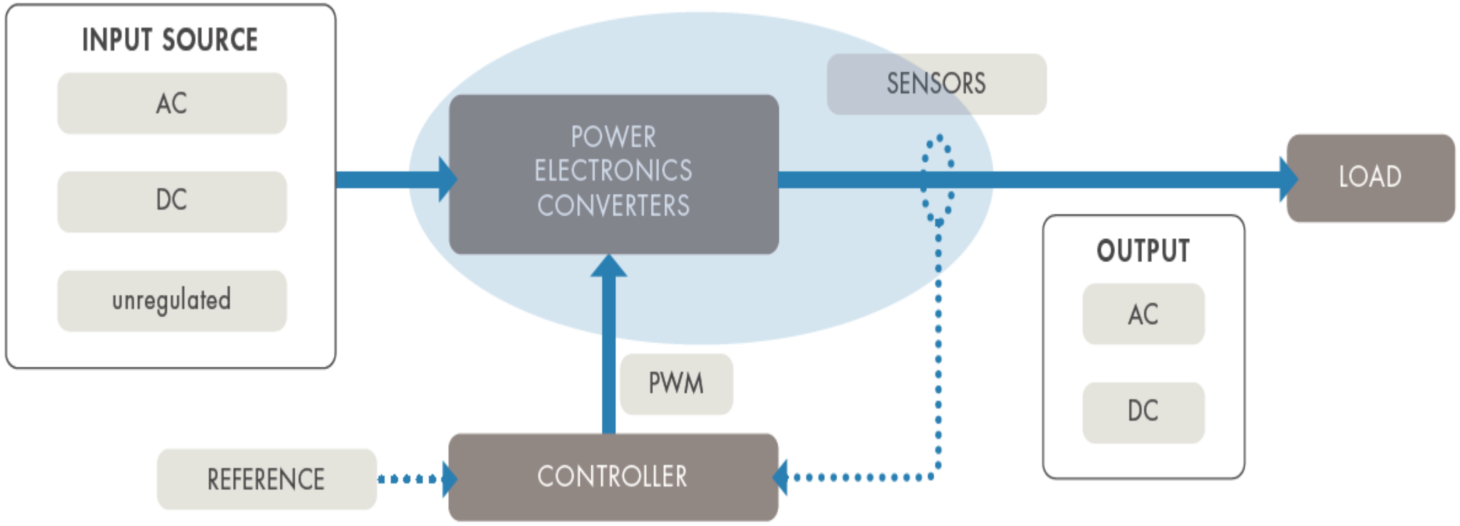
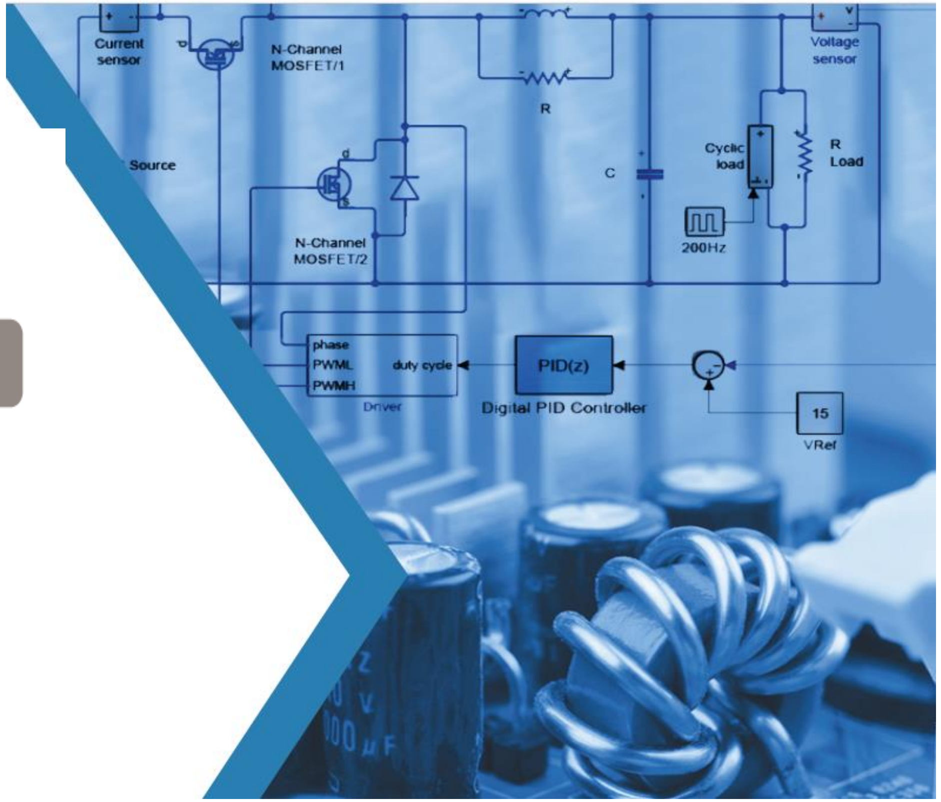
MATLAB EXPO 2019

Design Efficient DC-to-DC Power Converters

Juan Sagarduy – Fredrik Håbring

Power Electronic Systems





Power Electronics Applications

Electric vehicles and charging stations

Rail

Renewable energy

Lighting

Why Simulink for Power Electronics Control?

- Extensive library of sources and loads
  - PV arrays, Batteries, Motors, Power Converters

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  - PV arrays, Batteries, Motors, Power Converters

- Broad range of power electronics models (fidelity)
  - Average value >> fast ideal switching >> physics-based

Why Simulink for Power Electronics Control?

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- Broad range of power electronics models
  - Average value, fast ideal switching, physics-based
- Advanced control design capabilities
  - Auto-tuning in time & frequency domains for single and multiple loops

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  - C for microprocessors, HDL for FPGAs

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Customers routinely report 50% faster time to market

Murata Used Simulink to Model the EMS Controller and Power Electronics, Run simulations, and Generate Production Code

Challenge

Reduce time-to-market for the company's first energy management system product trial

Solution

Use Model-Based Design with Simulink to model the controller and power electronics, run simulations, and generate production code implemented on Piccolo™ and Delfino™ 32-bit microcontrollers made by TI

Results

- Control software development time reduced by more than 50%
- Defect-free code generated
- Project ramp-up time shortened

Murata flexible three-phase energy management system with lithium-ion battery.

Model-Based Design with Simulink enabled us to reduce time-to-market, which was a significant advantage for us. Because we were not expert programmers, modeling and simulating our control design and then generating quality C code from our models was essential to produce a working system as quickly as possible."

- Dr. Yue Ma, Murata Manufacturing Co., Ltd.

Challenges for Power Electronics Engineer

A. Easy access to physical insights (source/load, thermal cooling, peak voltages/currents…)

B. Systematic testing of embedded software (operating range, fault scenarios…)

C. Early detection of errors in software development

D. Increasing demands with Electrification
(regulation, industry standards on safety, power quality)

Our Project Today

DC/DC LED Developer's Kit

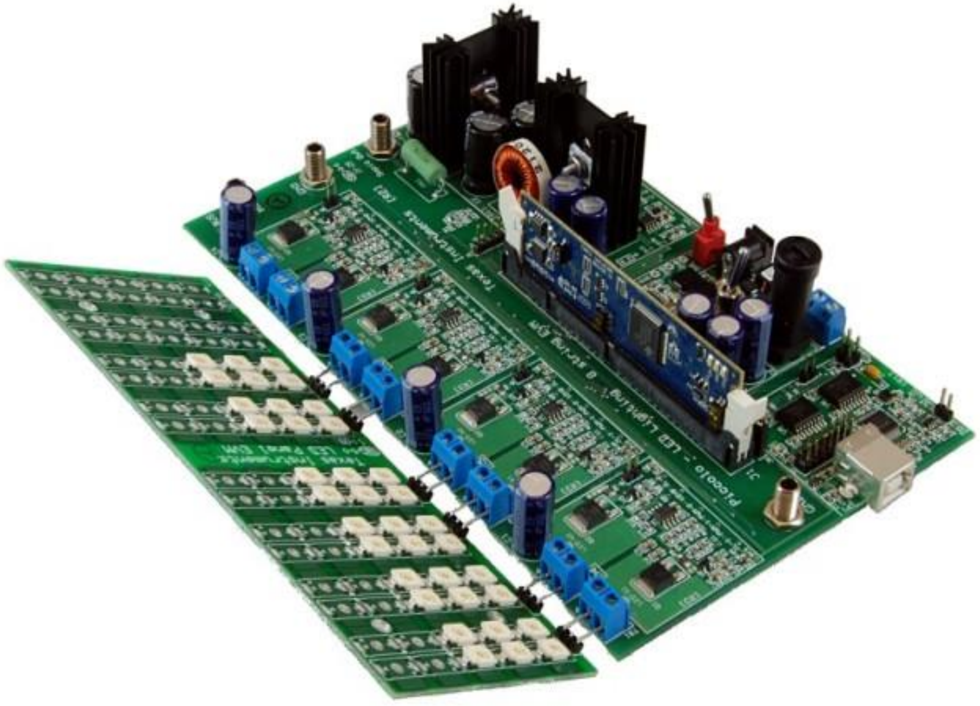


Fig 1: TMDSDCDCLEDKIT

LED Head Lamp

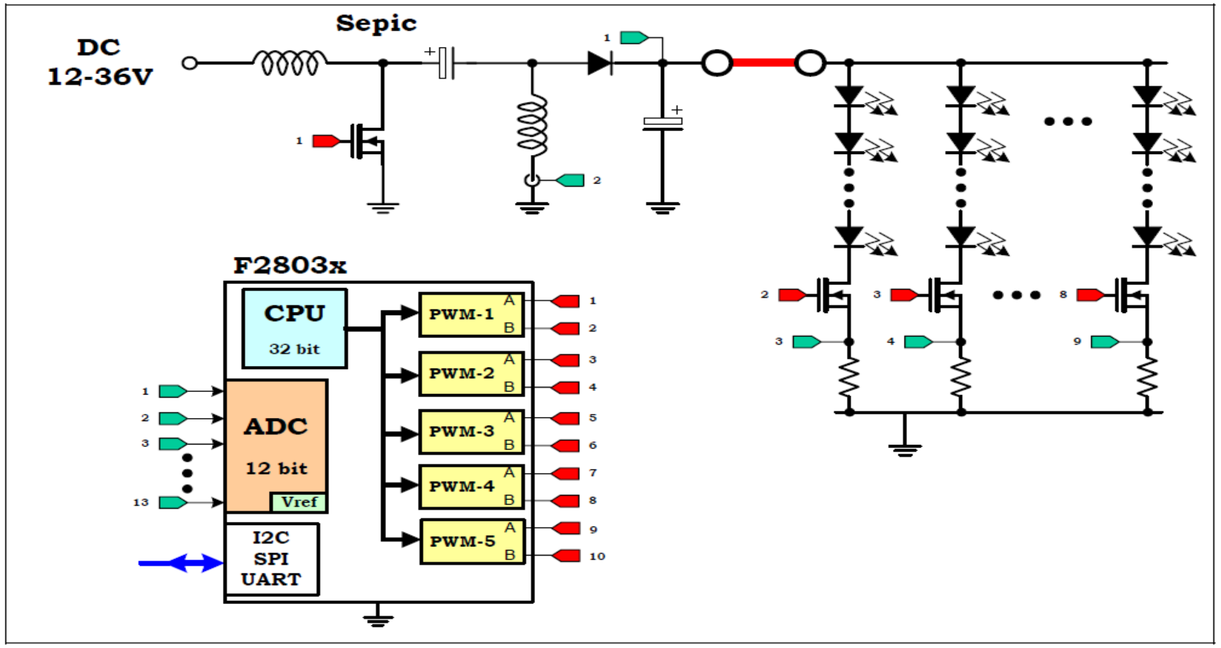


Fig4: DC/DC LED Lighting Board Block diagram with F28035

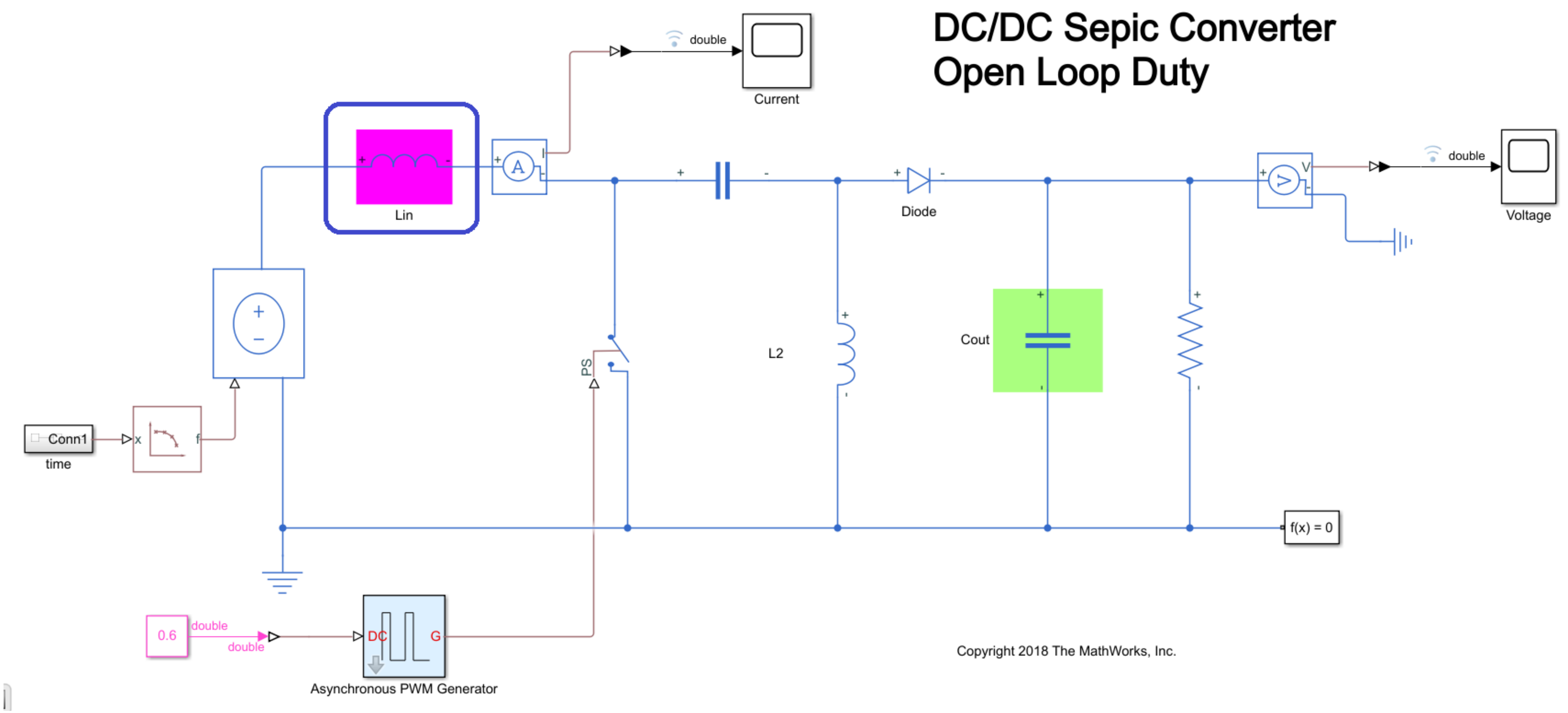
Power Converter Design Workflow.

Let's get started!

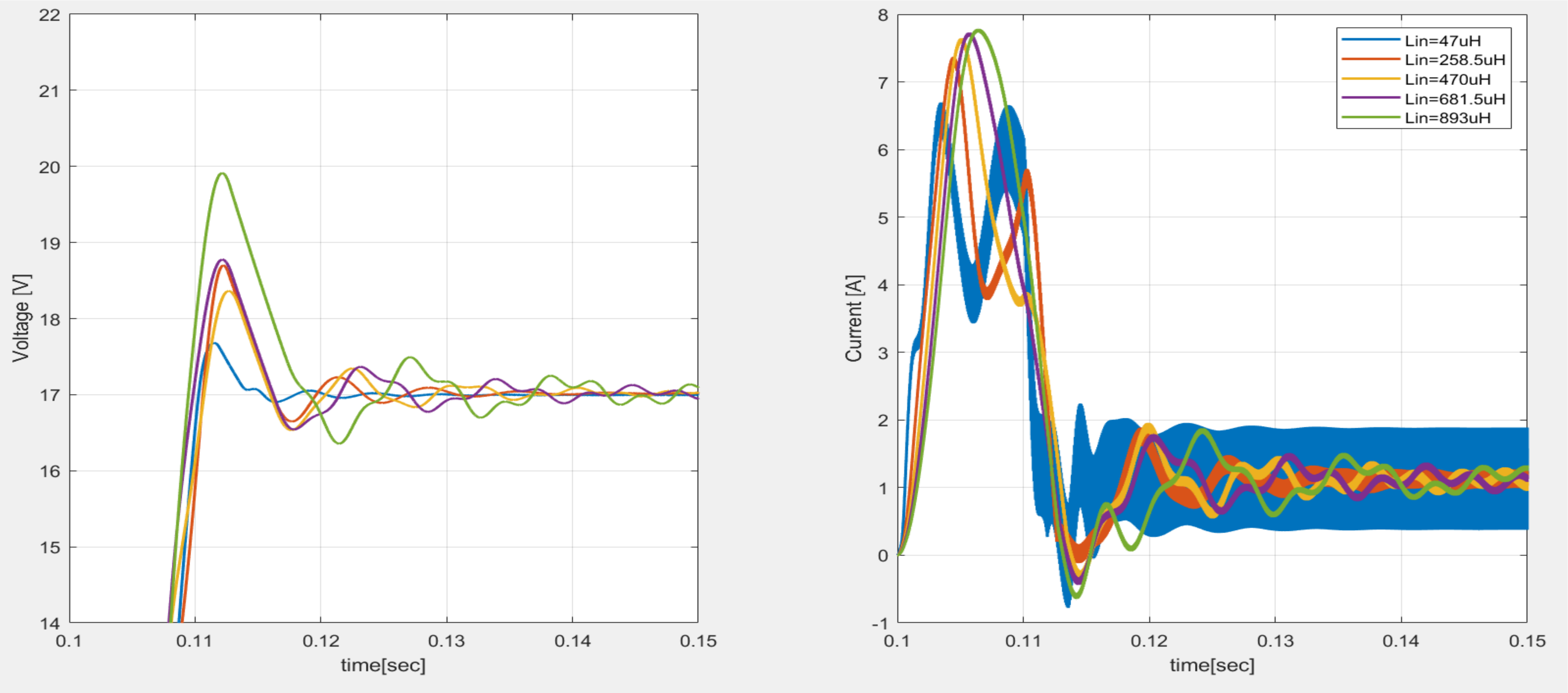
Power Converter - Design Workflow Tasks

1. **Component sizing (inductor, capacitor) & Design Exploration**
2. Determine thermo-electric behaviour of the converter (calibration)
3. Design control algorithm >> time/frequency domain specifications
4. Implement power electronic controls on an embedded processor

Design Exploration – Impact of inductor



Design Exploration – Impact of Inductor (results v-i)



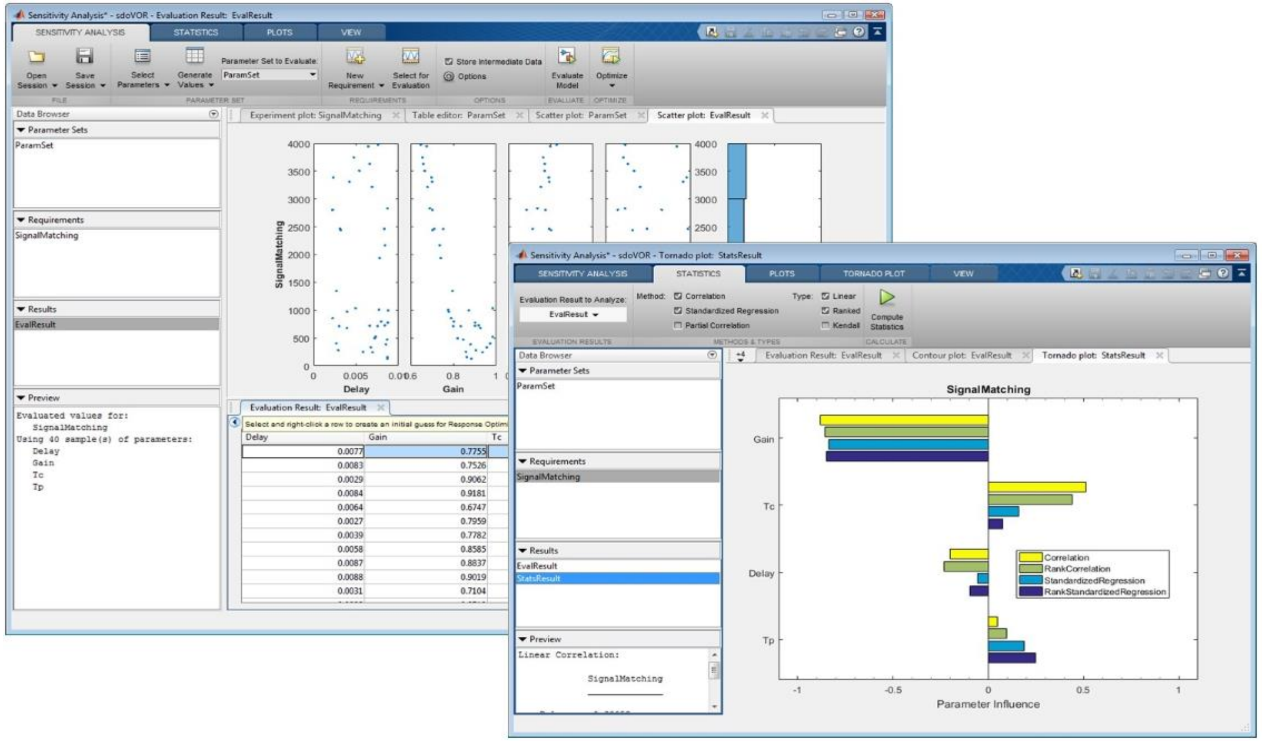
Design Exploration – Synergy between MATLAB & Simulink

<u>Parameter sweep</u>

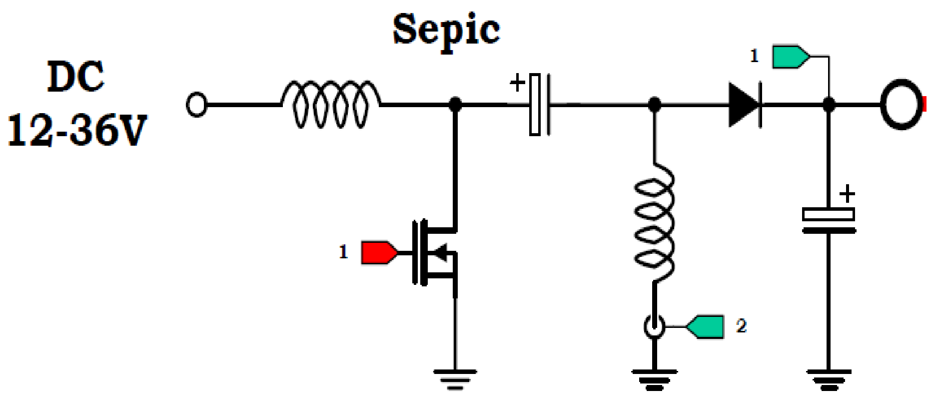
- MATLAB scripting
- *parsim* (parallelization)

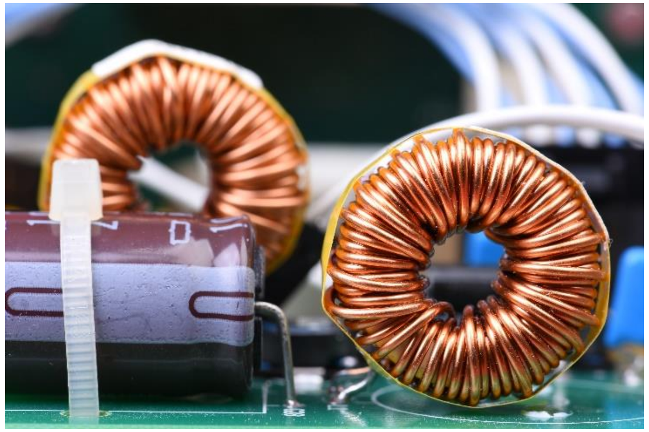
<u>Sensitivity analysis (Montecarlo)</u>

- optimization algorithms
- statistical distribution(s)
- parallel computing



Recap: Component Sizing & Design Exploration





What we did:

- Use simulation to design DC to DC converters
- Optimize component sizing using simulation driven analysis

Power Converter Control Design Workflow Tasks

1. Component sizing (inductor, capacitor) & Design exploration
2. **Determine thermo-electric behaviour of the converter (calibration)**
3. Design control algorithm based on time/frequency domain specification
4. Implement power electronic controls on an embedded processor

TEXAS INSTRUMENTS
CSD16323Q3
SLPS224C – AUGUST 2009 – REVISED NOVEMBER 2016

CSD16323Q3 N-Channel NexFET™ Power MOSFET

1 Features

- Optimized for 5-V Gate Drive
- Ultra-Low Q_g and Q_{gd}
- Low Thermal Resistance
- Avalanche Rated
- Lead-Free Terminal Plating
- RoHS Compliant
- Halogen Free
- SON 3.3-mm × 3.3-mm Plastic Package

2 Applications

- Point-of-Load Synchronous Buck Converter for Applications in Networking, Telecom and Computing Systems
- Optimized for Control or Synchronous FET Applications

3 Description

This 25-V, 3.8-mΩ, 3.3 × 3.3-mm SON NexFET™ power MOSFET has been designed to minimize losses in power conversion and optimized for 5-V gate drive applications.

Product Summary

T_A = 25°C		TYPICAL VALUE		UNIT
V_{DS}	Drain-to-Source Voltage	25		V
Q_g	Gate Charge Total (4.5 V)	6.2		nC
Q_{gd}	Gate Charge Gate-to-Drain	1.1		nC
$R_{DS(on)}$	Drain-to-Source On Resistance	V_{GS} = 3 V	5.4	mΩ
		V_{GS} = 4.5 V	4.4	
		V_{GS} = 8 V	3.8	
V_{th}	Threshold Voltage	1.1		V

Device Information(1)

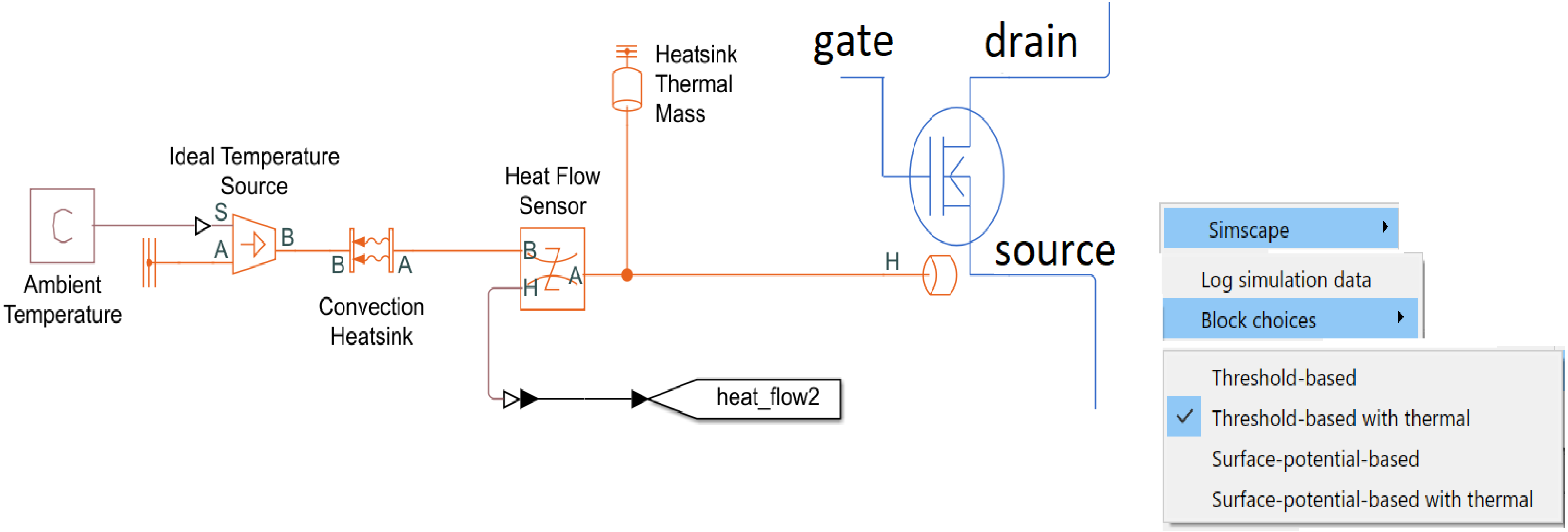
DEVICE	MEDIA	QTY	PACKAGE	SHIP
CSD16323Q3	13-Inch Reel	2500	SON 3.30-mm × 3.30-mm Plastic Package	Tape and Reel
CSD16323Q3T	7-Inch Reel	250		

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Absolute Maximum Ratings

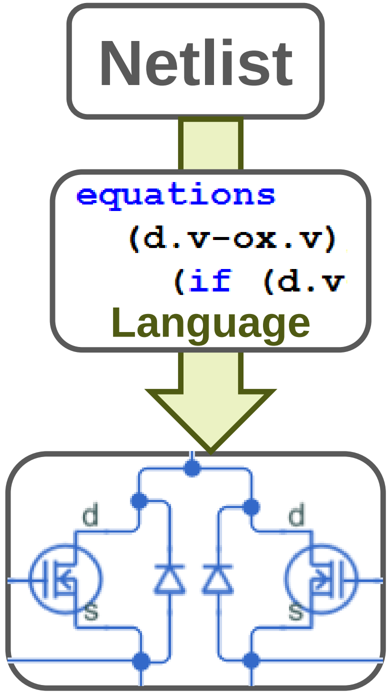
T_A = 25°C (unless otherwise stated)		VALUE	UNIT
V_{DS}	Drain-to-Source Voltage	25	V
V_{GS}	Gate-to-Source Voltage	+10 / –8	V
	Continuous Drain Current (Package Limit)	60	

Determine Thermal behaviour – Multi-domain (Simscape)



New: Convert SPICE models into Simscape components

- Incorporate manufacturer data into simulation models (concurrent engineering)
- Smoothly parameterize the model by importing SPICE netlists



testMosfetNetlist.txt

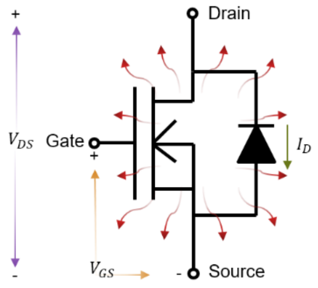
```
.FUNC  Idiode(Usd,Tj,Iss)  {exp(min(lo
.FUNC  Idiod(Usd,Tj)       {a*Idiode(U

.FUNC  Pr(Vss0,Vssp)   {Vss0*Vss0/Rm+V

.FUNC J1(d,g,T,da,s,x)  {a*(s*(exp(mi

.FUNC QCds(x)  {Cds3*min(x,x1)+Cds0*ma
```

subcircuit2ssc →

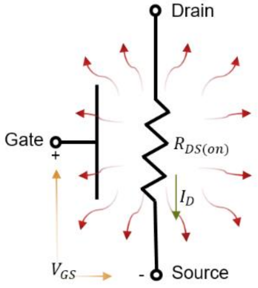
testMosfetNetlist.txt | ipt015n10n5_l1.ssc

```
components(ExternalAccess=observe)
    X1 = test.s5_100_f_var(a=act,rsp=r
        rs=rs,rp=rd,dc=dc,rm=rm);
    RG = elec.passive.instrumented_res
    LG = foundation.electrical.element
        i_L.priority=priority.none);
    RSA = elec.passive.instrumented_re
    LS = foundation.electrical.element
```

Recap: Determine thermal behaviour of converter (calibration)

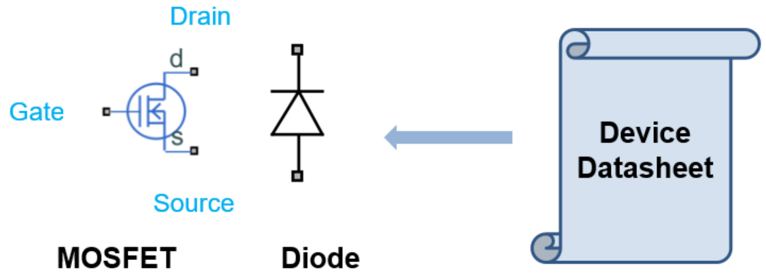


Switching loss



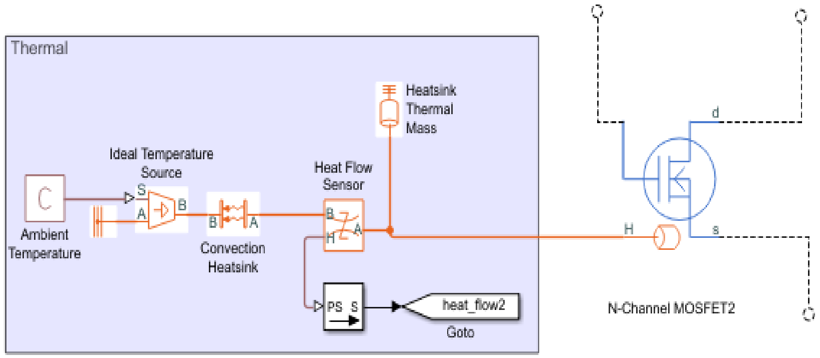
Conduction loss

Device Blocks



What we did

- Calibrate MOSFET model individually
- Model non-linear switching behavior of SEPIC converter with MOSFET component (Simscape Electrical)
- Leverage the multi-domain simulation capability of Simscape in understanding the thermal dynamics



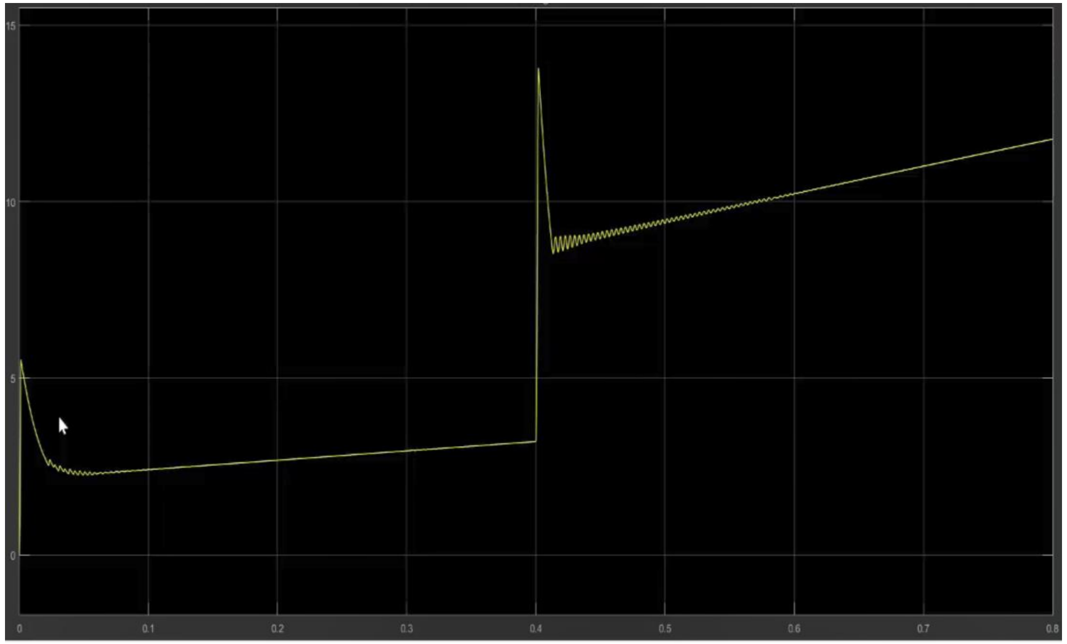
Power Converter Control Design Workflow Tasks

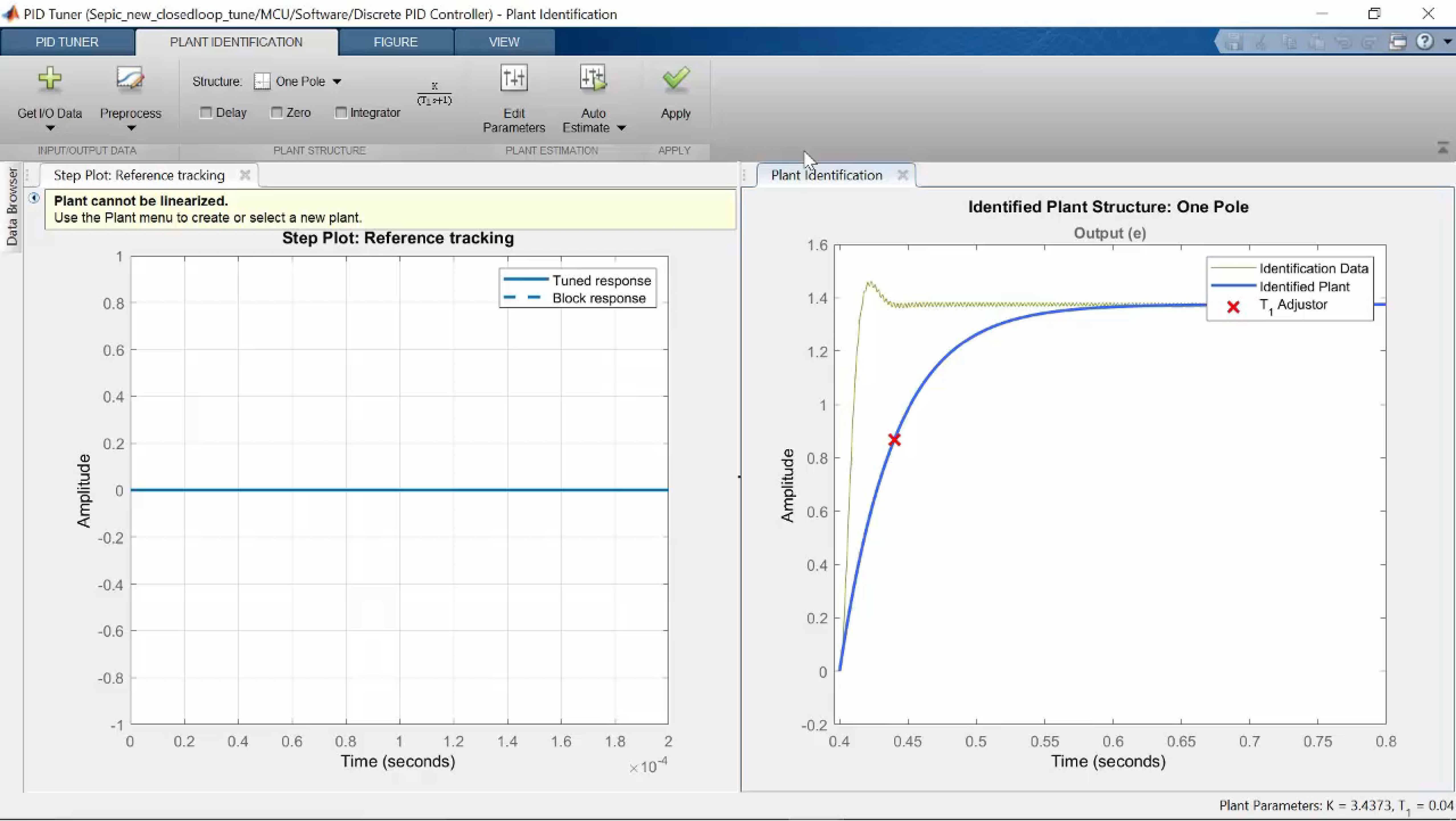
1. Component sizing (inductor, capacitor) & Design exploration
2. Determine thermo-electric behaviour of the converter (calibration)
3. **Design control algorithm >> time/frequency domain specifications**
4. Implement power electronic controls on an embedded processor

Design Control Algorithms

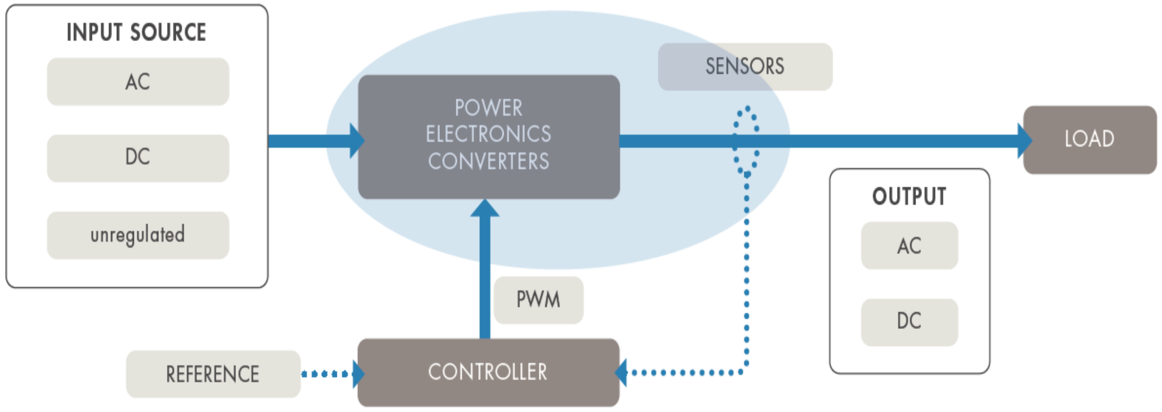
<u>Starting point</u>

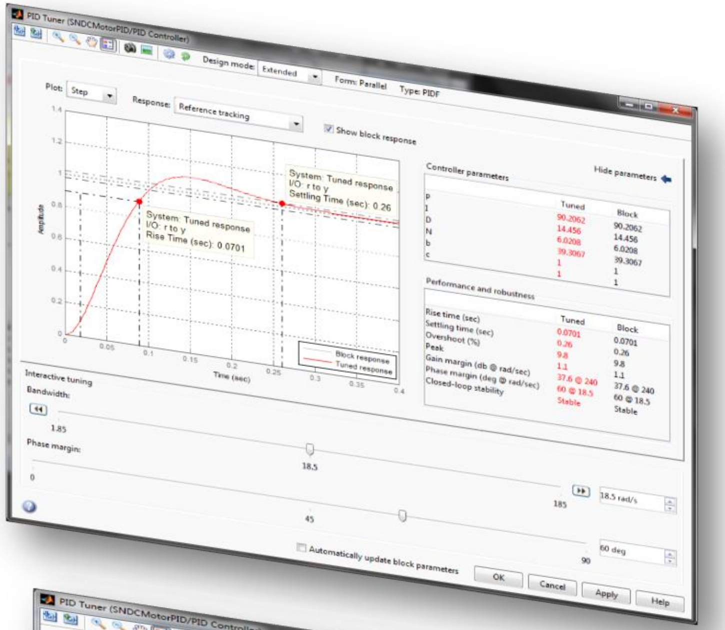
- controller is out of tune
- plant can’t be linearized

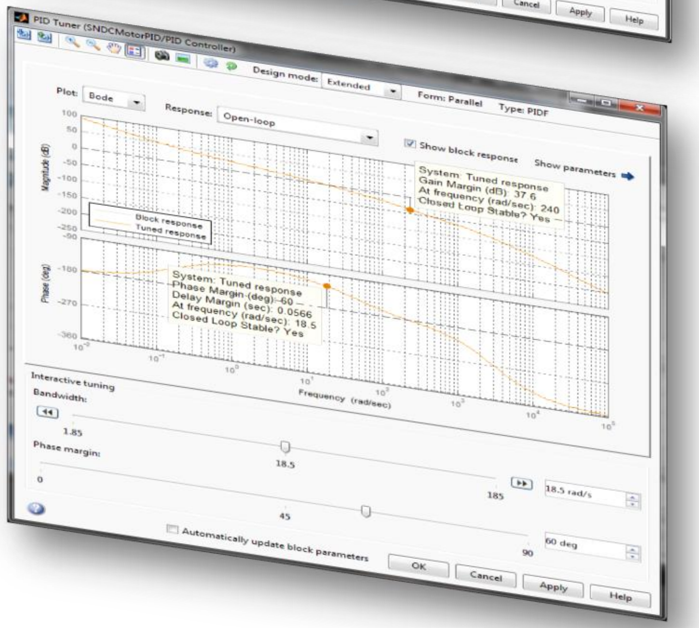



PID Tuner (Sepic_new_closedloop_tune/MCU/Software/Discrete PID Controller) - Plant Identification
PID TUNER
PLANT IDENTIFICATION
FIGURE
VIEW
Get I/O Data
Preprocess
Structure: One Pole
Delay
Zero
Integrator
Edit Parameters
Auto Estimate
Apply
INPUT/OUTPUT DATA
PLANT STRUCTURE
PLANT ESTIMATION
APPLY
Data Browser
Step Plot: Reference tracking
Plant cannot be linearized.
Use the Plant menu to create or select a new plant.
Step Plot: Reference tracking
Tuned response
Block response
Amplitude
Time (seconds)
Plant Identification
Identified Plant Structure: One Pole
Output (e)
Identification Data
Identified Plant
T1 Adjustor
Amplitude
Time (seconds)
Plant Parameters: K = 3.4373, T1 = 0.04

Recap: Design Control Algorithm Based on Time/Frequency Domain Specifications







What we did

- Identify plant model from input output simulation data
- Use auto tuning algorithms to tune the control gains

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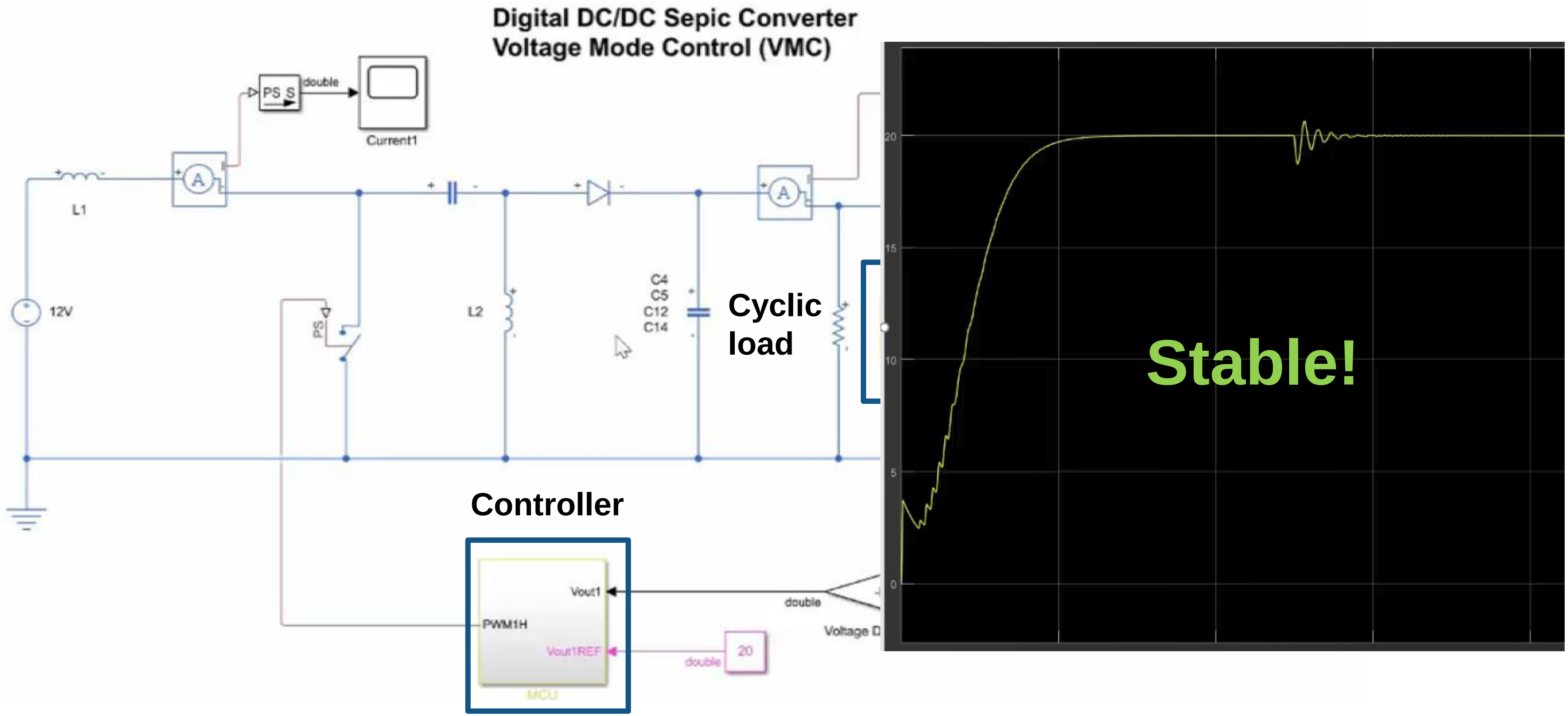
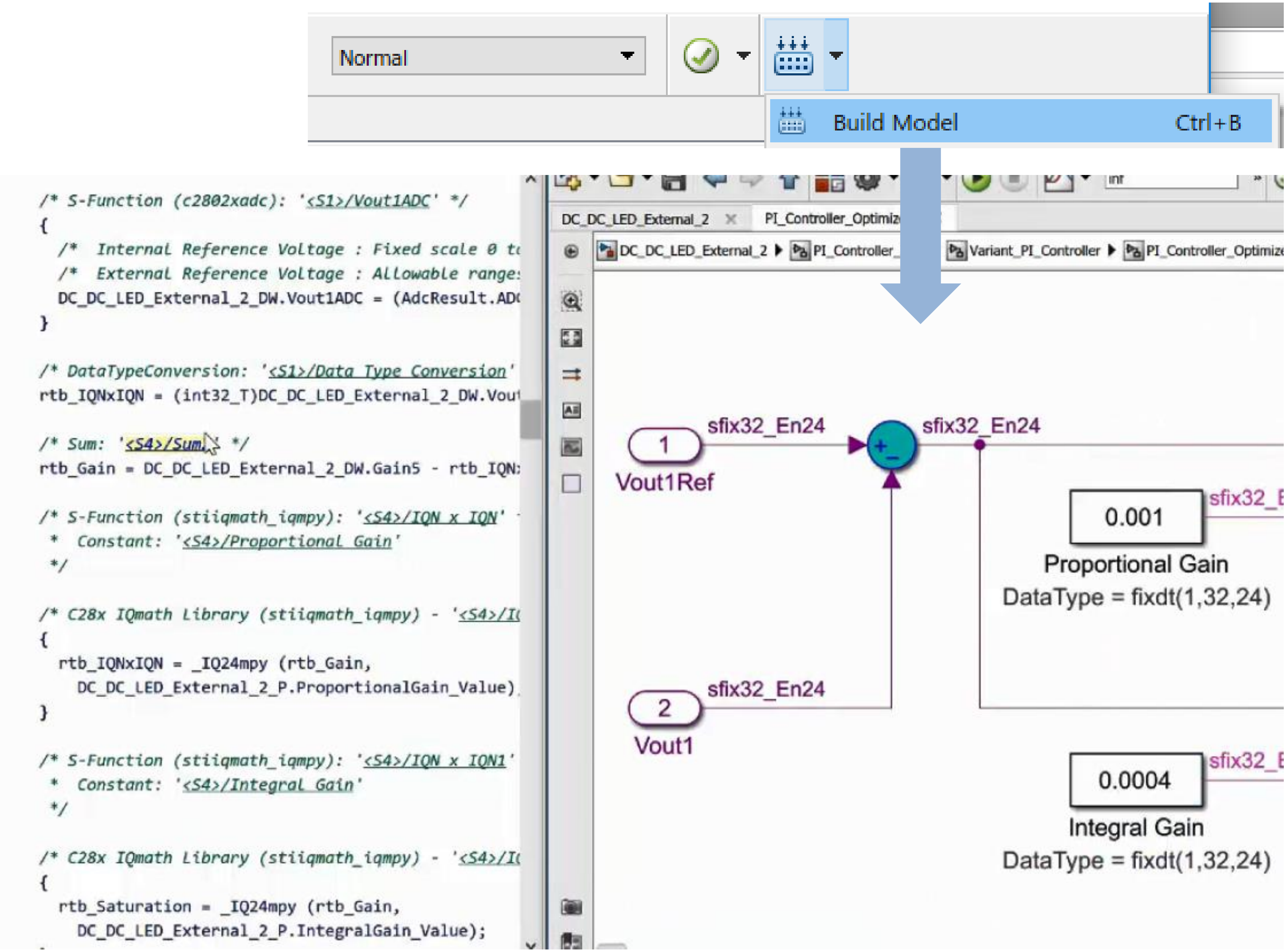
Verify Controller Stability



Implementing Controller on an Embedded Processor

1. Generating C code
2. Traceability between model and code
3. Integrating code into embedded procesor



3. Integrating Code into Embedded Procesor

A. Hand-written software project

Embedded Software Project Pseudo-Code

```
Main()
{
    Commands_Init
    PWM_Init
    ADC_Init
    Encoder_Init

    Controller_Init

    while(1) {
    }
}
```

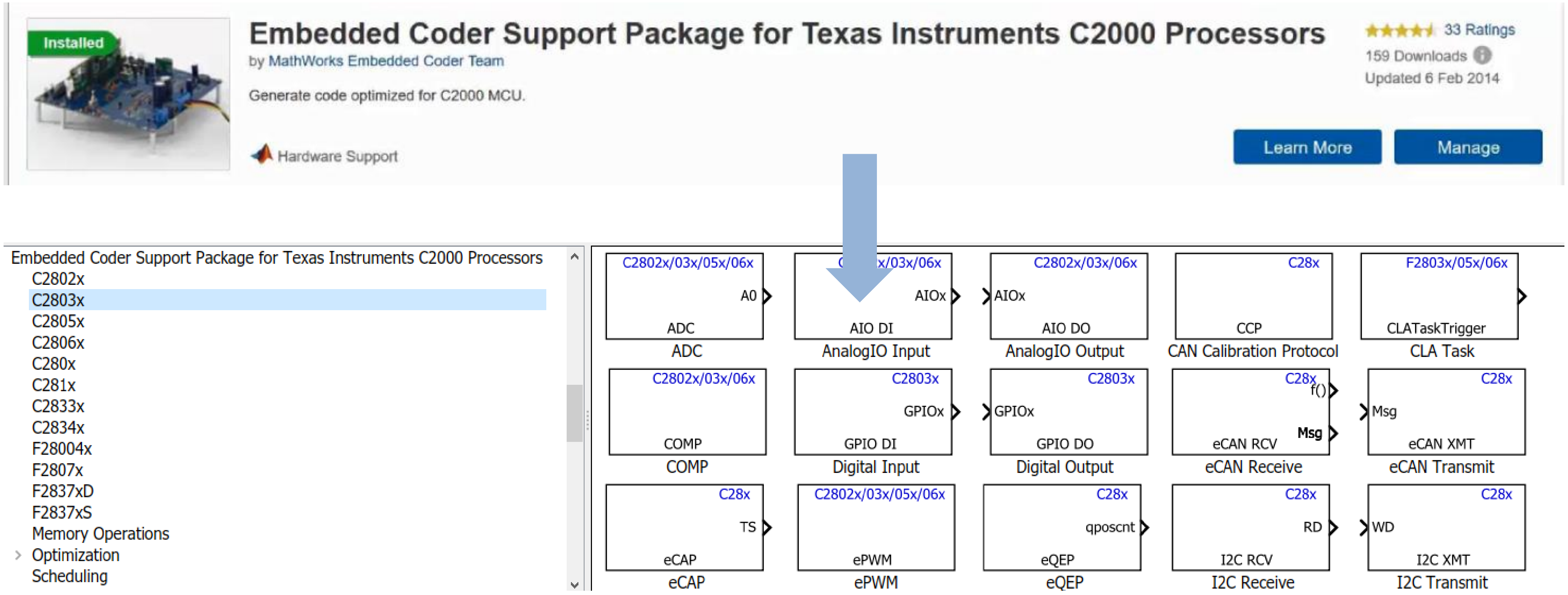
```
InterruptServiceRoutine()
{
    Commands_Read
    ADC_Read
    Encoder_Read

    Controller

    PWM_Write
}
```

3. Integrating Code into Embedded Procesor

B. Prototyping from Simulink



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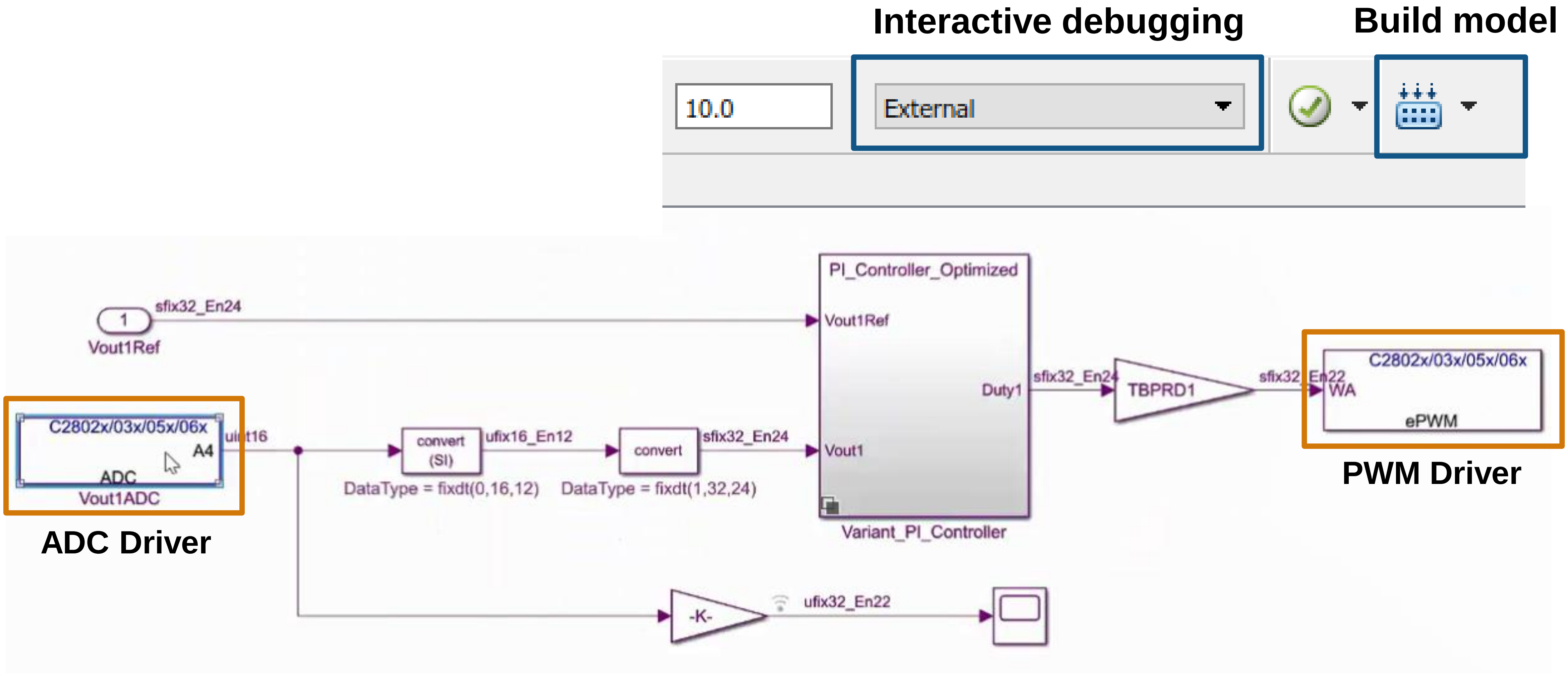
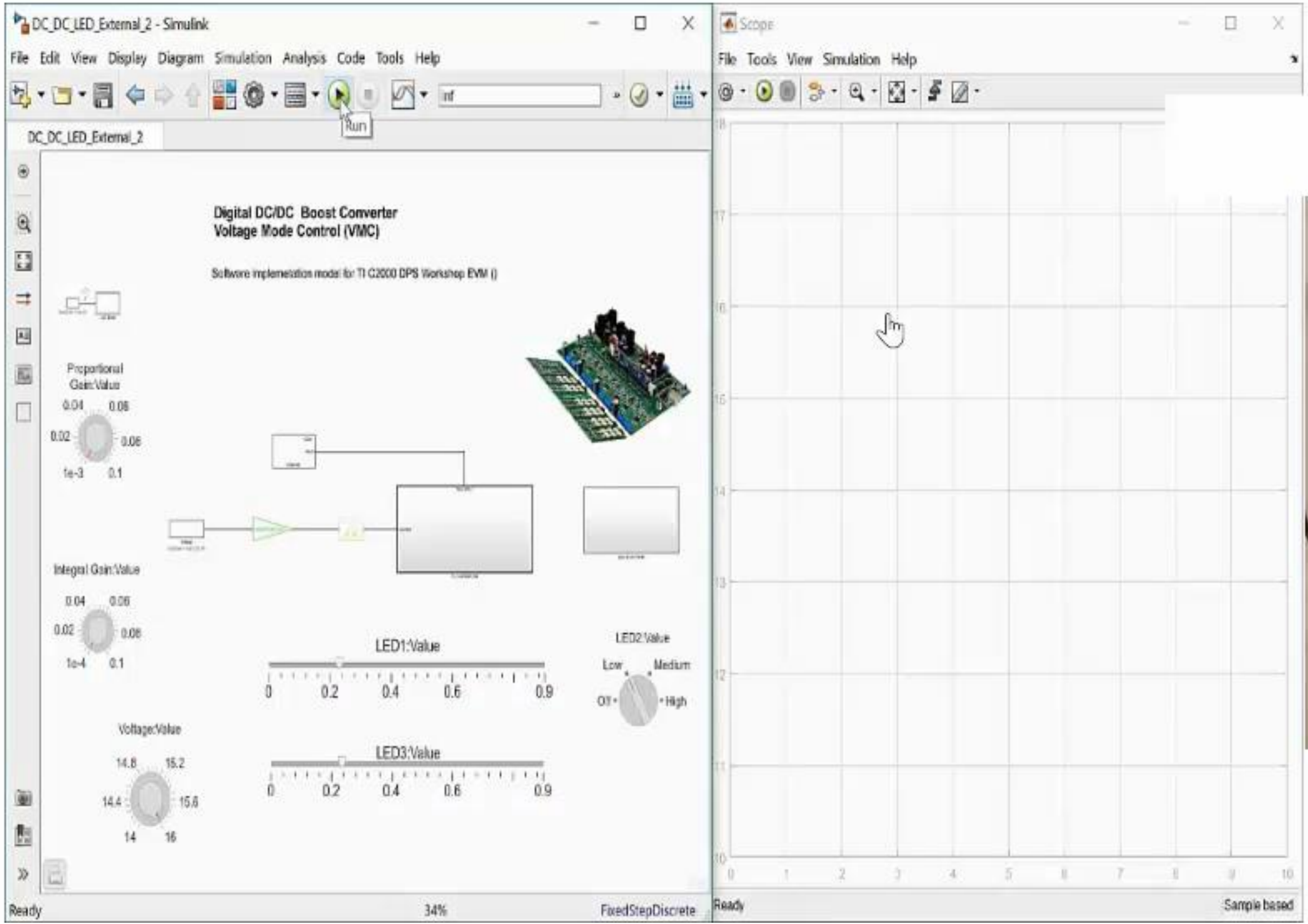
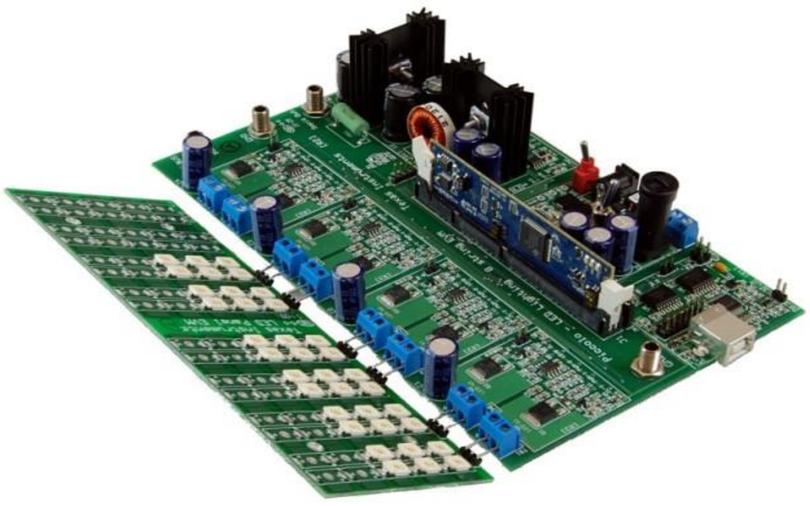
B. Prototyping from Simulink

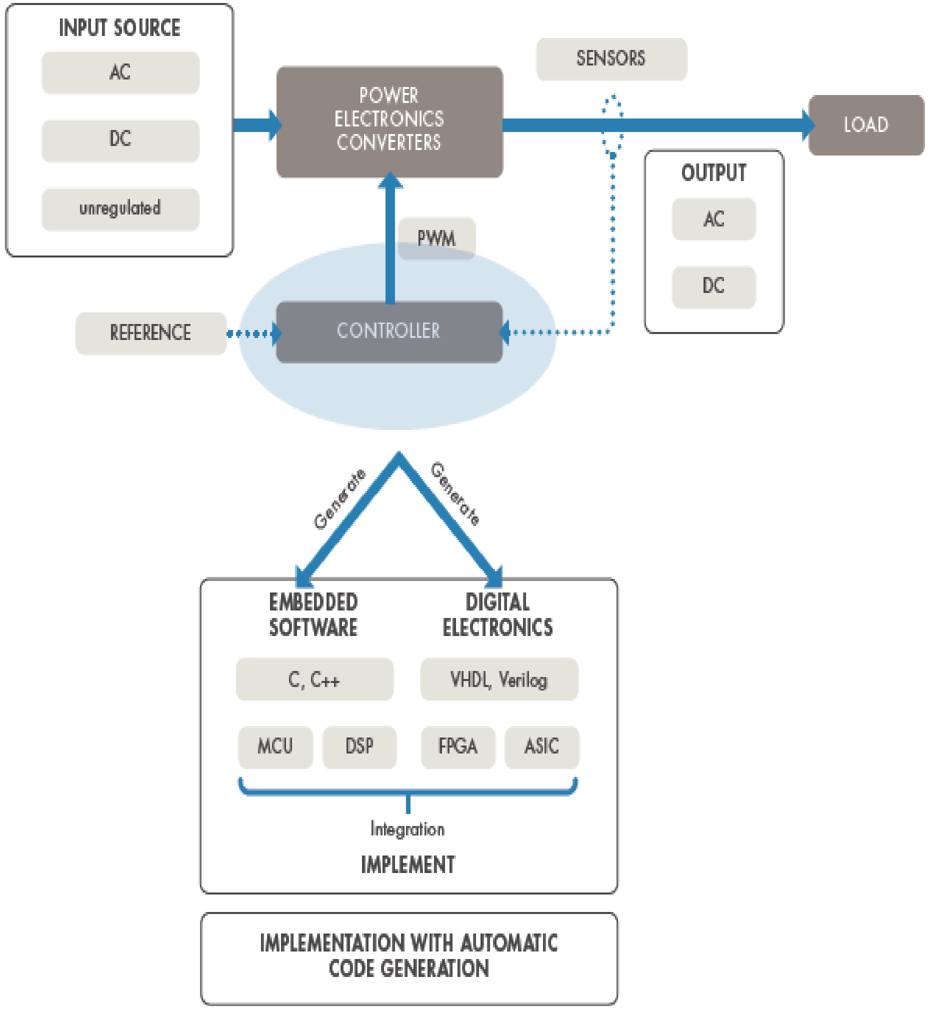


Implementation of the power electronic controls on an Embedded Processor



Recap: Implement Power Electronics Control on an Embedded Processor





What we did:

- Verify the controller for various test cases
- Generate code from MATLAB and Simulink models optimized for embedded controllers

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ABB Accelerates the Delivery of Large-Scale, Grid-Connected Inverter Products with Model-Based Design

Challenge

Accelerate the design and delivery of large, grid-connected power inverter products

Solution

Use Model-Based Design to model, simulate, and generate control software for modular, scalable power electronic building blocks

Results

- Prototypes delivered in two weeks, not three months
- Defect-free, optimized code generated
- Potential damage to test equipment mitigated

A cabinet of Power Electronic Building Blocks (PEBBs).

“Simulink and Embedded Coder enabled us to open the door to new markets. With increased productivity from extensive simulation and efficient code generation, we have confidence in our ability to produce the systems that larger customers are asking for in the time frames they want.”

- Dr. Robert Turner, ABB

Why Simulink for Power Electronics Control?

- Extensive Libraries
- Power electronics models
- Advanced control design
- Automatic Code Generation

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Any questions?