MATLAB EXPO 2019

Developing Battery Management Systems using Simulink

Chris Lim Application Engineering Group



Motivation

Collaboration



Short Iteration Cycles





High Integrity System







Components of the BMS

Software

Electronics

Battery Pack



Supervisory tasks SOC estimation Contactor management Isolation monitoring Fault detection and recovery Thermal Management Current & Power Limits Charge specific behaviour

MATLAB EXPO 2019



Block Voltage, Temperature Measurement Cell Diagnostic Cell Balancing





Where do you start?



Name the Model!





Building Models in Simulink and Simscape

Block Count: **09**

Block Count: **6**





Start with Simulation





Thermal Model MATLAB EXPO 2019



Pack

System





Building and Fitting Equivalent Circuit Models



Fitting Equivalent Circuit Models using Parameter Estimation

📣 MATLAB R2019a			– 0 ×
HOME PLOTS APPS	- 2, 5, 6, 6, 6, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7,	? Search Docum	rentation 👂 🛓 Chris 🗸
🛃 🛃 🕂 🔽 🗔 Find Files	L Community		
New New New Open 💽 Compare New Script Live Script 👻 👻	bort Save at Workspace V Clear Workspace V Clear Commands V Simulink Layout V Parallel V V Learn MATLAB		_
FILE	VARIABLE CODE SIMULINK ENVIRONMENT RESOURCES		A
< 🔶 🛅 🖾 💭 📙 🕨 C: 🕨 MATLAB 🕨 Cu	omerFacing + MATLAB_Expo_031019 + code + Battery_System + CellParamEst		م •
Current Folder	0 Command Window	Workspace	۲
🗋 Name 🔺	New to MATLAB? See resources for <u>Getting Started</u> .	Name 🔺	Value
Autosave Simulink Model or Library Suction Library Mathematical Stream Stre		C1 Capacity Em QuiseData QuiseData QuiseData QuiseData R0 R1 SOCLUT SocLUT SocLUT Cot ts_Current Cot_SvOrtage yout	11x1 double 27.6250 11x1 double 1x1 struct 0 11x1 double 11x1 double 11x1 double 11x1 double 11x1 double 1x1 double 1x1 double timeseries 1x1 double timeseries 1x1 double timeseries 1x1 double
plotPulseData.m (Function)			

MATLAB EXPO 2019

MathWorks[®]



Develop your Algorithms



Cell_Voltages 4.2 4.2 4.2 4.3 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.4 5.3.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.5.5 7.





Building a BMS in Simulink and Stateflow

PROJECT PROJECT SHORTCUTS Image: Short of the set of the se	
August Control of Control	Ā
MANAGE G2-NDDELS 03-VERIFICATION Views All Project (152) Piles Name A Stats Classification Dig Dependency Analysis B CellParamEst Stats Classification	*
Yews All Project (15) Price Staus Classification Price Coll Cassification Price Coll Cassification Price Coll Coll Coll Price Doc Coll Coll Price Doc Coll Coll Price Doc Coll Coll Price Ibit Coll Coll Coll Price Doc Coll Coll Coll Price Doc Coll Coll Coll Price Ibit Coll Coll Coll Price Requirements Coll Coll Coll Price System Coll Coll Coll Coll Price System Coll Coll Coll Coll Coll Price System Coll Coll Coll Coll Coll Coll Price System Coll Coll Coll Coll Coll Coll Coll Col	(H) (A)
Image Status Classification Image	Tree V Q
Battery_System_Configuration.m CREADME.md Design	
Labels V	
Erails Details	~
Select a file to view details	L ₈



Run Closed-Loop Simulations of BMS and Plant model

📣 Project - Battery_System									8. 	o ×
PROJECT PROJECT SHO	RTCUTS							(<u>2</u> , .	646696	
New Organize Shortcut Groups	BMS_Requirements	 01a - ECM Simulink 01b - ECM Simscape 02 - Cell Parameter Estimation 	 03 - BMS State Machine 04 - BMS ECU 05 - BMS System 	01 - State Machine Requireme	nts	_				-
MANAGE GENERAL	01 - REQUIREMENTS	02 - MODE	LS	03 - VERIFICATION						-
Views	All Project (152)								P V Layou	it: Iree 🗸 🥨 🕈
Dependency Analysis	Image: Controller Image: Controller <t< td=""><td>1_Configuration.m</td><td>2</td><td></td><td></td><td></td><td>Design</td><td></td><td></td><td></td></t<>	1_Configuration.m	2				Design			
Labels V	Details									~
the Classification						Select a file to view details				



Test and Verify Algorithms





Link Requirements to Implementation

📣 Project - Battery_System								- 0	\times
PROJECT PROJECT SHO	ORTCUTS						P	5 e 🗗 🕐) 💿 💿
2. 4	_	1a - ECM Simulink	1 03 - BMS State Machine						
New Organize	BMS_Requirements	01b - ECM Simscape	14 - BMS ECU	01 - State Machine Requirements					
Shortcut Groups		02 - Cell Parameter Estimation	15 - BMS System						100
MANAGE GENERAL	01 - REQUIREMENTS	02 - MODE	LS	03 - VERIFICATION					
Views	All Project (152)						2	Layout: Tree >	~ @•
Files	🗋 Name 🔺			Status		Classification			
or peperdency Analysis	CellParamEs	t							
	Data_Scripts			1					
	I Doc			· 🔄					
	E Lib								
	Plant			 - E 					
	Requirement Slcache	5		Y 😁					
	src			1					
	System Tests								
	gitattributes	1		*					
	.gitignore			×					
	README.md	em_Configuration.m				Design			
	_								
Labels	Details								~
	- comp								
					Select a file to view details				



Test and Verify against Requirements

Autor Autor	📣 Project - Battery_System		- 0 ×
	PROJECT PROJECT SHO	DRTCUTS	
	7. 4.	a 01a - ECM Simulink a 03 - BMS State Machine	
	LaunchDoc	BMS_Requirements 01b - ECM Simscape 04 - BMS ECU	
	Shortcut Groups	№ 02 - Cell Parameter Estimation % 05 - BMS System	
	MANAGE GENERAL	01 - REQUIREMENTS 02 - MODELS 03 - VERIFICATION	
a be b be a be b be <td>Views</td> <td>All Project (152)</td> <td>P 🕅 Layout: Tree - 🔘 -</td>	Views	All Project (152)	P 🕅 Layout: Tree - 🔘 -
All operation Andreas All operations Andreas All op	Files	Name A Status	Classification
ated V Ated V <td< td=""><td>Dependency Analysis</td><td>🗄 🔤 CellParamEst 🗸 🚰</td><td></td></td<>	Dependency Analysis	🗄 🔤 CellParamEst 🗸 🚰	
ability Provide a structure of the structure		B Controller ✓ D	
ability Programments ability Programments ability Programments ability Programments ability Programments Pr			
etter versetter of the second			
atet v tet tet tet tet veo debis		Plant V	
ate to the first of the first o		🗄 🧧 Requirements 🗸 🖓	
atel Second status atel Second status		src	
Abbit Cardination Abbit Cardination Abbit Cardination Abbit Cardination Abbit Cardination		🗄 🧧 System	
white Person Person white Main Person Person		aitattributes	
whether we details Parigon			
Adds V Adds V Securitation Securitation		Battery, System_Configuration.m	Design
atets ★ Characterizion Beats Beats Beats Setet a file to view details Setet a file to view details			
stede			
ated v Custification Details Setet a file to view details.			
abels > abels > abels > abels > Sectorization Sectorization			
abek v € Cessificaion Bekst affe to view details			
abels Del Cessification Del Cessification Del Cessification Seiect a file to siver details Seiect a file to siver details			
ateis to Clustification Beals Seect a file to view details			
abeis > abis > abis > abis > abis > balais Select a file to view details			
abels v tet S Classification			
abels > at bets > at Classification Details beta Select a file to view details			
abels > abels > abels > abels > abels > behalis > behalis Select a file to view details:			
abels > B ⁻ Classification Belais Select a file to view details			
abels > Image: Select a file to view details			
abels > Abels <td< td=""><td></td><td></td><td></td></td<>			
Labels v R- Classification Entry Classification Select a file to view details			
abels abels abels abels abels belaits Select a file to view details			
Labels			
Labels v and Classification Details Select a file to view details			N
Labels V H Classification			ьé
ubels > B I Classification > B I Classification > Select a file to view details			
Details Note: Select a file to view details	Labels		
Select a file to view details	⊞- ⁽¹⁾ Classification	Details	v
Select a file to view details			
Select a file to view details			
		Selecta	a file to view details



Generate C/C++ Code From BMS Algorithm Models





Generate C/C++ Code From BMS Algorithm Models

📣 Project - Battery_System								- 0 ×
PROJECT PROJECT SH	ORTCUTS						2 2 6 4 htt	
2. 4		1 01a - ECM Simulink	a 03 - BMS State Machine	Cot Clote Hashing Descriptions				
New Ornanize	BMS_Requirements	01b - ECM Simscape	💁 04 - BMS ECU	01 - State Machine Requirements				
Shortcut Groups		2 02 - Cell Parameter Estimation	1 05 - BMS System	- State macinite resis				
MANAGE GENERAL	01 - REQUIREMENTS	02 - MODELI	5	03 - VERIFICATION				
Views	All Project (152)						27	Layout: Tree 🗸 🎯
Files	🗋 Name 🔺			Status		Classification		
Dependency Analysis	CellParamEs Controller Controller Data_Scripts Doc Doc Doc Lib Requirement socache src -gitattibutes -gitattibutes Gitattopy Syste README.md	ts em_Configuration.m		也也如此也也也。 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2		Design		
Labels .	✓							
B Classification	H Start							
					Select a file to view details			
	71							



Perform HIL Testing for BMS ECUs



Testing ECUs with Battery Cells

- Longer test cycles
- Difficult to reproduce results
- Limited test automation
- Difficult to test fault conditions



Perform HIL Testing for BMS ECUs





Workflow for BMS Development





Summary

Multi-Domain

Long Iteration Cycles

High Integrity System











Test and Verify Behaviour

Collaborate Across Domains

Reduce Iteration Time



Building Blocks for BMS Development

Physical Modelling



Parameter Estimation



Requirements Linking



MATLAB EXPO 2019

Code Generation



Test Automation

	ser Results and Artifacts	Test for Dynamic Response X Start Page X					
• T FuterSuperces	ior lests	Test for Dynamic Response	Erabe				
• 🖾 Simulator (ests	HuterSuppressionTests + SimulationTests + Test to Durantic Response					
+ C Real-lime Te	esb	Simulation Test					
		- DESCRIPTION					
		REQUIREMENTS Resource Security 1	tan - Rom				
			🕈 Add - 📋 Cente				
		- SYSTEM UNDER TEST					
		Model Fudedkappressiondividem (C) Harness	H S F C				
		• TEST HARNESS					
		EIMULATION SETTINGS OVERRIDES					
		PARAVETER OVERRIDES	1				
		+ CALLDACKS					
	77.	• INFUTE	1				
a second s	The Service Tests	+ OUTPUTS					
agasami Jama	EVAEGUINDARDevisi, TEST	CONFIGURATION SETTINGS OVERBIDES					
ane scaton		CONTRACTOR OF LINKS ANTICIDED					
everans lame ocation lecanthy	PluterSuppressionTests »						
ione cation feratory finabled	FlutterSuppressionTests +						

Model Checks

Modeling Standards for Secure Coding (CERT C, CWE, ISO/IEC TS 17961)
 Check configuration parameters for secure coding standards
 Check for blocks not recommended for C/C++ production code deployment
 Check for blocks not recommended for secure coding standards
 Check for blocks not recommended for secure coding standards
 Check for blocks not recommended for secure coding standards
 Check for blocks not recommended for secure coding standards
 Check for blocks not recommended for secure coding standards
 Check for blocks not recommended for secure coding standards
 Check for blocks are expressions without a default case
 Check for switch case expressions on signed integers
 Check for equality and inequality operations on floating-point values
 Check integer word lengths
 Check The overflow
 Chetect Division By Zero
 Chetect Violation of Specified Intermediate Minimum and Maximum Values



Learn More about Battery Management System Design

WHITE PAPER

Developing Battery Management Systems with Simulink and Model-Based Design



Battery Modeling Search MathWorks.com Examples and How To Battery Management System Development in Simulink (7:17) - Video Lithium Battery Model with Thermal Effects for System-Level Analysis (24:05) - Video Automating Battery Model Parameter Estimation using Experimental Data (25:28) - Video Real-Time Simulation of Battery Packs Using Multicore Computers (22:57) -Video Battery Simulation and Controls - Consulting Services Sifting Through Multisource Data for Safer Battery Materials with Machine Learning - Article Papers High Fidelity Electrical Model with Thermal Dependence for Characterization and Simulation of High Power Lithium Battery Cells - IEEE 2012 Battery Model Parameter Estimation Using a Layered Technique - SAE 2013 Simplified Extended Kalman Filter Observer for Battery SOC Estimation -SAE 2013 Battery Pack Modeling, Simulation, and Deployment on a Multicore Real Time Target - SAE 2014 Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications - SAE 2015



Additional EXPO Talks

- Simplifying Requirements-Based Verification with Model-Based Design
 - Fraser Macmillen
 - 15:45 17:00, Master Classes
- Predictive Maintenance with MATLAB
 - Phil Rottier
 - 15:45 17:00, Innovation Auditorium
- Developing Fit-For-Purpose Simscape Models to Support System and Control Design
 - Rick Hyde
 - 16:15 17:00, Model-Based Design



Fraser Macmillen, MathWorks



Philip Rottier, MathWorks



Rick Hyde, MathWorks