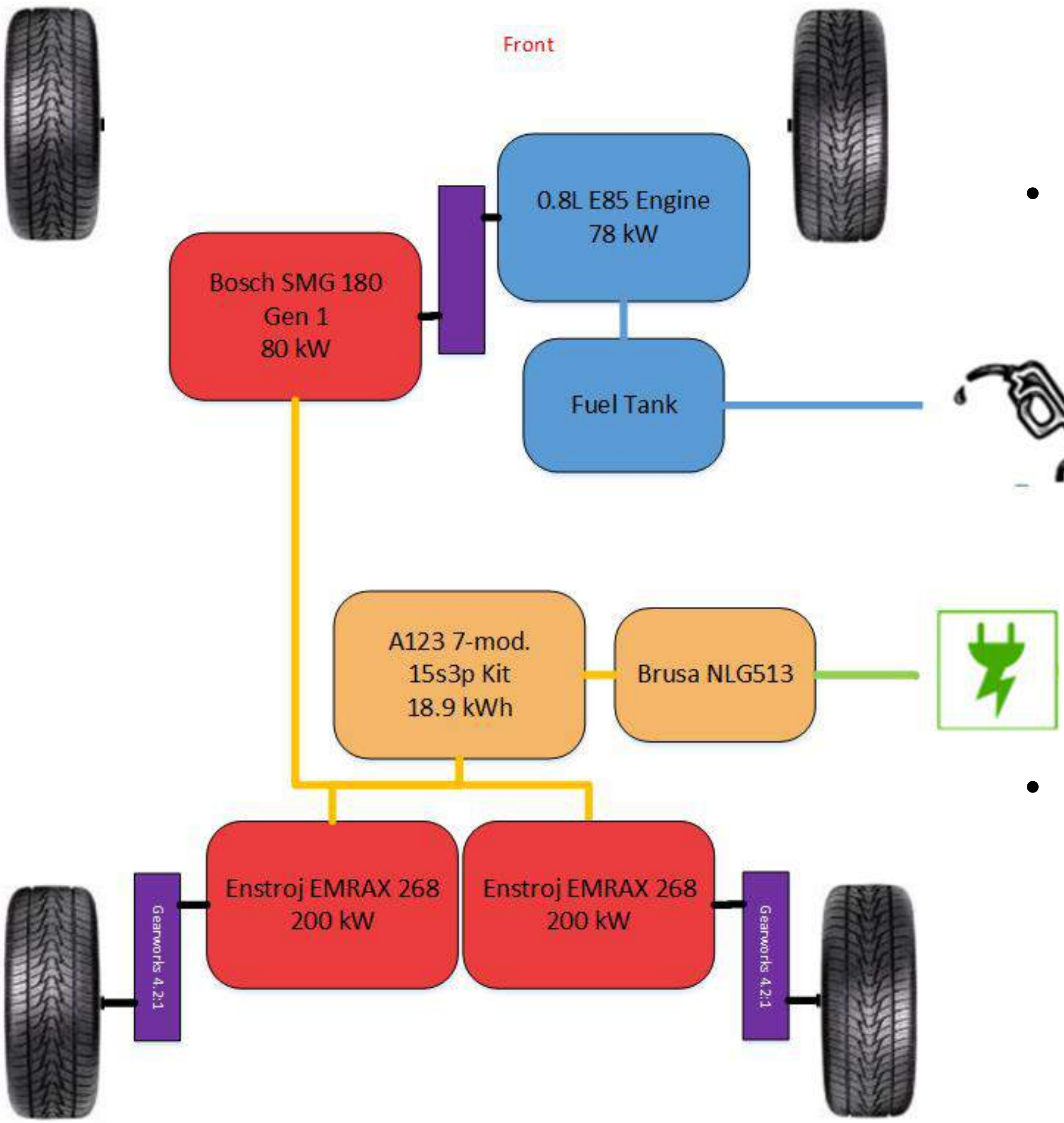
UWECOCAR

ELECTRICAL PRESENTATION

Jake Garrison and James Goin

Torque Vector Series PHEV



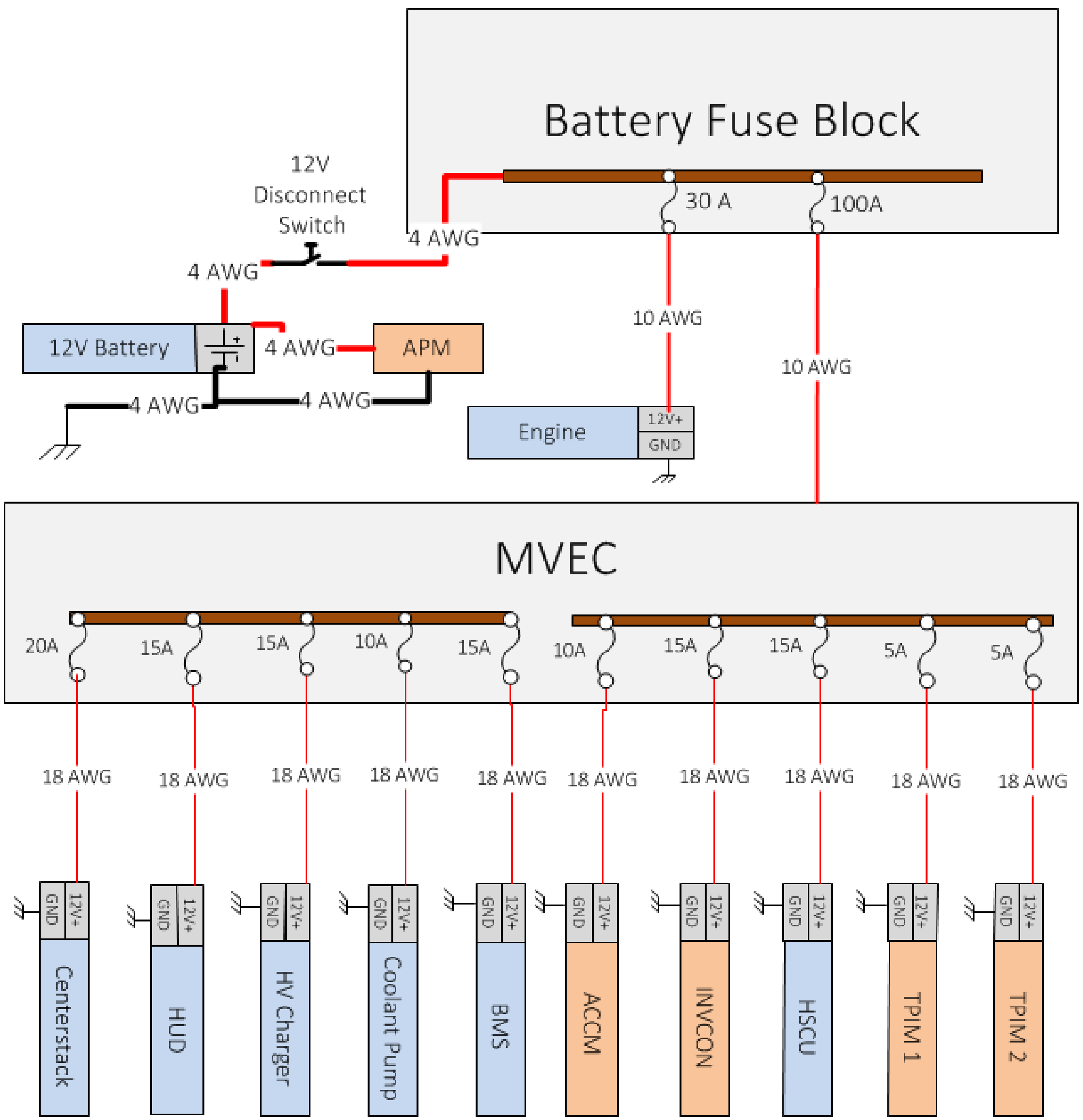
- Performance
  - IVM-60 mph: 5.3s
  - 50-70 mph: 2.9s
  - Top Speed: 137 km/h (85 mph)
  - EV Range: 80 km (50 miles)
  - Power: 400 kW (536 hp)
  - Torque: 4200 Nm (3098 lb ft)
- Unique Characteristics
  - Torque Vectoring
  - Electric Drivetrain

UW ECOCAR

LV SUBSYSTEM

LV CIRCUIT DIAGRAM

Added components



Legend

Accessory Power Management	APM
Head-Up Display	HUD
Battery Management System	BMS
Accessory Climate Control Module	ACCM
Hybrid Supervisory Control Unit	HSCU
Inverter	TPIM
Multiplexed Vehicle Electrical Center	MVEC

Grounding

Power line

Blue components — Low Voltage

Orange components — High Voltage

Author: Marissa Reid & Shiyu Xia & Jiajun He
Date: 5/14/2015
Revision: 8
Approved By: Jake Garrison

LOAD CHARACTERIZATION

Accessory Draws (Added Components)	
Component	Nominal (A)
Air Pump	18
Unitek BamoCar D3 (2)	2.8
Radiator Motor	18
ETAS	2.5
Coolant Pump	25
Volt ACCM	0.125
BCM	10
A123 Components (BMS CMS EDM)	2.35
Centerstack	4.5
HUD	3.5
Bosch SMG 180 Gen 1	0.5
Bosch INVCON Gen 2.3	0.5
Total	**116.775**

Battery Specifications (Optima YellowTop)	
Capacity (Ah)	75
Reserve Capacity (min)	155
Minimum Cranking Voltage (V)	10.5
Minimum Cranking SOC (%)	20
Cold-Cranking Amps (A)	900

Parasitic Draws		
Component	Nominal (mA)	Max (mA)
Radio	12	22
Powertrain Control Module	19	44
Keyless Entry Module	12	15
Oil Level Module	5	10
Light Control Module	4	7
Illuminated Entry	13	22
HVAC Power Module	11	31
Heated Windshield Module	9	20
Electronics Control Module	14	33
ETAS	20	44
Auto Door Lock	6	11
Anti-Theft System	6	8
Body Control Module	11	19
Multi-Function Chime	6	16
Retained Accessory Power (RAP) Module	6	22
Twilight Sentinel Module	7	11
ON Star Module	8	16
Total	169	351

Parasitic Depletion from 100% to 20% SOC	
Nominal at 115 mA	2.1 weeks

LV SIMULATION OVERVIEW

Overview

- Cranking transient analysis
- Steady state parasitic load analysis

Features

- Made in Simscape
- Adaptive physical battery and starter model
- User-defined:
  - Battery chemistry
  - Accessory loads
  - Custom duty cycle
  - Cranking load profile
  - Efficiency

MathWorks®

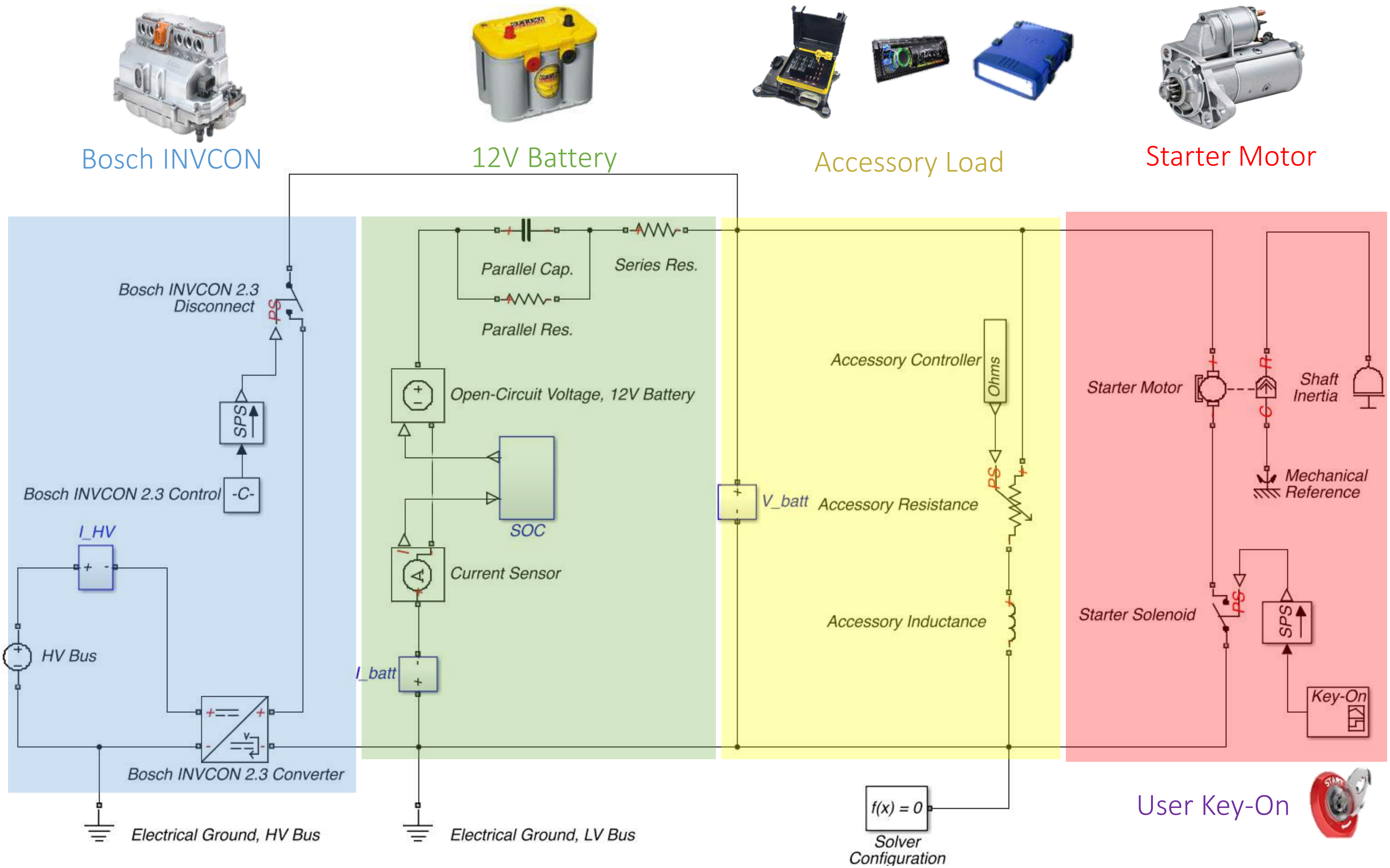
Limitations

- Lack of component specs and stock vehicle benchmarks
- Only major loads accounted for
- Poorly defined duty cycle
- Impedance parameters
- 12V battery chemistry undecided
- Runtime versus precision

Assumptions

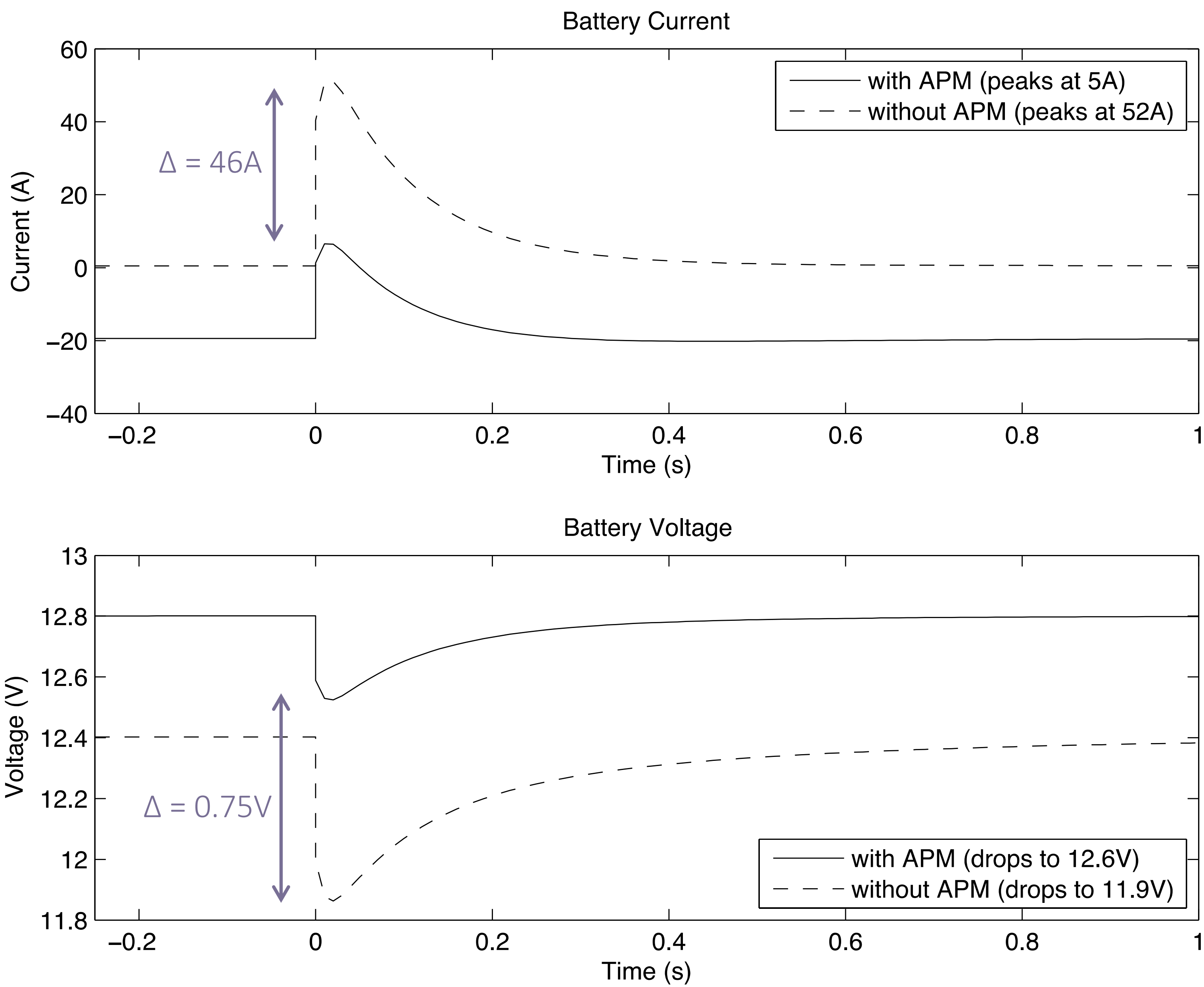
- Stock Camaro loads
- Motor cranking load
- Constant load duty cycles
- Constant ambient temperature

LV BUS MODEL



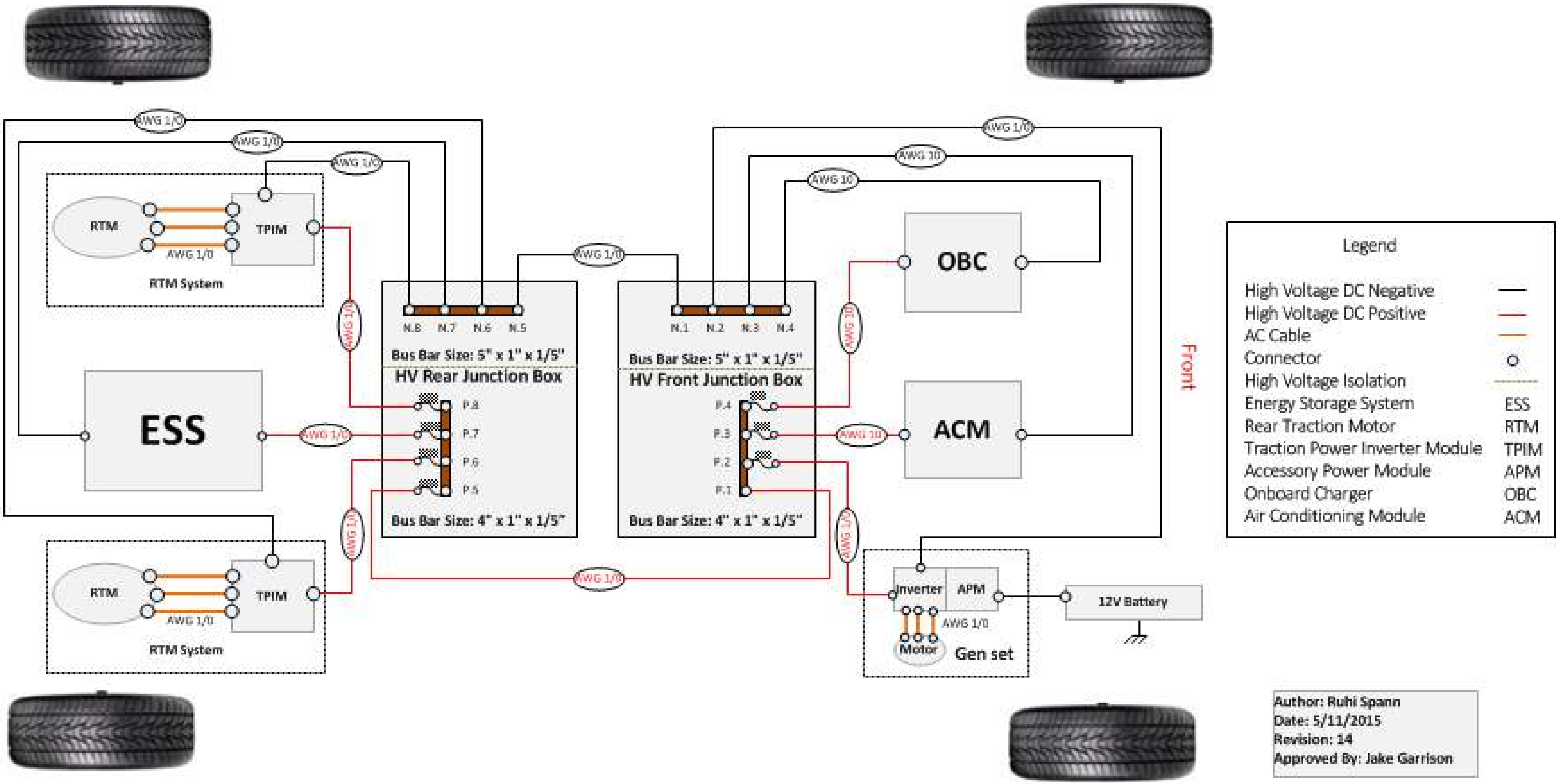
Bosch INVCON
12V Battery
Accessory Load
Starter Motor
Bosch INVCON 2.3
Disconnect
PS
SPS
Bosch INVCON 2.3 Control
-C-
I_HV
HV Bus
Bosch INVCON 2.3 Converter
Electrical Ground, HV Bus
Parallel Cap.
Series Res.
Parallel Res.
Open-Circuit Voltage, 12V Battery
SOC
Current Sensor
I_batt
Electrical Ground, LV Bus
Accessory Controller
Ohms
V_batt
Accessory Resistance
Accessory Inductance
f(x) = 0
Solver
Configuration
Starter Motor
Shaft
Inertia
Mechanical
Reference
Starter Solenoid
Key-On
User Key-On

CRANKING SIMULATION



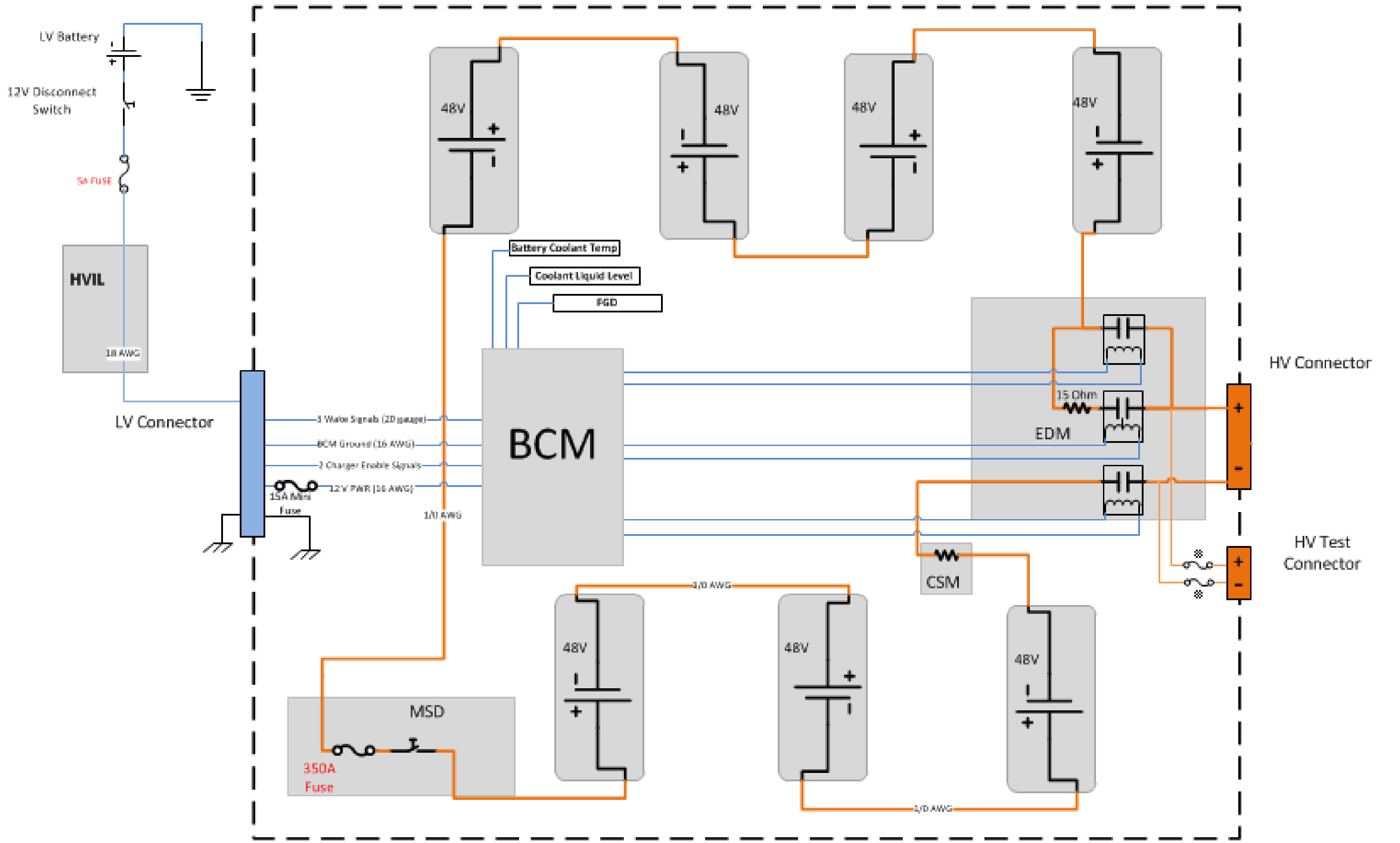
HV SUBSYSTEM

HV CIRCUIT DIAGRAM



A123 SYSTEMS BOSCH BRUSA DENSO

ESS DIAGRAM



Wires and Bus Bars

Low Voltage Wire
High Voltage Cable 1/0
High Voltage 20 AWG

Symbols

Fuse
Contactor Coil
Contactor
Manual Switch
Kilovac Contactor

Devices

Manuel Service Disconnect	MSD
Current Sense Module	CSM
Electrical Distribution Module	EDM
Measurement and Balance Board	MBB
Battery Control Module	BCM
High Voltage Interlock Loop	HVIL
Flammable Gas Detector	FGD

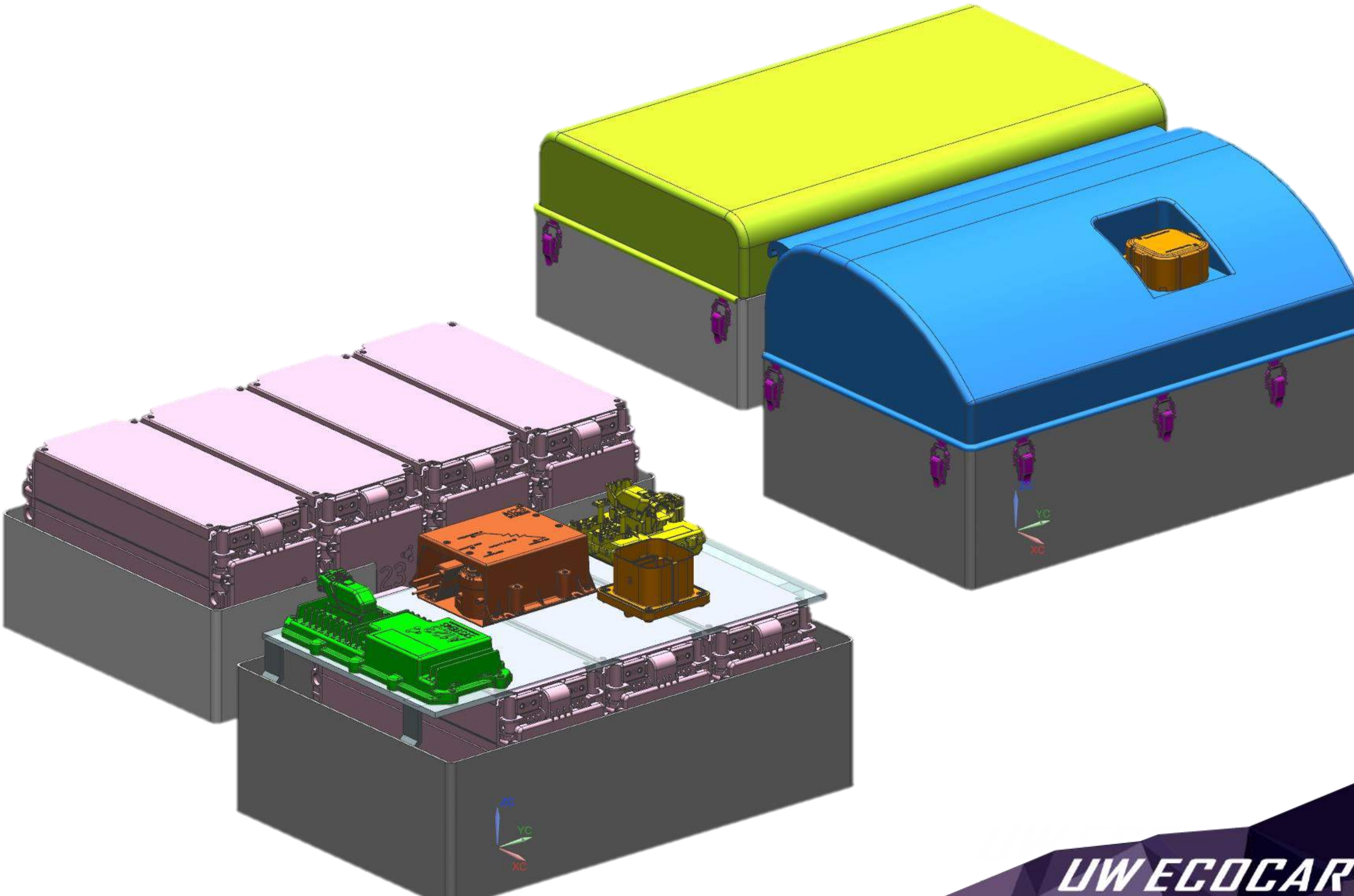
Battery Chemistry

A123 3P2S Battery
Lithium Iron Phosphate

Author: Sherry Chen
Ruhi Spann

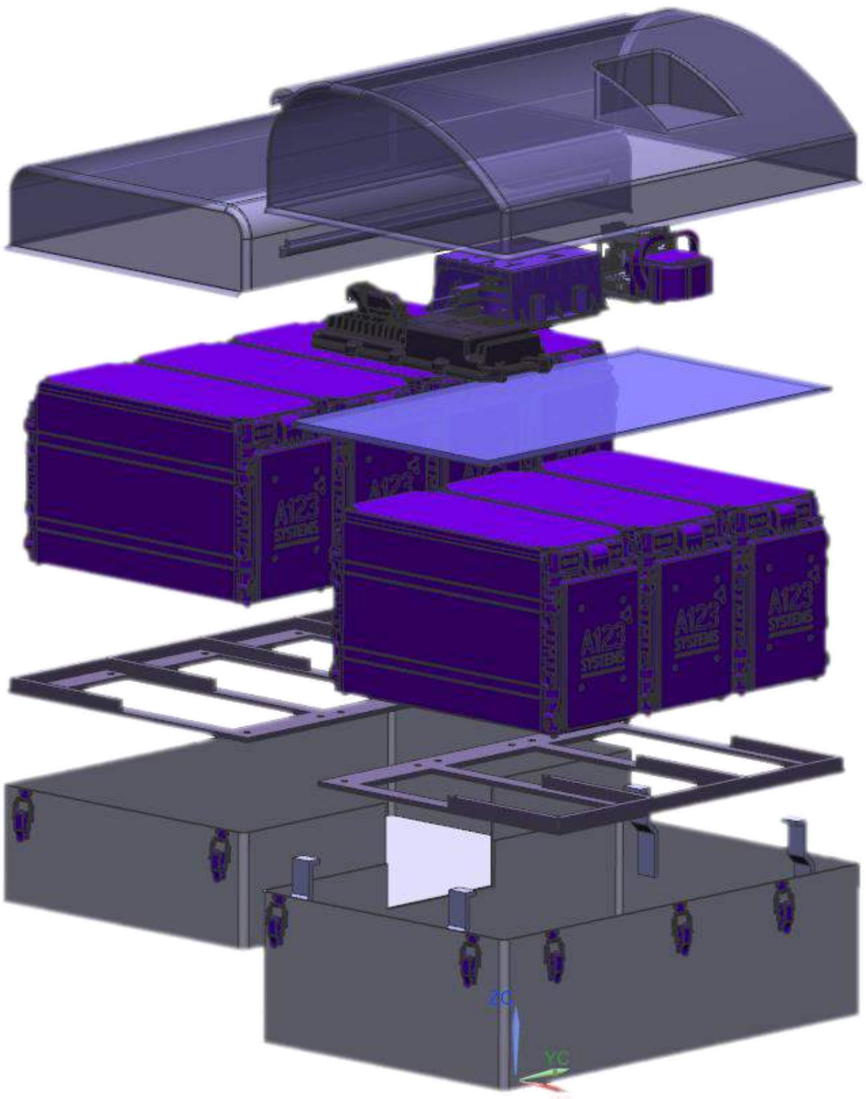
Date: May 16th, 2015
Revision 2
Approved By: Jake Garrison

ESS DEVELOPMENT



UW ECOCAR

ESS DEVELOPMENT



Energy Storage System	
Voltage	350 V
Capacity	18.9 kWh
Range	50 miles
Modules	7
Packaging	15s3p
Chemistry	Li-Ion Phosphate

HV SIMULATION OVERVIEW

Overview

- Bus ripple analysis
- Bus charge and discharge analysis
- Fuse melting analysis

Features

- Made in Simscape
- Physical Li-Ion pack model
- Compatibility with LV model
- User-defined:
    - Battery parameters
    - Switching frequencies
    - Load impedance

MathWorks®

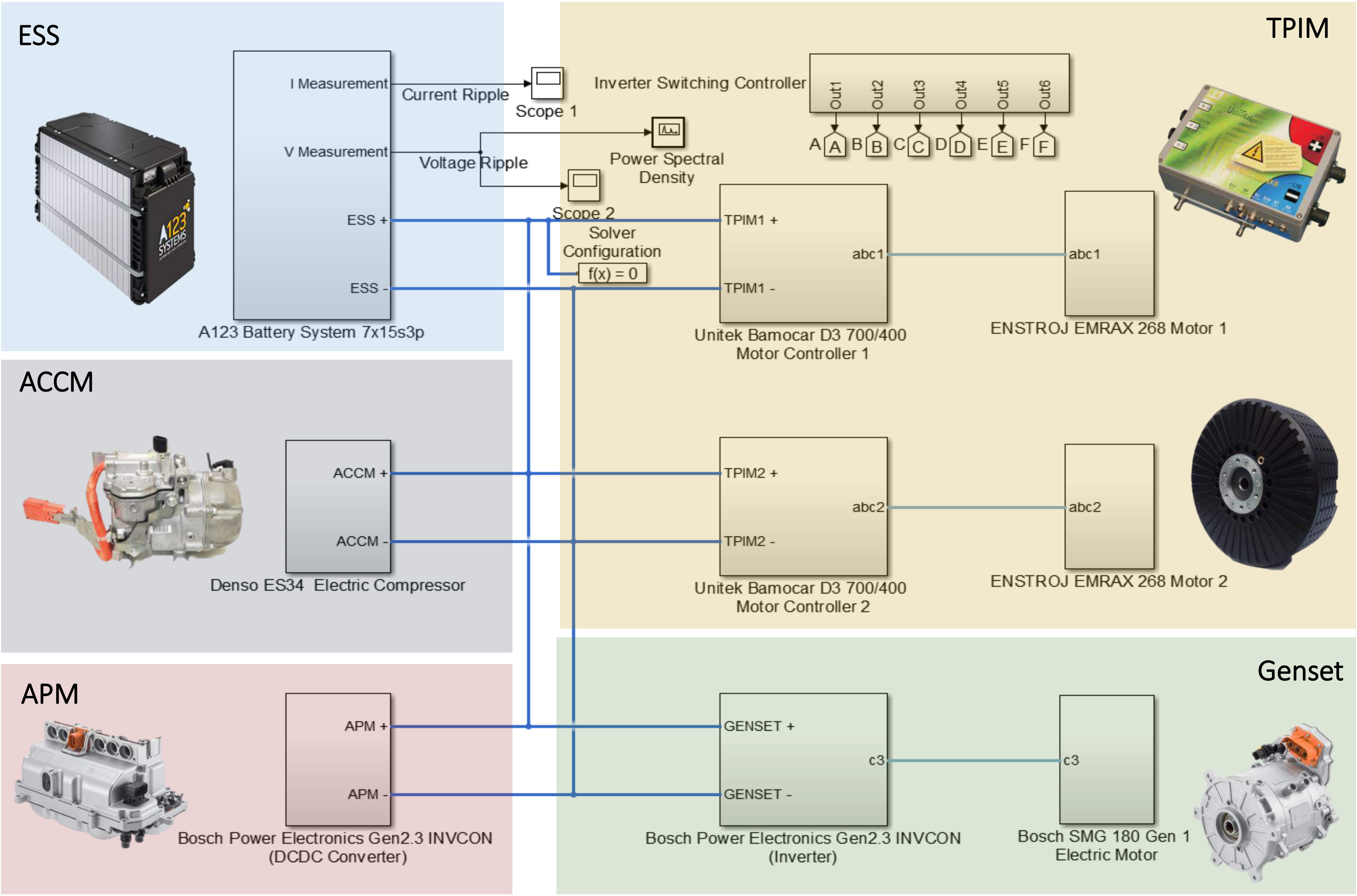
Limitations

- Lack of component specs
- Impedance parameters
- Transient profiles
- No drive cycle support (yet)

Assumptions

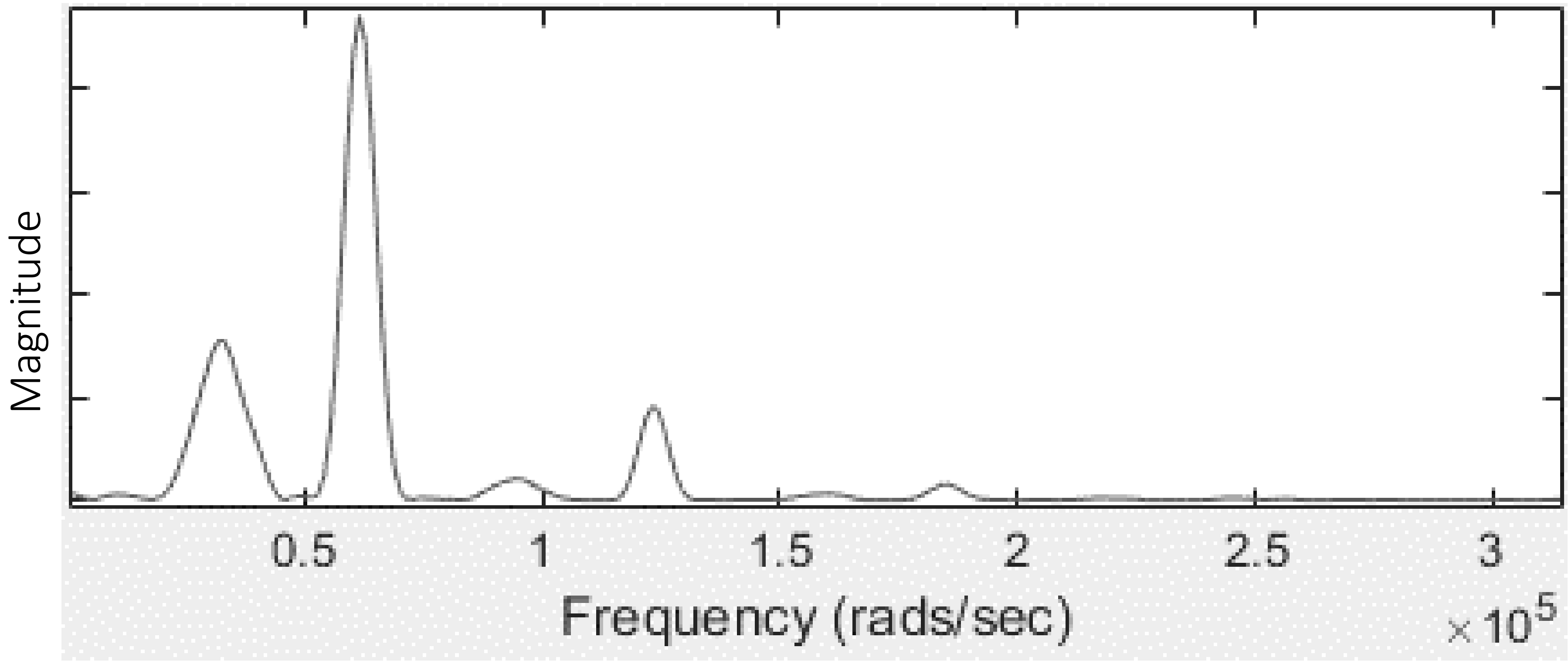
- Component spec sheet parameters
- Worst case scenario
- Switching frequency bounds 8 to 24 kHz
- Constant ambient temperature
- Constant motor torque (for now)
- Harness resistance is negligible

HV MODEL


ESS
I Measurement
Current Ripple
Scope 1
V Measurement
Voltage Ripple
Power Spectral Density
Scope 2
ESS +
ESS -
A123 Battery System 7x15s3p
Solver Configuration
f(x) = 0
TPIM
Inverter Switching Controller
Out1
Out2
Out3
Out4
Out5
Out6
A B C D E F
TPIM1 +
abc1
TPIM1 -
Unitek Bamocar D3 700/400 Motor Controller 1
abc1
ENSTROJ EMRAX 268 Motor 1
ACCM
ACCM +
ACCM -
Denso ES34 Electric Compressor
TPIM2 +
abc2
TPIM2 -
Unitek Bamocar D3 700/400 Motor Controller 2
abc2
ENSTROJ EMRAX 268 Motor 2
APM
APM +
APM -
Bosch Power Electronics Gen2.3 INVCON (DCDC Converter)
Genset
GENSET +
c3
GENSET -
Bosch Power Electronics Gen2.3 INVCON (Inverter)
c3
Bosch SMG 180 Gen 1 Electric Motor

HV BUS RIPPLE

Spectral Density

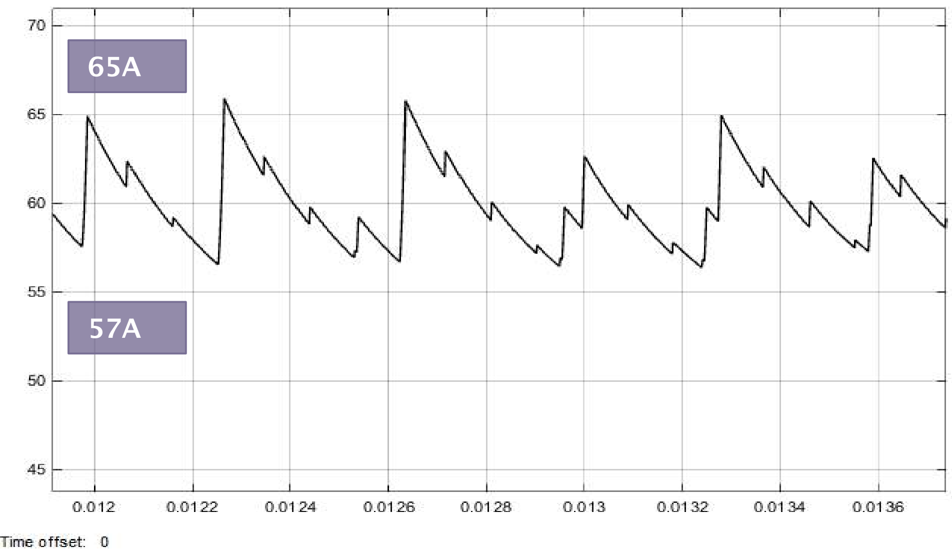


Ripple Analysis	Frequency (Hz)	5,570.42	10,345.07	19,098.59
	Voltage Ripple (V)	5	6	4
	Current Ripple (A)	6	8	2

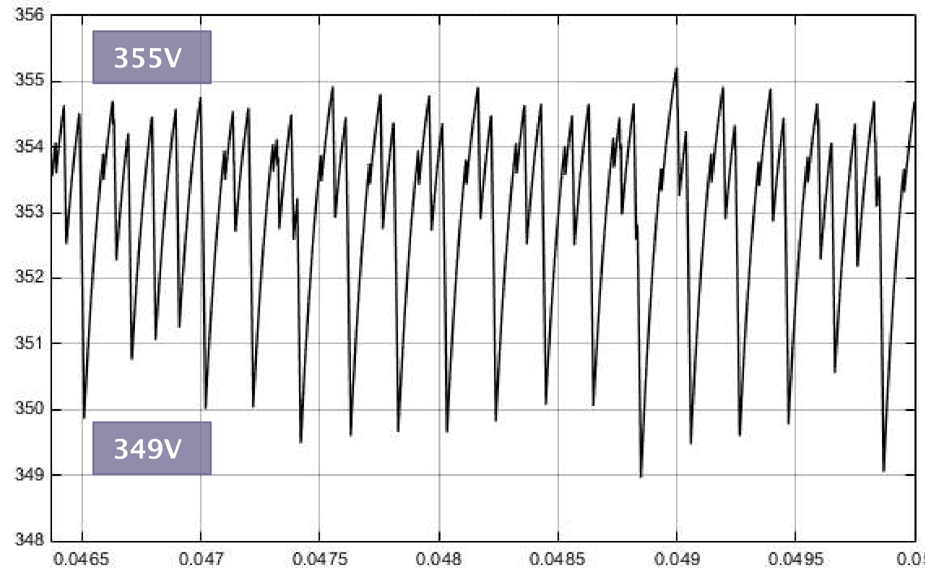
UW ECOCAR

HV BUS RIPPLE

Current Ripple

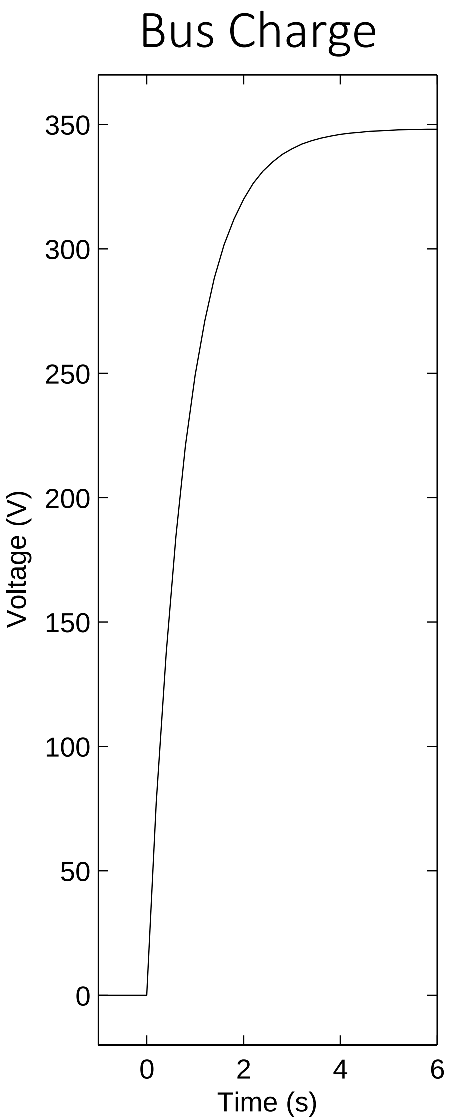


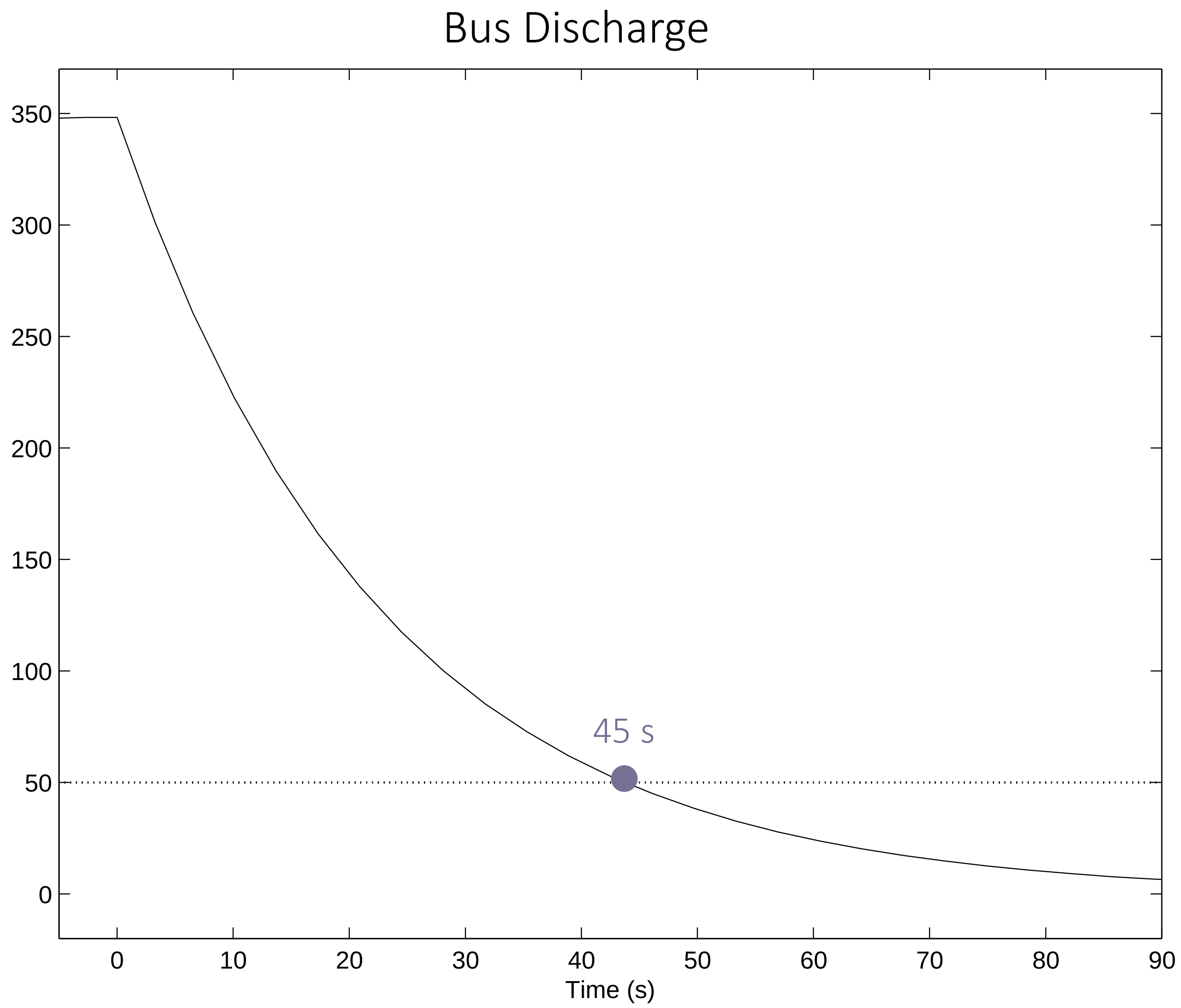
Voltage Ripple



Ripple Analysis	Frequency (Hz)	5,570.42	10,345.07	19,098.59
	Voltage Ripple (V)	5	6	4
	Current Ripple (A)	6	8	2

BUS CHARGE AND DISCHARGE





FUSE AND WIRE SELECTION

FUSING OVERVIEW

Load Conditions

- Nominal and peak current
- Operating voltage
- Load Type (capacitive or resistive)

Source Conditions

- Power output
- Ambient temperature (derating)
- Short-circuit current (I2t analysis)
- Intended cycle life

Standards

- UL certified
- IEC 60269 standard
- Mersen design reviews

WIRING OVERVIEW

Exrad XLE Cable Specifications

- High voltage and current
- Automotive grade
- High dielectric insulation
- High temperature tolerance
- High bend radius
- Shielded (reduce EMI)
- Orange

Conditions

- Fuse blows before cable fails

Standards

- UL 758 and ISO 6722 accordance
- SAE certified
- Champlain design reviews

SELECTION OVERVIEW

Component	Fuse Size (A)	Wire Gauge (AWG)	Wire Ampacity (A)	Nominal Current (A)	Peak Current (A)
Charger	12	10 Shielded	80	12.25	12.75
Genset Inverter	300	1/0 Shielded	339	210	400
TPIM (Inverter)	200	1/0 Shielded	339	200	400
ACCM	20	10 Shielded	80	12.5	25.6
Junction Fuse	350	1/0 Shielded	339	250	500
ESS	350	1/0 Shielded	339	180	612

Note: load profiles approximated from supplier specification sheet

GENSET INVERTER EXAMPLE

Source

ESS

- $V = 375$ VDC
- $R = 0.05\ \Omega$
- $i_{sc} = 7.34$ kA

1/0 Cable →

Fuse

- 300 A rated
- $\Delta t_{peak} >> 100$ s
- Max $V = 700$ VDC
- Max $i_{sc} = 100$ kA

1/0 Cable →

Load

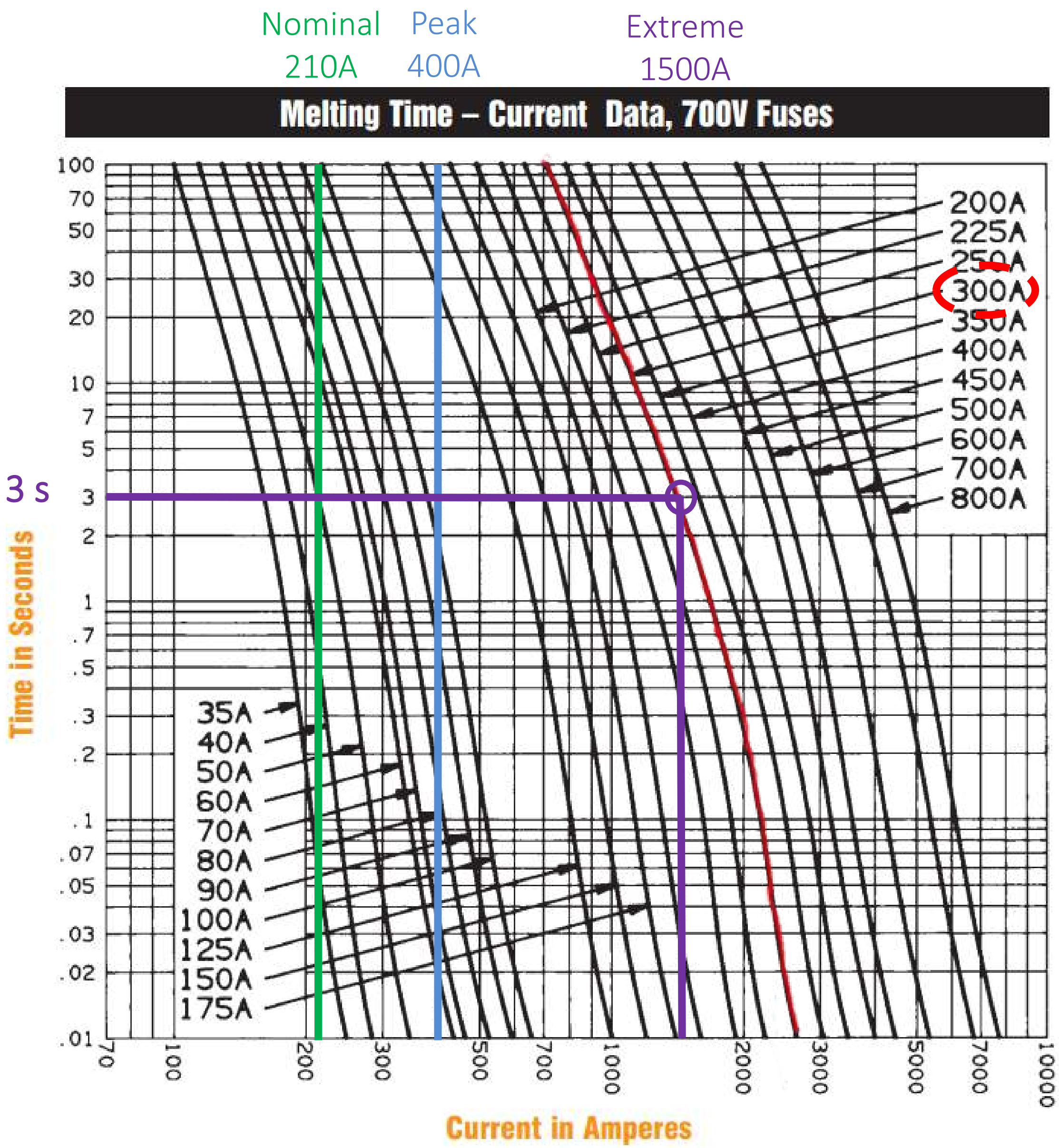
Genset Inverter

- $i_{avg} = 210$ A
- $i_{peak} = 400$ A
- $\Delta t_{peak} = 45$ s

Requirements

- Capacitive load = time delay fuse to prevent nuisance blows
- 1.5 x 210 A (nominal) ≈ 300 A (rule of thumb)
- Allowed time at peak current:
  - 45 s (Genset Δt_{peak}) < 150 s (fuse) < 300 s (cable)
- Max voltage
  - 375 VDC (ESS) < 700 VDC (fuse) < 1000 VDC (cable)
- Short circuit current
  - 7.34 kA (ESS) < 100 kA (fuse)

GENSET INVERTER FUSE



300 A Fuse Specification

Model: Mersen A70QS300

- Type: Time Delay
- Max Voltage: 700 VDC
- Impulse: 100 kA I.R
- Temperature: 25°C

Parameter	Current (A)	Melt Time (s)
Nominal	210	>> 100
Peak	400	>> 100
Extreme	1500	3
Short Circuit	7.3k	< 0.01

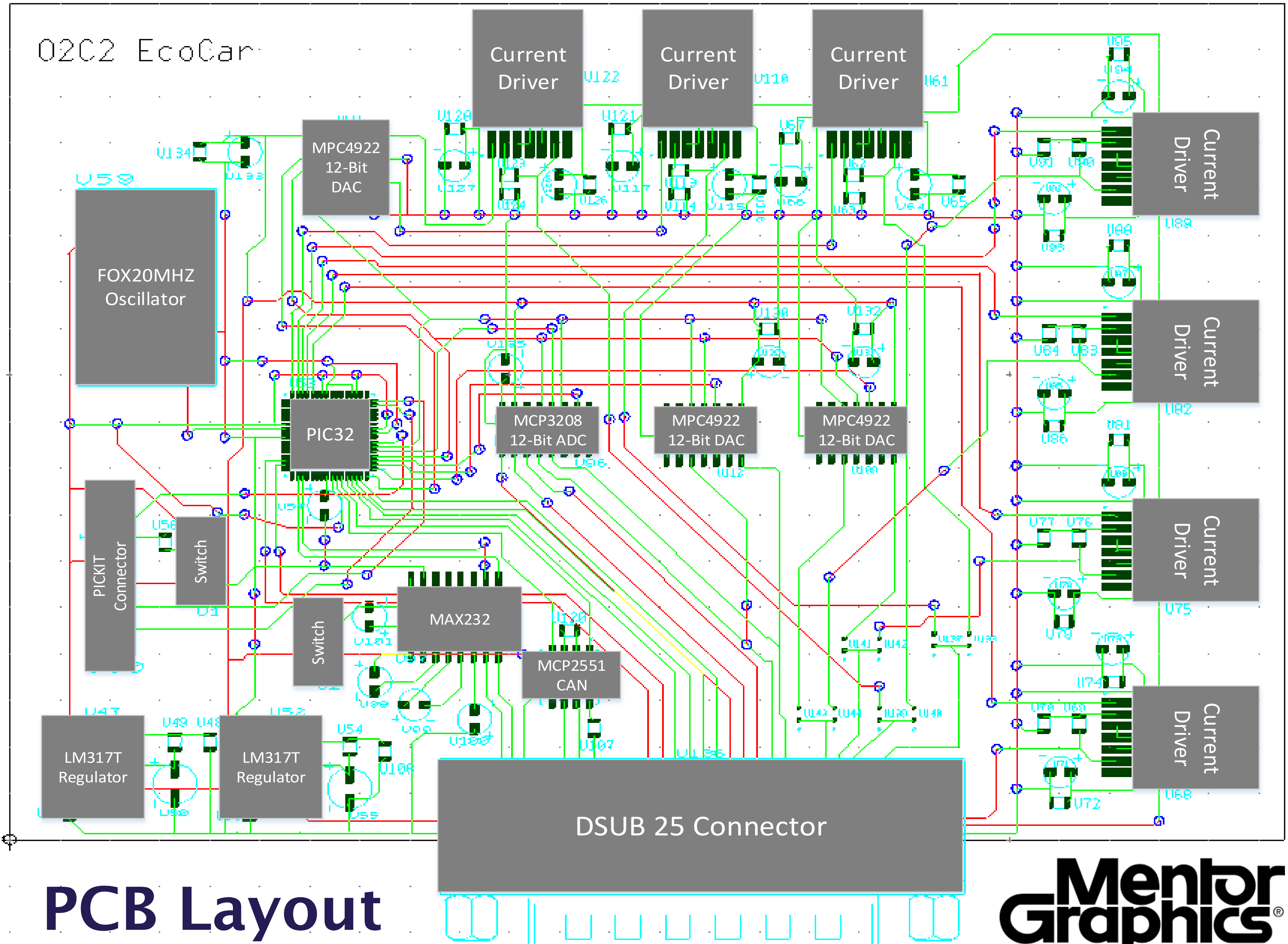
UW ECOCAR

Custom Embedded Controller

OUR OWN CAR CONTROLLER (O2C2)

O2C2

- CAN / RS232
- Configurable channels
- Real-time commands and feedback
- Features:
  - 8-channel 12-bit ADC
  - 6-channel 12-bit DAC
  - 16 digital IO
  - 7 current drivers
  - Pulse width modulation
  - Custom driver set

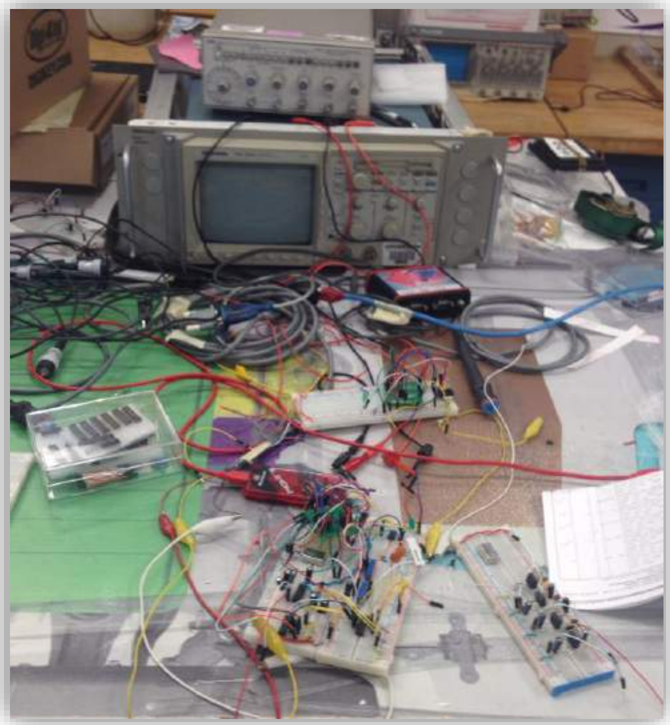

O2C2 EcoCar
Current Driver
Current Driver
Current Driver
Current Driver
Current Driver
Current Driver
Current Driver
MPC4922 12-Bit DAC
FOX20MHZ Oscillator
PIC32
MCP3208 12-Bit ADC
MPC4922 12-Bit DAC
MPC4922 12-Bit DAC
PICKIT Connector
Switch
Switch
MAX232
MCP2551 CAN
LM317T Regulator
LM317T Regulator
DSUB 25 Connector

PCB Layout

LV BENCH TESTING

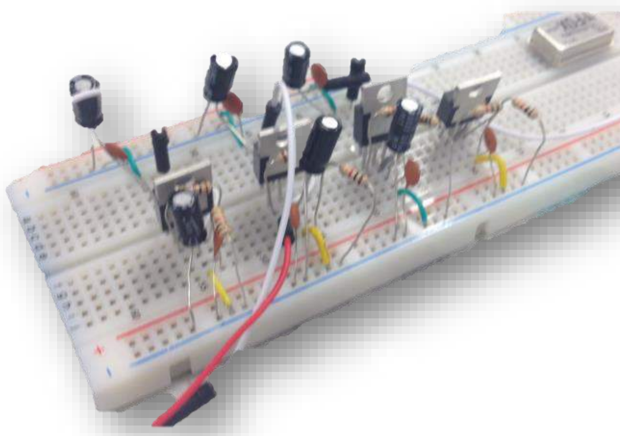
Embedded Design Project

- Documentation
- Part sourcing
- Prototyping
- Harness design
  - HIL harness
  - In vehicle harness
- HIL validation



freescale™
semiconductor

dSPACE



APPLICATIONS

Examples

- Smarter MVEC + breakout
- Aerodynamic shutter control
- Fail-safe motor speed sensors
- Control non-CAN devices
- Smarter charge management system

UW ECOCAR

NON-POWERTRAIN EMBEDDED CONTROL SYSTEM

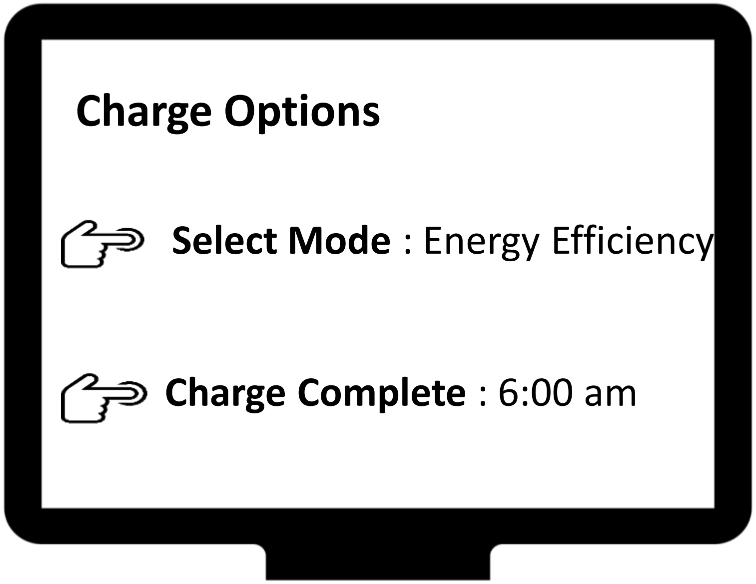
Charge Management System

Reductions in energy consumption

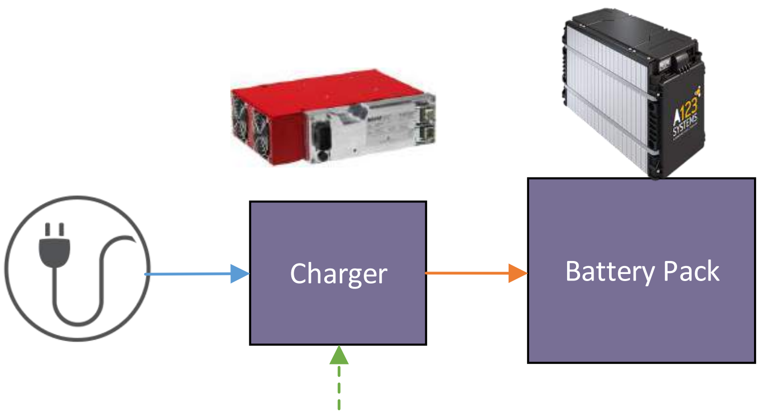
- Direct 12V grid power
- Minimizing cooling pump use
- Optimizing the charger

High level requirements

- User input
  - Charge complete
  - Input modes
    - Efficiency
    - Fast
    - Cost
- Operating requirements
  - CAN communication
  - 12V power



STANDARD SYSTEM - BLOCK DIAGRAM



Legend

12 V Line

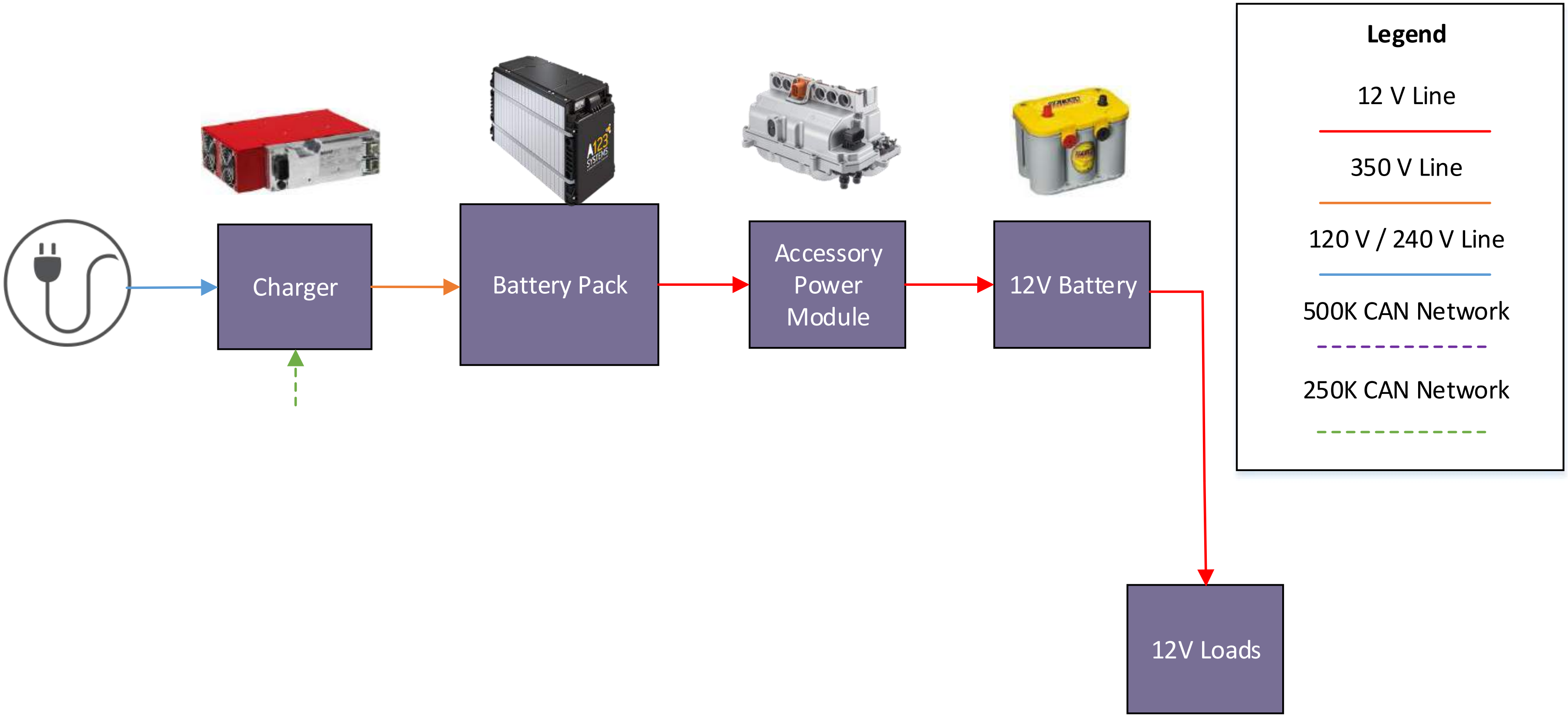
350 V Line

120 V / 240 V Line

500K CAN Network

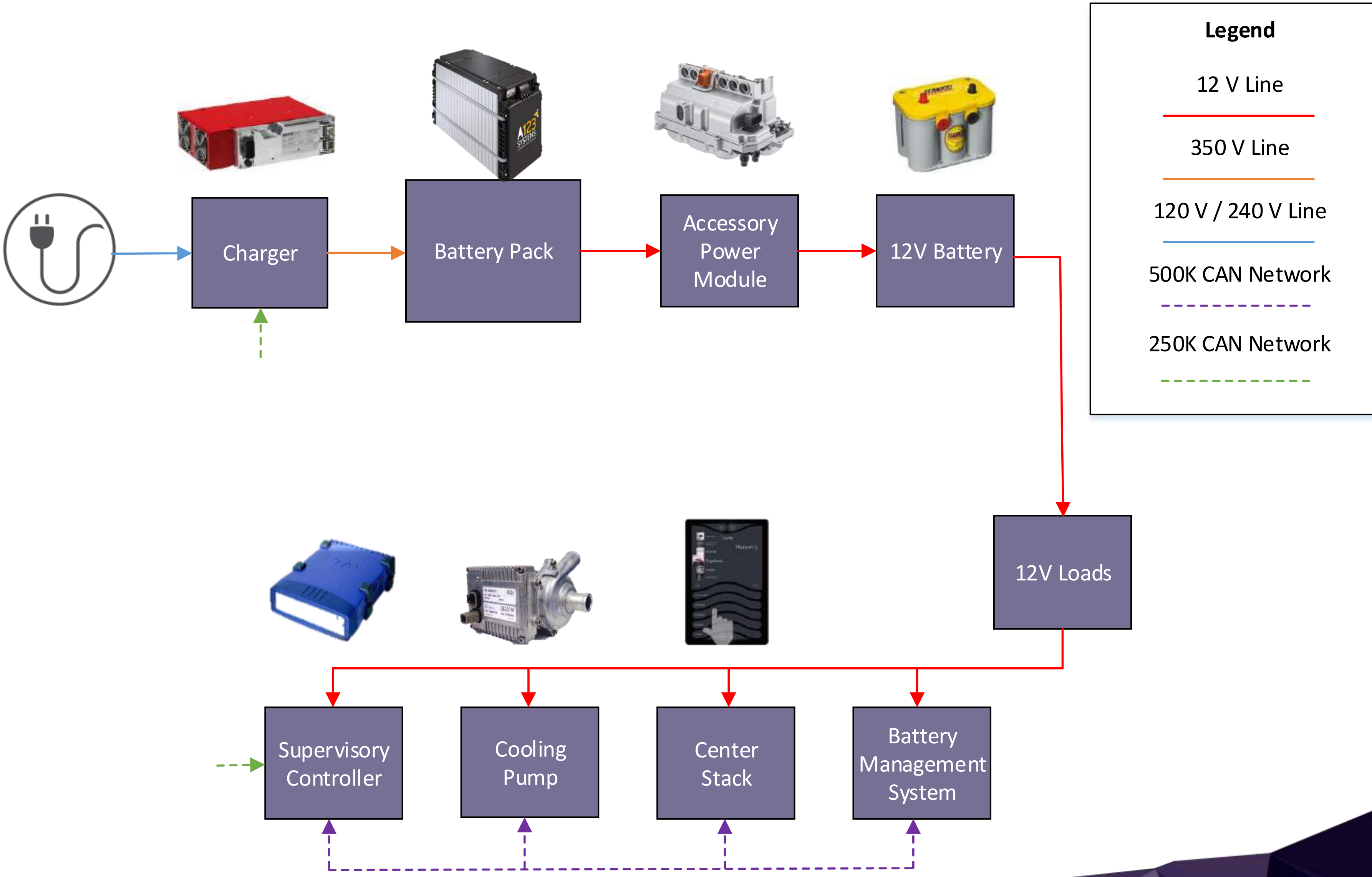
250K CAN Network

STANDARD SYSTEM - BLOCK DIAGRAM



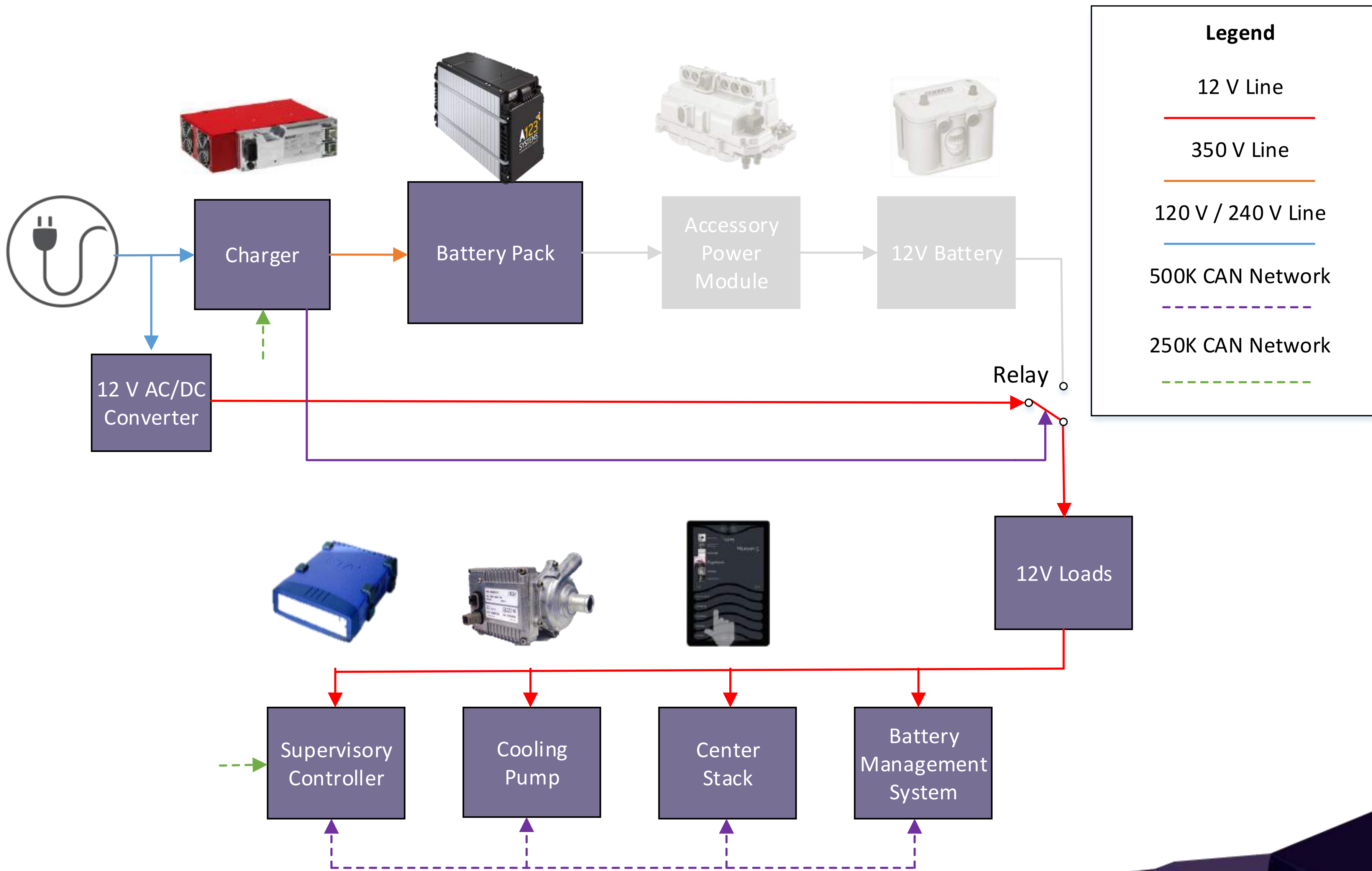
UW ECOCAR

STANDARD SYSTEM - BLOCK DIAGRAM



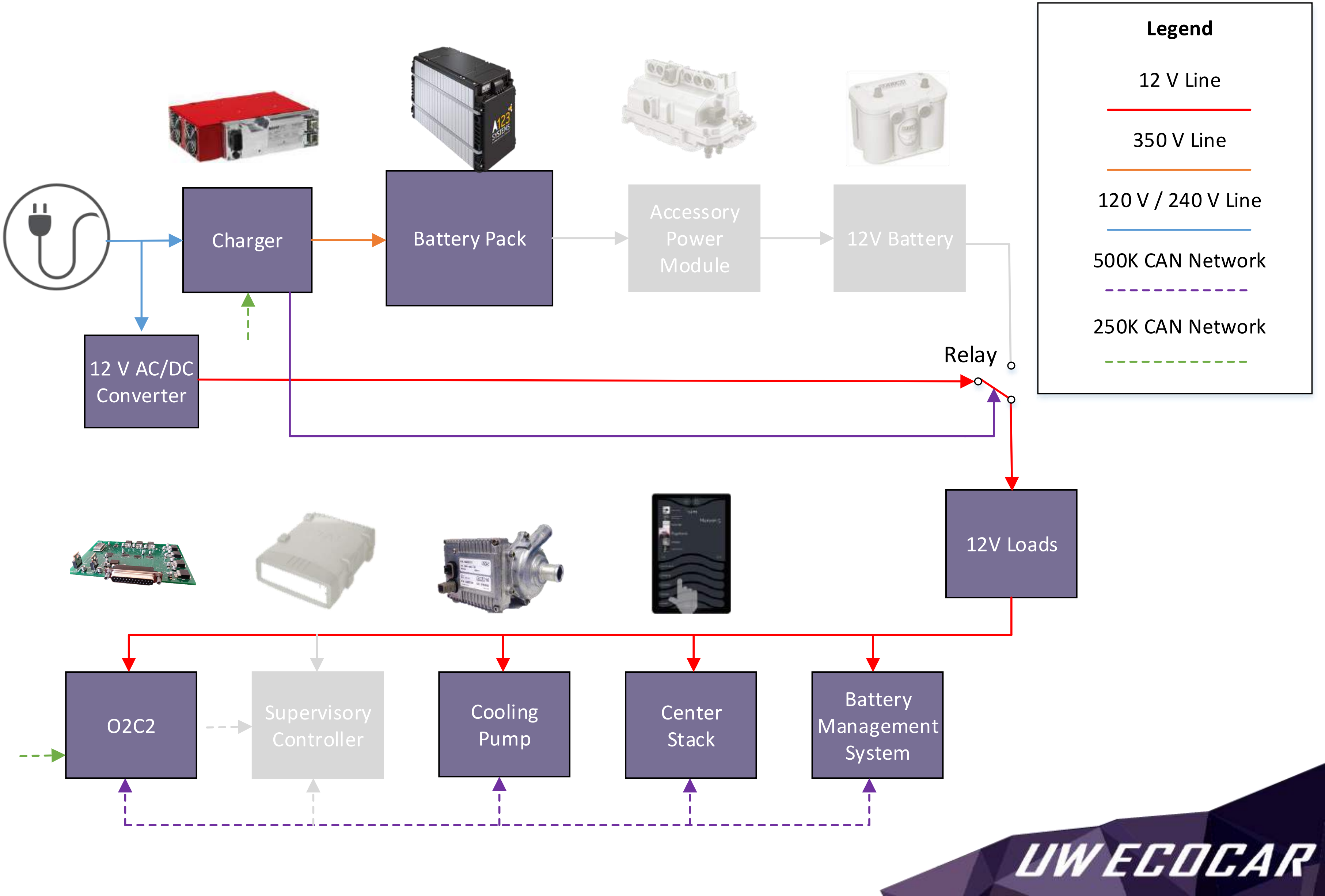
UW ECOCAR

OPTIMIZED SYSTEM - BLOCK DIAGRAM

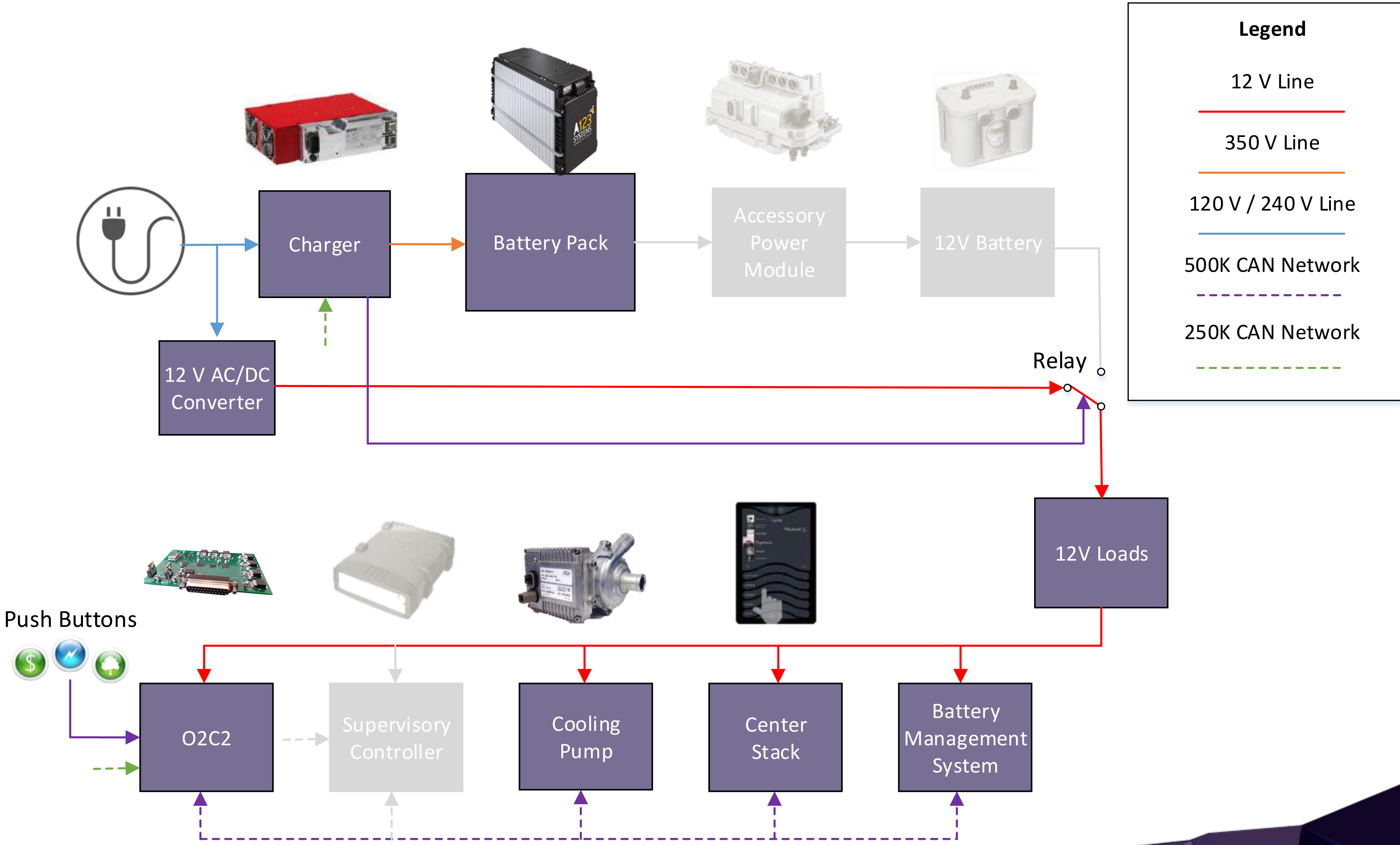


UW ECOCAR

OPTIMIZED SYSTEM - BLOCK DIAGRAM



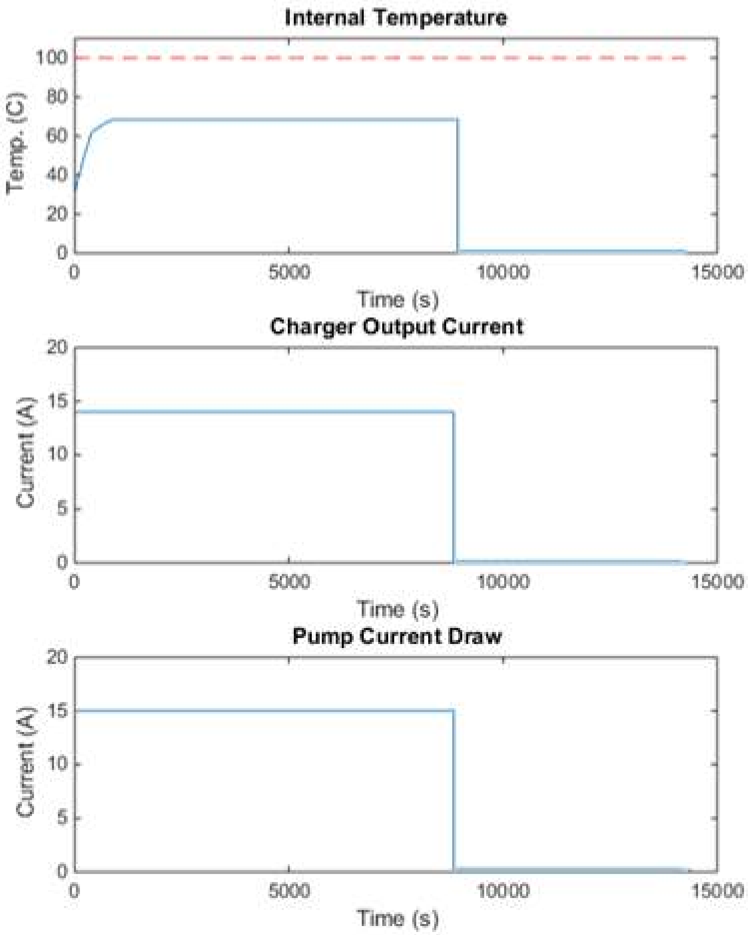
OPTIMIZED SYSTEM - BLOCK DIAGRAM



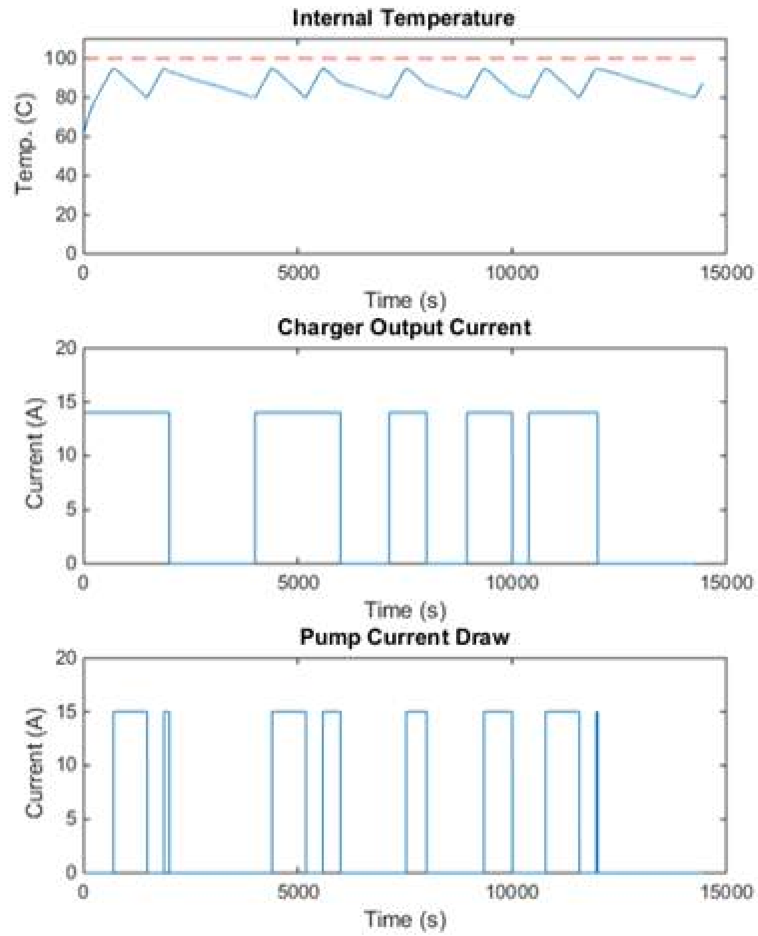
UW ECOCAR

CHARGER AND PUMP CONTROL STRATEGY

Standard Charge Cycle



Optimized Charge Cycle



Results from 20% to 80% state of charge at 25°C ambient temperature

MathWorks®

NET EFFICIENCY GAIN

Category	Original Use (W)	Modified Use (W)	Percent Savings Per Category
Minimizing pump use	192	115	25-40%
Direct 12V grid power	264	243	8%
Charging optimization	5100	4845	3-4%
Total power saved	**5556**	**5083**	**6-7.7%**

Total Energy Savings = 7.7%

UW ECOCAR

OPERATING LIMITATIONS

Component	Rating
02C2	
Input Voltage Range	4.2-30 V
ADC	12-bit accuracy
DAC	12-bit accuracy
Memory	256kB
Clock	20 MHz
CAN	< 1 Mb/s
Temperature	0 - 120 C
Electromagnetic Interference	> ~4 inches from high voltage
AC/DC Power Supply	
Input Voltage	120/240 V +/- 12 V AC(50-65Hz)
Max Power	500 W
Relay	
Control Voltage	8-17V VDC
Max Current	50A

O2C2

12V Power Supply

Relay

UW ECOCAR

UTILIZED COMMUNICATION BUSSES

RS232

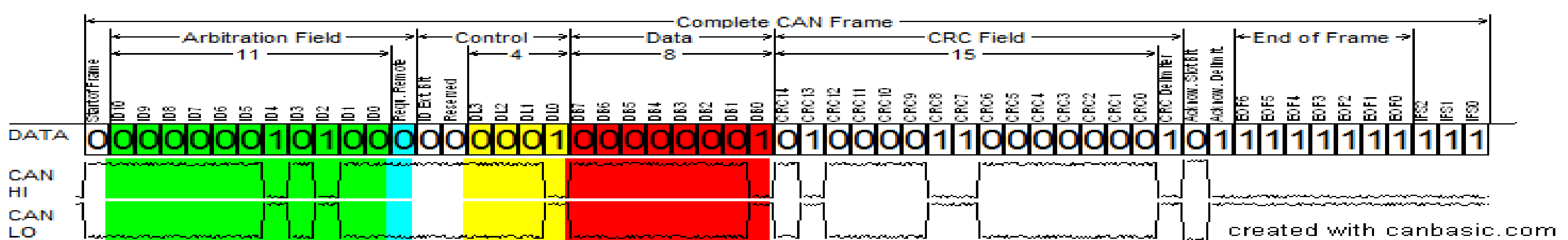
- Desktop development board
- HIL validation

CAN

- Slave controller
- Simple master controller
    - Receiving values for optimization algorithm
    - Setting optimal values

Used Network Data

Signal	Name	Type
Battery Pack		
State of Charge	bcm_soc	TX
Charger		
Temperature	getChargerTemp	TX
Current Request	setChargerCurrent	RX
Measured Current	getChargerCurrent	TX
Enable	setEnable	RX
Cooling Pump		
Measured Current	CP1_current	TX
Coolant Temp	CP1_temperature	TX
Pump Request	setPumpSpeedRpm	RX
Enable	pumpOn	RX
Center Stack		
User Mode	userMode	TX
Charge By Time	chargeByTime	TX



TOP 5 DFMEA LINE ITEMS

Failure Mode	Effects	Cause of Failure	Prevention	Detection	RPN	Action
Insufficient Power	Unable to turn on	Poor or damaged power supply	Durable and high quality supply	Not on CAN network	(7 * 3* 2) = 42	Get better power supply
CAN Network Lost	Loss of communication	Connection is damaged or unconnected	Durable and high quality wires	No CAN Communication	(8 * 5 * 4) = 160	Disable all inputs and outputs that originated from slave control
Improper CAN Message	Improper or unknown CAN message received	Improper device communication	Proper CAN addressing, structure and communication	Improper or unknown CAN message received	(8 * 3 * 7) = 168	Throw flag and keep checking messages
EMI Corruption	Signal corruption	Too close to high voltage	Shielding, metal containers, keep away from high voltage	Improper messages, signals or corruption	(9 * 3 * 5) = 135	Determine source of EMI, increase proximity from and proper shielding
Overpowered	Fuse blown	Power surge, short, or over loaded	Fuse and proper power supply	Fuse blown	(8 * 3 * 3) = 72	Determine source of issue, correct it and replace fuse

SEVERITY X OCCURRENCE X DETECTION = RISK PRIORITY NUMBER (RPN)

Improper CAN Message Handling

- CAN Message
  1001..1100..1011
- Begin Validate by O2C2
- Structure Check: ID Extension Field
  1001..1100..1011
- Structure Check: Data Field
  1001..1100..1011
- Cyclic Redundancy Check:
  1001..1100..1011
- Throws Error Flag
- Checks Next Message

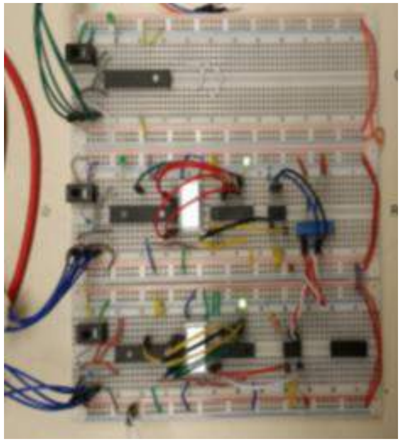
DESIGN TRADE-OFFS

Charge Management

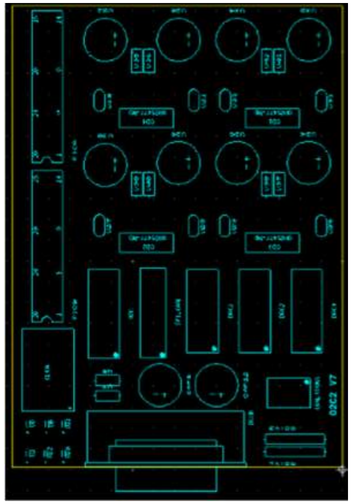
- Charge time
- Static parameters
- Complexity

O2C2

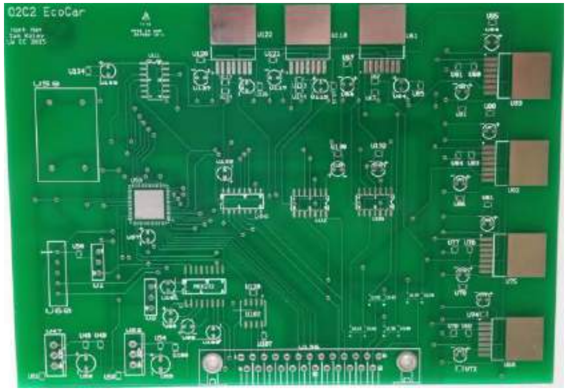
- Comfort and time
- Simplicity vs size
- Precision and features



Revision 1



Revision 2



Revision 3

UW ECOCAR

FUTURE EVALUATION

- Directly measure power consumption with and without the Charge Management System

- Optimization based on real parameters

- Dynamic parameters

UW ECOCAR

Knowledge transfer

KNOWLEDGE TRANSFER

Collaboration

- Slack
- Google Drive
- Wiki
- Safety Binder

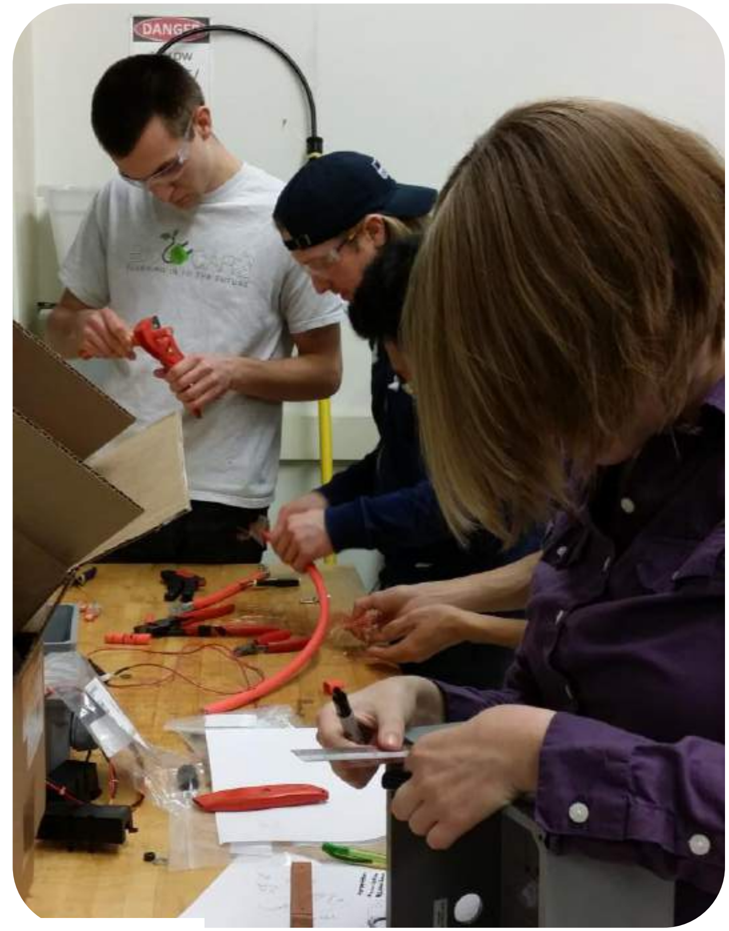
Training

- Weekly Design Review
- Training Workshops
- Extensive Lead training
- Weekly meetings
- Recruiting young members
- Capstone projects

Lessons Learned

- Time management
- Collaboration
- Professionalism
- Effective communication
- Priority setting

HV HARNESS WORKSHOP



Snap-on

CHAMPLAIN CABLE

UW ECOCAR

THANK YOU

U.S. DEPARTMENT OF ENERGY

GM

EcoCAR3

Advanced Vehicle Technology Competition

QUESTIONS?