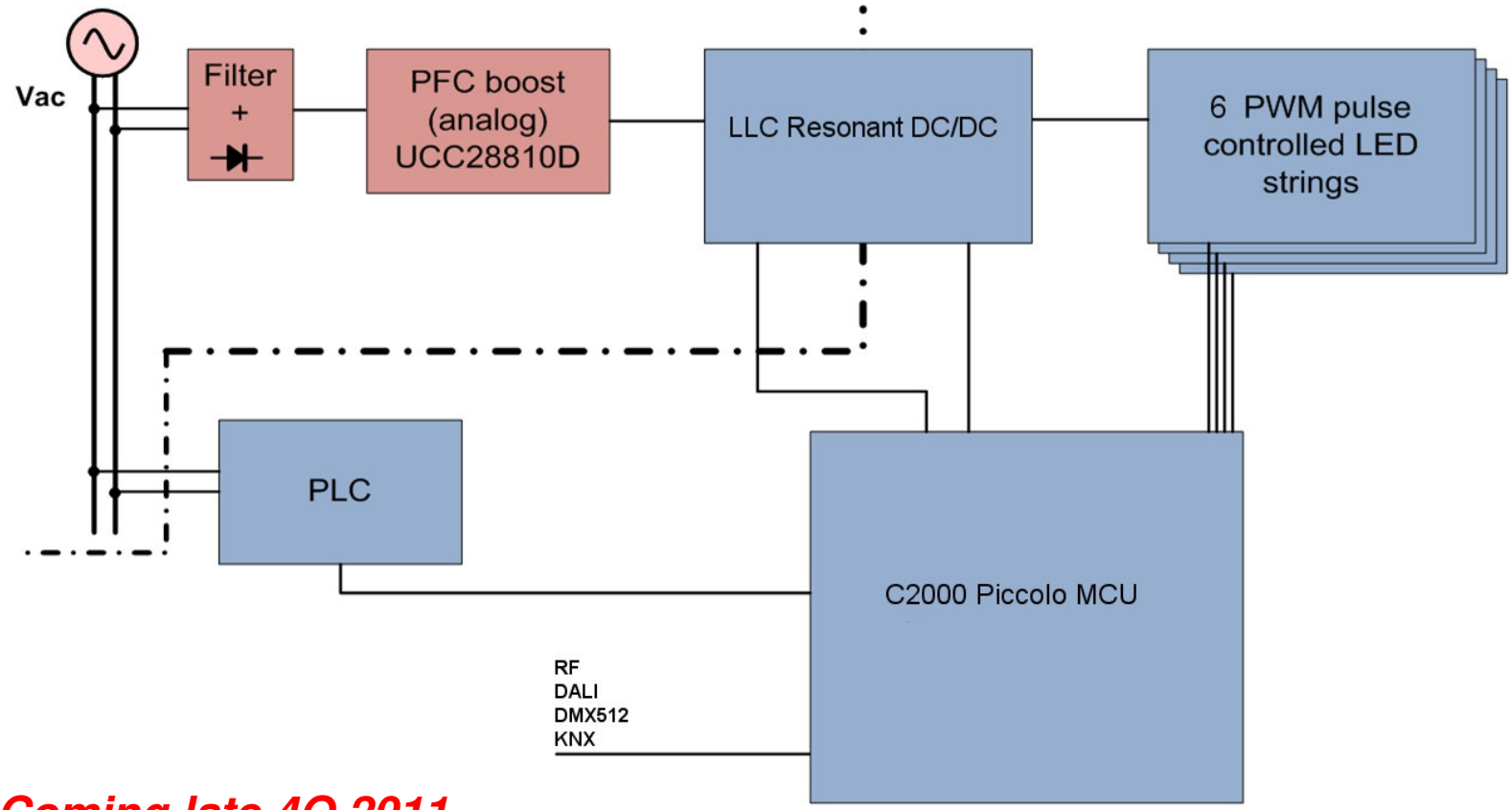
Texas Instruments

C2000 LED Lighting Developer's Kits

	TMDSDCDCLEDKIT	TMDSRGBLEDKIT
Topology	•Single SEPIC DC/DC stage driving 8 LED strings	•6x Boost DC/DC stages •2x SEPIC DC/DC stages •(Individual power stages for each LED string)
Control Scheme	•PWM Dimming	•Average current-mode control (linear dimming)
Number of Strings	•Up to 8 strings of same length and same type LEDs	•Up to 8 LED strings of variable lengths and LED types
Device	•Piccolo F28035 controlCARD	•Piccolo F28027 controlCARD
Benefits	• Low cost, single power supply design • Individual LED string dimming • Good for applications involving redundant usage of same-type LEDs and same-length LED strings	• Flexible design topology allows variable length LED strings and LED types • Individual LED string dimming • Capable of providing separate voltage levels for the red, green, and blue color components of RGB LED's • Also good for non-RGB LED applications where variable string length or variable LED type are desired

C2000 Future LED Kits

Isolated AC/DC + Communications LED Developer's Kit



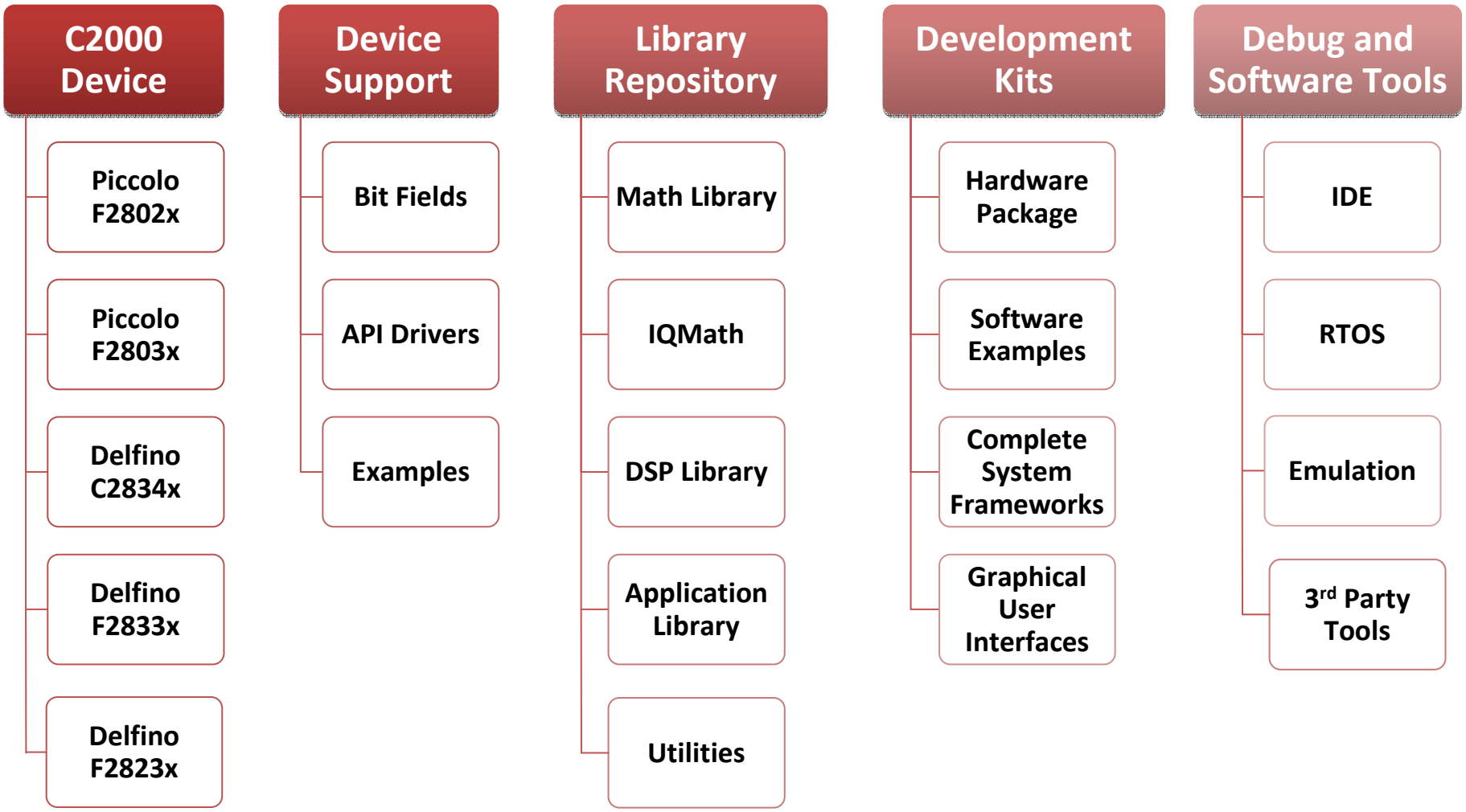
Coming late 4Q 2011

C2000 LED development kit featuring integrated communications support.

Development Support

ControlSUITE, Emulator, Flash Programming Tools, Simulation Software

controlSUITE Content Snapshot

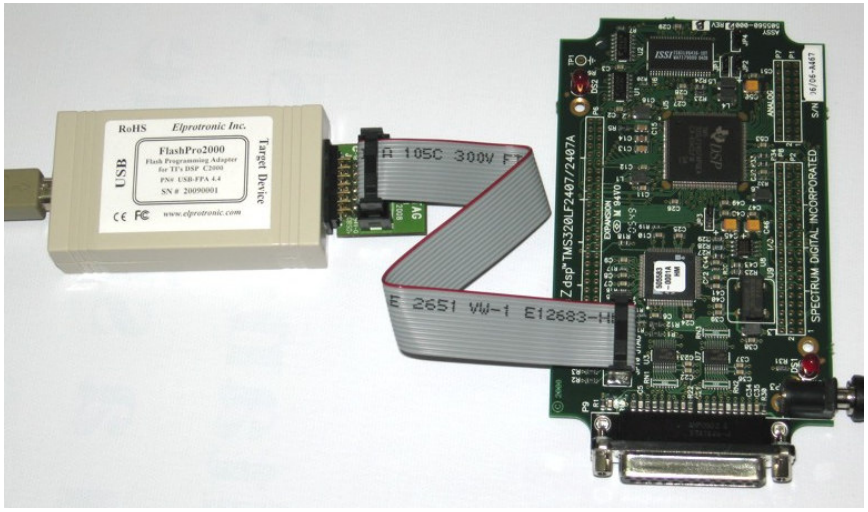


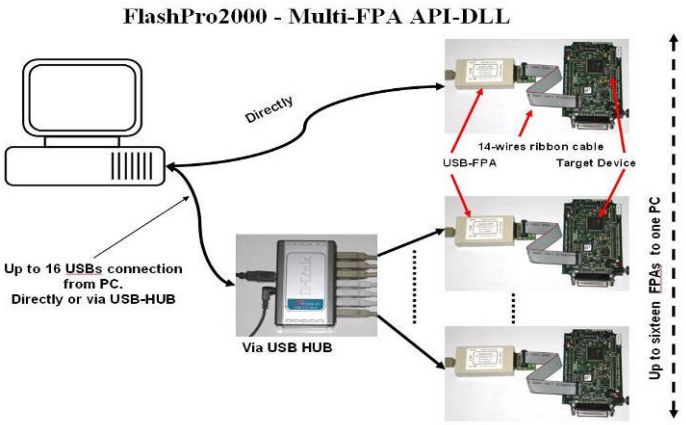
Wide Selection of Emulators

Third Party	Emulator	Part Number	Description	Price
Spectrum Digital	XDS100	TMDSEMU100U-14T	Ultra low cost USB JTAG emulator based on TI's XDS100 emulation technology. Available from the TI eStore.	$79.00
Blackhawk	USB2000	TMDSEMU2000U	Low cost XDS510 class, C2000 only USB emulator. Available from the TI eStore.	$299.00
Spectrum Digital	XDS510LC	See Spectrum Digital's Website	Low cost XDS510 class, C2000 only USB emulator.	$249.00
Spectrum Digital	XDS510USB	See Spectrum Digital's Website	USB XDS510 emulator, works with multiple TI processors, including C2000	$1,299.00
Signum Systems	JTAGjet-C2000	See Signum System's Website	XDS510 class USB C2000 only emulator.	$595.00
Signum Systems	JTAGjet-C2000-ISO	JTAGjet-C2000-ISO	XDS510 class, C2000 only, USB 2.0 emulator with optically isolated JTAG	$795.00
Signum Systems	JTAGjet-C2000F-ISO	JTAGjet-C2000F-ISO	XDS510 class, C2000 only, USB 2.0 emulator with optically isolated JTAG and Flasher-C2000 utility	$995.00

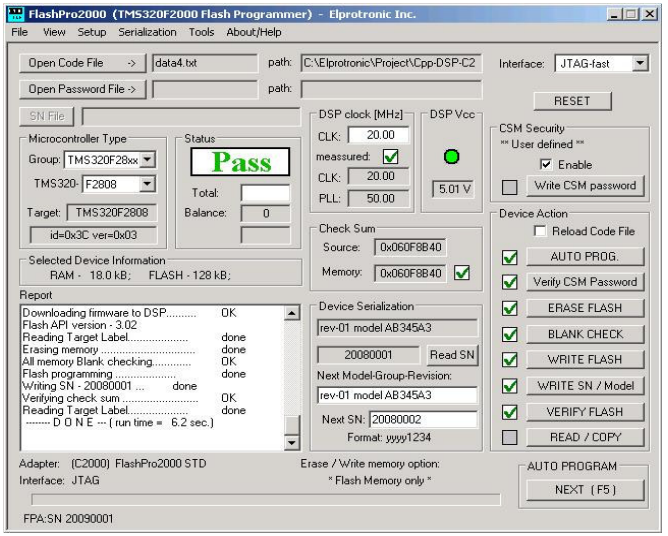
- Emulators also available from Beijing Wintech, Seed, Realtime, LSD, and ZLG in Asia
- Visit TI web and vendor web sites for latest update

Low-Cost Production Flash Programming





- Full Speed USB 1.1 (12 Mb/s) communication interface
- DSP can be programmed via JTAG or SCI-BOOT interface (TTL level-0-3V)
- TMS320F2808 with 128 kB Flash each can be programmed in 11 seconds, and can be erased, blank checked, programmed and verified in 22 seconds
- Up to 16 USB-FPA can be connected to one PC.

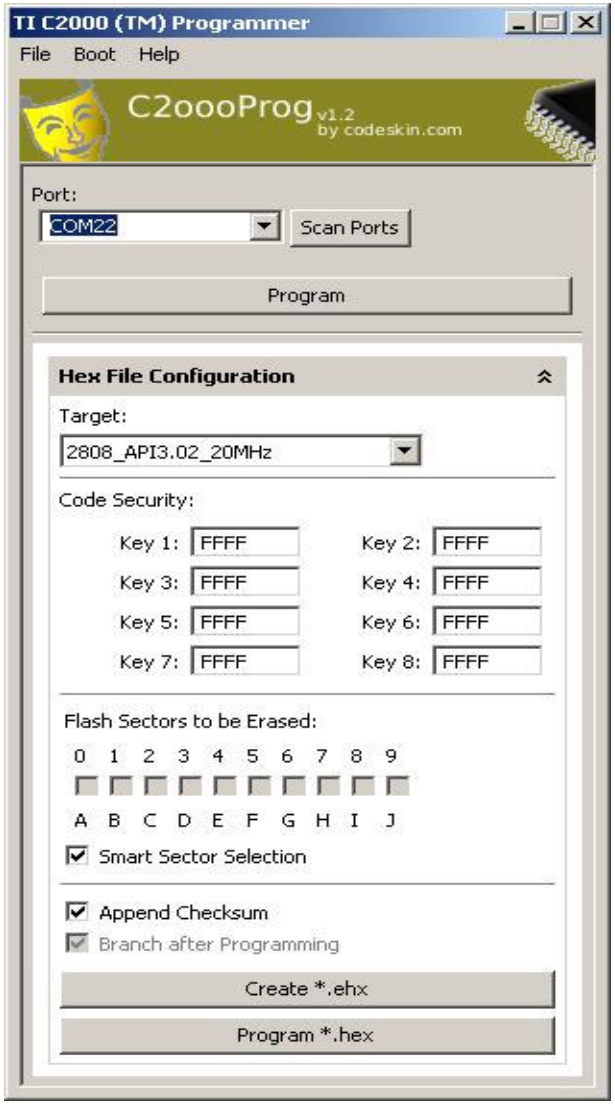


- ***FlashPro2000*** **- USB Flash Programmer starting at $219 from**
  - www.elprotronic.com

Low-cost Flash Serial Programming Tool

- **Fast communication protocol** that works reliably with USB-to-RS232 converters
- **Smart detection of** which Flash **sectors** need to be erased (or manual section selection if desired)
- Automatic **32-bit CRC** (Cyclic Redundancy Checksum) generation and programming (allowing the firmware to verify the Flash integrity at MCU bootup)
- Reads standard **Intel Hex** file, allowing for other data (such as FPGA code) to be programmed into MCU Flash
- Creates and loads **Extended Hex Files** which contain the program data as well as the target configuration
- Creates and loads **Remote Hex Files** which contain a URL to an extended hex file stored on the Internet
- Can be called by other programs using **command line options**, for example for **batch programming**
- **DTR/RTS** control for resetting MCU in bootload mode

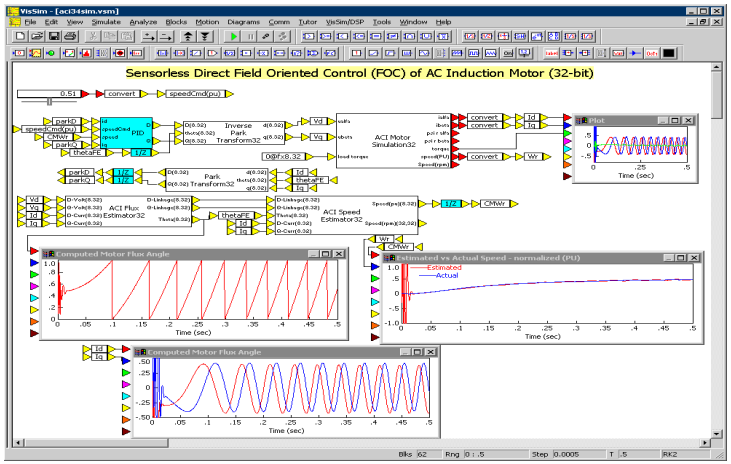
- Free download available from CodeSkin at http://www.codeskin.com/



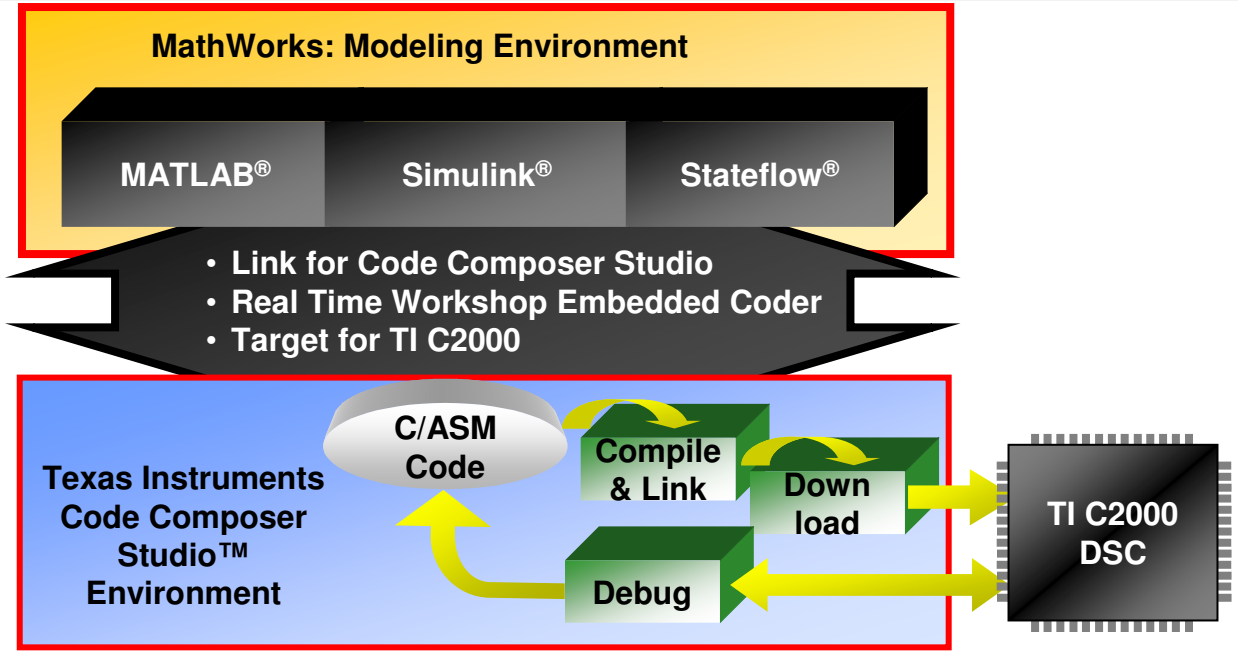
C2000 Modeling & Code Generation

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

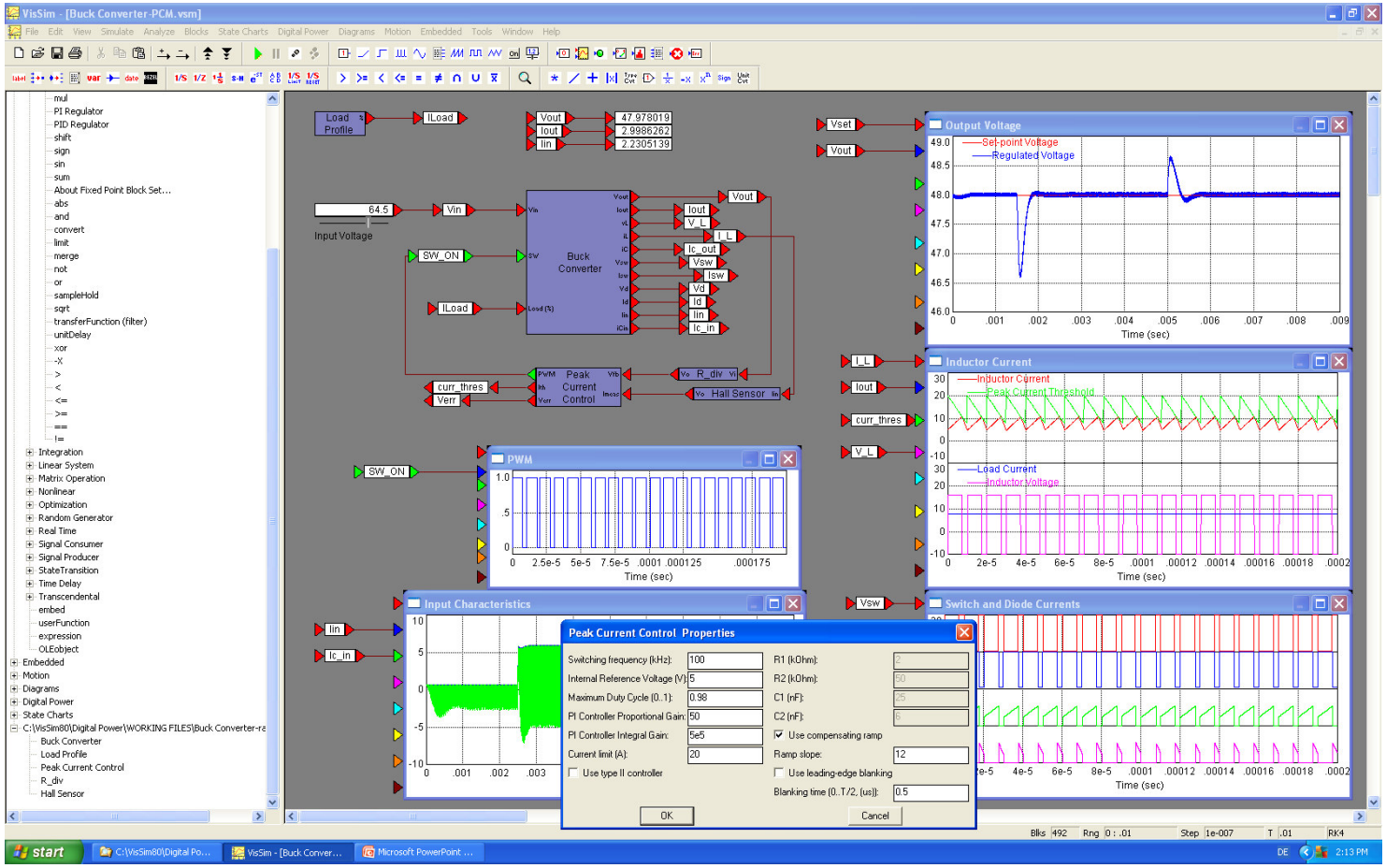
www.vissim.com



The Mathworks Support for C2000



VisSim: Digital Power Preview
DPBS available Q311



Familiar Analog Environment

Q & A

Thanks!