Designing Digital Control Loops and Firmware

for Switch-Mode Power Supplies

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

Digital Control of Switch-Mode Power Supplies

Presented by Andreas Reiter

April 17th 2024

SMART | CONNECTED | SECURE

Power Conversion

Agenda

- Digital Power Supply Control Overview
- Rapid Prototyping
- System Firmware Development & Test
- Summary

Agenda

Digital Power Supply Control Overview

Rapid Prototyping

System Firmware Development & Test

Summary

Different Flavors of Digital Control

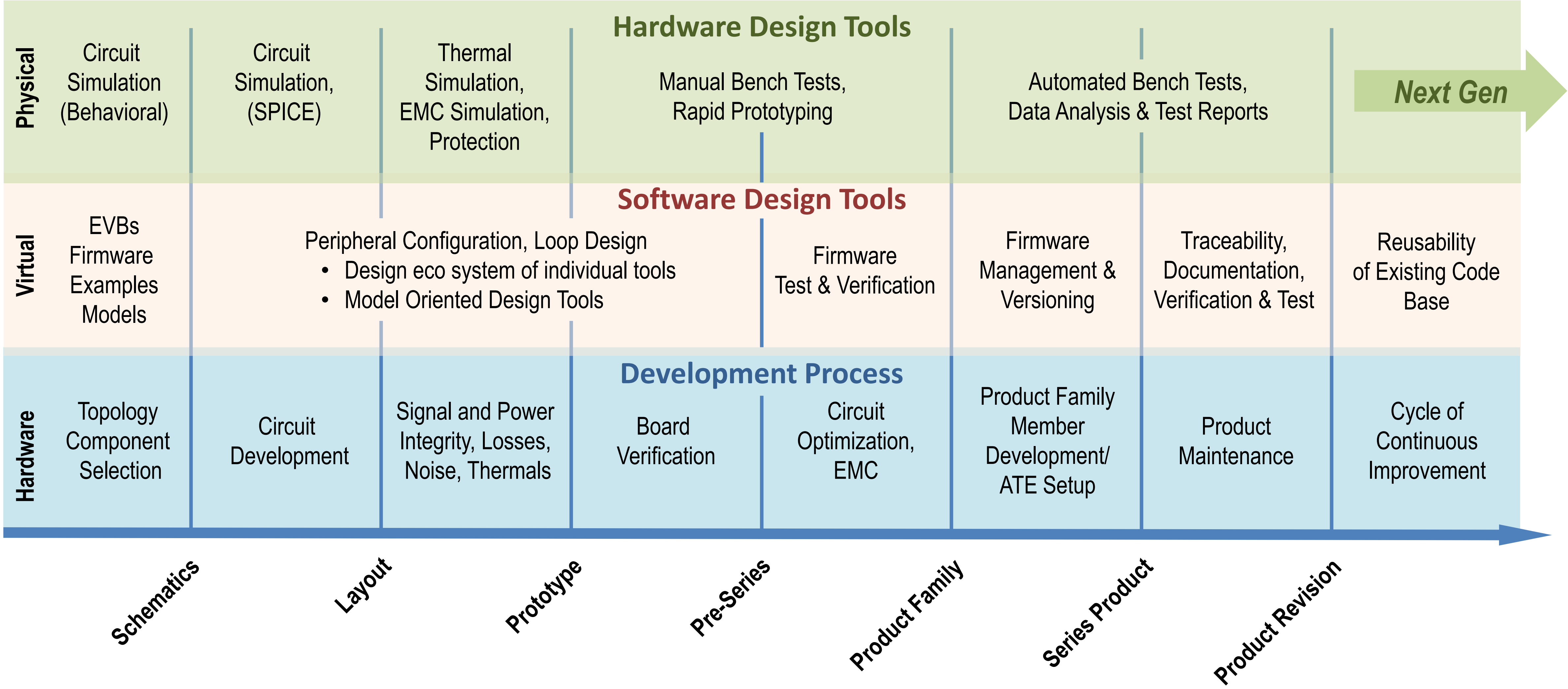
- **Encapsulated**
  - Switchers and PWM Controllers with digital logic providing enhanced features, usually configured in hardware (e.g. resistors, capacitors)
- **Integrated, Software Configurable**
  - Switchers and PWM Controllers with digital interfaces (e.g. I2C/PMBus™) to be configured by external, proprietary software (PC) or an external MCU
- **Integrated, Programmable**
  - Switchers and PWM Controllers with open MCU core and dedicated peripherals require firmware development design & programming tools
- **Discrete, Programmable**
  - Bare MCUs/DSPs to be fully programmed by end-user, requiring external auxiliary power supply and components

DSP Special Requirements

- **Low-Noise Design Guidelines**
  - Power Supply and Power Integrity
  - Signal Integrity and ADC Front-End Design
- **Protection & Safety**
  - FuSa Manuals (ISO26262) provided by CPU vendor
- **Firmware Robustness & Quality Guidelines**
  - Motor Industry Software Reliability Association MISRA-C
  - (A)SIL Standards IEC 61508, ISO 26262, IEC 60730
- **Firmware Management & Versioning**
  - Git, Distributed Team Collaboration Versioning Tool (e.g. Github, Bitbucket)
  - **(A**utomotive) **S**oftware **P**rocess **I**mprovement **C**apability d**E**termination (A)SPICE

Switch-Mode Power Supply Design Process

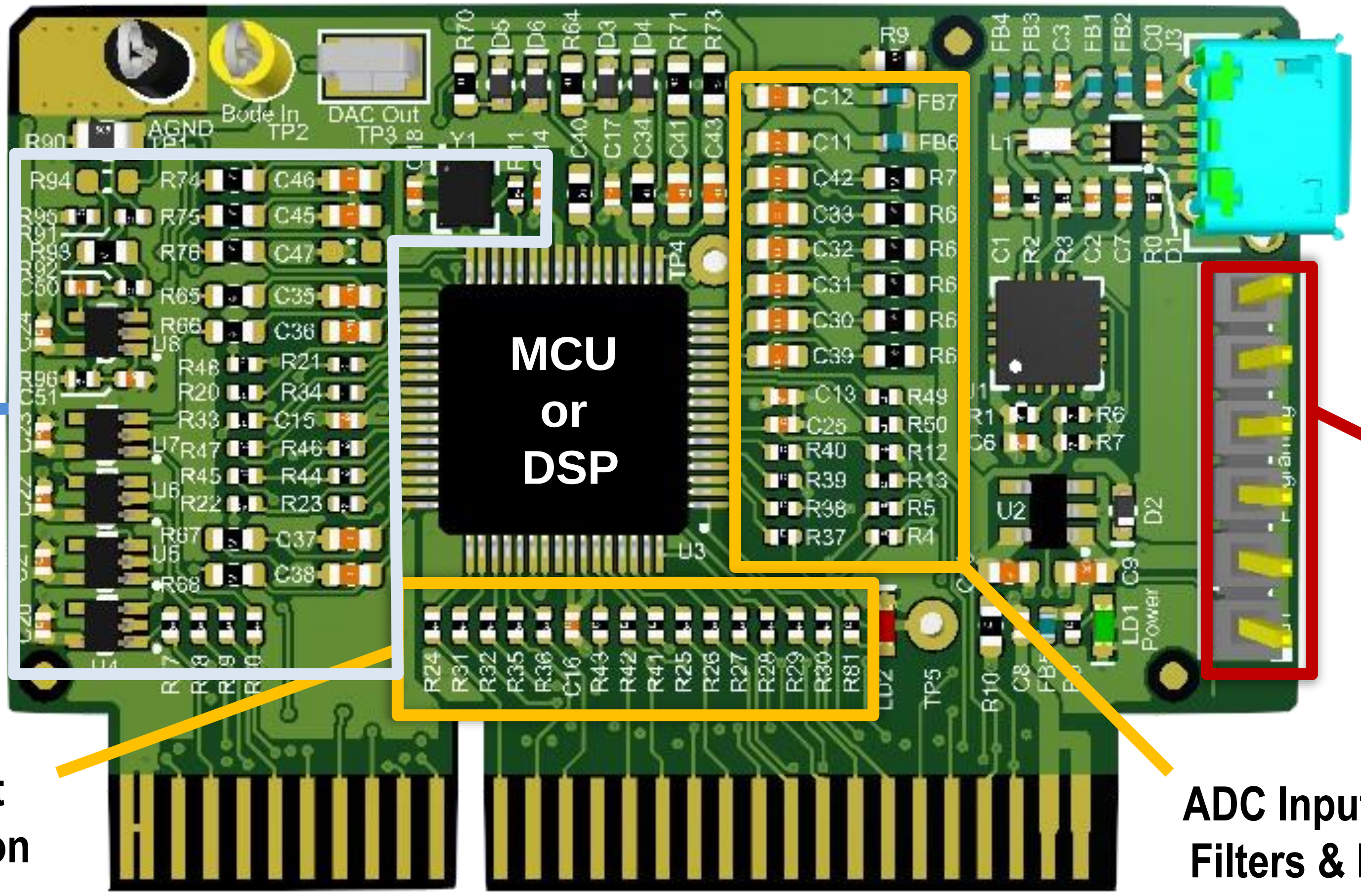
From Schematics to Production and beyond



EVBs & Circuit Design Guidelines

Example: dsPIC33CK512MP606 Digital Power Plug-In Module

Optional Signal Conditioning & Clock Components



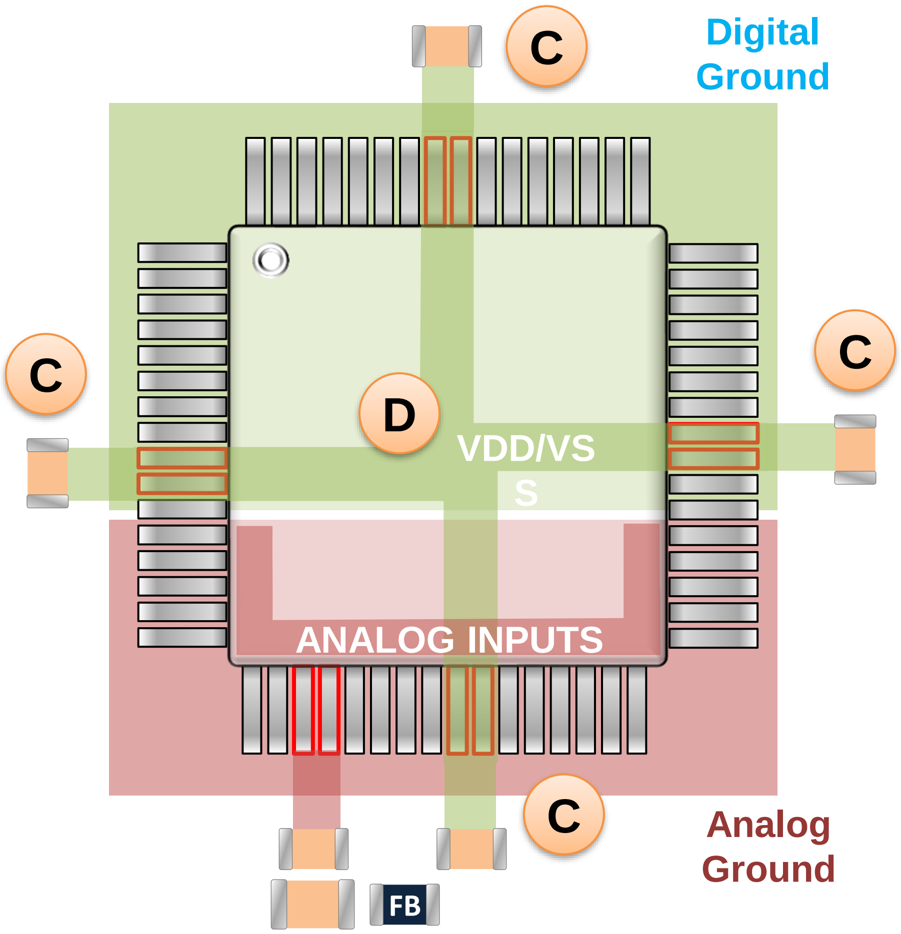
Programming & Debugging Interface

GPIO Current Limit and Surge Protection

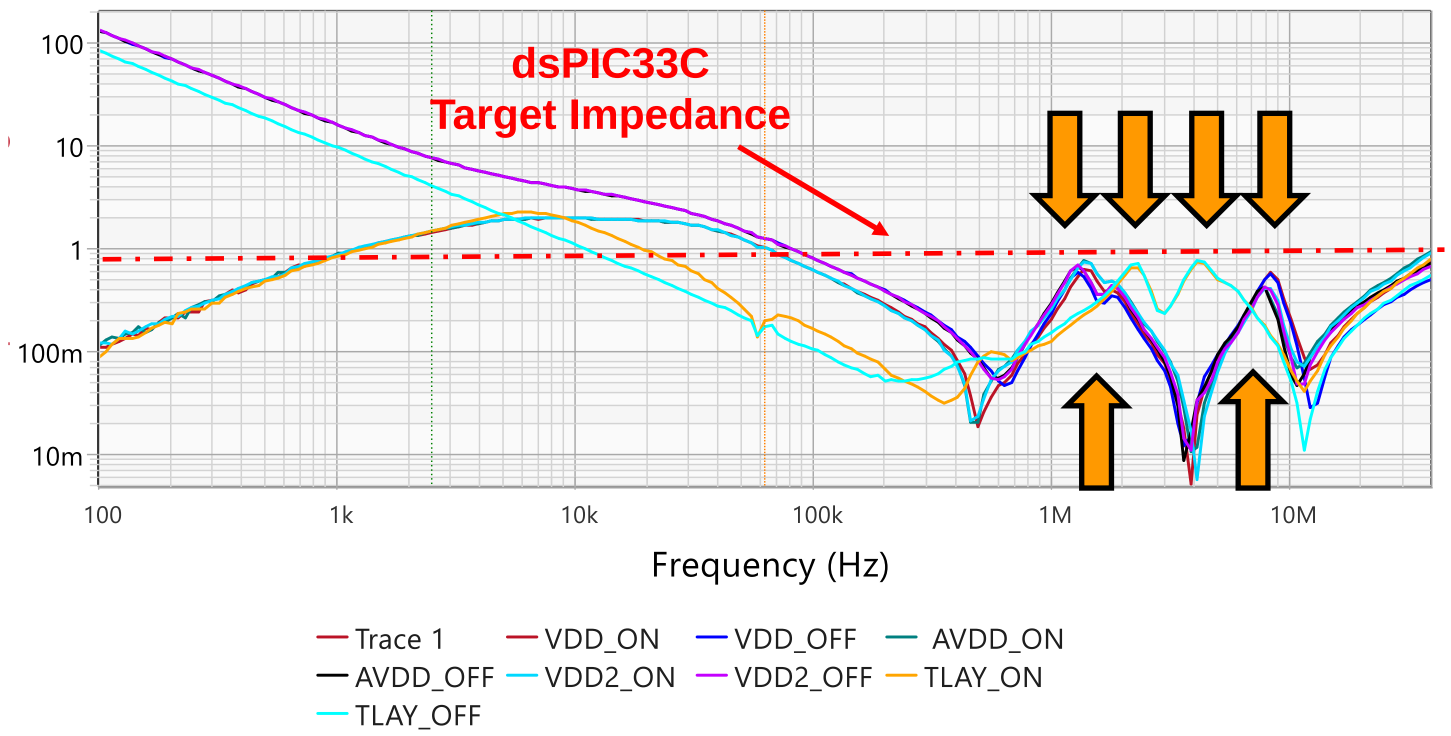
ADC Input Anti-Alias Filters & Decoupling

Low-Noise Design Guidelines

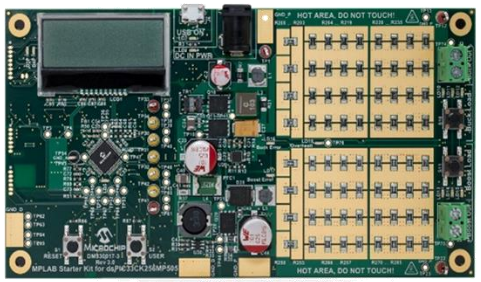
Supply Rail Impedance Profile Measurement



VDD Impedance profile measured at every decoupling capacitor (unpowered and powered)



Digital Power Development Hardware



- **Starter Kits**

  Compact boards for conceptual evaluation and basic education, no further tools required

- **Evaluation Boards**

  Dedicated designs build to showcase control methods, topologies and component performance

- **Development Boards**

  Robust, well protected topology boards designed for firmware development and enhanced debugging and analysis

- **Reference Designs**

  “Close to Production” designs templates

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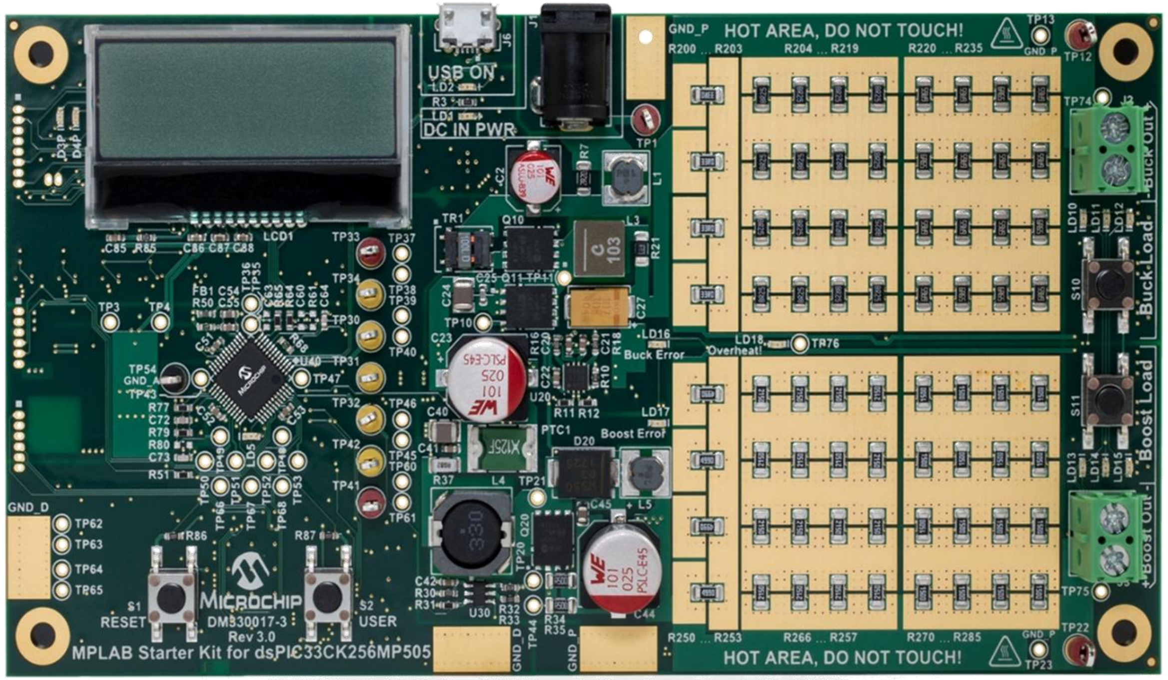
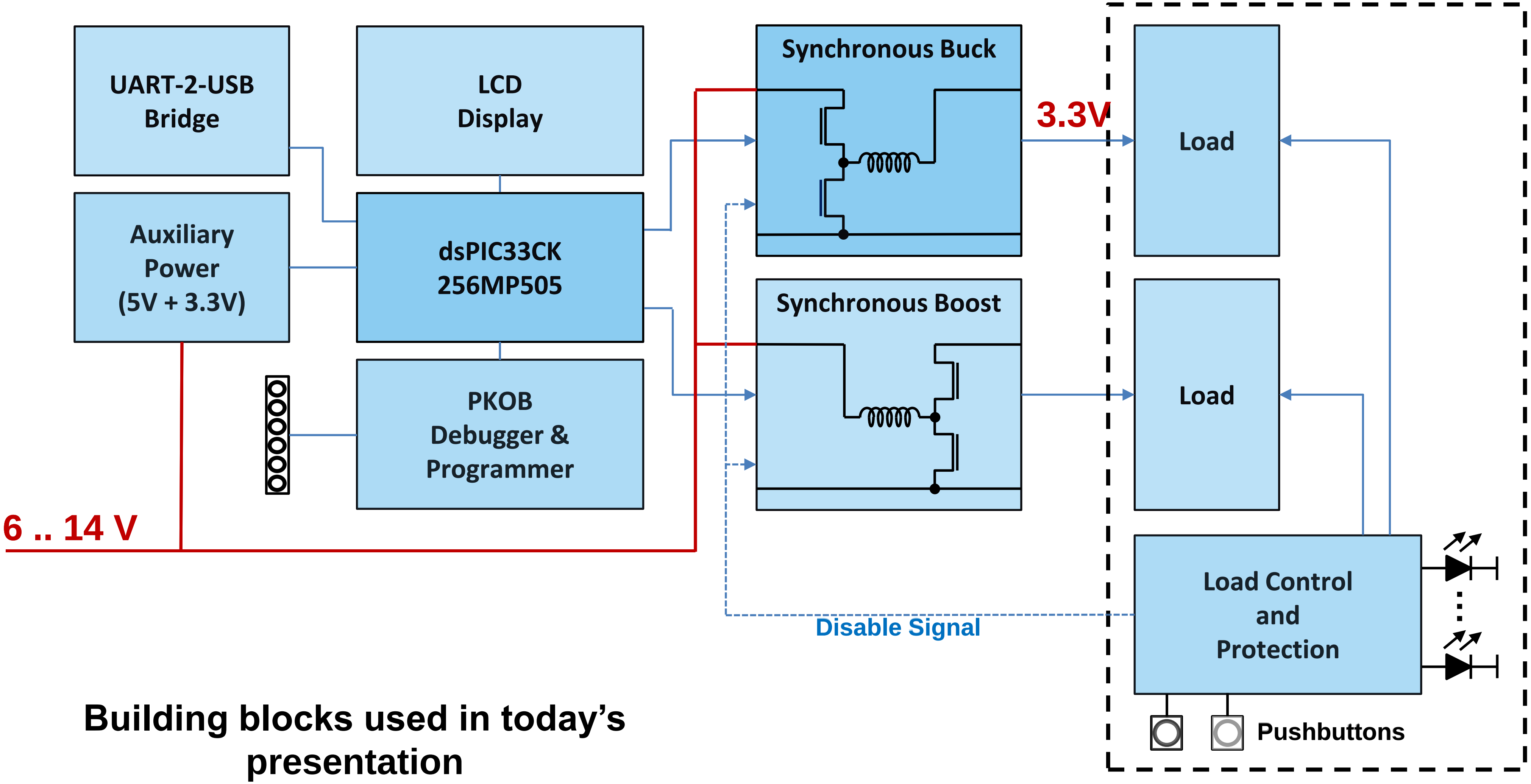
dsPIC33C Digital Power Starter Kit (DPSK3)

- **On-board dsPIC33CK256MP505 DSC**
- **PIC24F Auxiliary Microcontroller managing loads and protection circuit auto recovery**
- **Two Independent DC/DC Converter Topologies:**
  - Synchronous Buck Converter
  - Asynchronous Boost Converter
- **Independent resistive loads**
  - Four selectable Constant Load Levels
  - Three Selectable Step Load Levels
- **Protection circuitry**
  - Over Current Protection (OCP)
  - Over Voltage Protection (OVP)
  - Over Temperature Protection (OTP)
- **Development Features**
  - PKOB4 On-Board Programmer/Debugger
  - LC Display User Interface
  - USB/UART Bridge (Standard VCP)



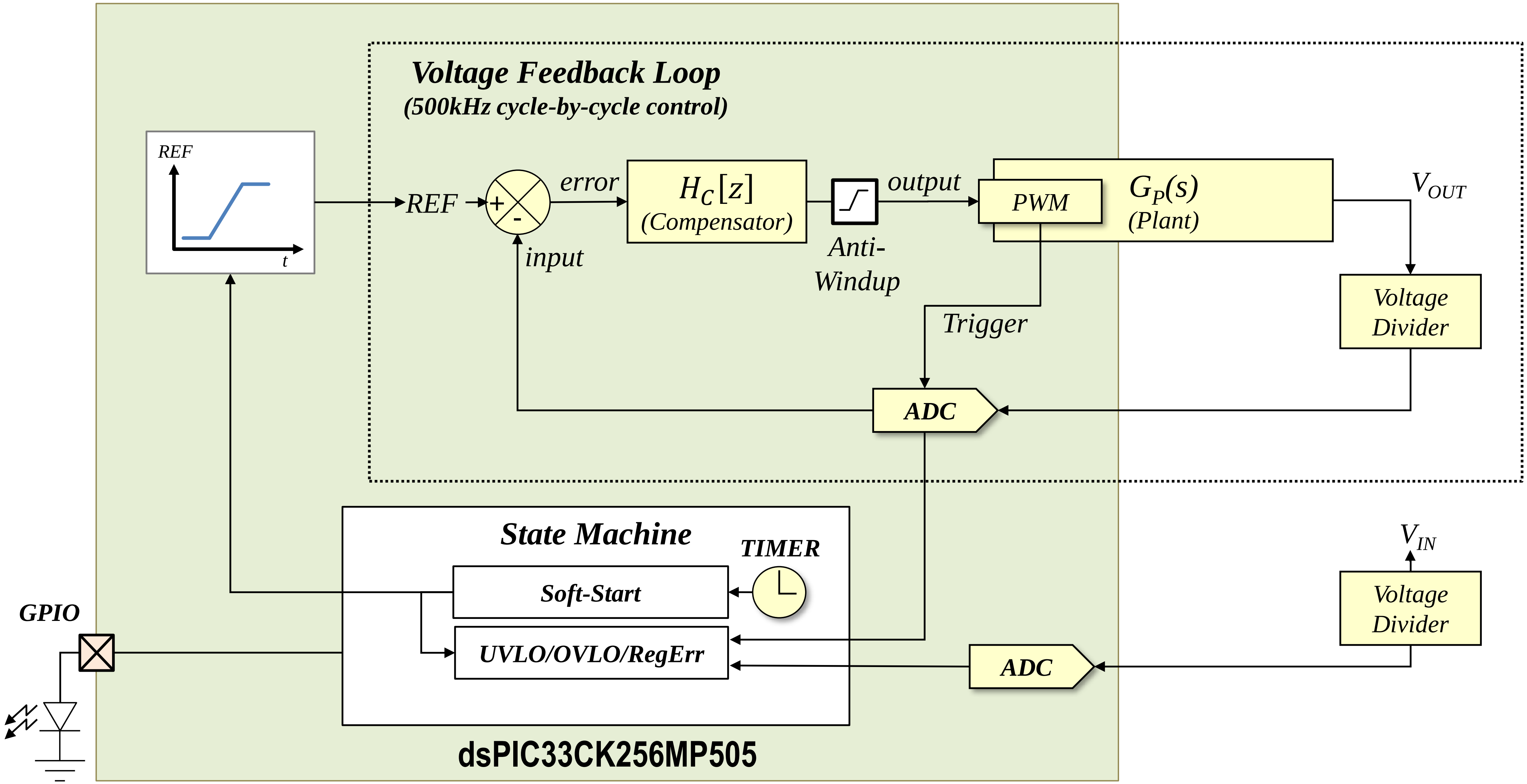
Part-No: DM330017-3

dsPIC33C Digital Power Starter Kit 3 (DPSK3)



Building blocks used in today's presentation

Control Software Block Diagram



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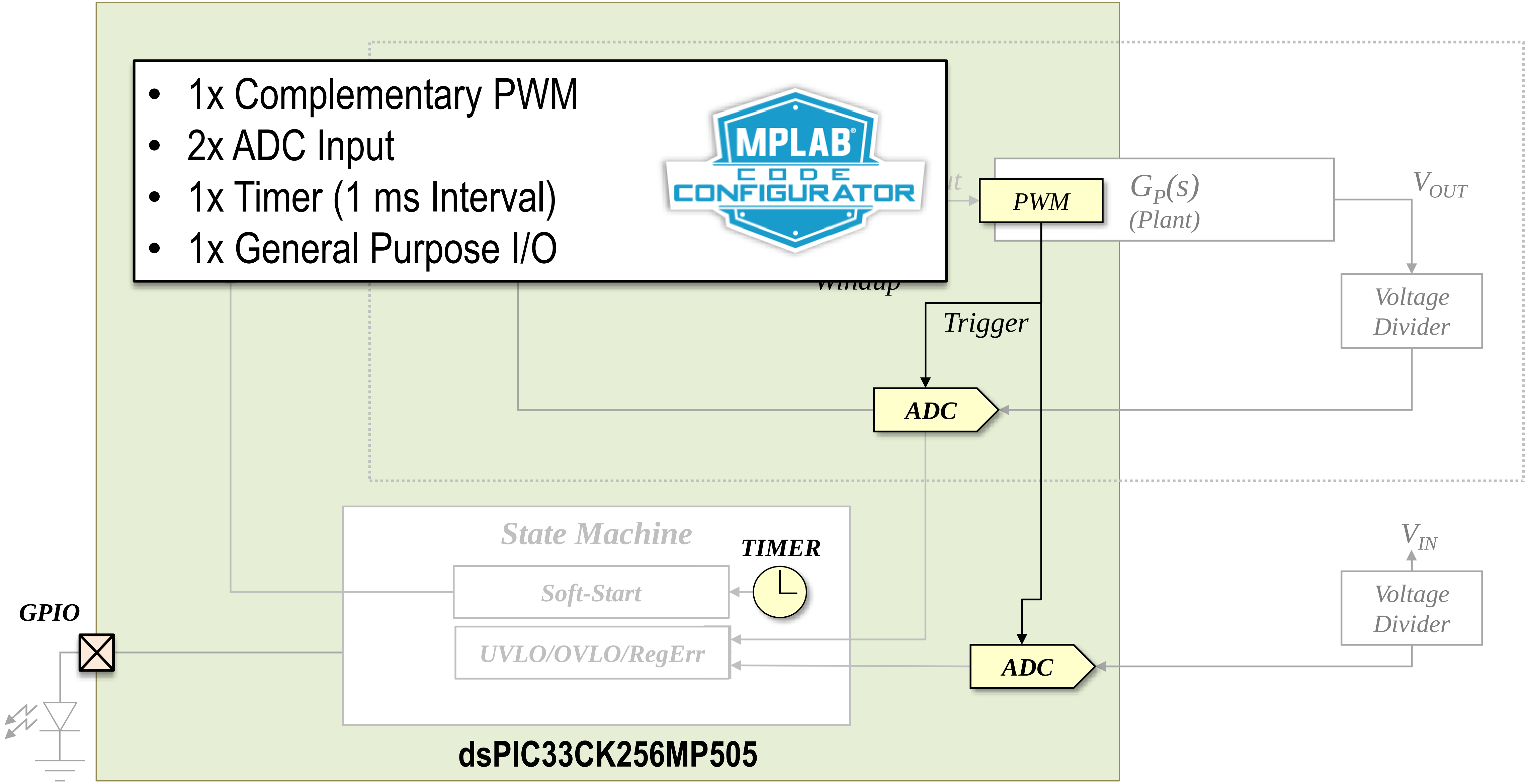
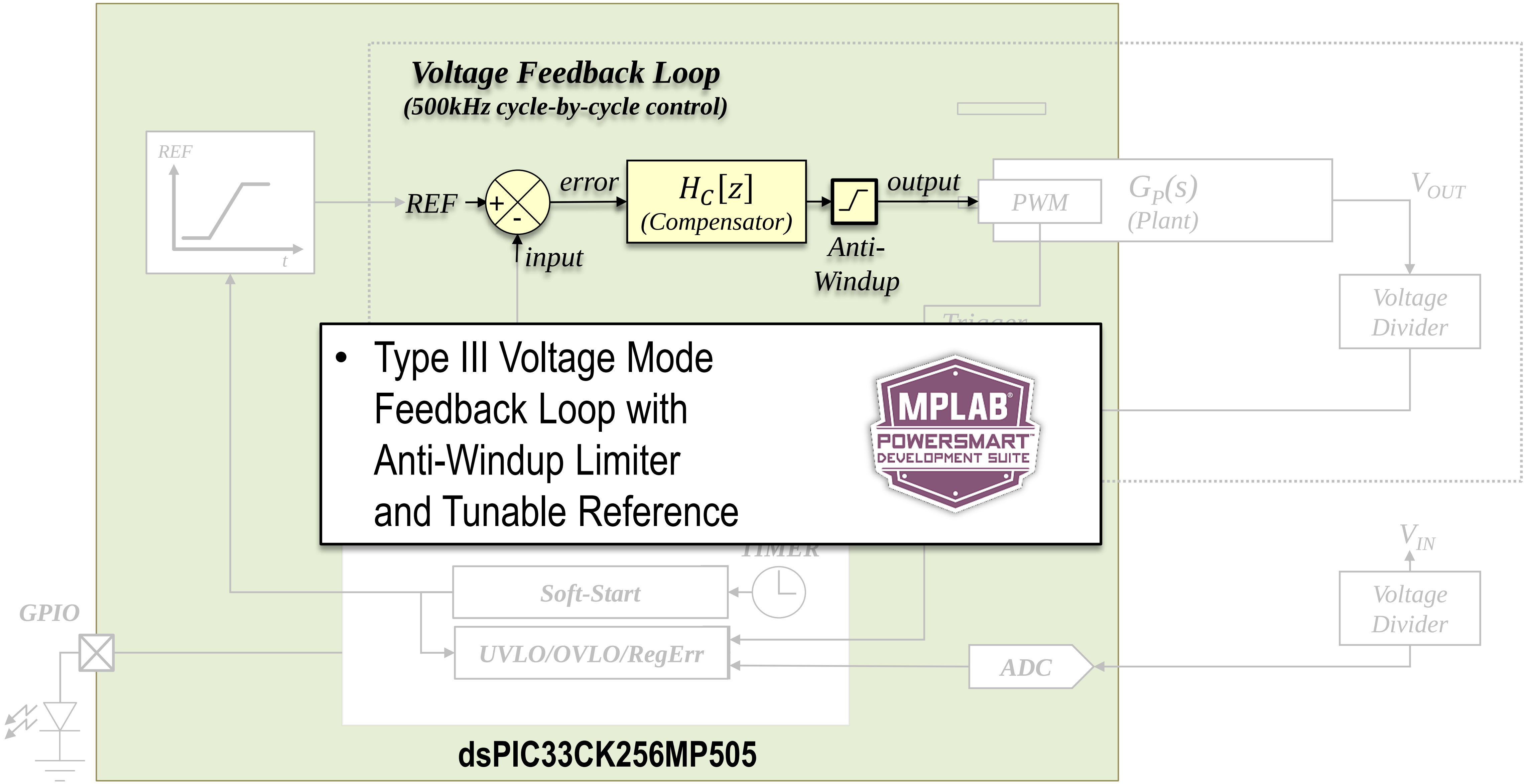
Control Software Block Diagram

- 1x Complementary PWM
- 2x ADC Input
- 1x Timer (1 ms Interval)
- 1x General Purpose I/O



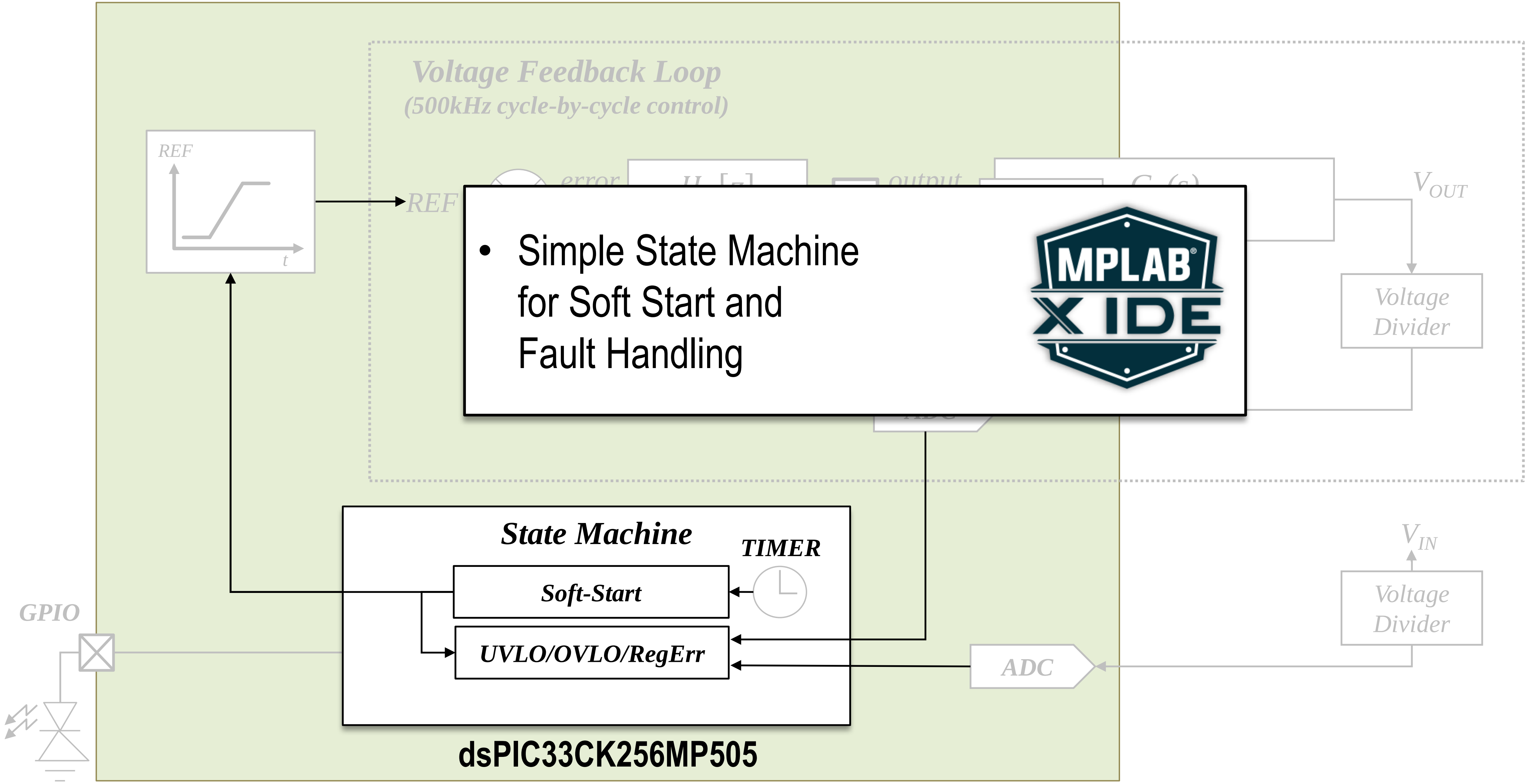
Control Software Block Diagram



- Type III Voltage Mode Feedback Loop with Anti-Windup Limiter and Tunable Reference

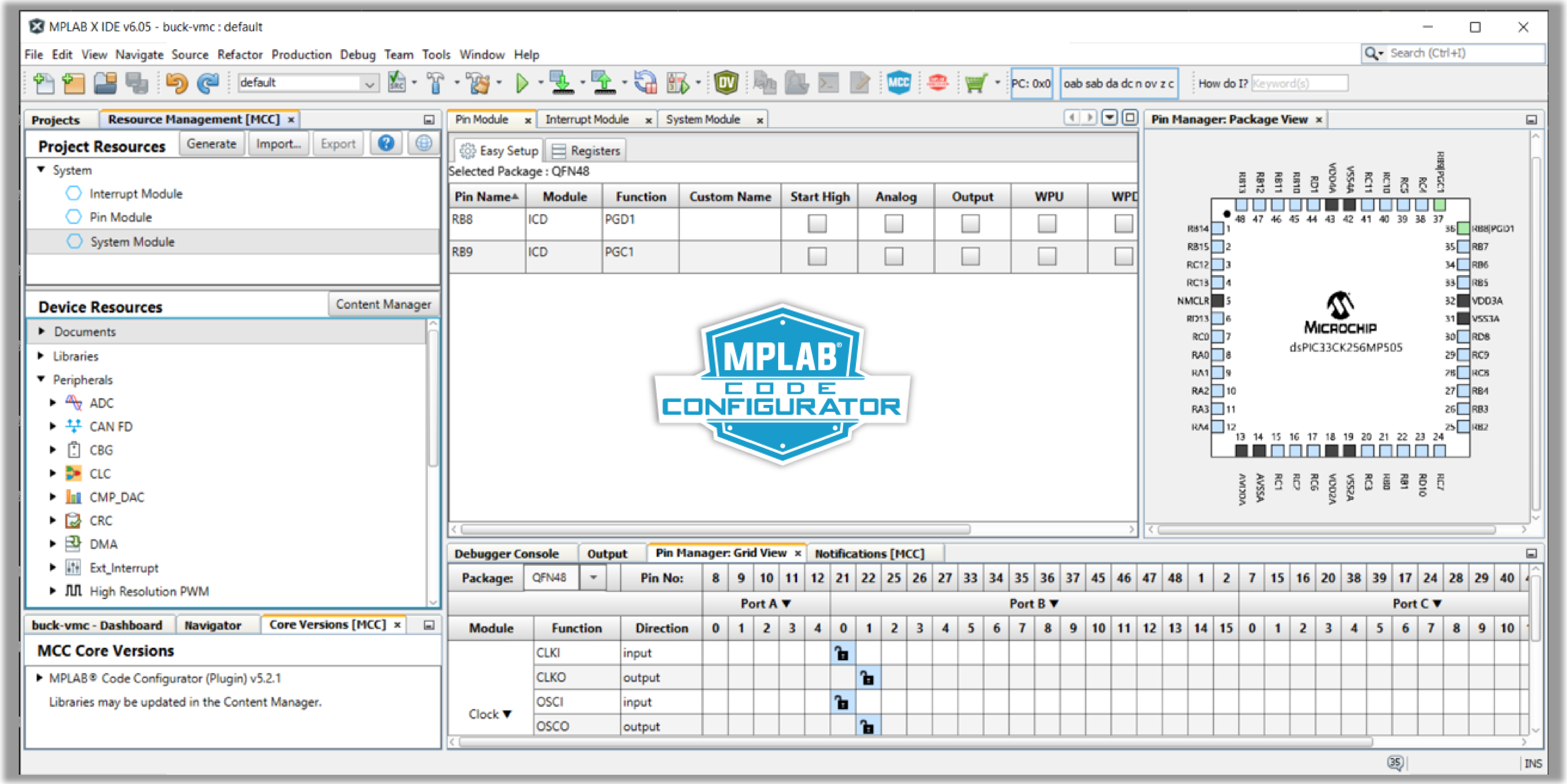
MPLAB POWERSMART DEVELOPMENT SUITE

Control Software Block Diagram

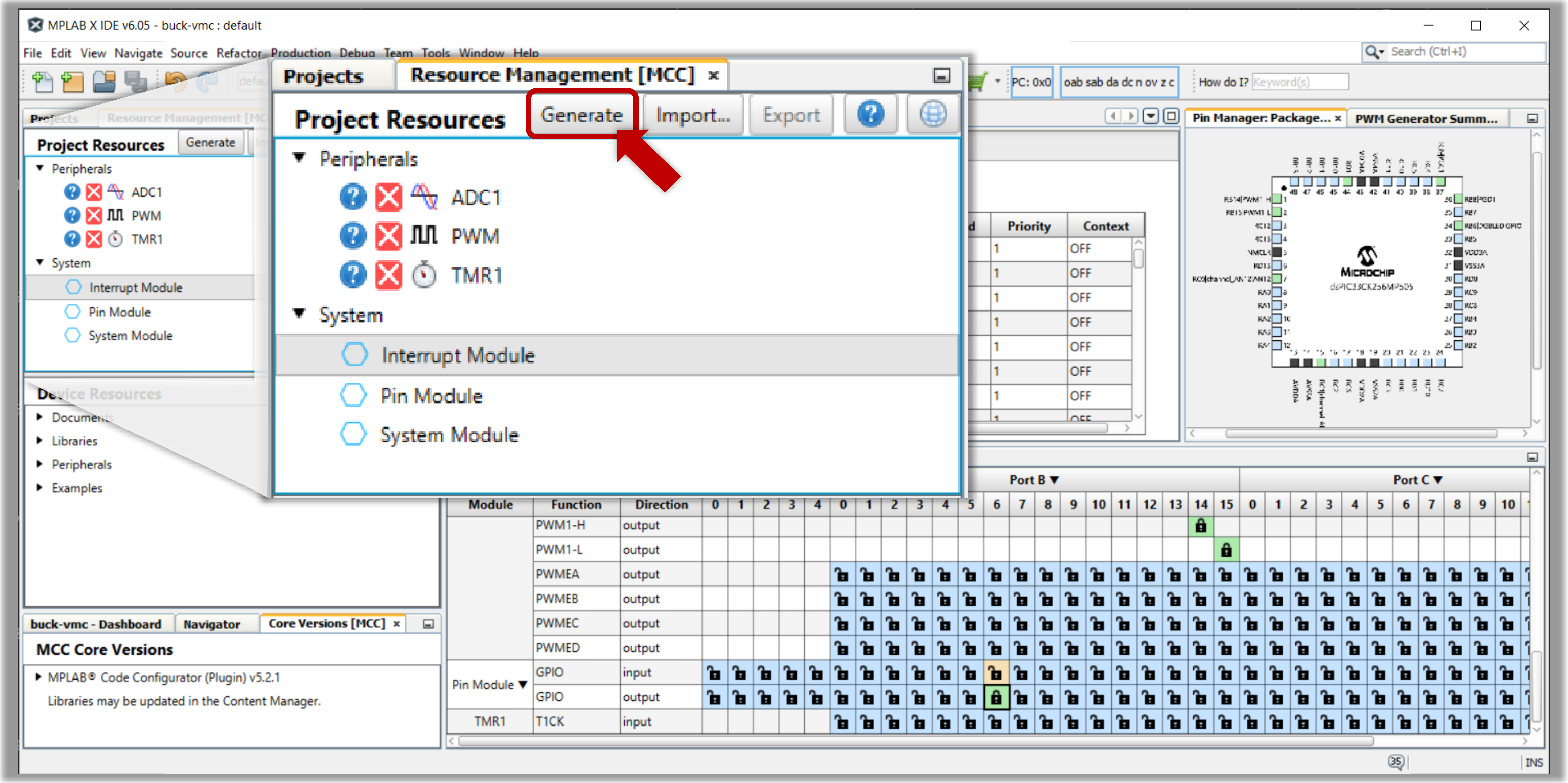


- Simple State Machine for Soft Start and Fault Handling

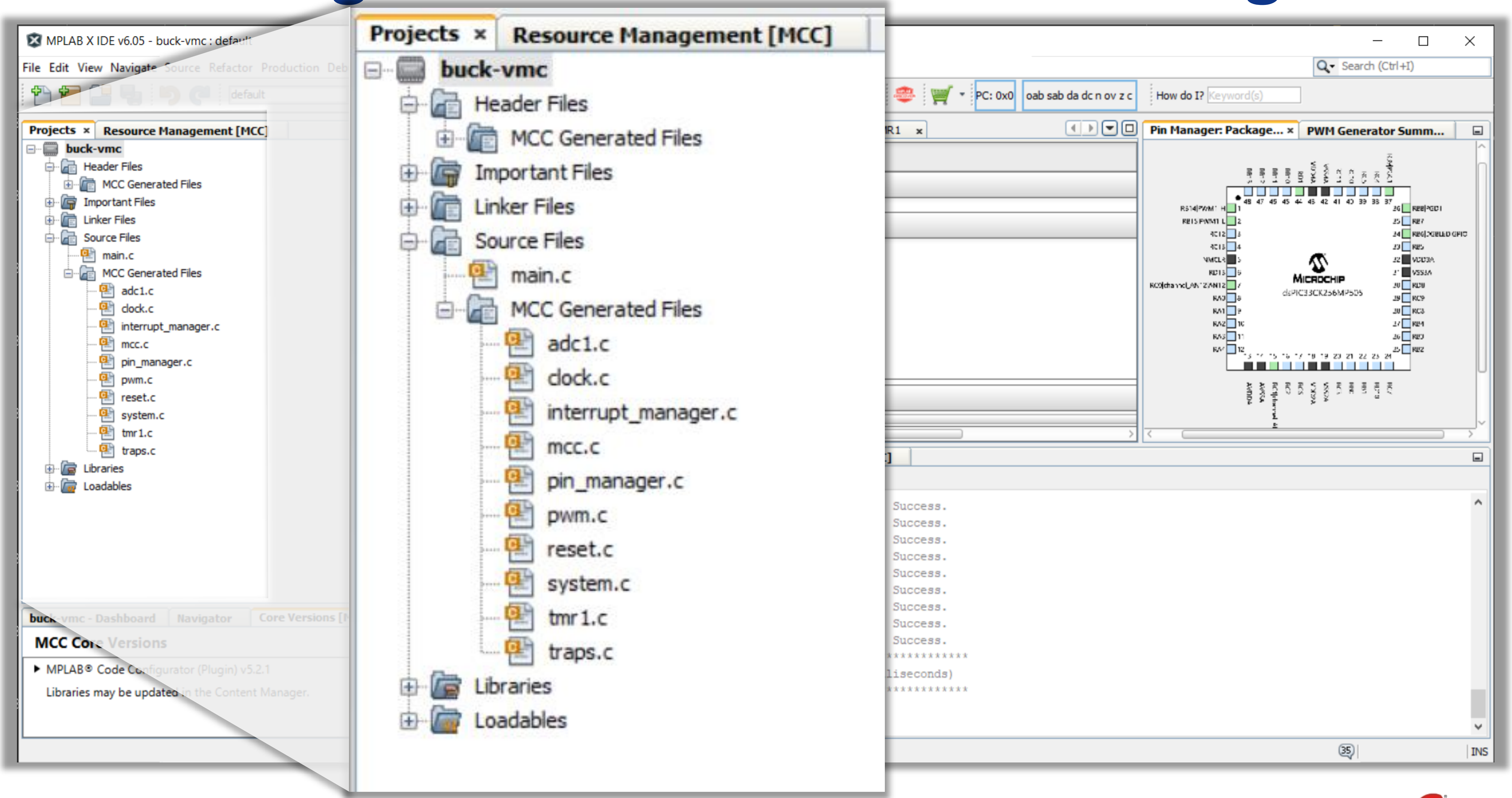
MCU Configuration MPLAB® Code Configurator



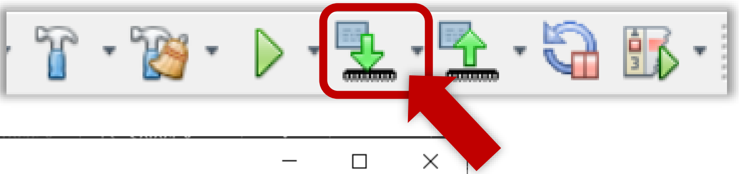
MCU Configuration MPLAB® Code Configurator

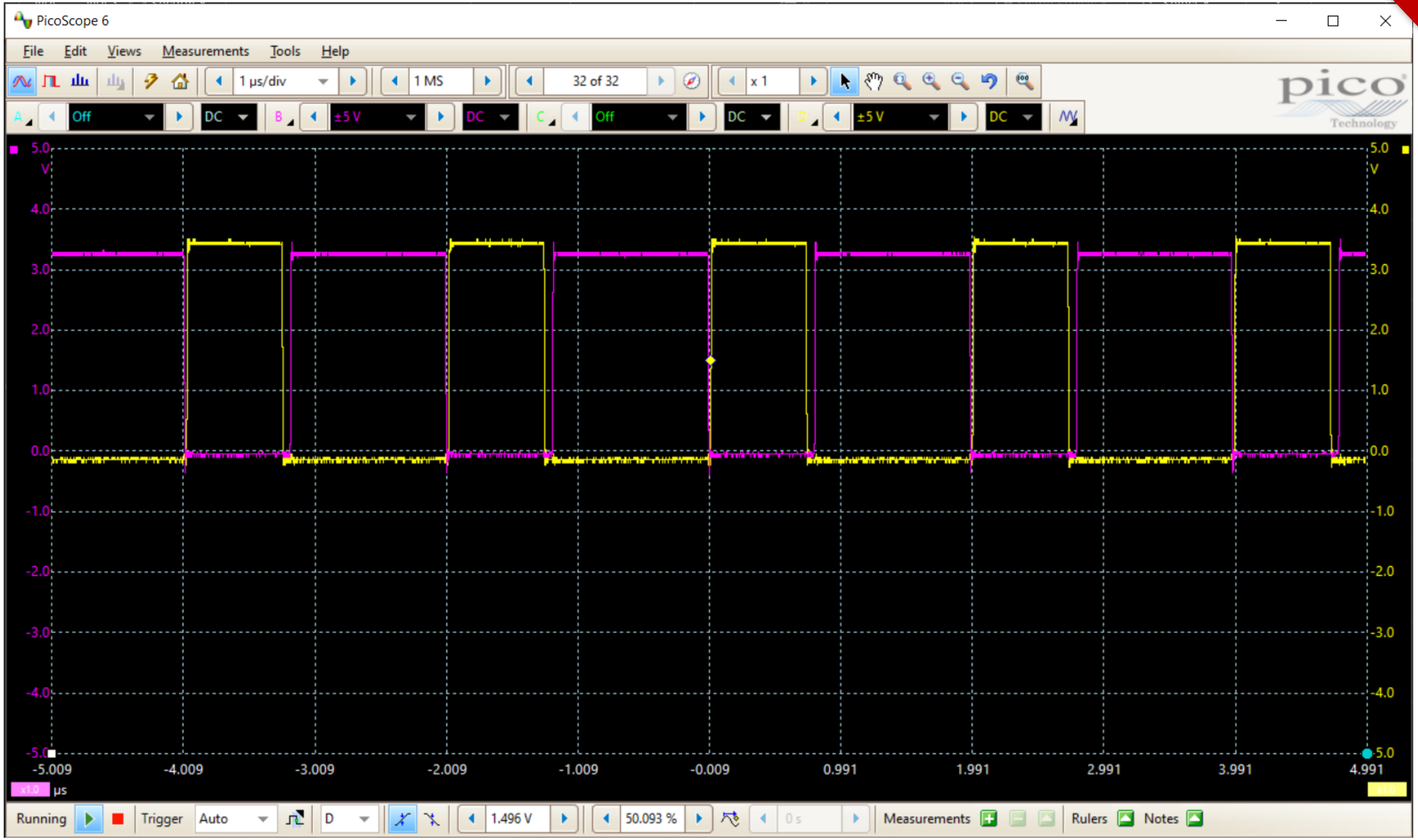


MCU Configuration MPLAB® Code Configurator

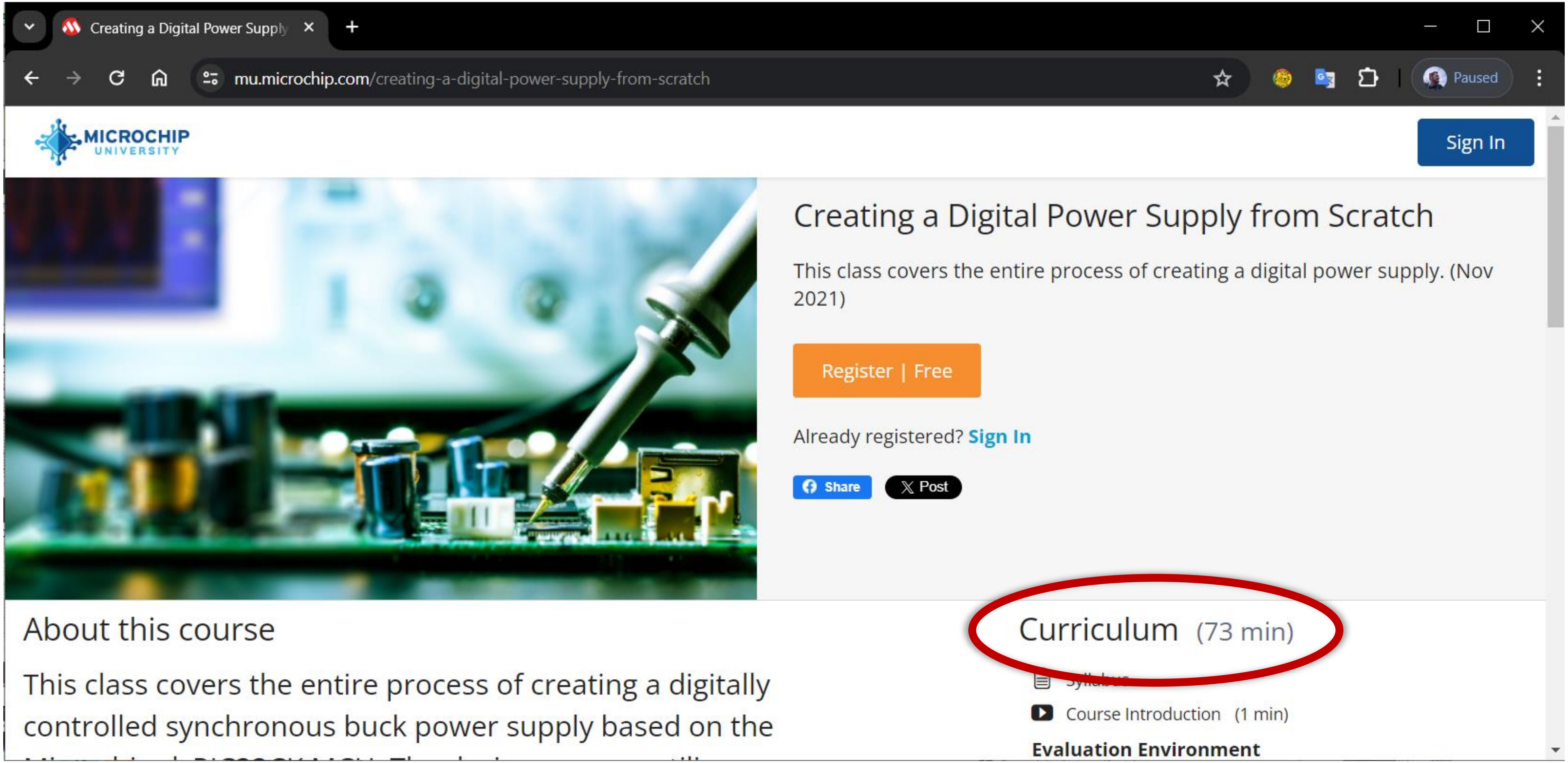


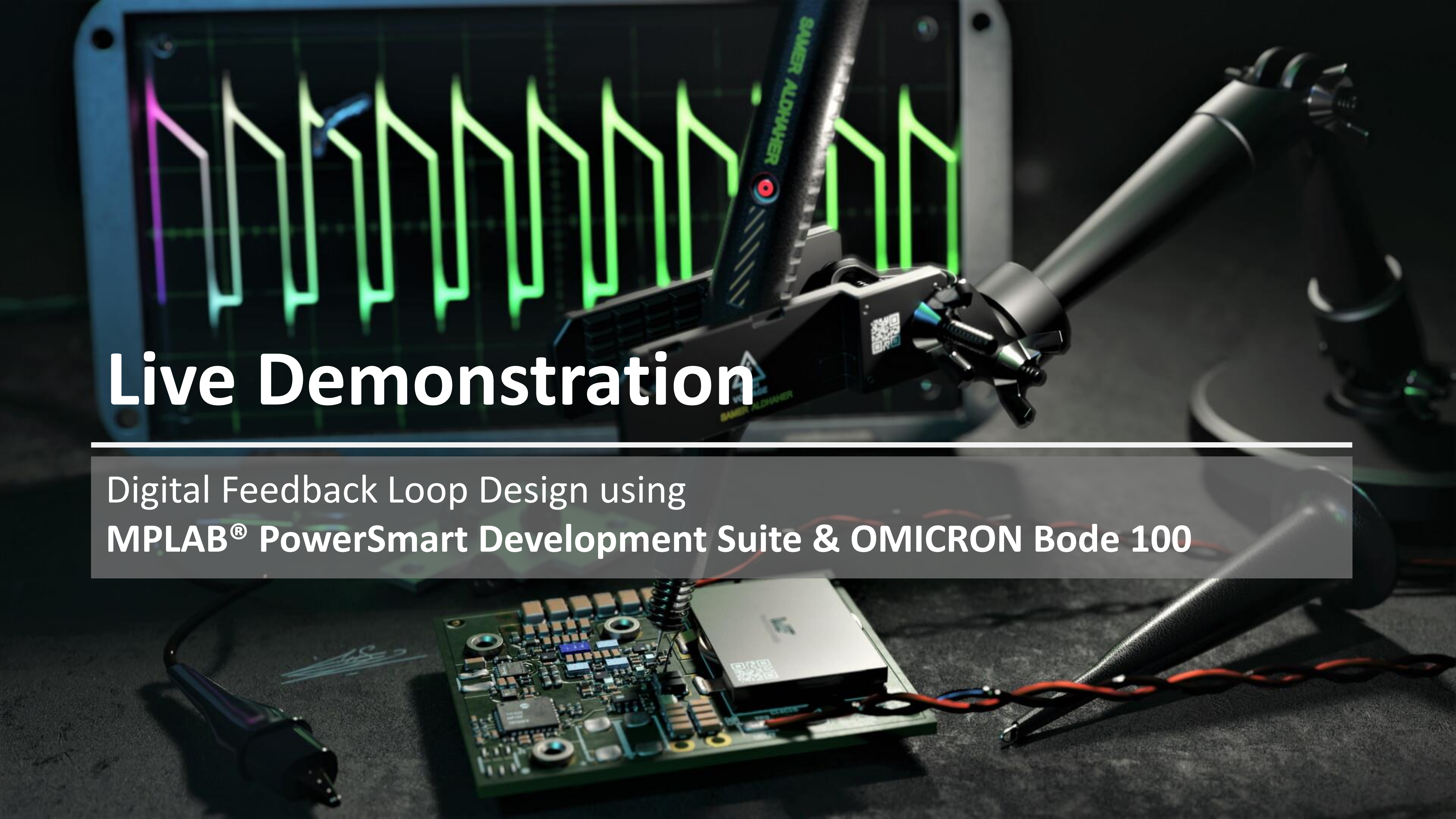
Program & Run Target Device





Complete Rapid Prototyping Course



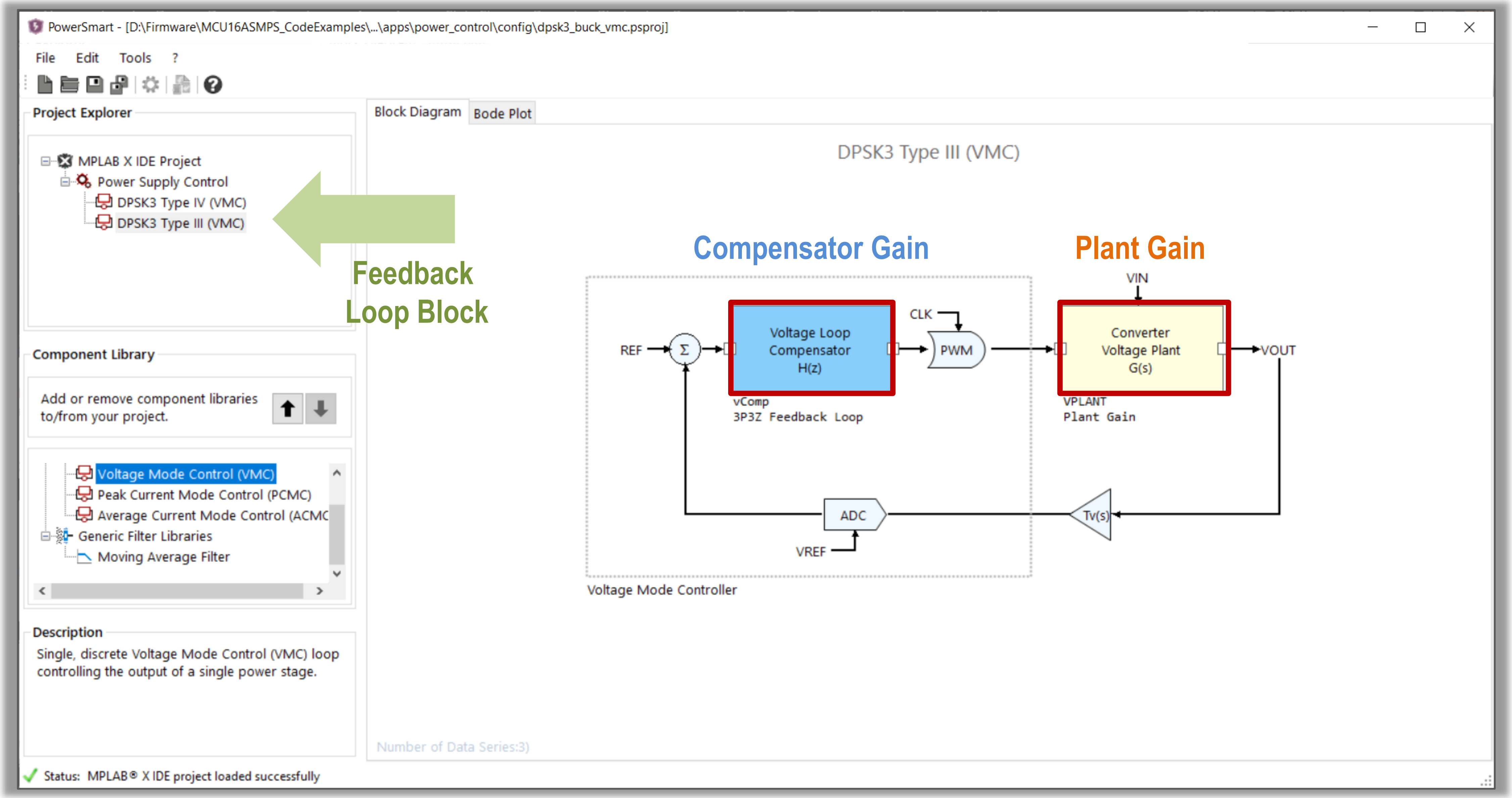


Live Demonstration

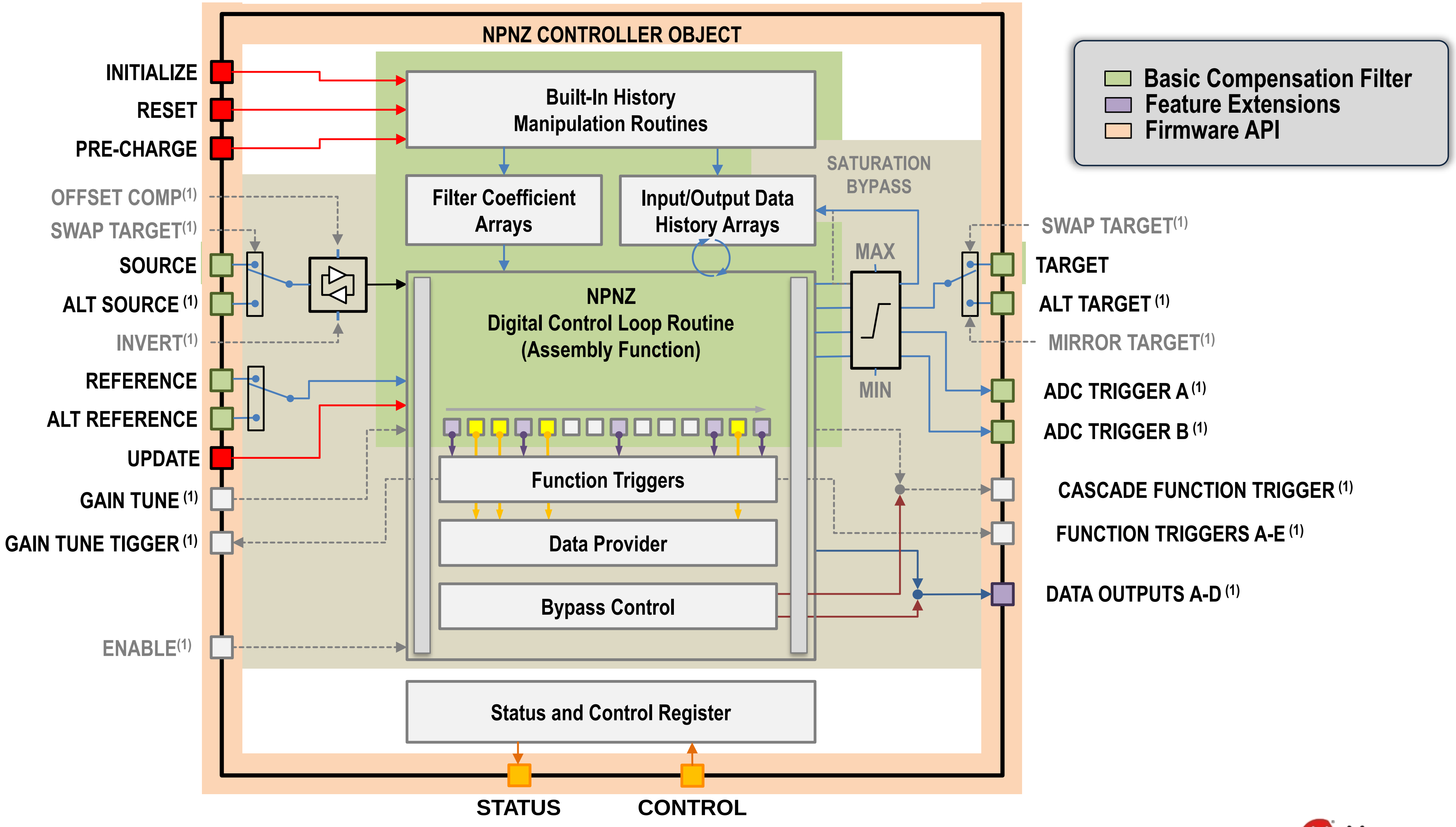
Digital Feedback Loop Design using

MPLAB® PowerSmart Development Suite & OMICRON Bode 100

MPLAB® PowerSmart™ Development Suite

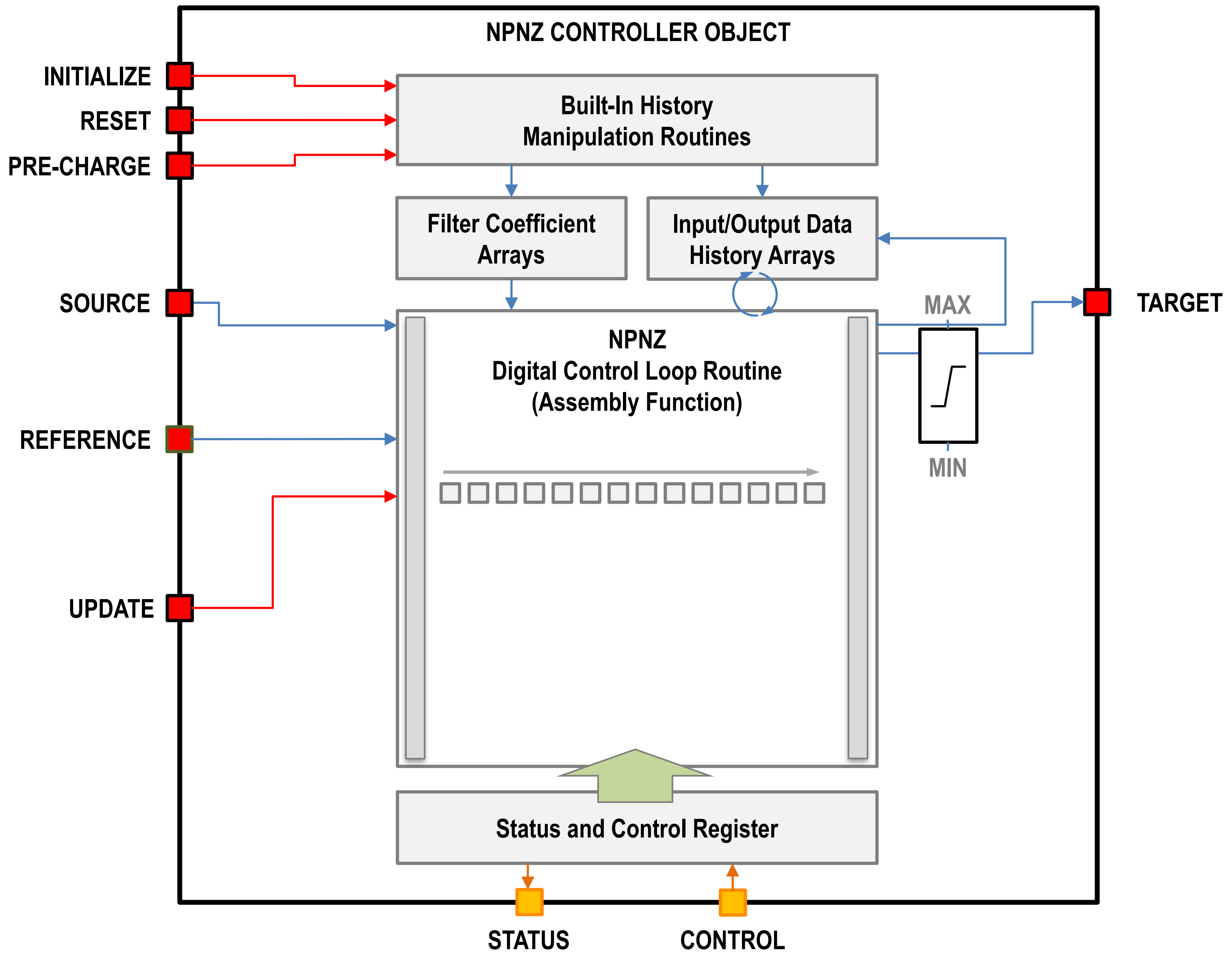


Complete Feedback Loop Block Diagram

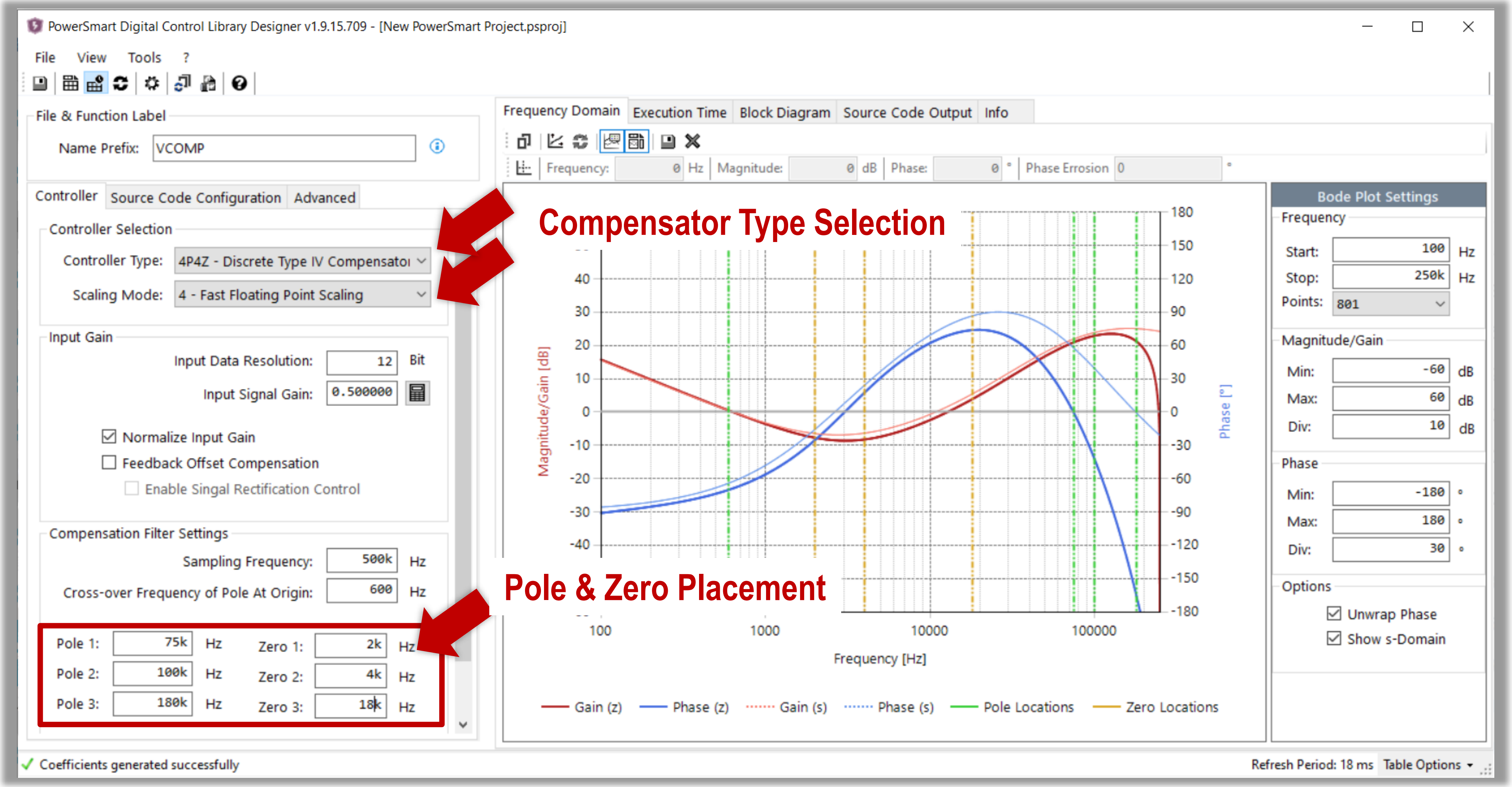


MICROCHIP

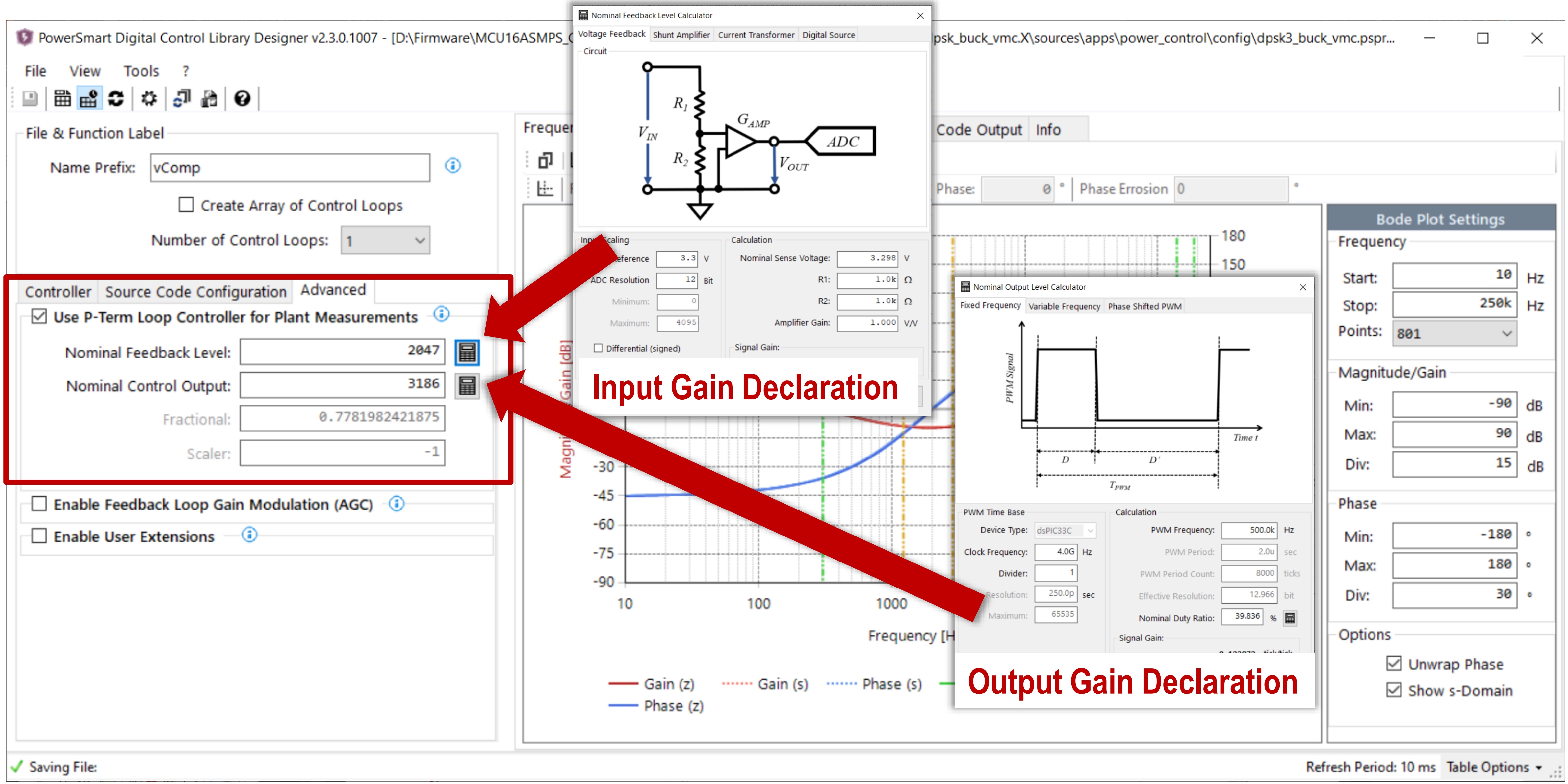
Basic Feedback Loop Block Diagram



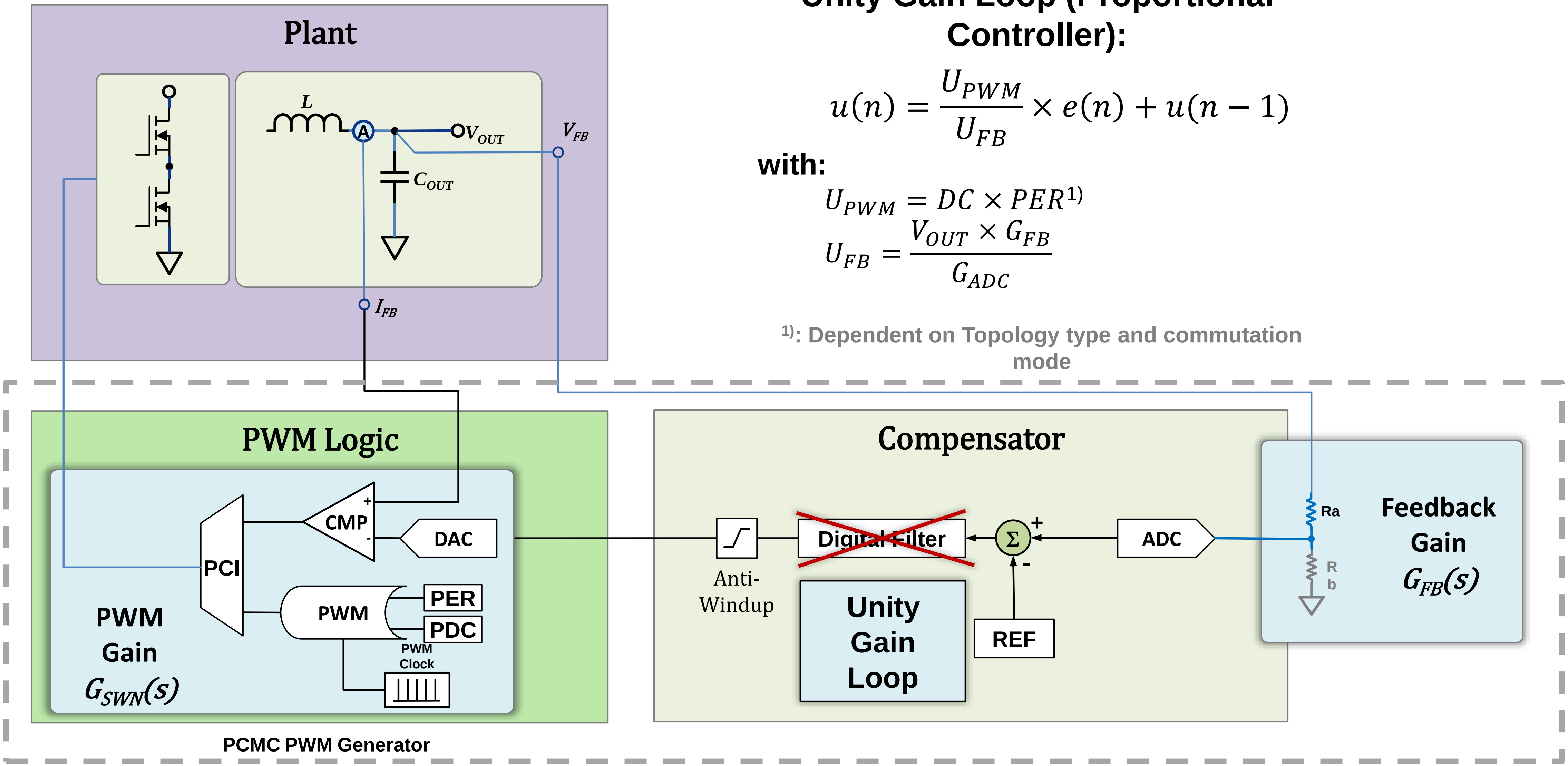
Control Loop Adjustment



Plant Measurement Setup



Plant Measurement



Unity Gain Loop (Proportional Controller):

$$u(n) = \frac{U_{PWM}}{U_{FB}} \times e(n) + u(n-1)$$

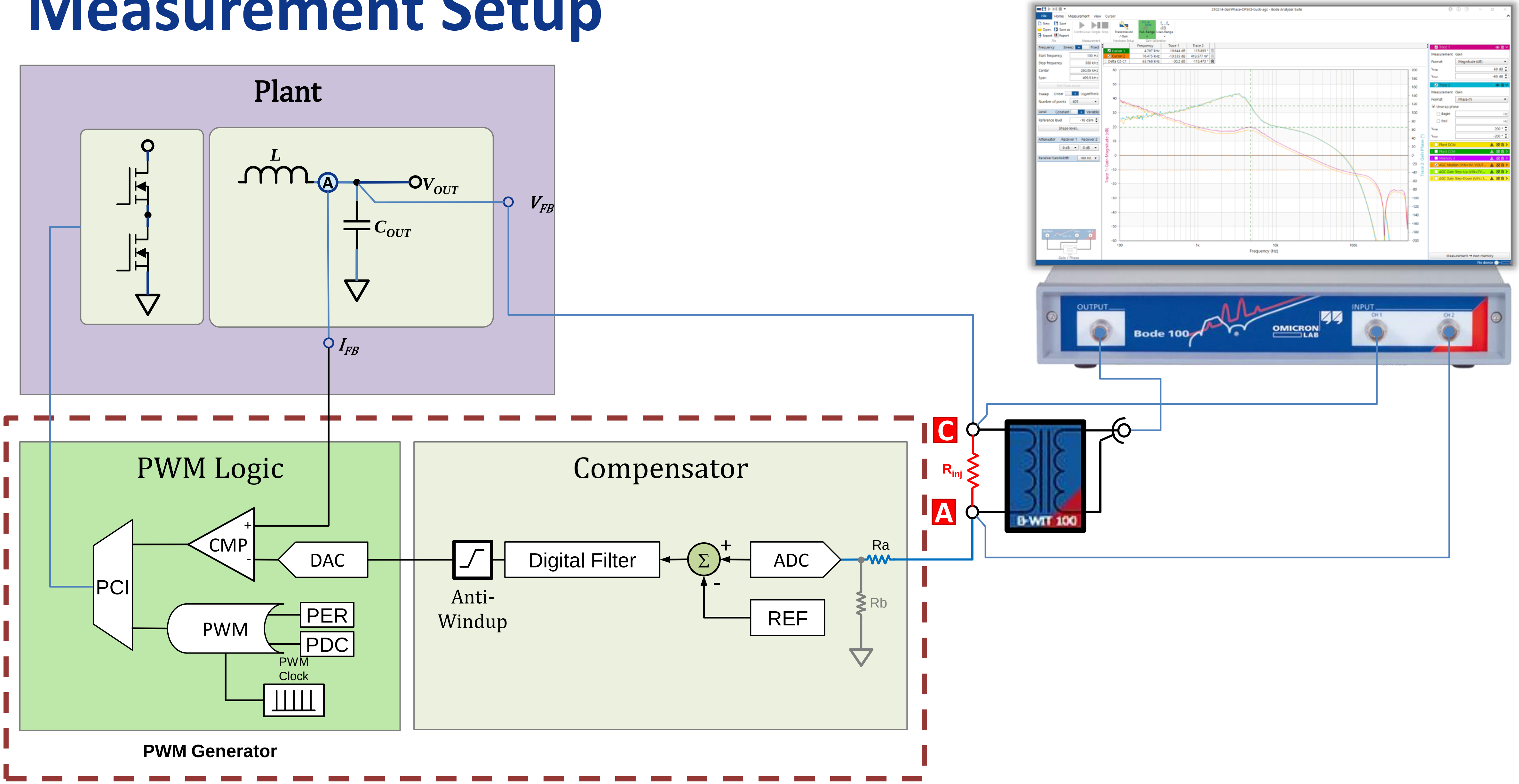
with:

$$U_{PWM} = DC \times PER^{1)}$$

$$U_{FB} = \frac{V_{OUT} \times G_{FB}}{G_{ADC}}$$

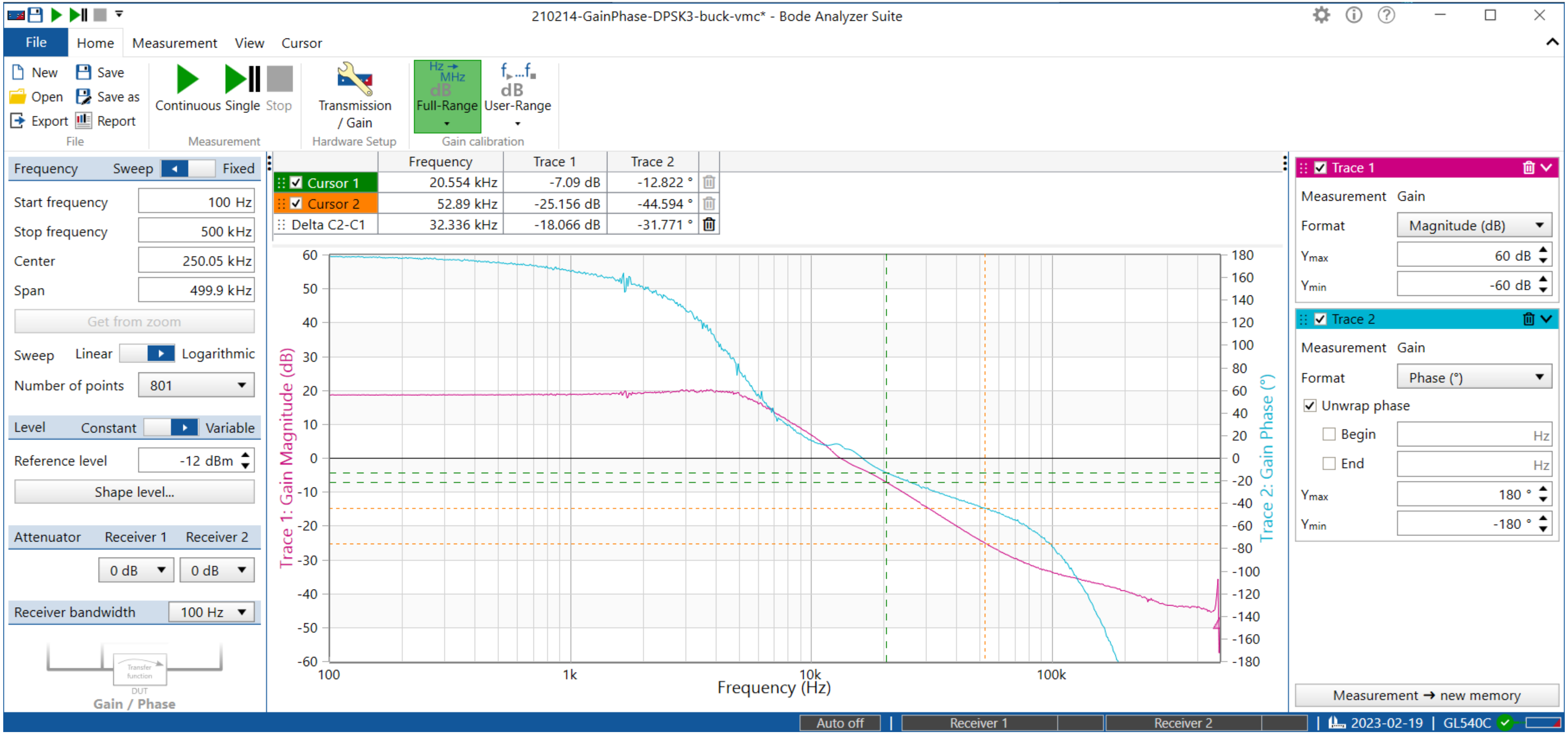
1): Dependent on Topology type and commutation mode

Measurement Setup

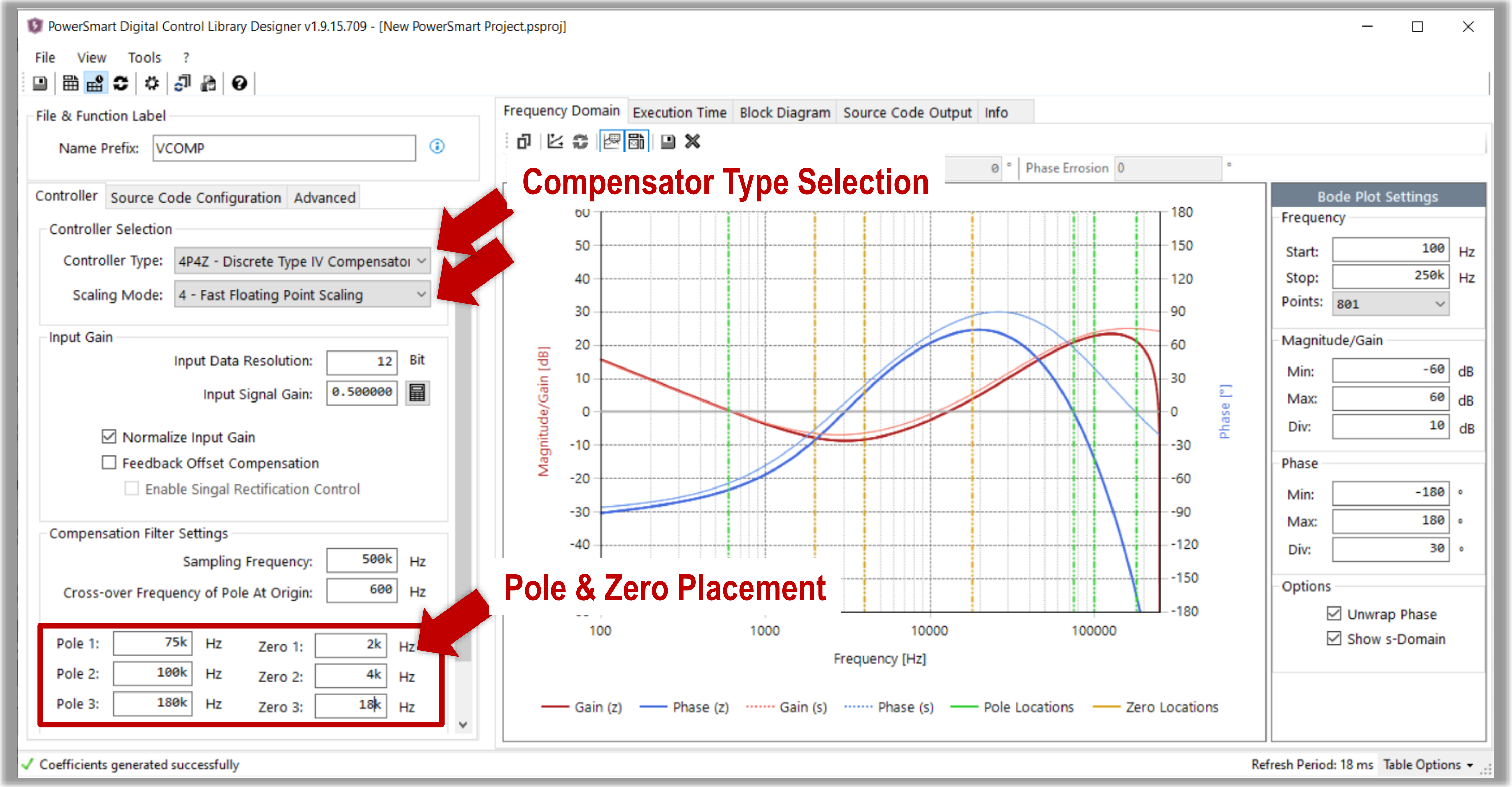


MICROCHIP

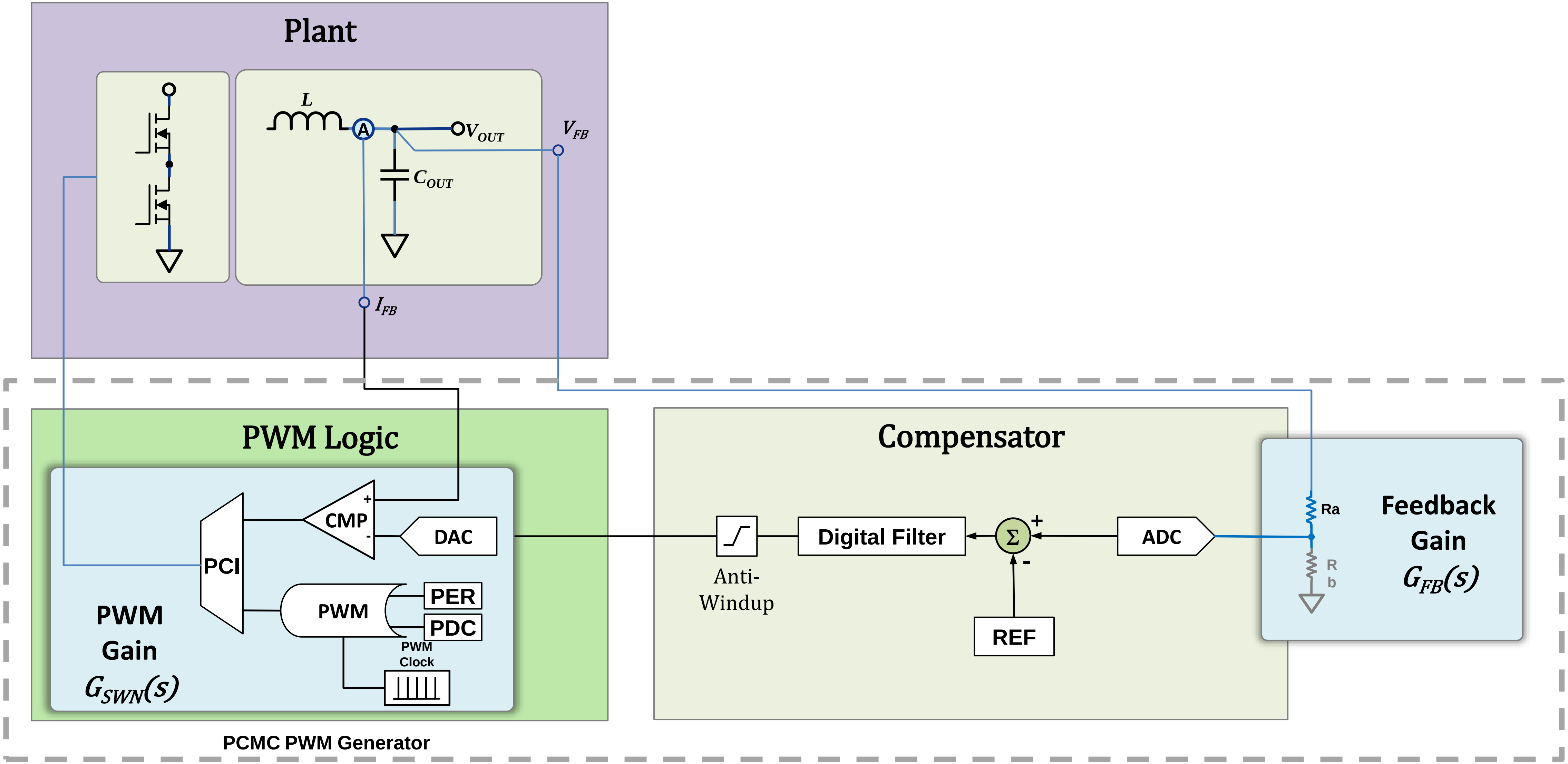
Plant Measurement Result



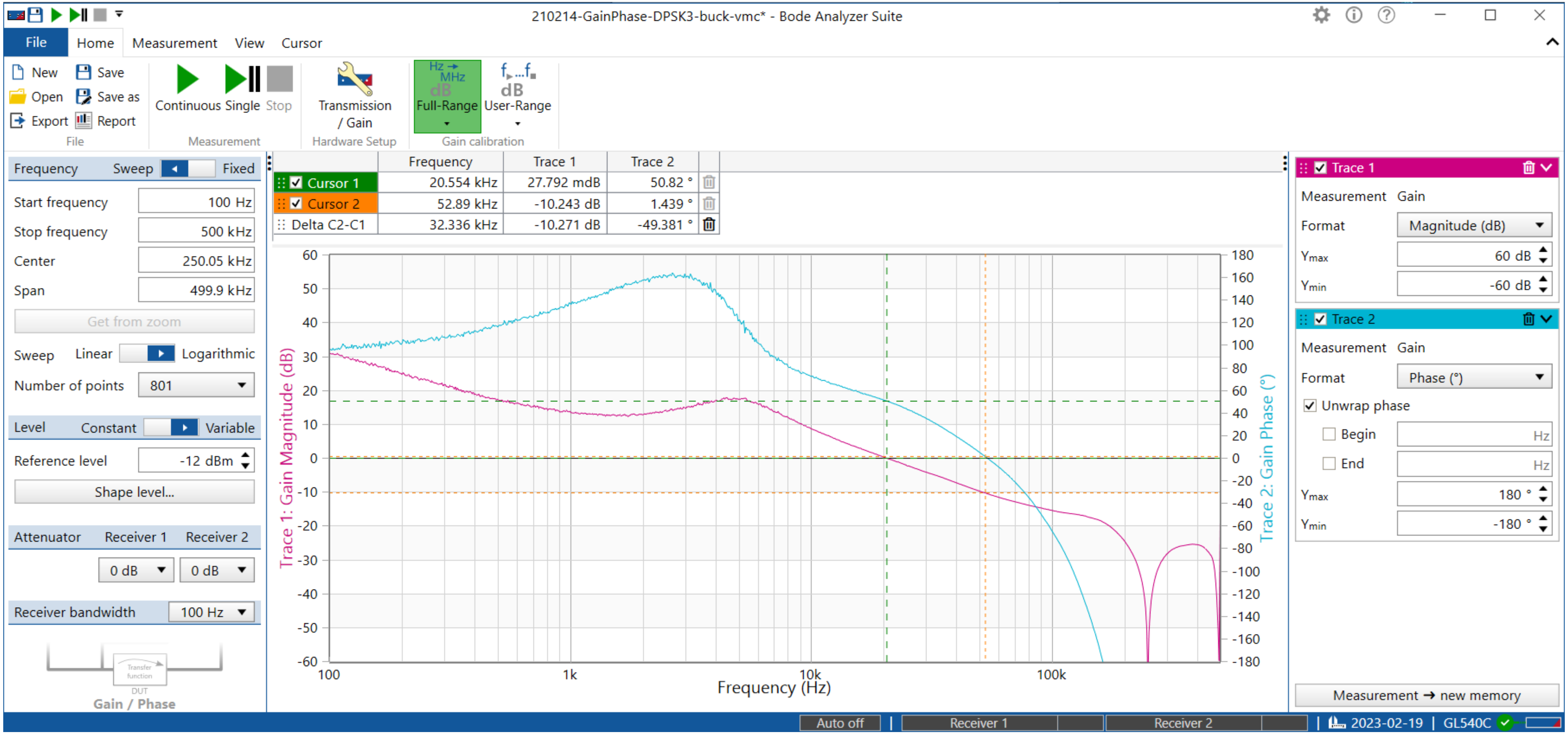
Control Loop Adjustment



Open Loop Measurement



Open Loop Gain Measurement



Agenda

Digital Power Supply Control Overview

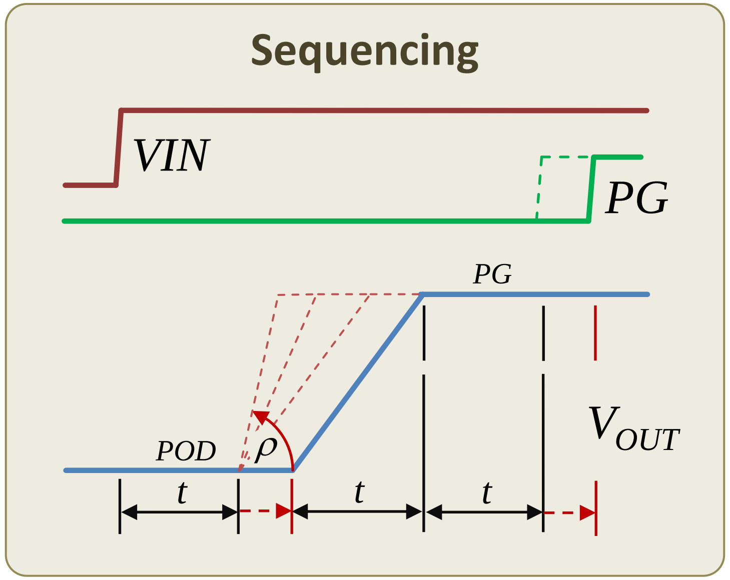
Rapid Prototyping

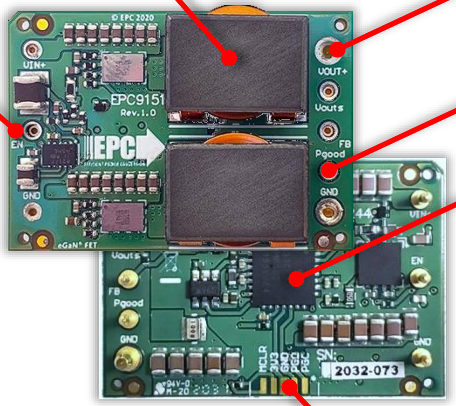
System Firmware Development & Test

Summary

Application Example

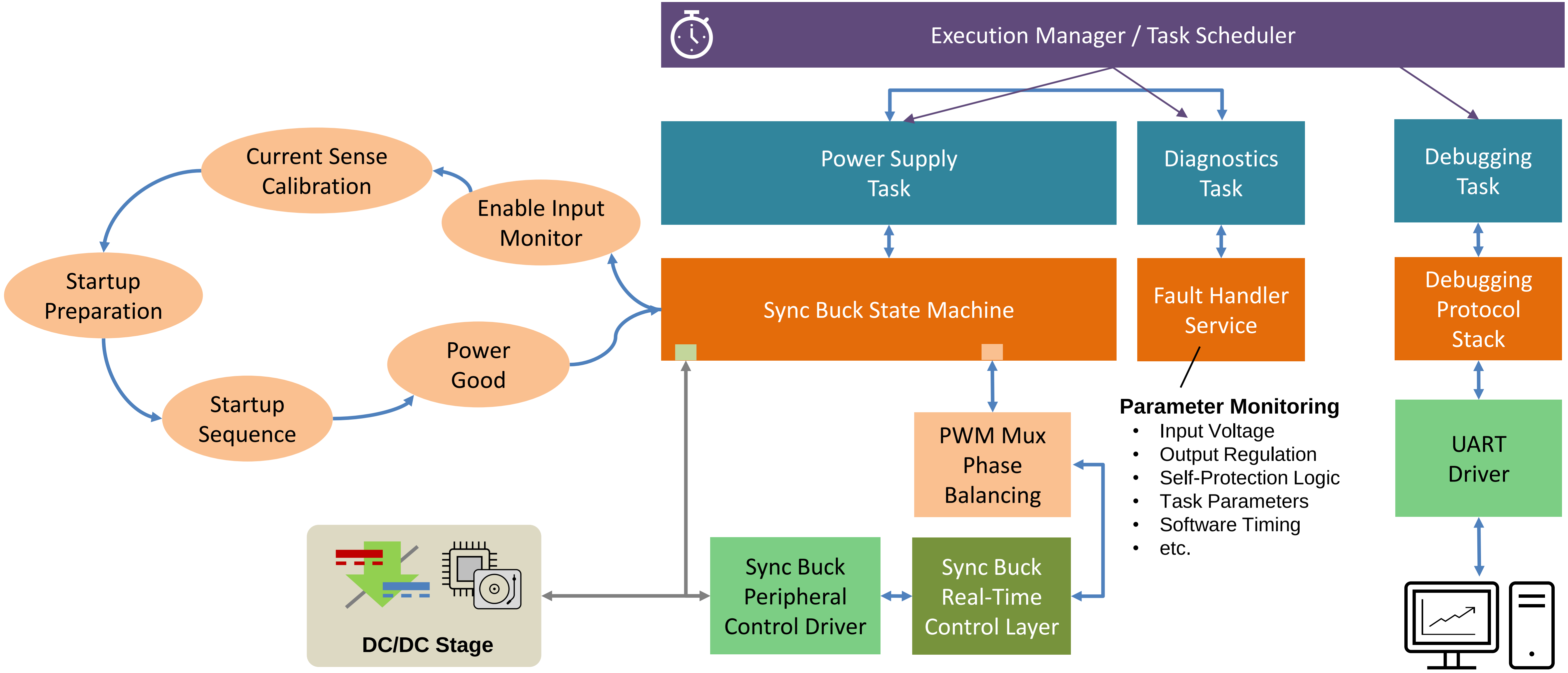
Intermediate DC/DC Bus Converter





Application Example

Intermediate DC/DC Bus Converter

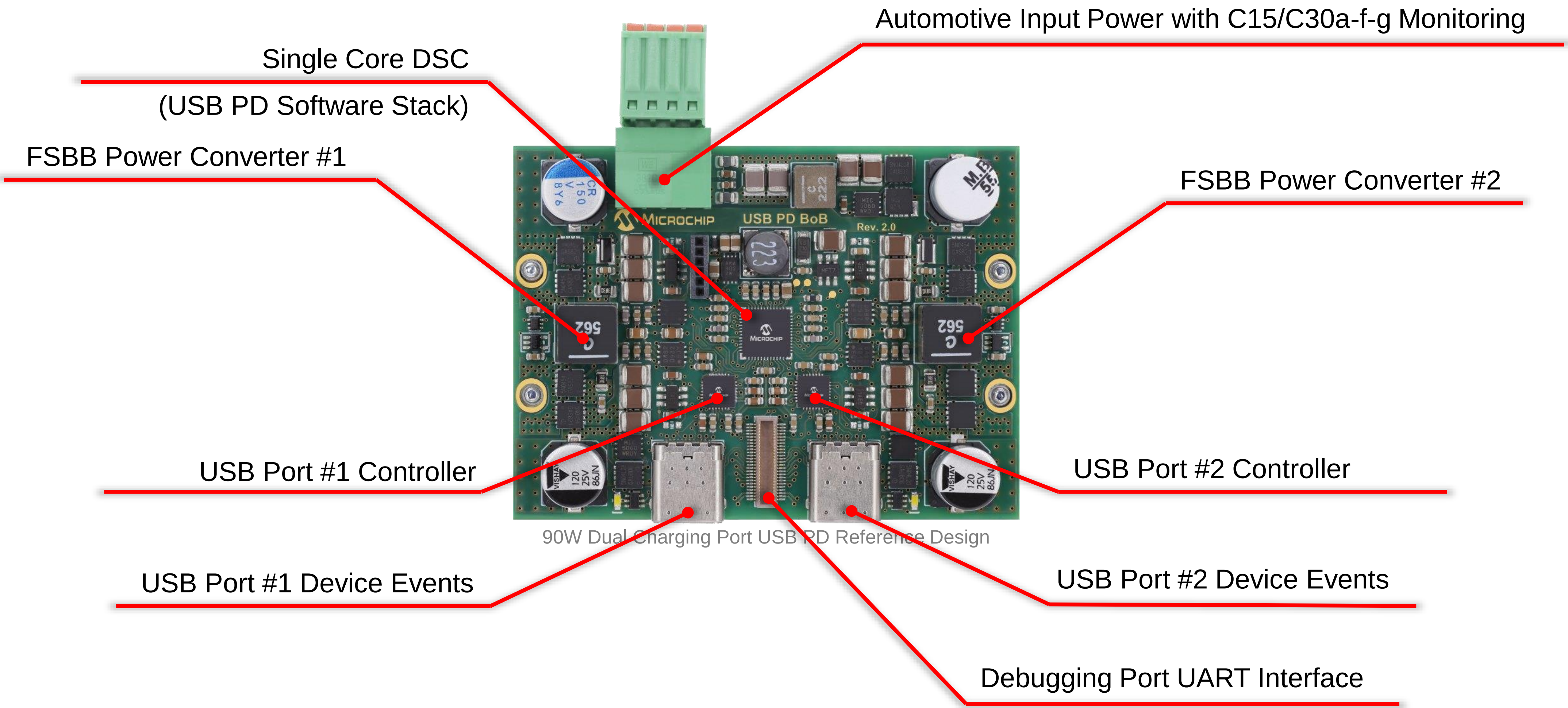


Parameter Monitoring

- Input Voltage
- Output Regulation
- Self-Protection Logic
- Task Parameters
- Software Timing
- etc.

Application Example

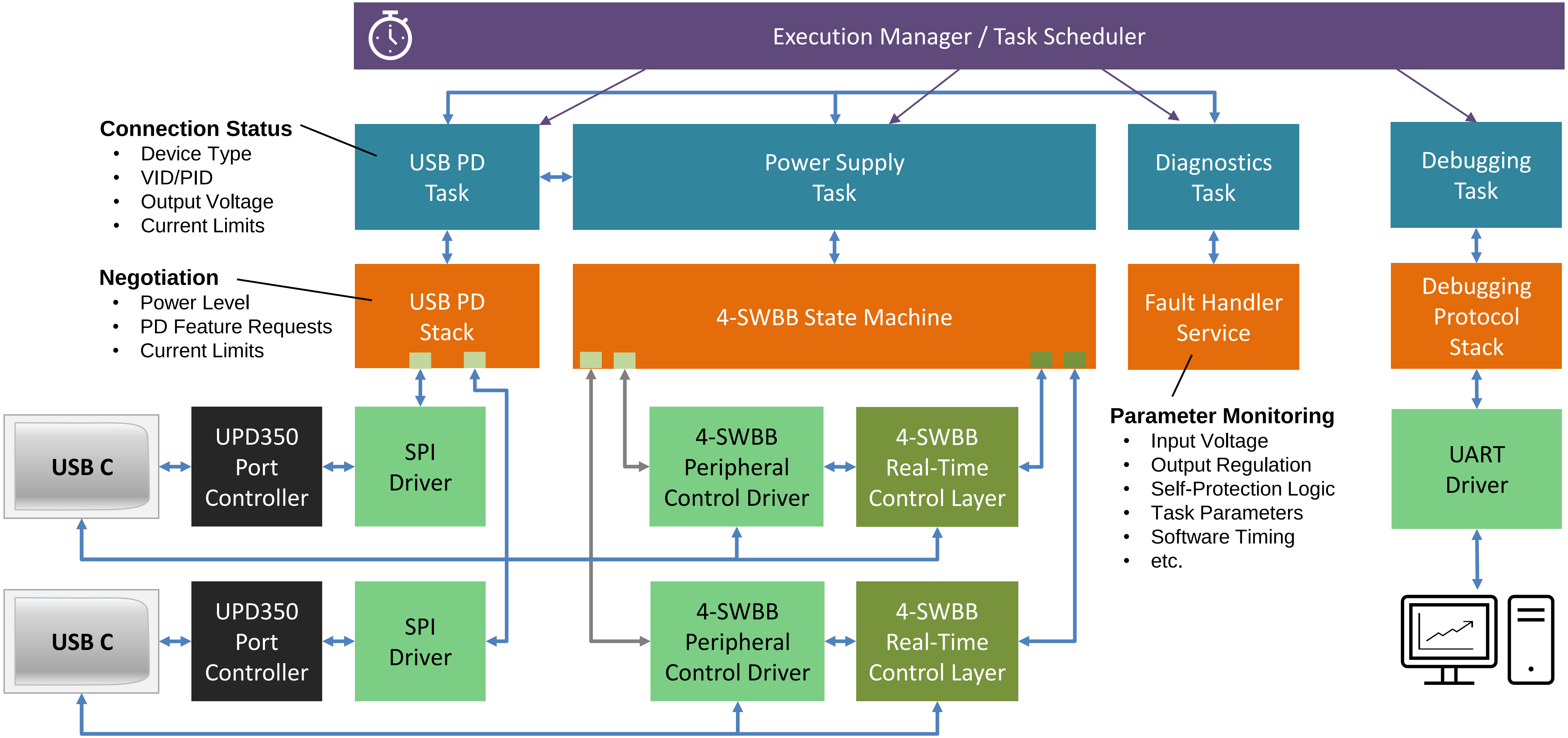
Dual Charging Port USB PD Design



90W Dual Charging Port USB PD Reference Design

Application Example

Dual Charging Port USB PD Design



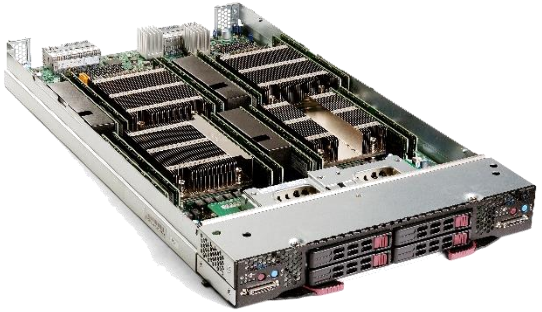
Application Example

Data Center AC/DC Power Supply

Isolation

AC-Input
Power Factor Correction

DC-Output
400V–to–48/12V Conversion

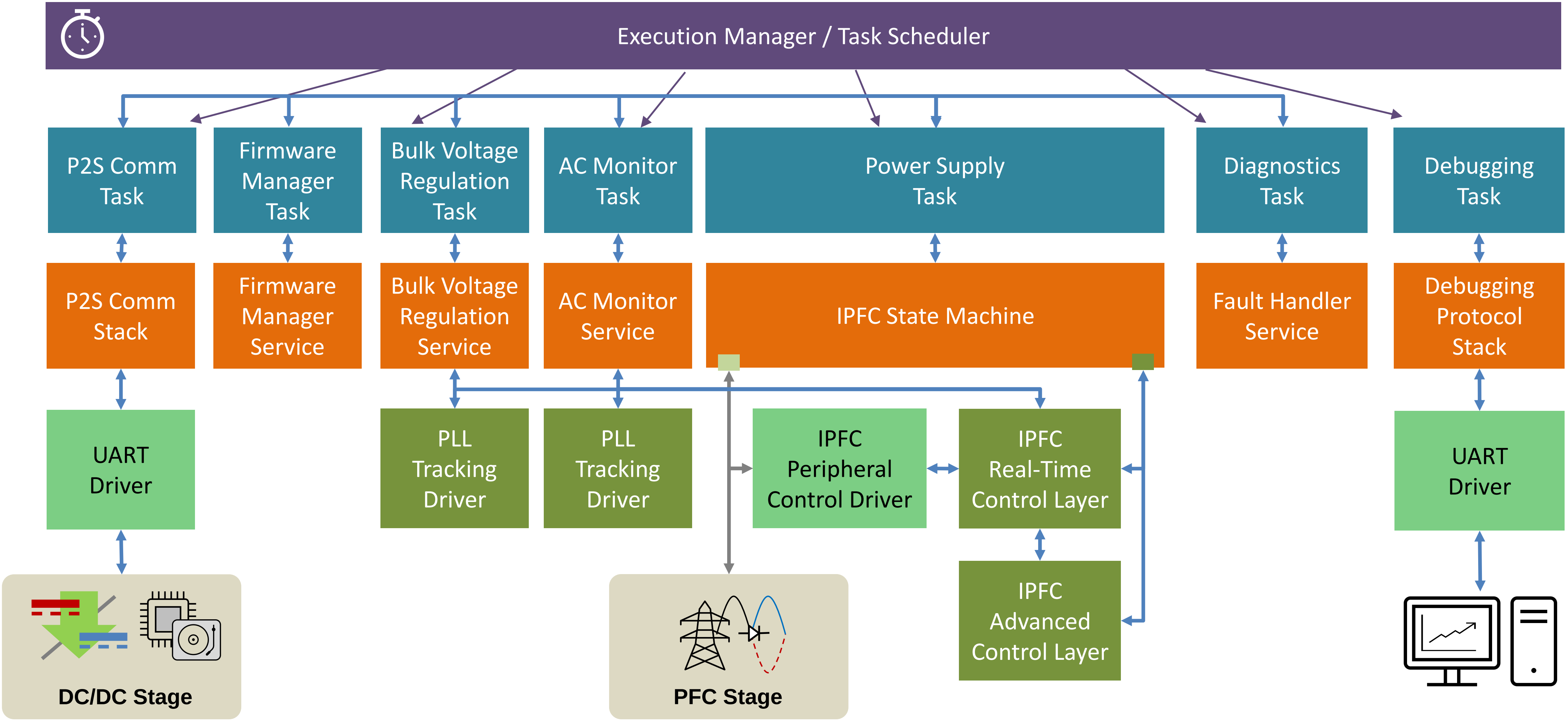


Primary Controller
- AC Input Tracking
- Power Factor Correction
- Bulk Voltage Regulation
- Auxiliary Power Control
- P2S Communication
- Energy Metering

Secondary Controller
- DC Output Regulation
- Current Sharing / Redundancy
- Fan Control
- S2P Communication
- Host Communication
- Firmware Update Management

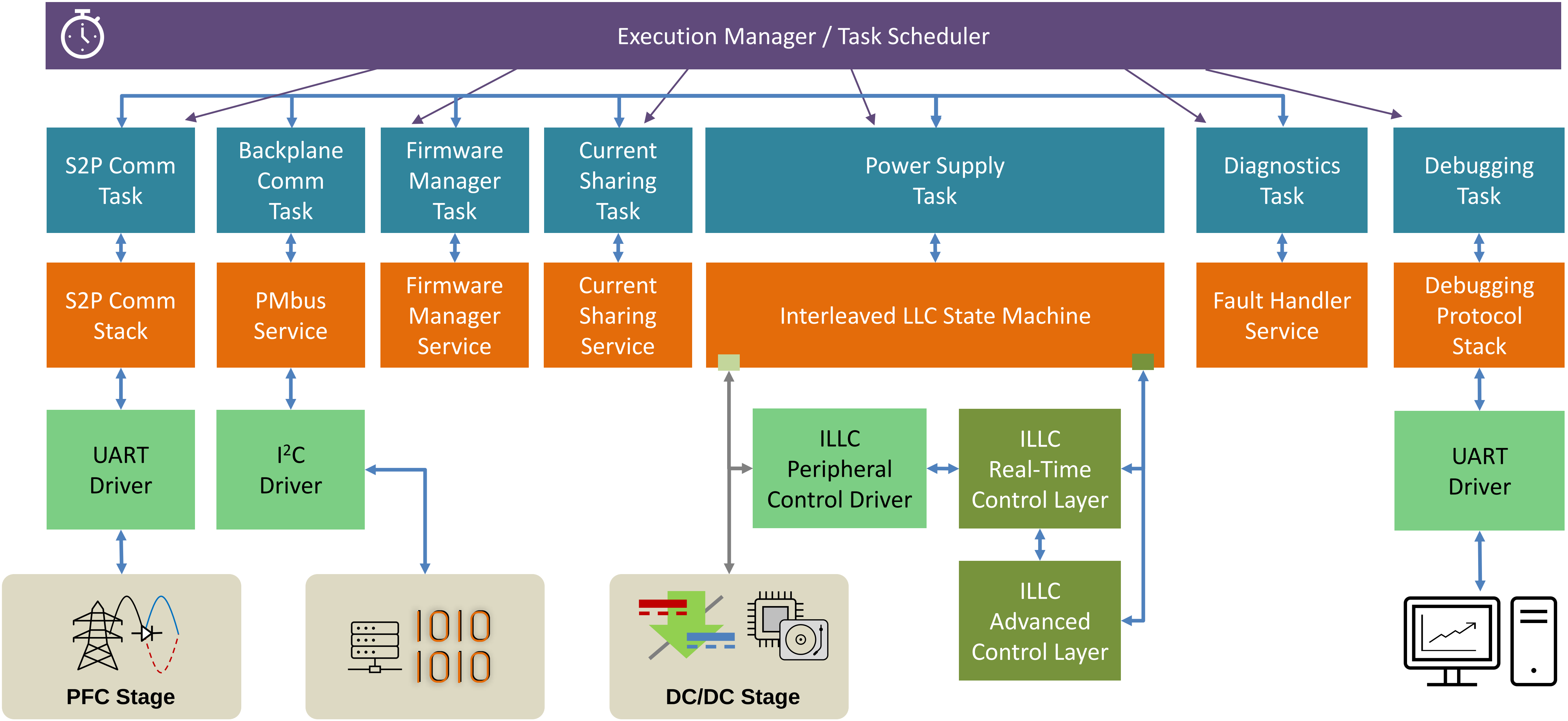
Application Example

Data Center AC/DC Power Supply – Primary Side Firmware



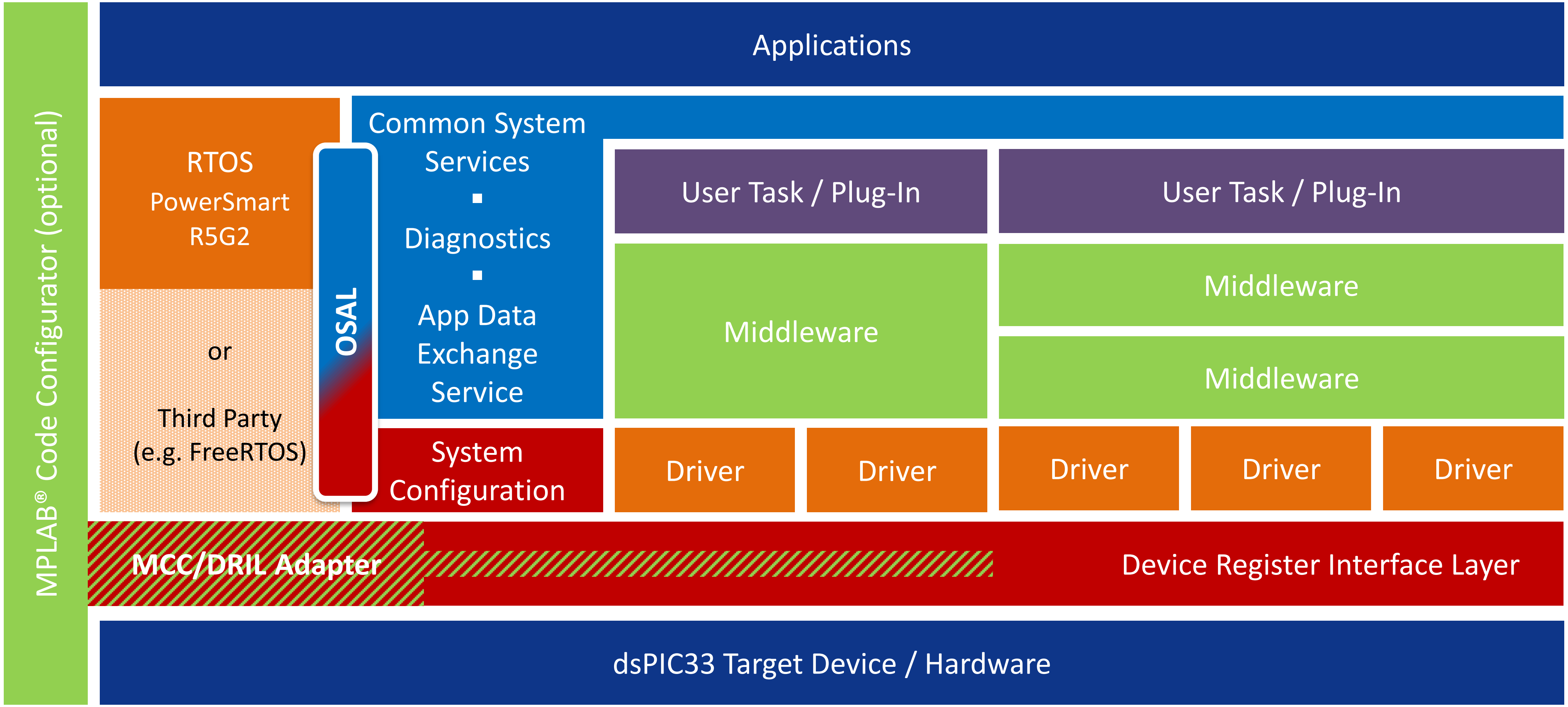
Application Example

Data Center AC/DC Power Supply – Secondary Side Firmware



MPLAB® PowerSmart™ Development Suite

MPLAB® PowerSmart™ Software Framework for dsPIC33 DSCs



MPLAB® PowerSmart™ Development Suite

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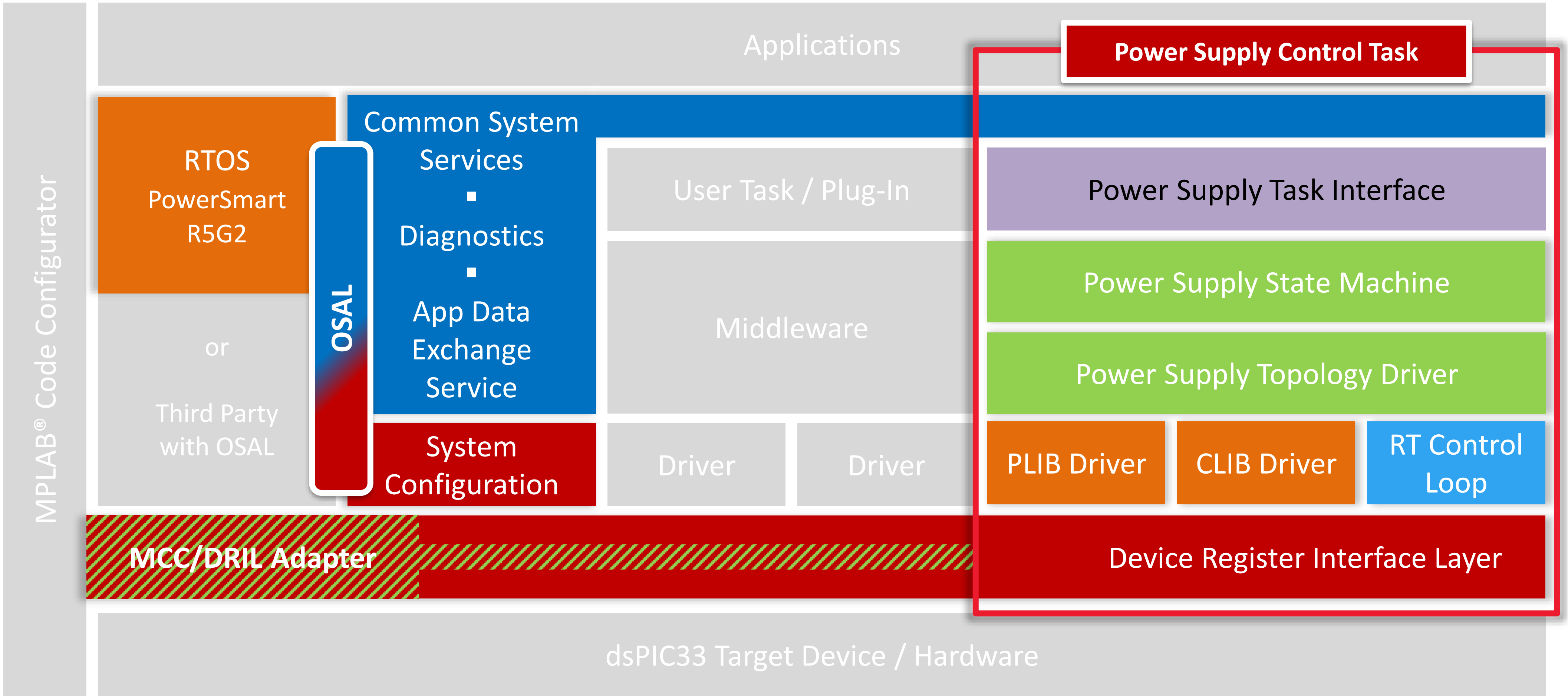
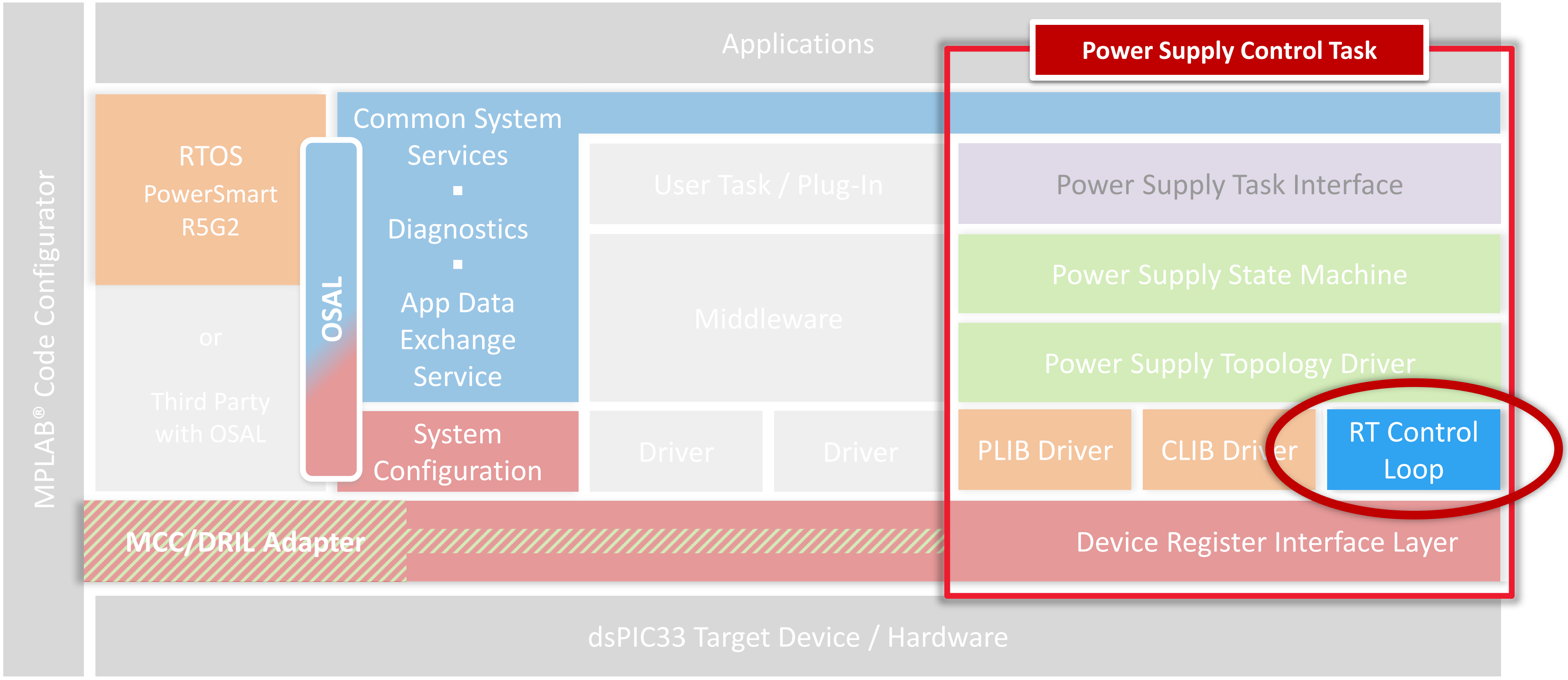


MPLAB® PowerSmart™ Development Suite

MPLAB® PowerSmart™ Software GUI Components for dsPIC33 DSCs



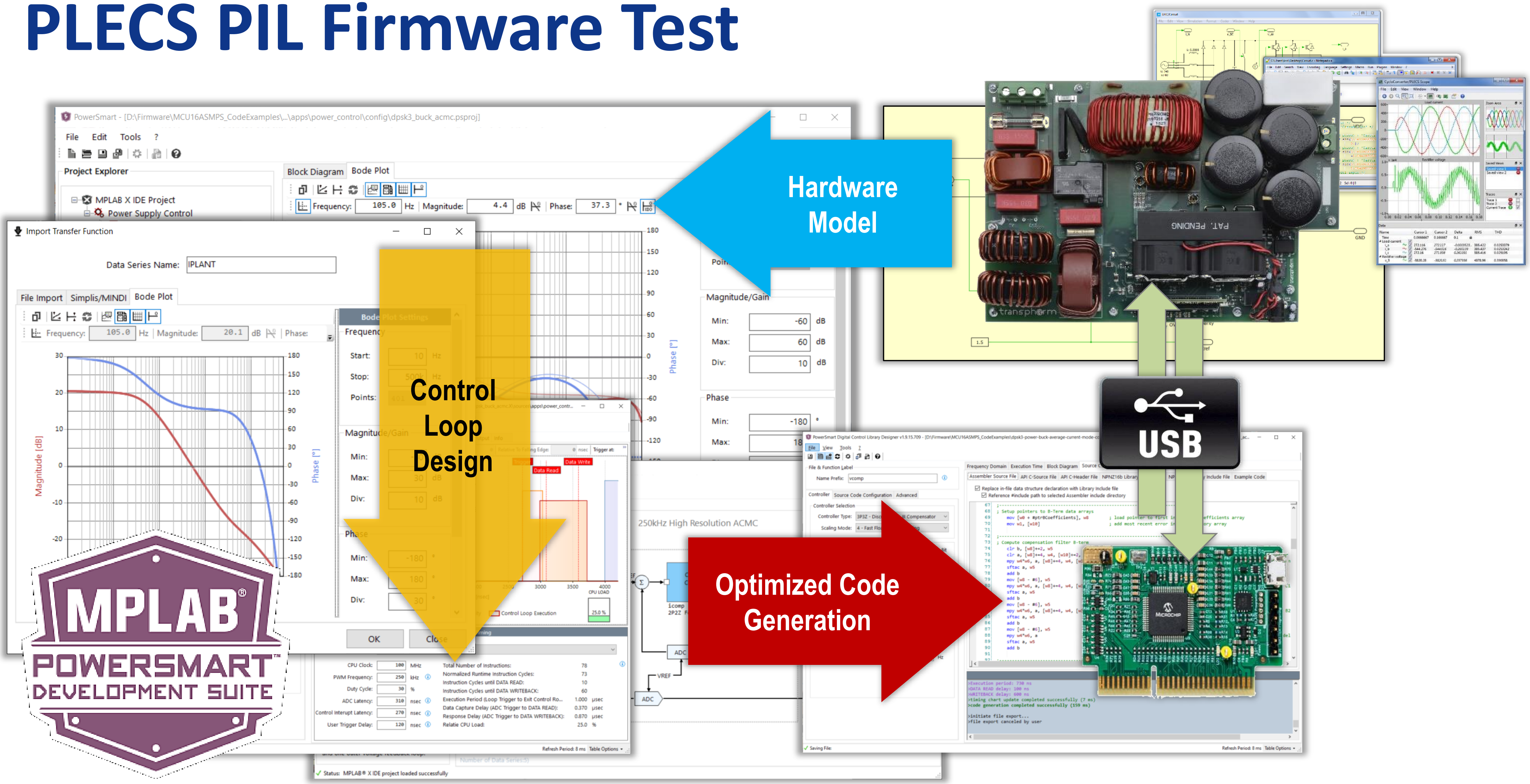
Model Oriented Design & Firmware Test

plexim
electrical engineering software

Using Plexim PLECS

- **What is PLECS?**
  - Behavioral circuit simulation, optimized for power electronics
  - Available as standalone software or as building block for MATLAB Simulink
- **Simulation Options**
- **Virtual Simulation**
  - System simulation using component models only
  - Additional coder and scripting allows state changes
- **Processor In the Loop (PIL)**
  - Virtual system circuit while executing real code on real target device
- **Real-Time Simulation using RT-Box**
  - Real time signal simulation stimulating real target device
  - Firmware now runs at full execution speed

PLECS PIL Firmware Test

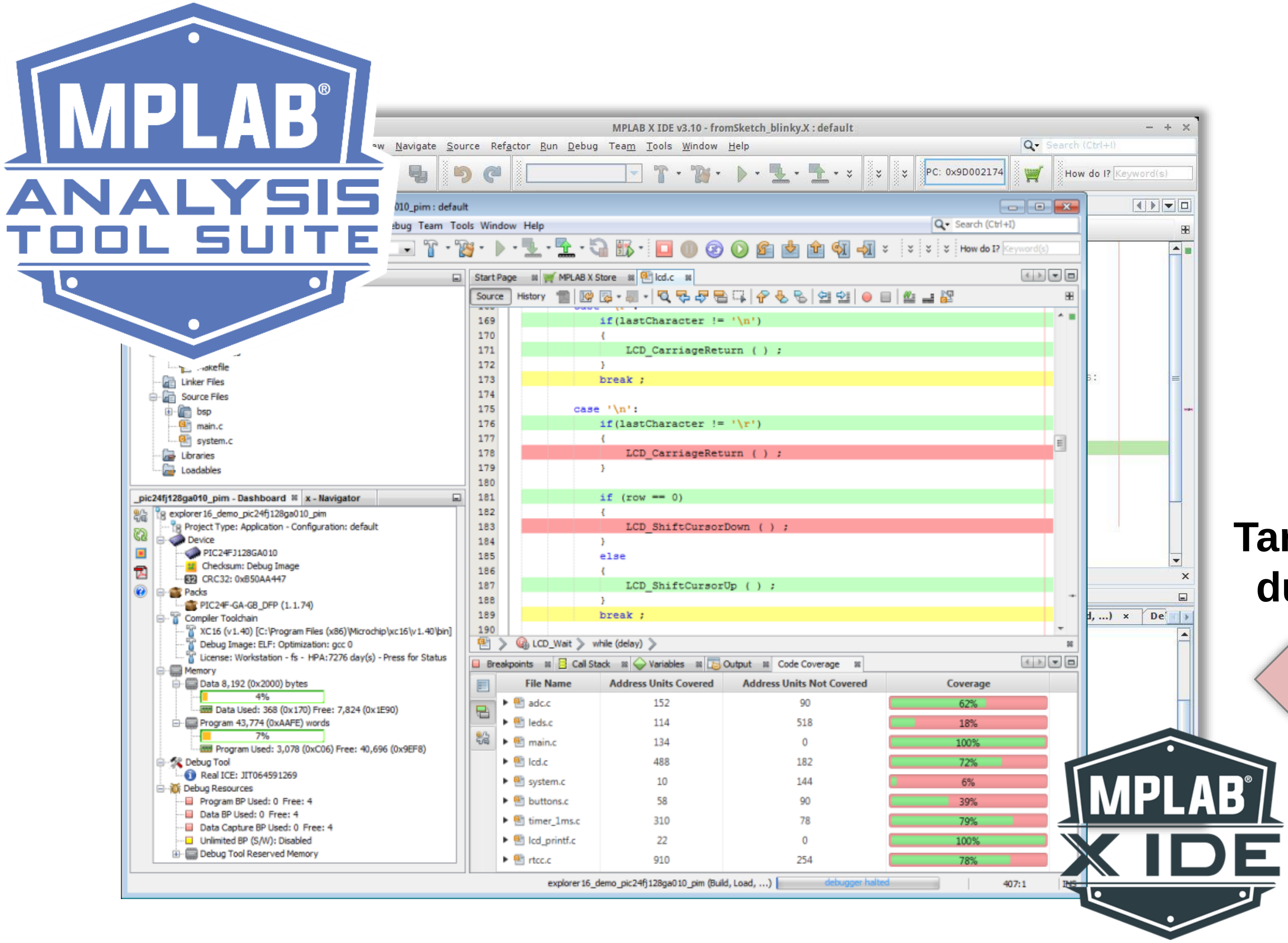


PIL Firmware Test

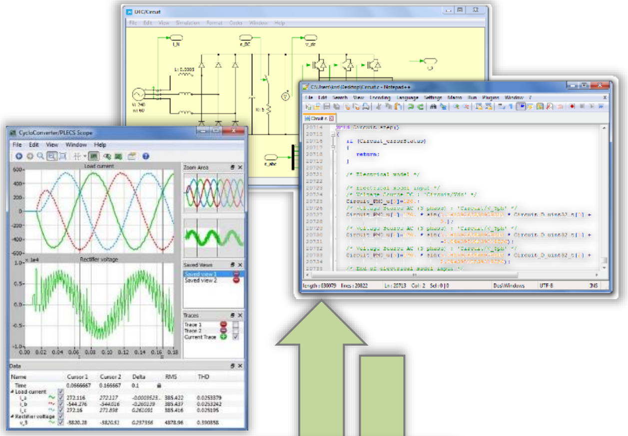
Using Plexim PLECS – PIL Simulation

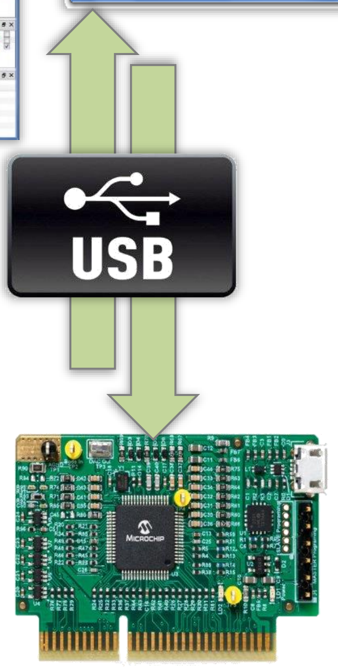
- **PIL allows to include the vendor IDE**
  - Firmware can run in debugging session, allowing to debug and troubleshoot firmware issues and observe internal data
  - Integrated Development Environment (IDE) Extensions can be enabled, such as Code Coverage Measurement
  - Virtual hardware allows simulation of catastrophic fault cases, (e.g. shorted FETs)

Firmware Debugging & Test



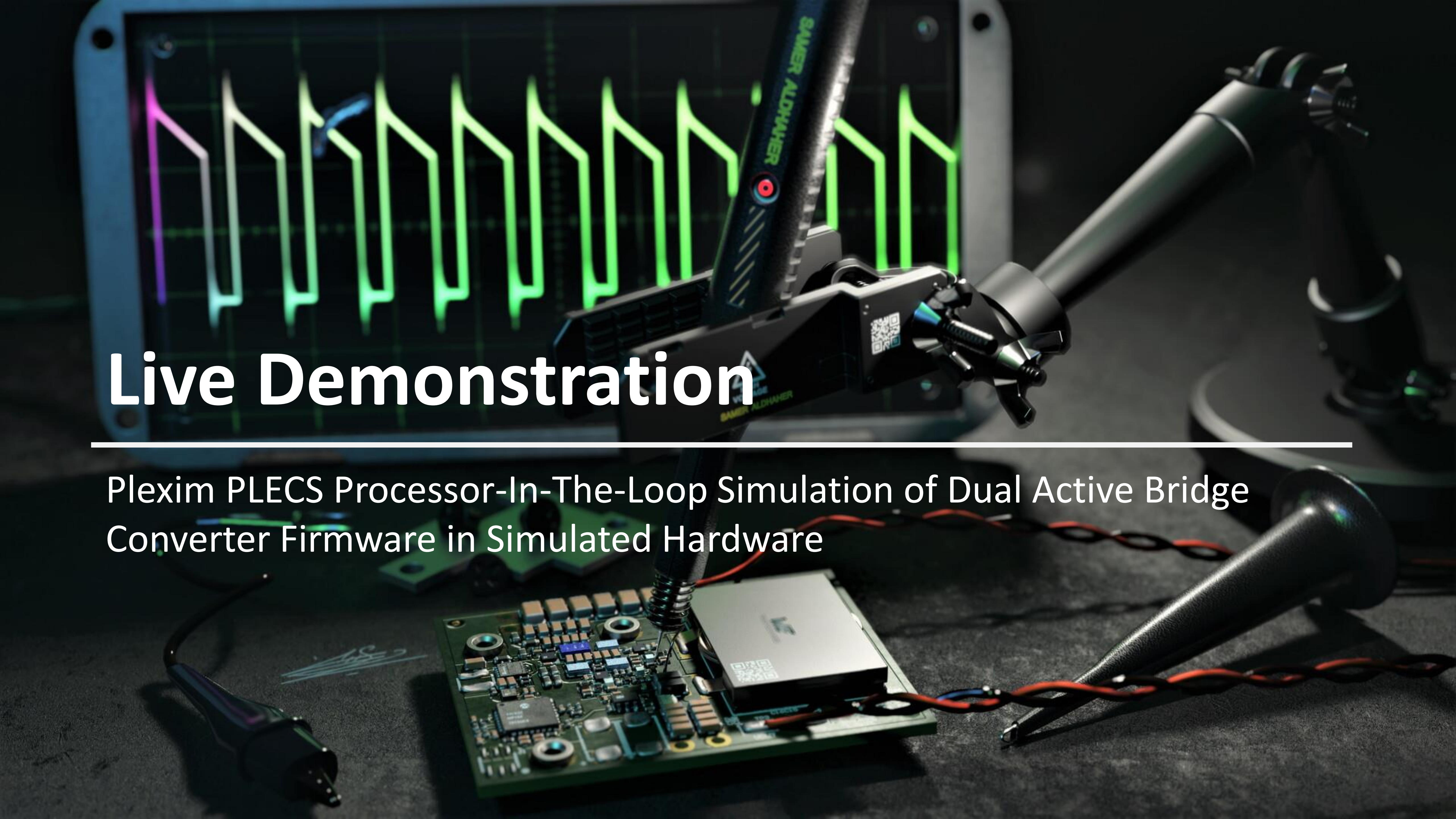
PLECS on Computer
runs the simulation





Target firmware test
during simulation

Target device
runs the firmware

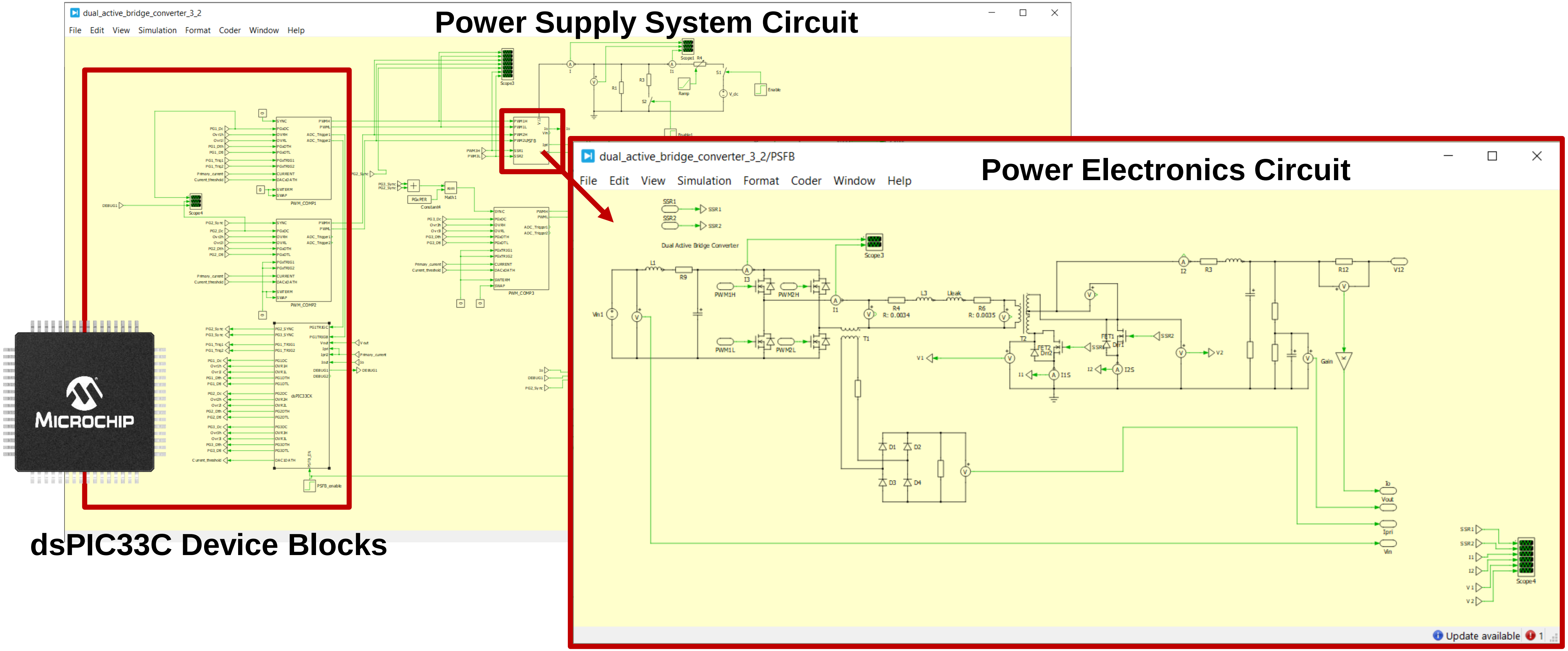


Live Demonstration

Plexim PLECS Processor-In-The-Loop Simulation of Dual Active Bridge Converter Firmware in Simulated Hardware

PLECS PIL Firmware Test Demo

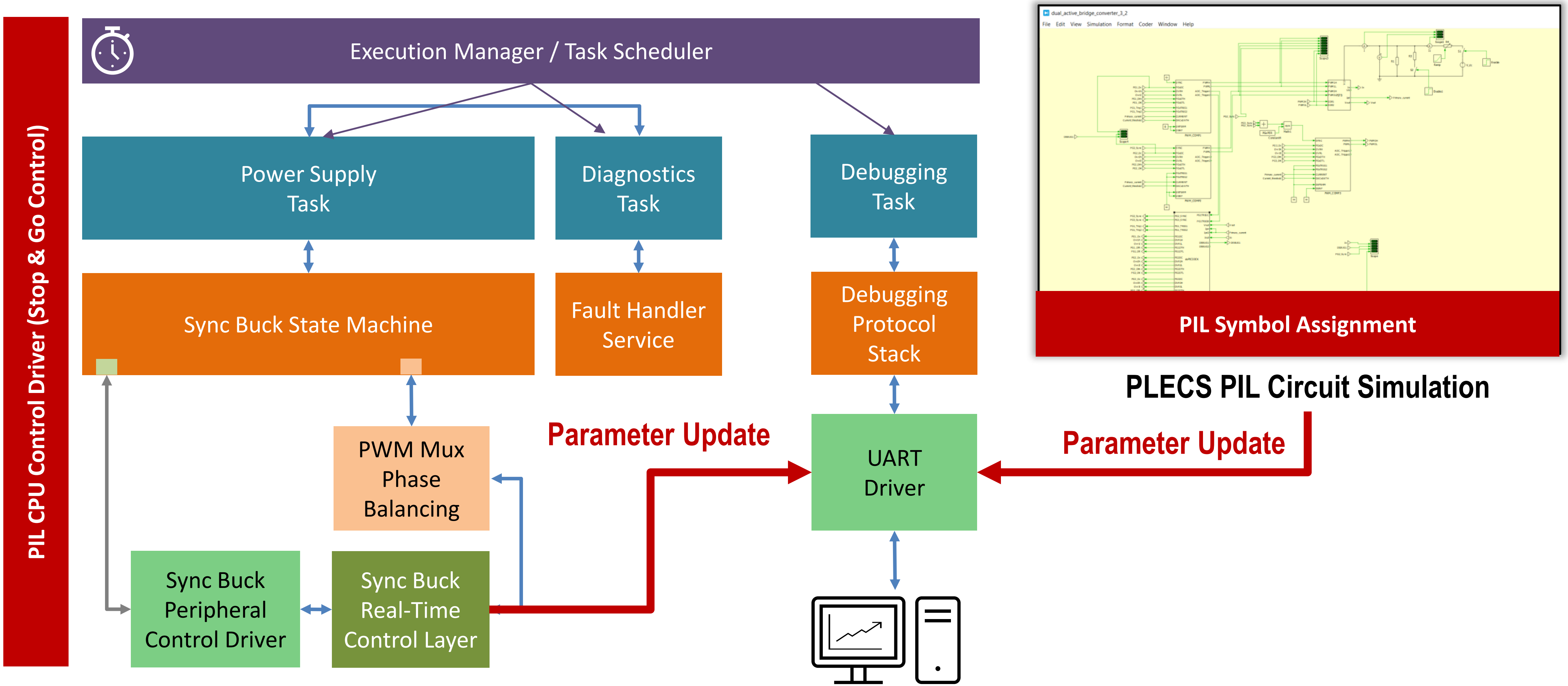
Firmware Test for Dual Active Bridge Converter



dsPIC33C Device Blocks

PLECS PIL Firmware Test Demo

Firmware Modification



Real-Time Feedback Loop Interrupt

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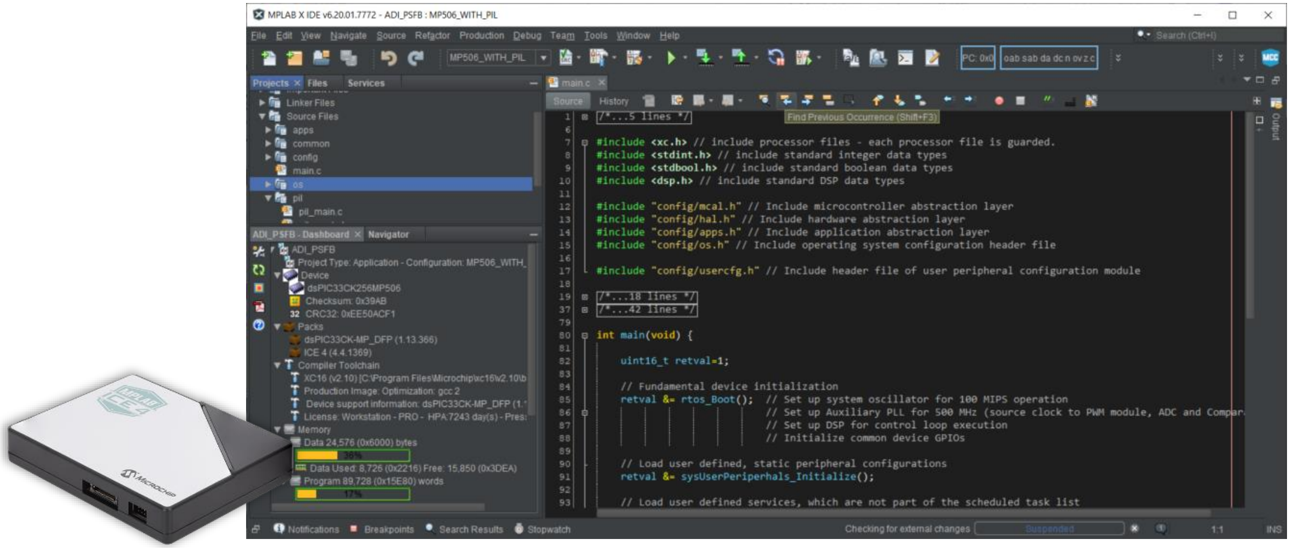
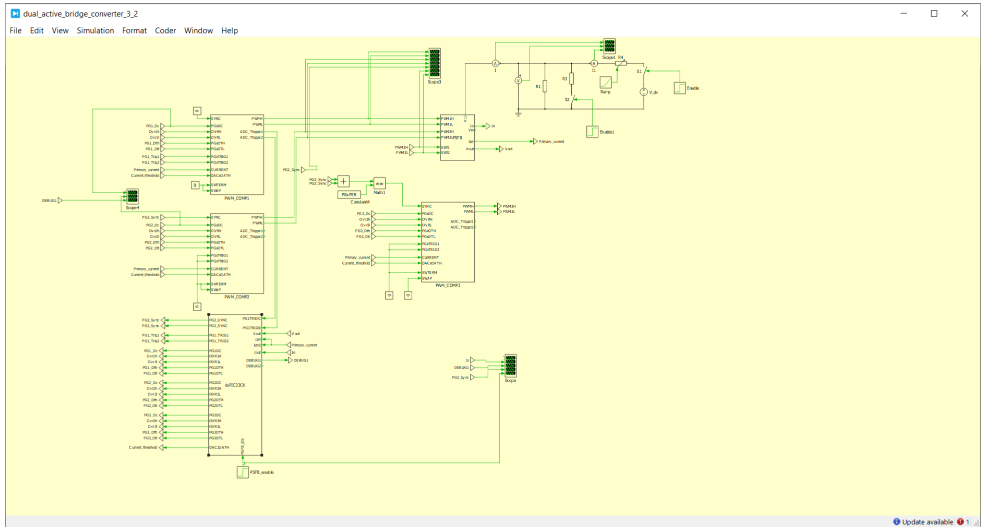
PLECS PIL Firmware Test Demo

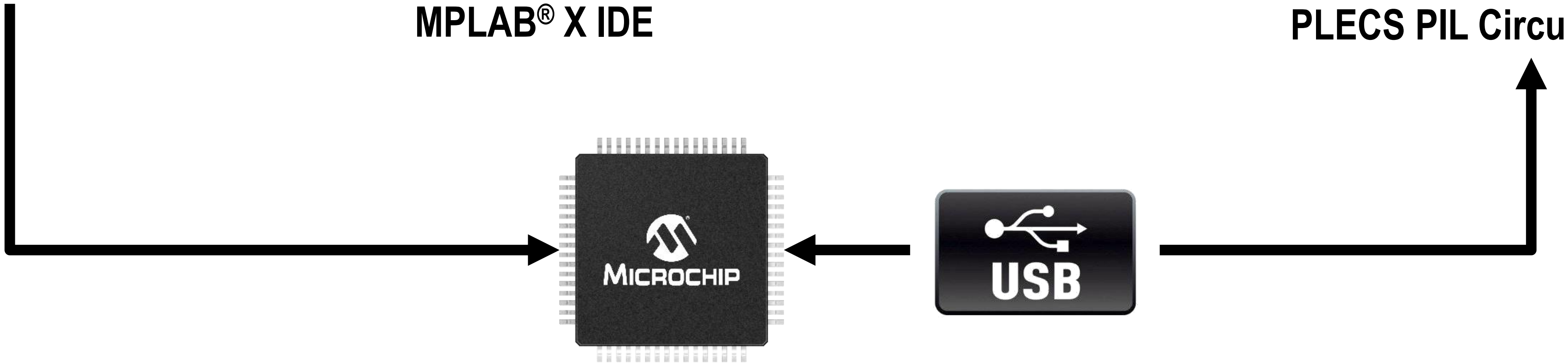
Firmware Test for Dual Active Bridge Converter



MPLAB® X IDE



PLECS PIL Circuit Simulation



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Summary

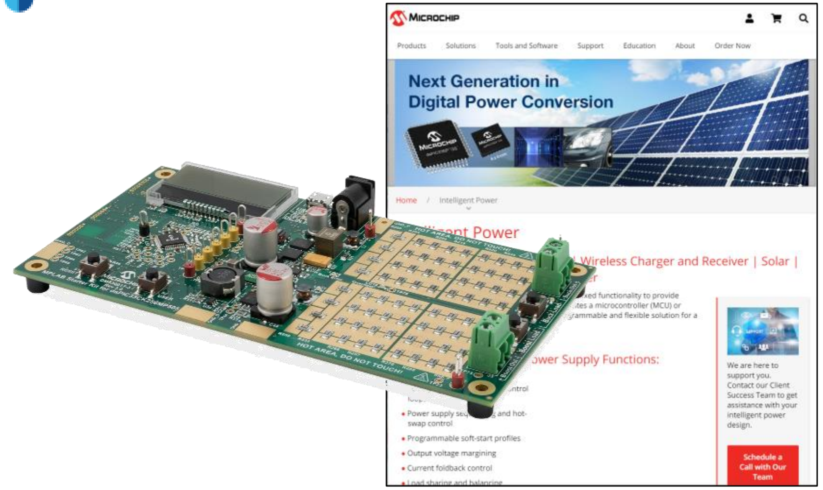
- Digital Control of switch-mode power supplies enables new topologies, solves non-linear control challenges, eases product family management and customization and makes products more robust

- However, introducing control firmware into the design requires additional test, verification and quality management infrastructure and skills

- Wide range of various design tool eco systems and templates offer extensive design support and help to cut design cycles short

Digital Power Training

- **Getting Started in Digital Power**
  - Intelligent Power Design Center:
    https://www.microchip.com/power
- **How-2 Starter Kits**
  - Digital Power Starter Kit 3 (Part-No. DM330017-3):
    https://www.microchip.com/dm330017-3
- **Self-Paced Training:**
  - Microchip University (Virtual Training Platform):
    https://secure.microchip.com/mu



- **Face-2-Face Workshops:**
  - Biricha Digital Power & PFC Workshop, **June 4th to 7th 2024**, Freiham near Munich
    Register under https://www.biricha.com/microchip.html

Q & A

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Thank You!

May the power be with you!

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Power Conversion

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Publication Information

Title: Designing Digital Control Loops and Firmware for Switch-Mode Power Supplies
Duration: 60 min
Presenter: Andreas Reiter, Senior Application Engineer Digital Power, Microchip Technology Inc.

Short Bio:

Andreas Reiter is Senior Applications Engineer for Digital Power Applications at Microchip Technology. Andreas has been working in power electronics since 1997 and is focusing on digitally controlled power conversion since 2006. Andreas' experience and interest include future requirement identification research and respective solutions development. His field of work ranges from supporting chip design teams in defining future features of semiconductor products to developing reference designs, concept boards and digital control loop algorithms for next generation switch mode power supplies. Focus applications at Microchip Technology are nodes in power distribution networks in data center and telecom, renewable energies and automotive electrification applications.