UW ECOCAR

Electrical Presentation

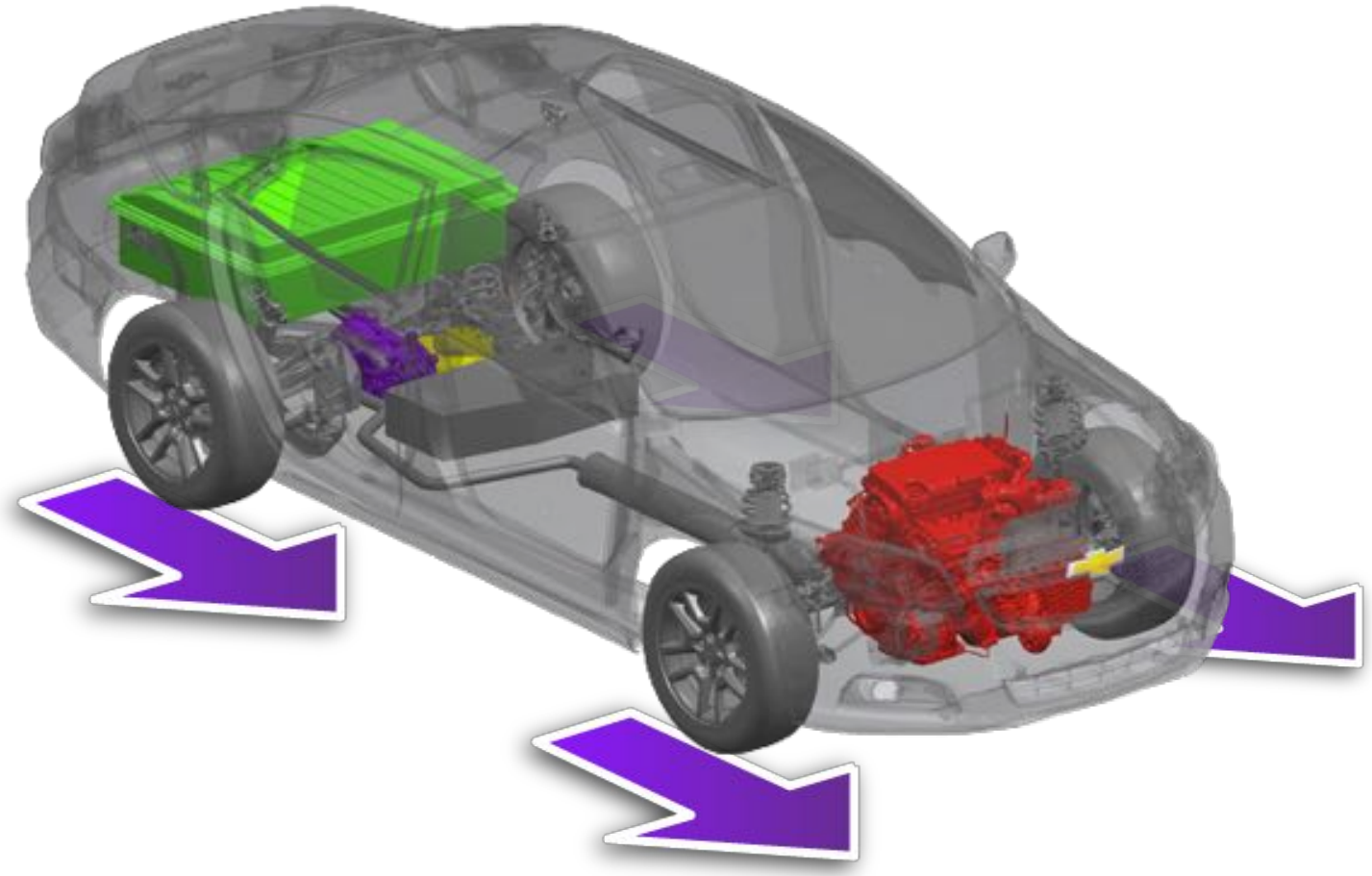
Brian Magnuson and Jake Garrison

Introduction

UW ECOCAR

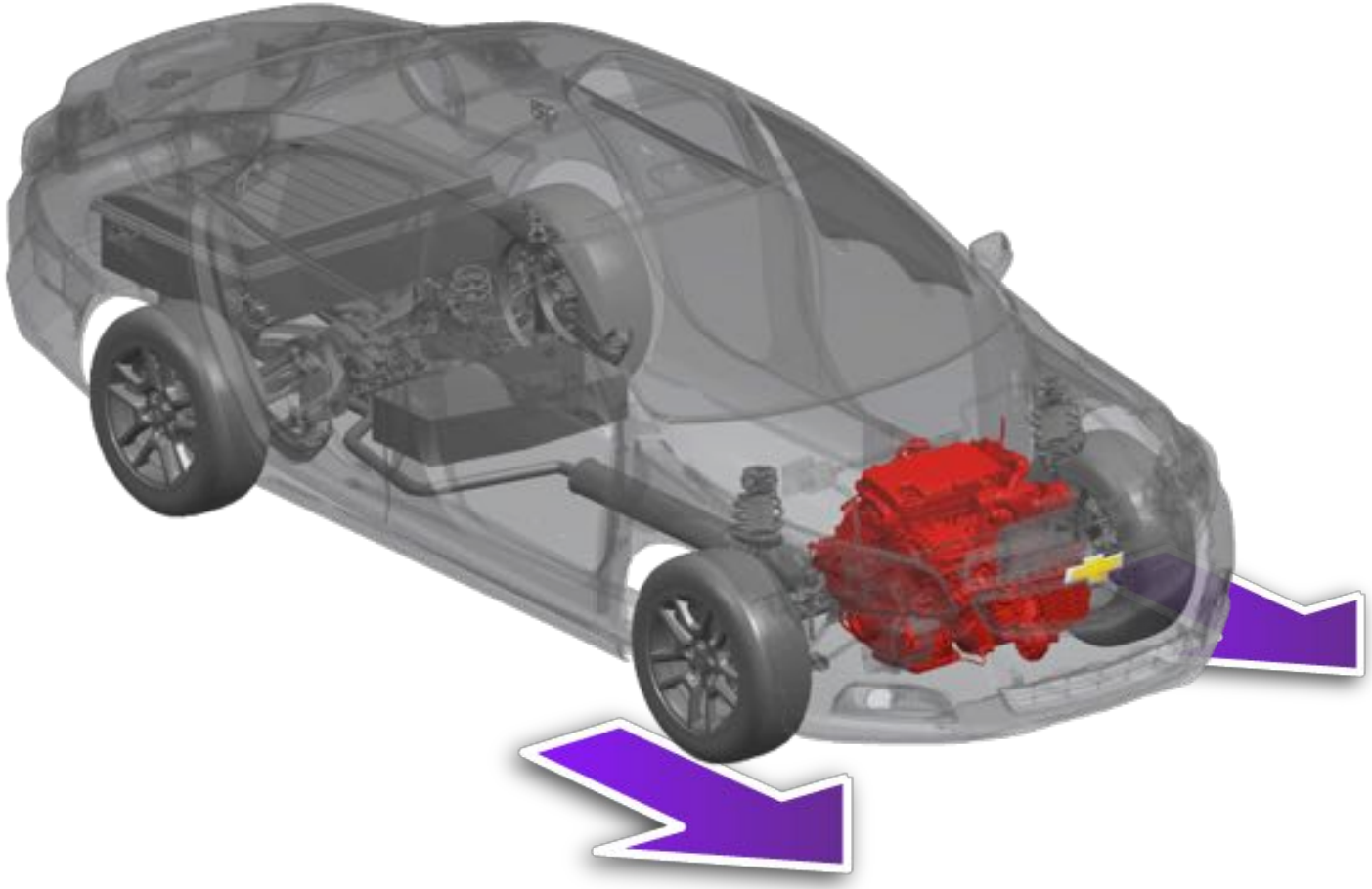
Vehicle Architecture

Architecture Summary



- Powertrain Blending
- Tractive Force
- Operating Modes

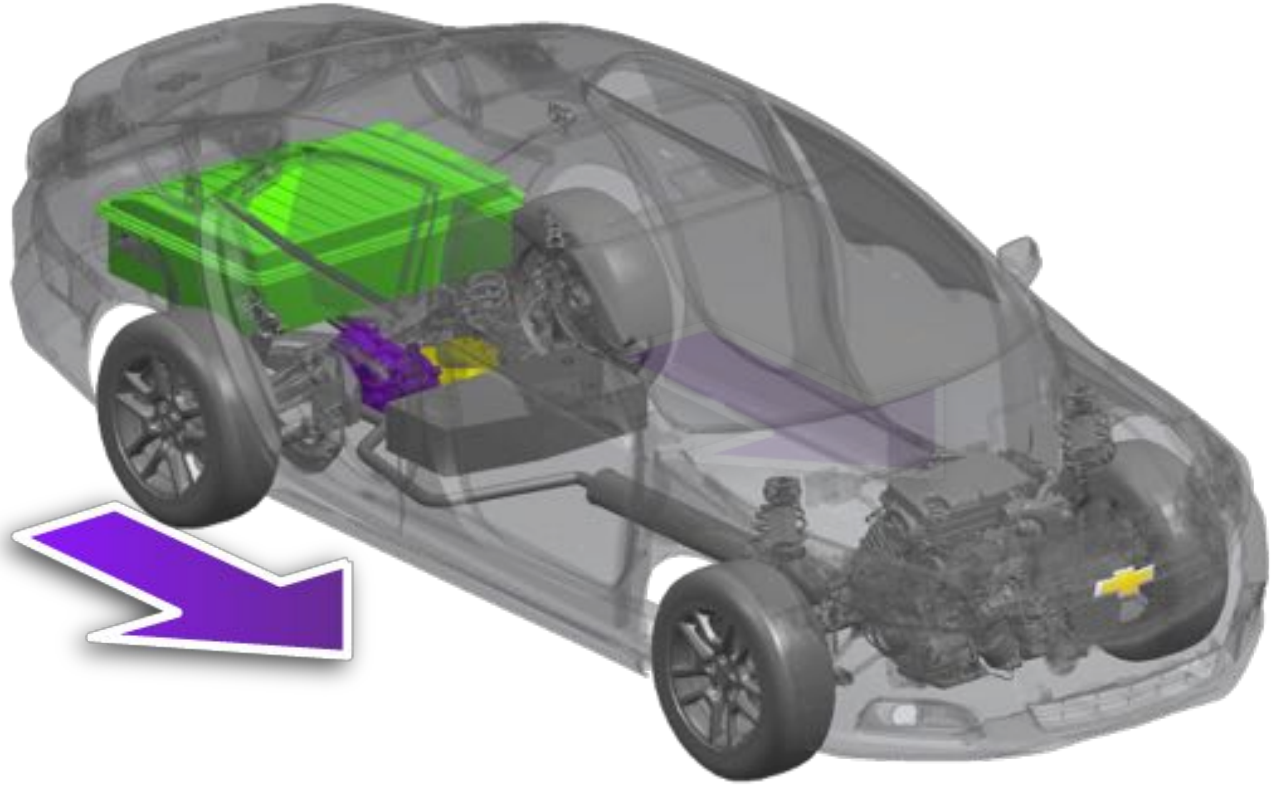
Forward Powertrain



Engine: GM 1.7L B20 Turbo-diesel

Trans: GM MH-8 6-speed

Rear Powertrain



Motor: AM Racing (Remy) HVH-250

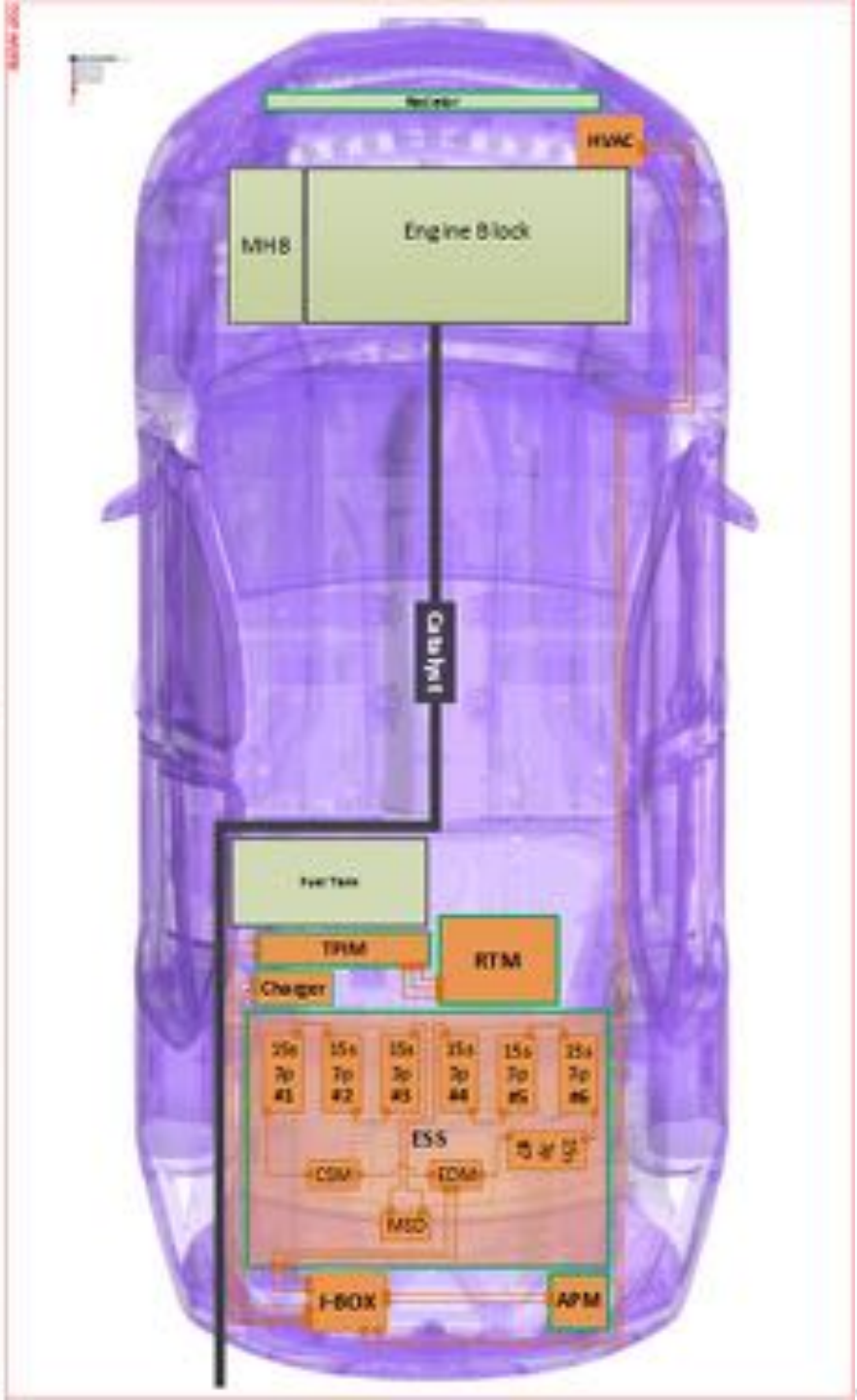
ESS: A123 7x15s3p

Gearbox: GKN 9.59:1

Inverter: Rinehart PM150DX

Block Connectivity Diagram

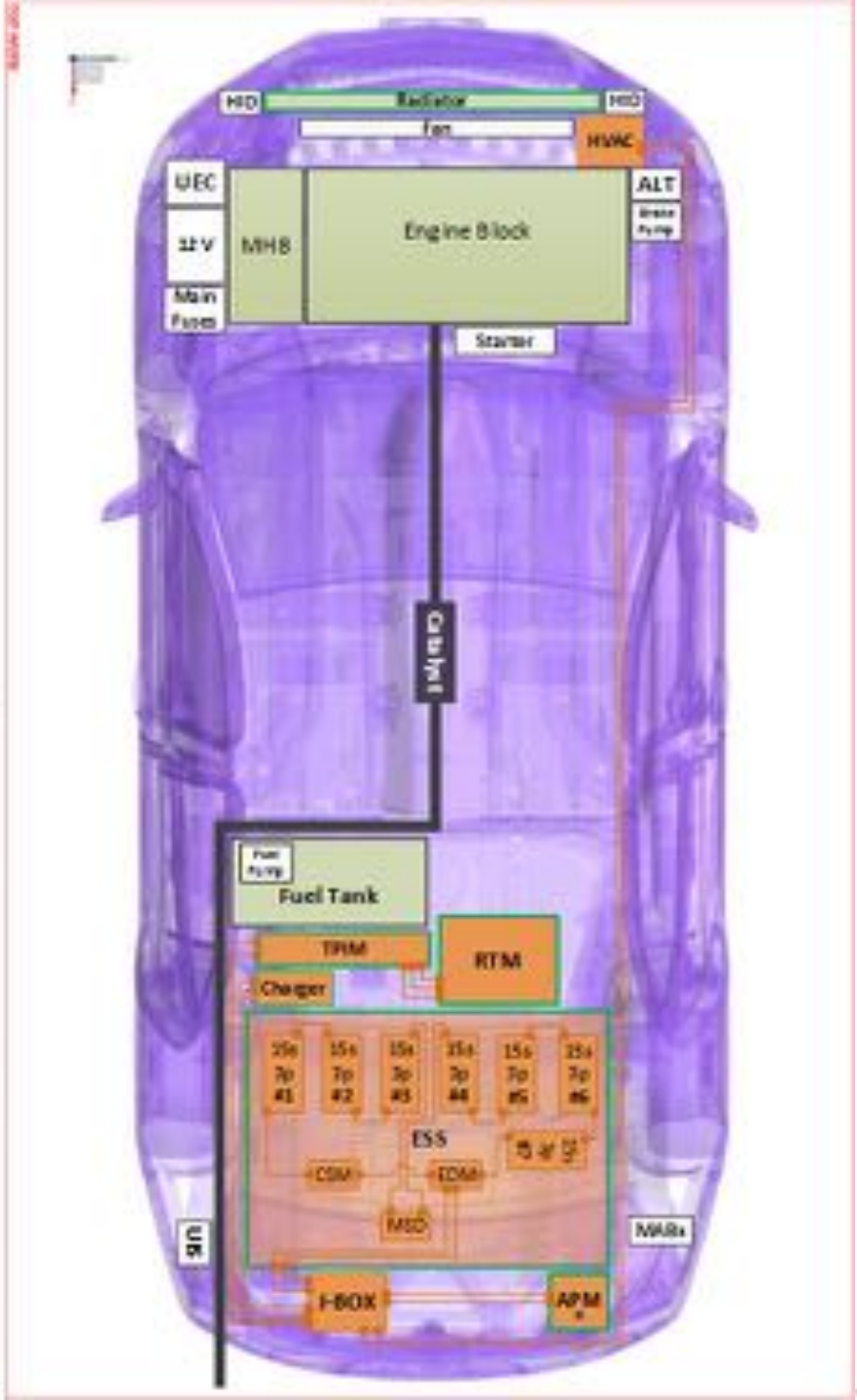
HV Block Connectivity Diagram



- Mechanical Components
- Exhaust Stream
- 12 V Components
- HV Components
- GM_HS Controller
- MOD Controller
- UW_HS Controller
- MS Controller
- Cooled Components

UW ECOCAR

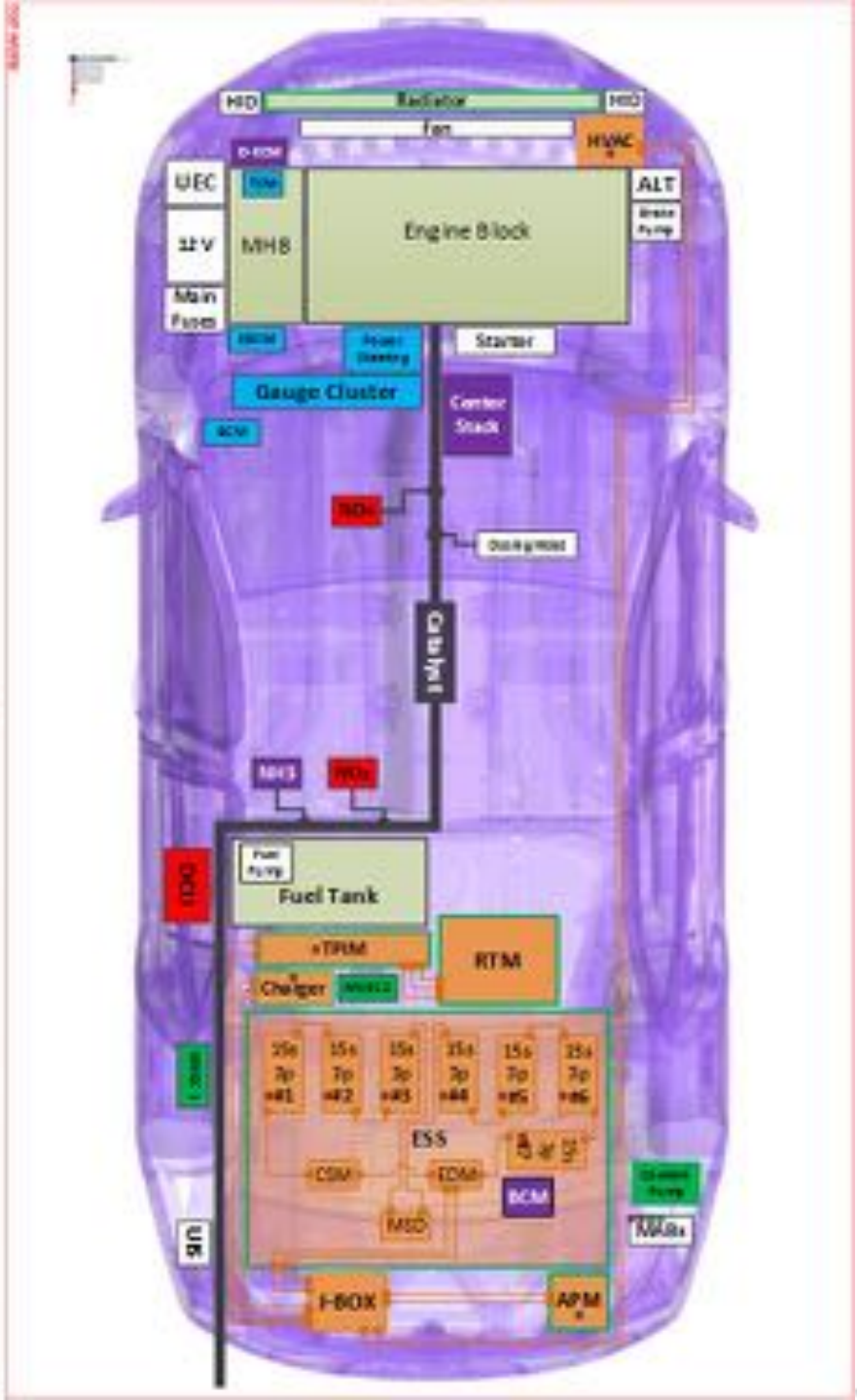
HV + Standard LV Block Connectivity Diagram



- Mechanical Components
- Exhaust Stream
- 12 V Components
- HV Components
- GM_HS Controller
- MOD Controller
- UW_HS Controller
- MS Controller
- Cooled Components

UW ECOCAR

Full Electrical Block Connectivity Diagram



UW ECOCAR

Fuse and Wire Selection

Fuse Selection Criteria

- **Load Conditions**
  - Nominal and Peak Current
  - Operating Voltage
  - Load Type (capacitive or resistive)
- **System Conditions**
  - I^2t analysis
  - Ambient Temperature
  - Short-circuit Current
  - Intended Cycle Life

Inverter Worked Example

Battery (ESS)

- V = 375 VDC
- R = .01 Ω
- i_{sc} = 3.75 kA

200A Fuse (Time Delay)

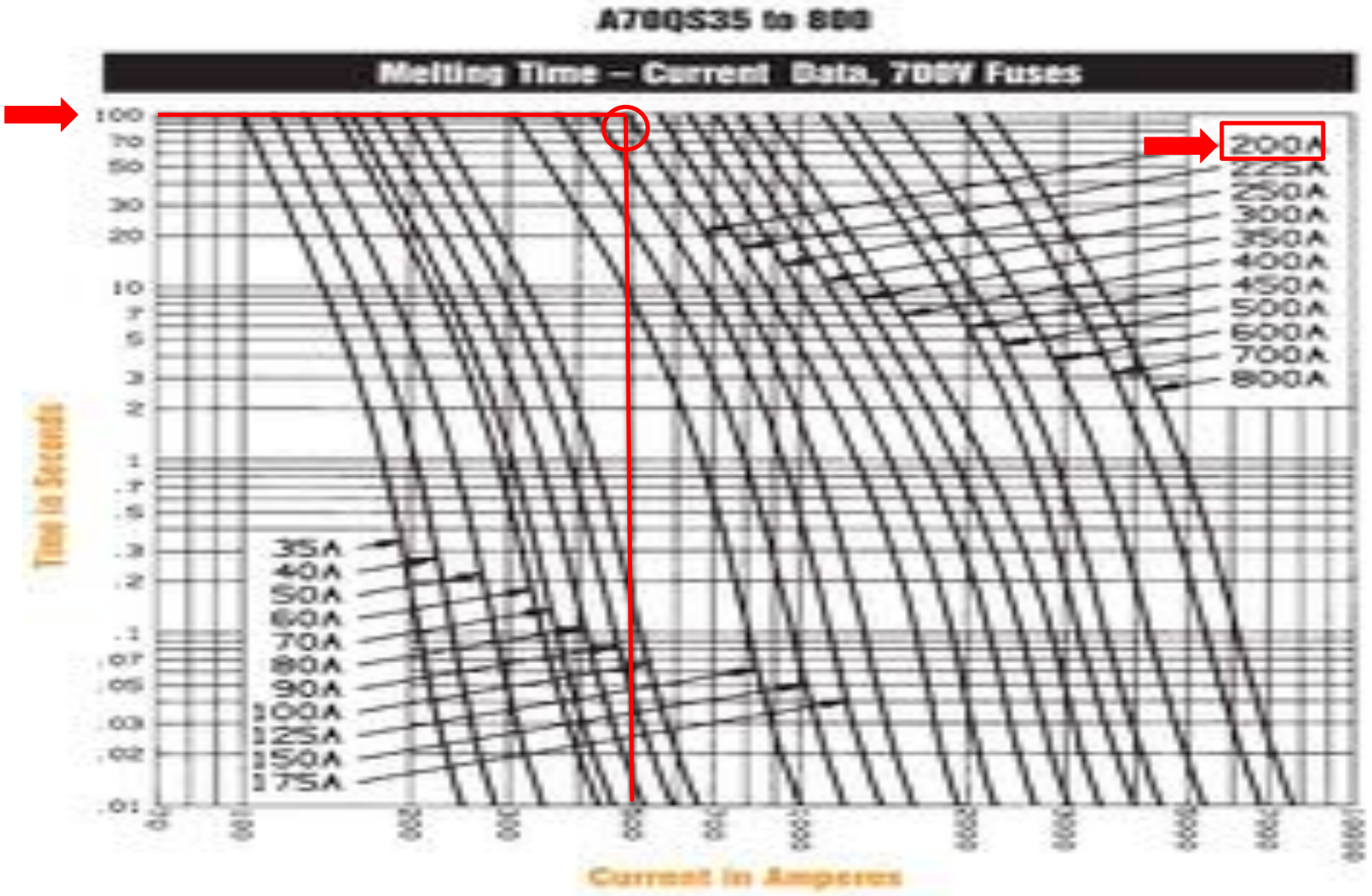
- Max V = 700 VDC
- Max i_{sc} = 100 kA
- I^2t = 16 kA^2s

Inverter (TPIM)

- i_{avg} = 150 A
- i_{peak} = 500 A
- Δt_{peak} = 30 sec

- 1.35 x 150 A ≈ 200 A sized fuse
- 700 VDC > 375 VDC
- Capacitive load = Time Delay fuse to prevent nuisance blows
- Short circuit (i_{sc}) << Max allowable i_{sc} of fuse

Peak Current Case

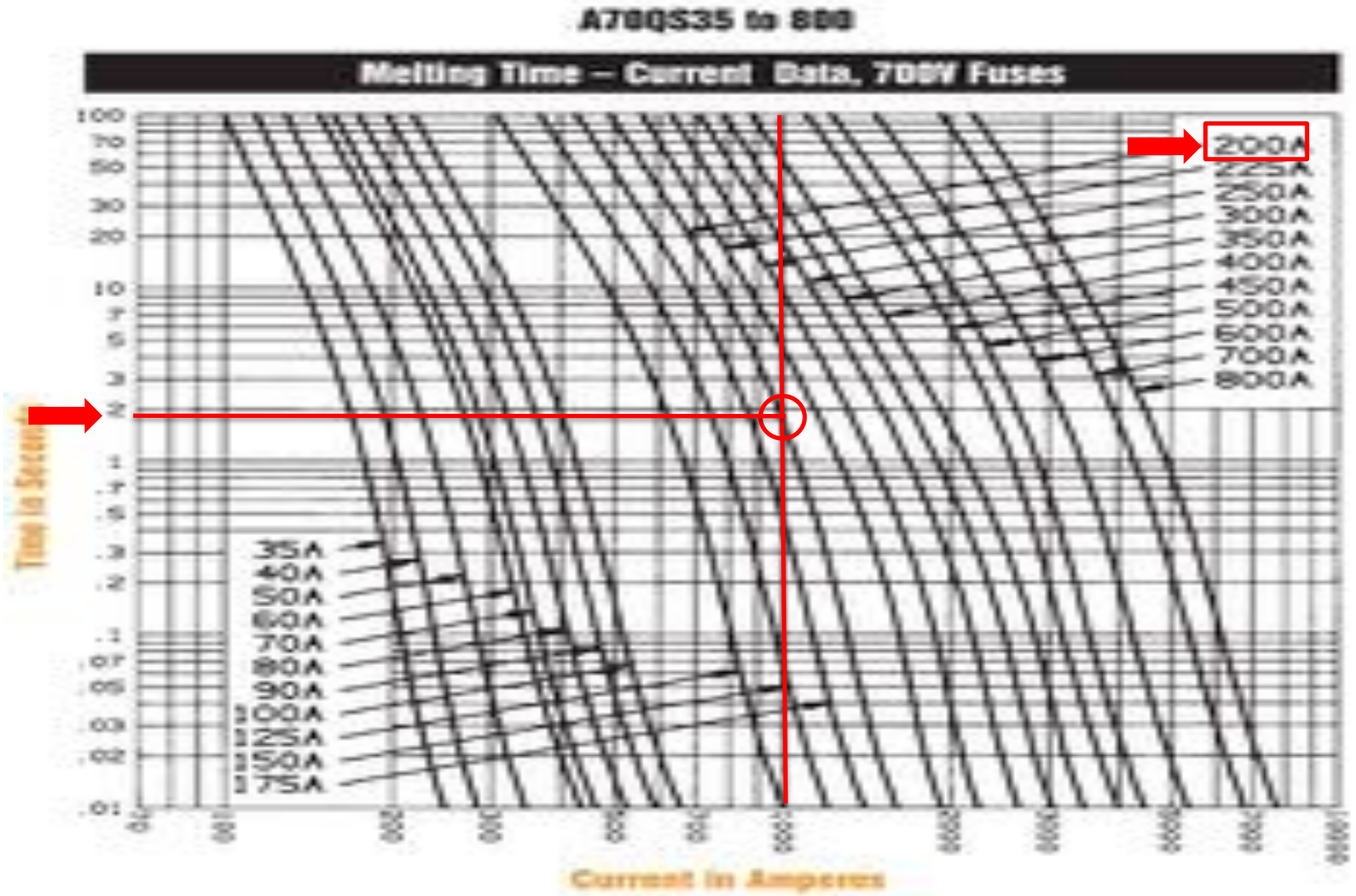


At our estimated peak the fuse wont blow for 100 seconds, preventing unwanted nuisance blows

Inverter (TPIM)

- i_{avg} = 150 A
- i_{peak} = 500 A
- Δt_{peak} = 30 sec

Extreme Current Case



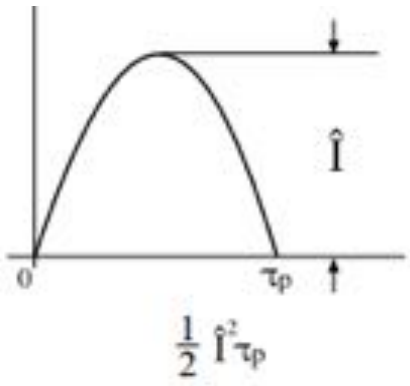
In the event of an overcurrent condition of 1 kA, our fuse will melt in under 2 seconds, preventing damage to the inverter

Still allows high current pulses to pass

I^2t Analysis

Inverter I^2t Analysis

- Energy escapes from the fuse as it melts
- Known as I^2t or fuse reaction time
- To prevent nuisance blowing due to transient pulses, ensure the following:



Inverter Pulse
- I = 1 kA
- τ = 10 ms

Transient Pulse I^2t < Max Fuse I^2t

5 kA^2t

16 kA^2t

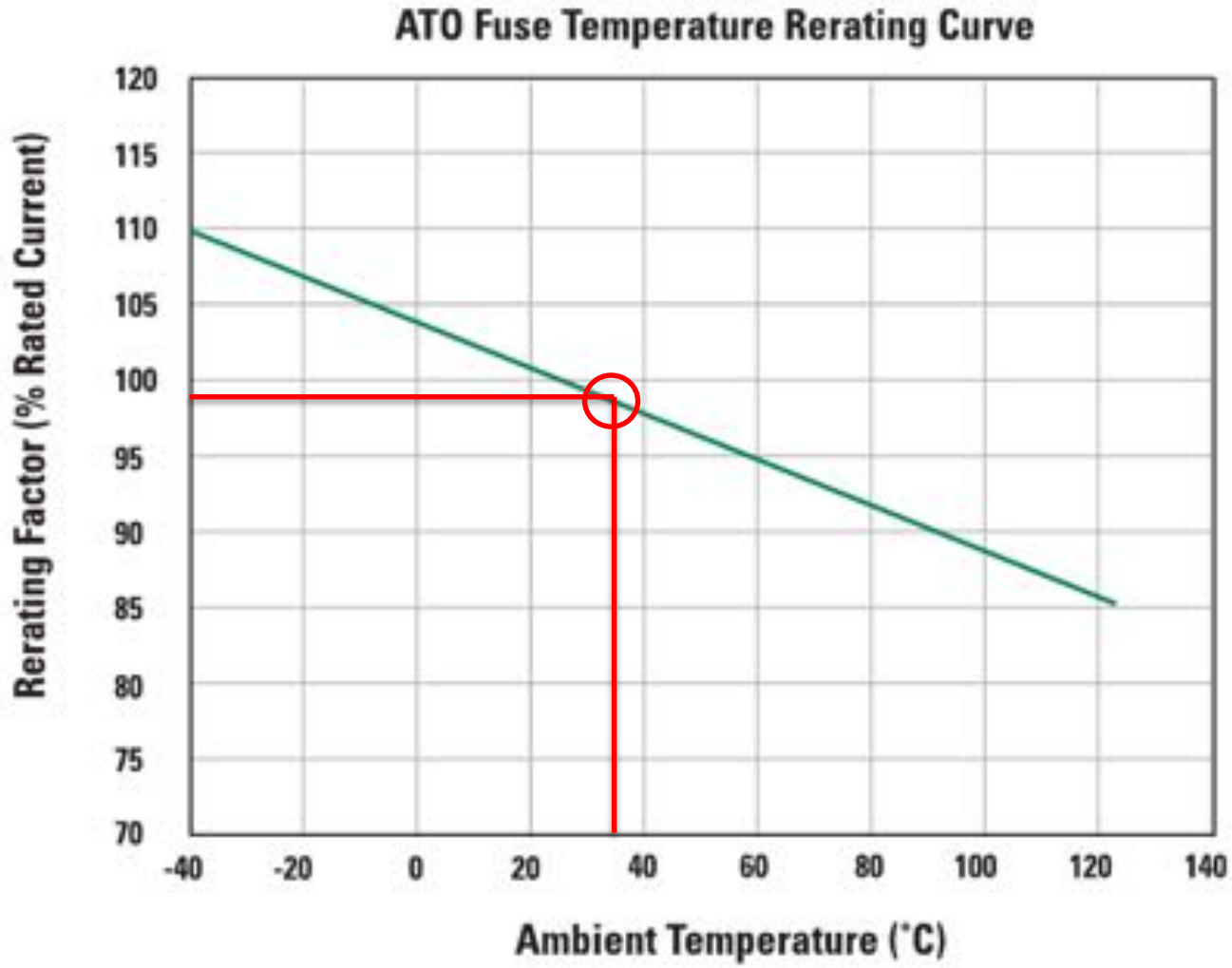
$1/2(1\ kA)^2(10\ ms) = 5000\ A^2s$

Under-Hood Derating

- Ambient hood temp after 103 mile EnEC event

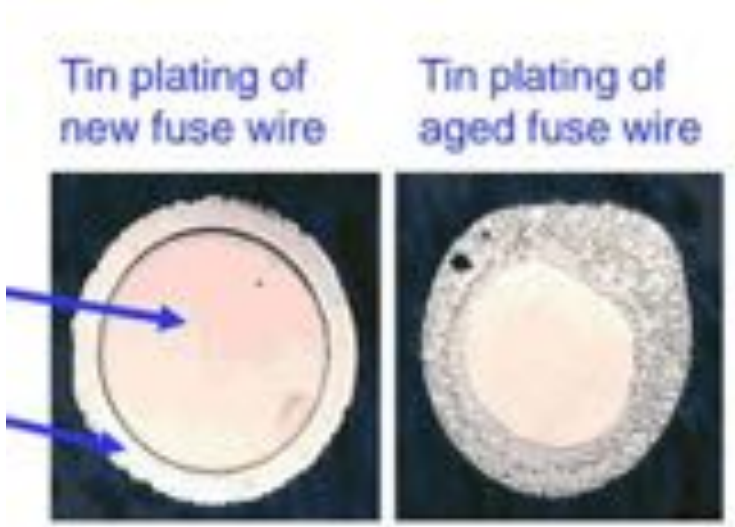
33° C

- < 2 % fuse derating at the measured temp
- Smaller effect on less sensitive fuses



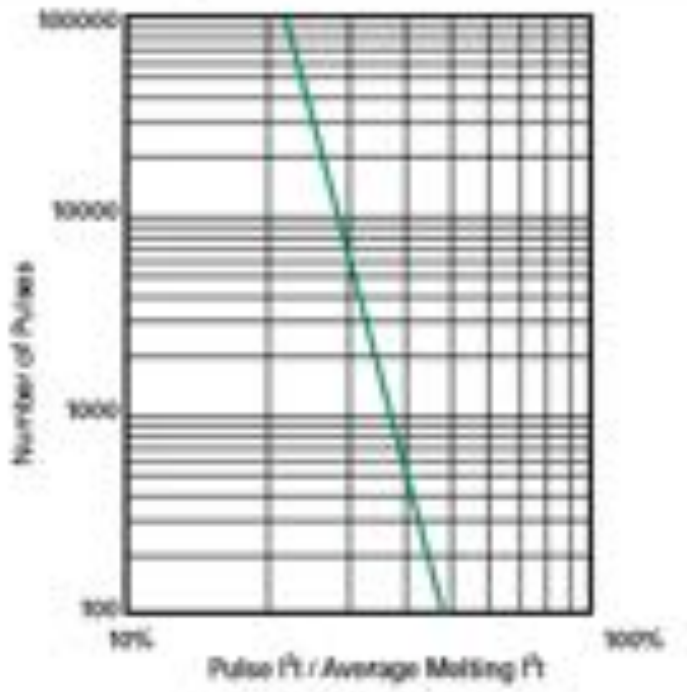
Life Cycle Analysis

Cycle life is found by calculating the ratio of the applied I^2t to the fuse's nominal melting I^2t, then looking at the table on the right



Each time a short overcurrent pulse flows through the fuse the element will heat up, and permanently change.
Enough pulses can cause failure

PULSE CYCLE WITHSTAND CAPABILITY	
100,000 Pulses	Pulse I²t = 22% of Nominal Melting I²t
10,000 Pulses	Pulse I²t = 29% of Nominal Melting I²t
1,000 Pulses	Pulse I²t = 38% of Nominal Melting I²t
100 Pulses	Pulse I²t = 48% of Nominal Melting I²t



Note: Adequate time (10 seconds) must exist between pulse events to allow heat from the previous event to dissipate.

HV Load Table

Component	Fuse Size (A)	Wire Gauge (AWG)	Max Wire Ampacity (A)	Nominal Current (A)	Estimated Peak Current (A)	Measured Peak Current (A)	Cycle Life
BRUSA (Charger)	15	10 Shielded	80	12.5	9.4	10	>1,000,000
TPIM (Rine)	200	1/0 Shielded	450	182*	500	425	>100,000
APM (DCDC)	8	10 Shielded	80	1.8*	10	7.8	>100,000
HVAC	25	8 Shielded	106	9	25	11	>1,000,000
ESS	350	1/0 Shielded	450	196*	350	402	>1,000,000

= at risk components

* indicates measured value

LV Load Table

Component	Fuse Size (A)	Wire Gauge (AWG)	Max Wire Ampacity (A)	Nominal Current (A)	Estimated Peak Current (A)	Measured Peak Current (A)	Cycle Life
ECM	50	10 (GM)	60	0.5	45		>100,000
APM	150	4 (GM)	200	9.4*	90	72	>100,000
MVEC 1*	**100**	**4**	**170**	**13**			>1,000,000
MABx	2	18	10	1			>1,000,000
TPIM2	5	18	10	2			>1,000,000
BCM	10	18	10	1.7	8	8	>1,000,000
Coolant Pump	10	16	30	5	15		>100,000
HVIL	5	18	10	0.6			>1,000,000
NOX	5	18	10	1.5			>1,000,000
NH3	5	18	10	1.2			>1,000,000
MVEC 2*	**100**	**4**	**170**	**25**			>1,000,000
Urea Injection	15	18	10	10			>1,000,000
NOX	5	18	10	1.5	22		>1,000,000
Fuel Pump	20	16	30	12			>100,000
ACCM	10	18	10	0.125			>1,000,000

= at risk components

*MVECs serve as a fuse/relay bus for the subsequent components
**All LV fuses are rated for temperatures from -40 to 125 degrees C

Load Accommodations and Efficiency

12 Volt Load and Accommodations

AGM Battery Specs		
Battery	CCA	Reserve (RC)
Group 35	620	100
AH	Initial Capacity	Min Engine Start Capacity
48	0.8	0.2

- **Increased current draw**
  - About 30 A total load added
- **Accommodations**
  - APM + Alternator
  - Upgraded 12 V battery

Efficiencies of 12 V System

- **Added Efficiencies**
  - 2 MVECs to reduce load
  - High Intensity Discharge Lamps
  - Improved controls algorithms

Cooling Pump Efficiencies

Test: Pump Speed vs High Voltage Current Draw Sweep

Target Result: Criteria 1: Maximum Battery Current (performance)

Target Result: Criteria 2: Minimum DC-DC current (energy use)

Motor Speed (rpm)	HV DC-DC current (Amps @ 350V)	Battery Pack Current (Amps @ 350V)
4500	2.50	1.51
4000	2.25	1.50
3500	2.10	1.50
3000	2.00	1.51
2500	1.95	1.53
2000	1.90	1.54
1500	1.83	1.52
1000	1.70	1.42
0	1.70	1.45

LV Parasitic Current

Parasitic Load

Component	Normal draw (mA)	Max draw (mA)
Anti-Theft	0	1
Auto Door Lock	1	1
Body Control Module	3.6	12.4
Central Processing System	1.6	2.7
Electronic Control Module	5.6	10
Electronic Level Control	2	3.3
Light Control Module	0.5	1
Oil Level Module	0.1	0.1
Powertrain Module	5	10
Retained Accessory Power	3.8	3.8
Radio	7	8
Coolant Pump	0.1	0.1
ACCM	0.3	0.3
HVIL	400	400
Total (mA):	30.6	453.7

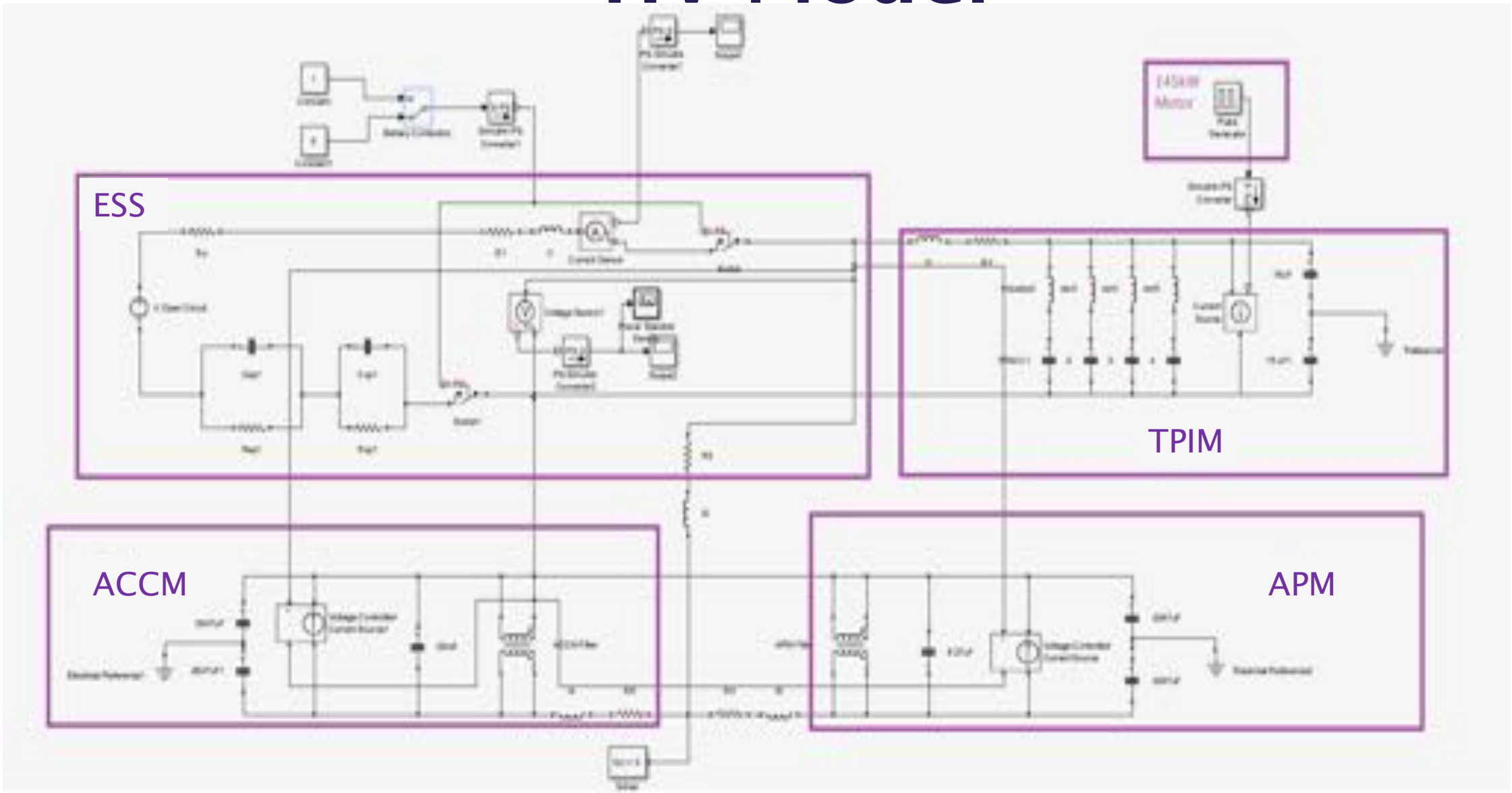
Battery Specs		
Battery	CCA	Reserve (RC)
Group 35	620	100
AH	Initial Capacity	Min Engine Start Capacity
48	0.8	0.2

HVIL Enabled		
Normal Time to drain battery (hr)	Min Time to drain battery (hr)	Min Time to drain battery (Weeks)
941.176	84.637	**0.504**

HVIL Disabled		
Normal Time to drain battery (hr)	Min Time to drain battery (hr)	Min Time to drain battery (Weeks)
941.176	715.084	**4.256**

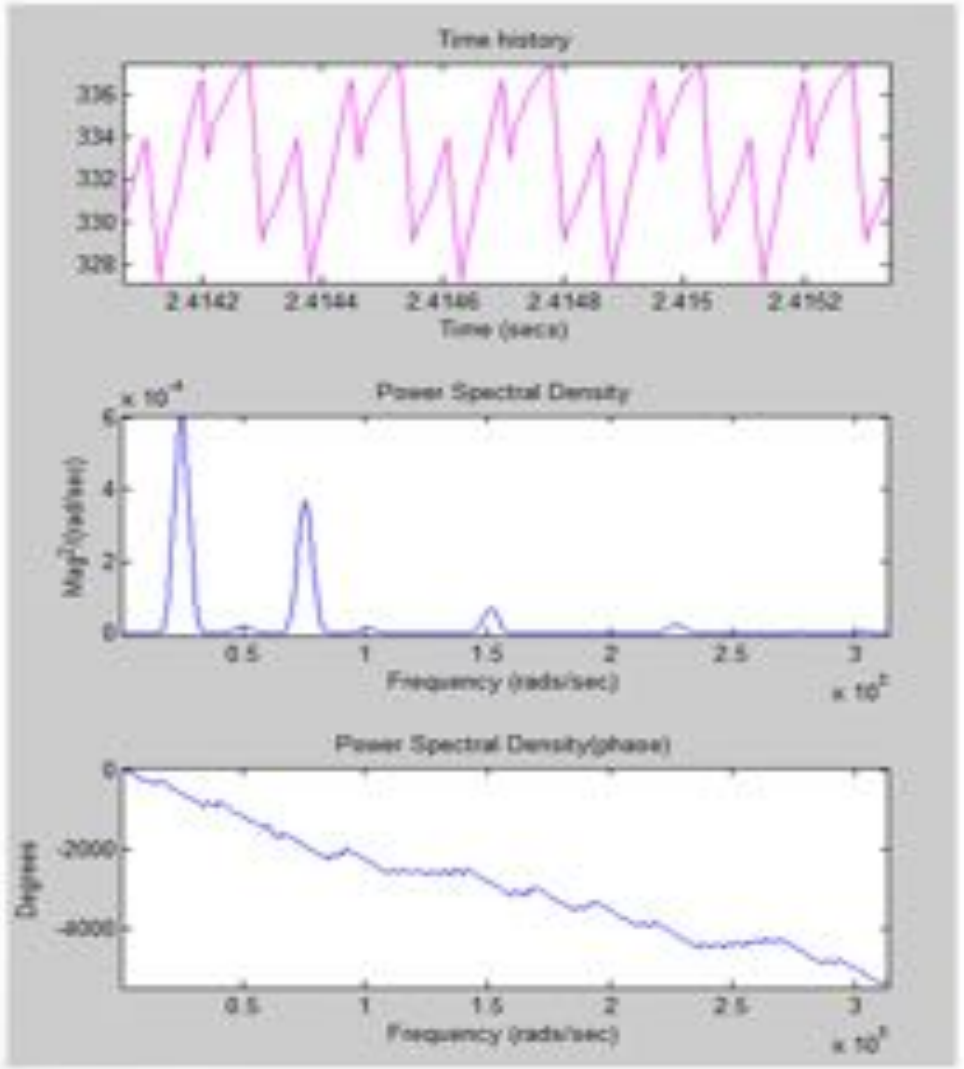
HV System Characteristics

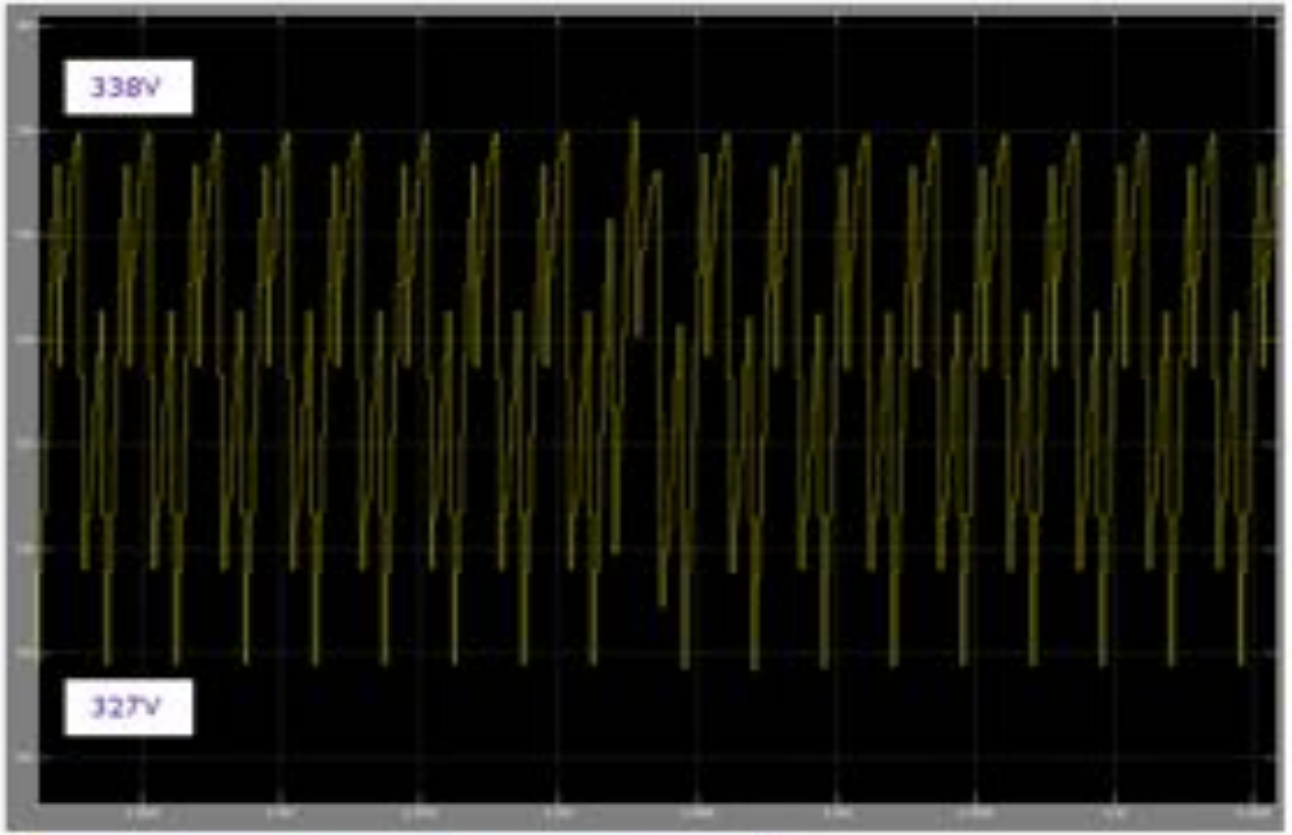
HV Model



HV Ripple Analysis

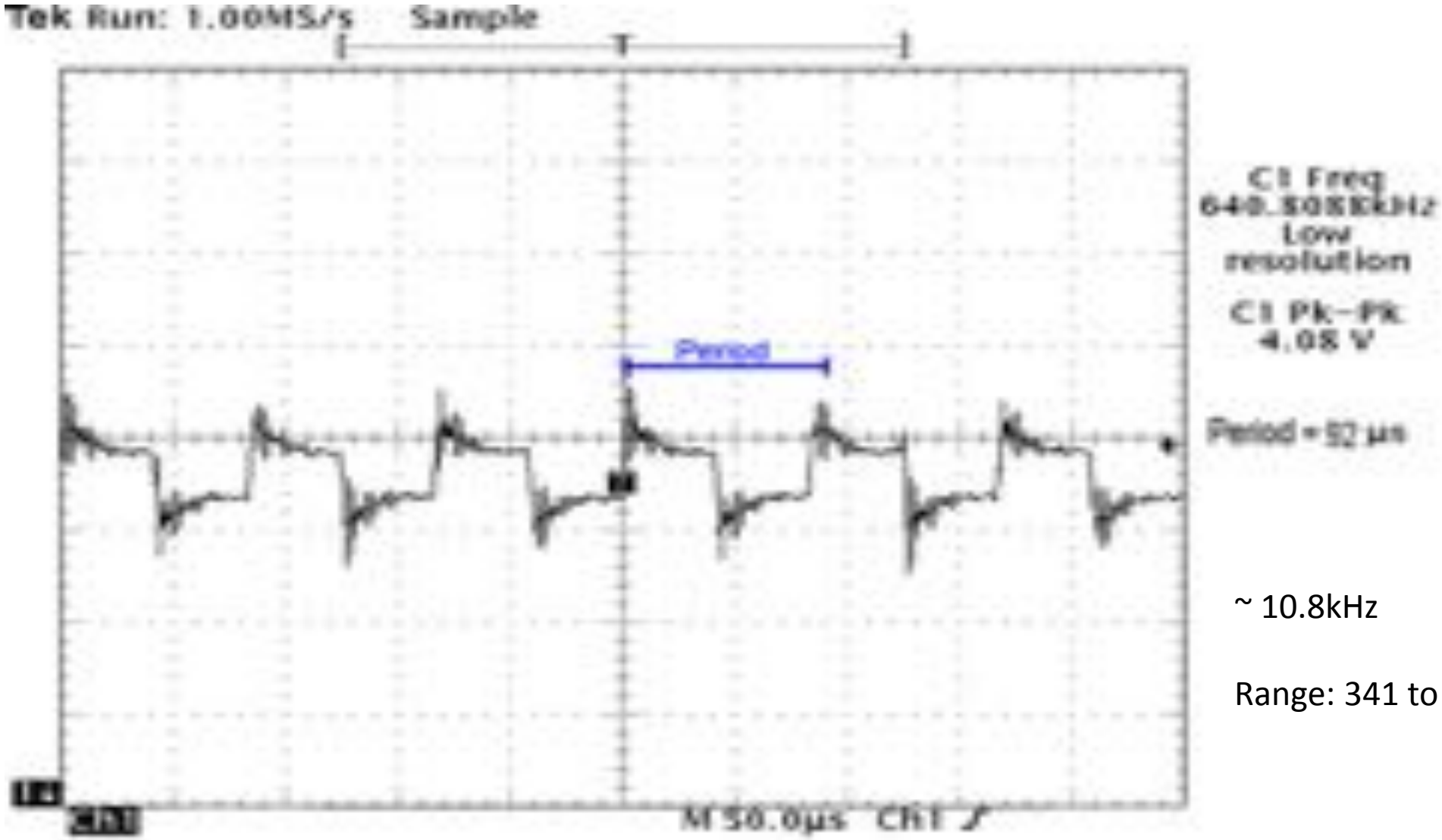
Simulation Results





Power Spectral Density	
Frequency (Rads/sec)	Frequency (htz)
25000	3978.876938
75000	11936.63081

In-Vehicle Results



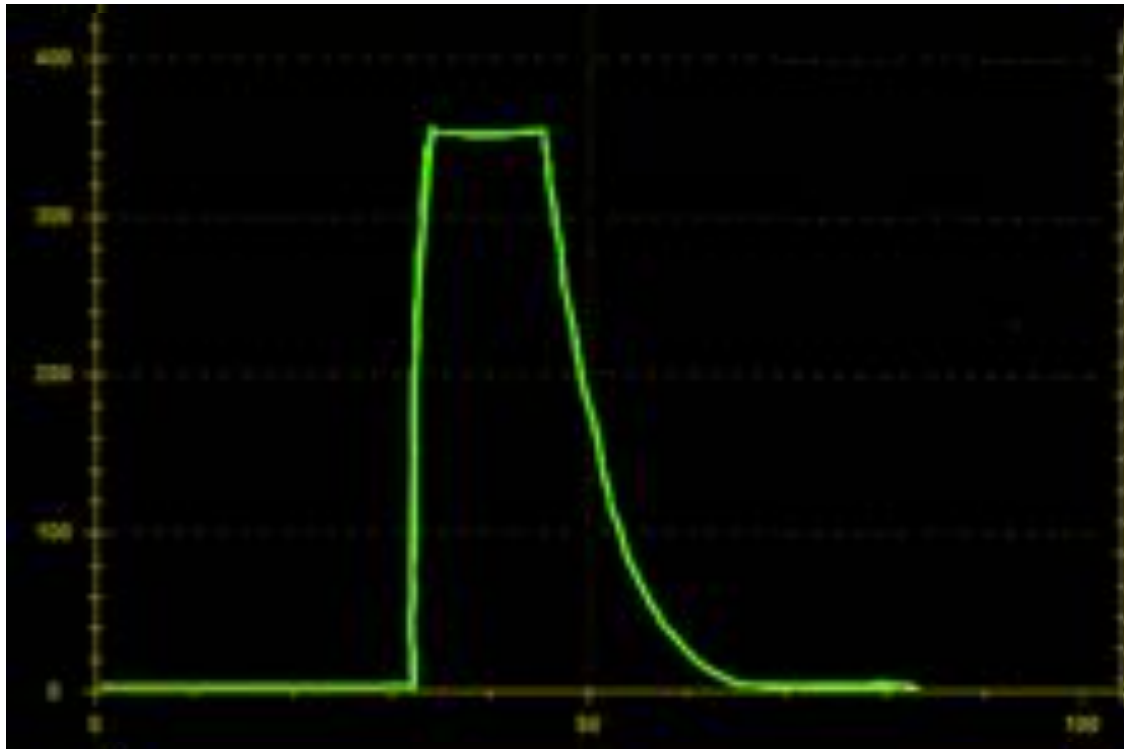
~ 10.8kHz

Range: 341 to 345 V

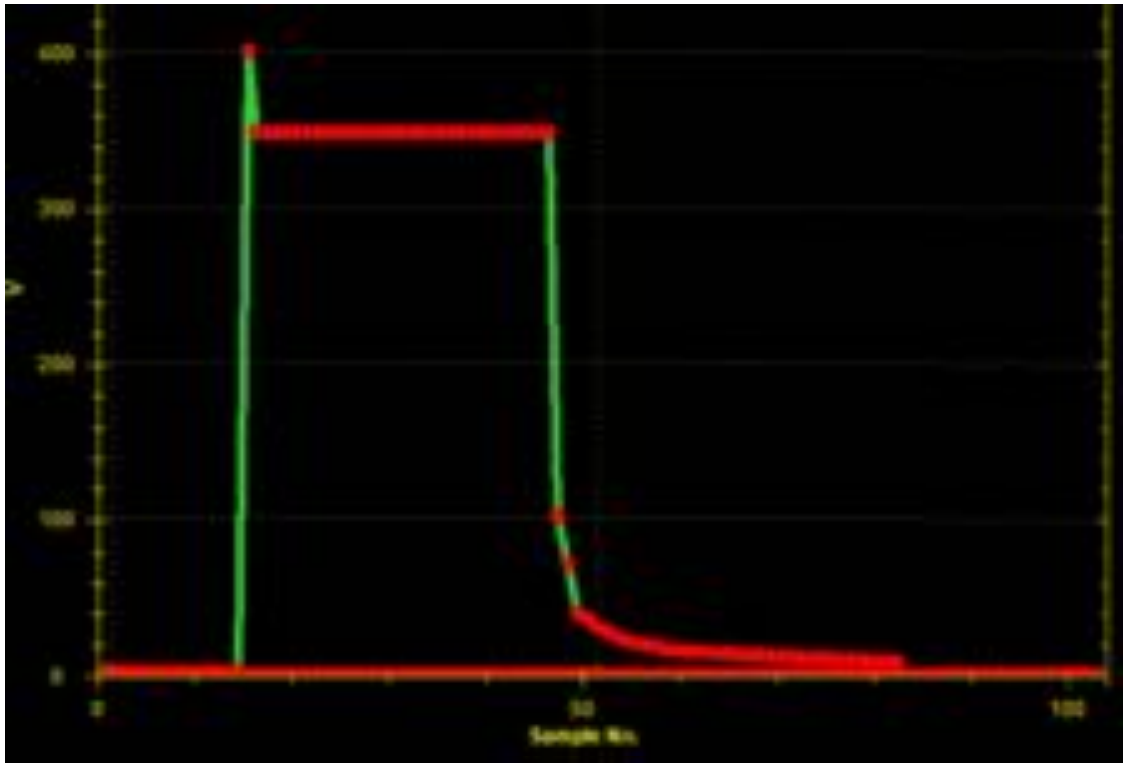
HV Bus Charge and Discharge

Charge and Discharge Results

Simulation

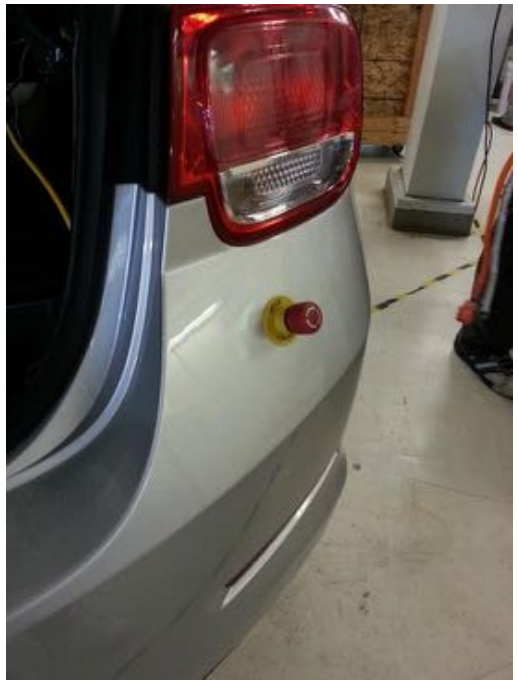


In-Vehicle Testing



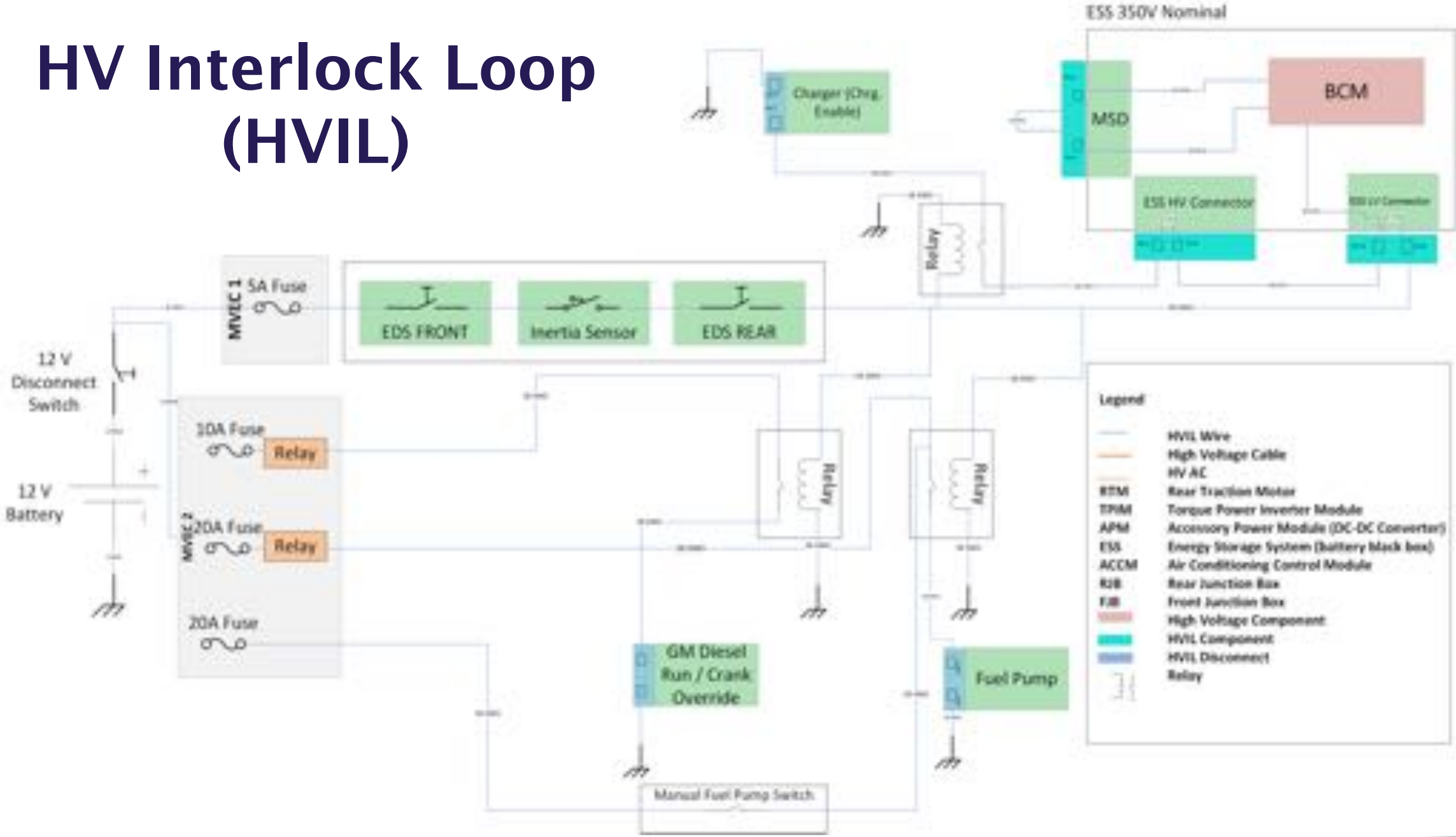
HV Safety and Serviceability

High Voltage Interlock Loop (HVIL)



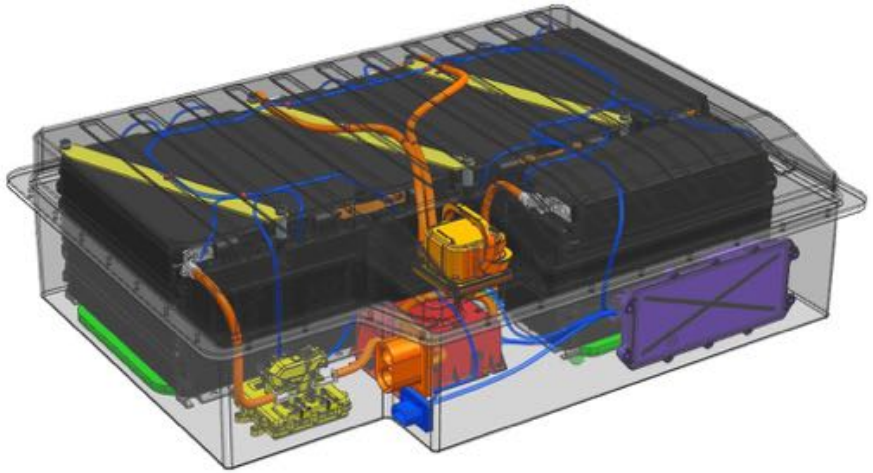
- **High voltage bus contactors are opened if:**
  - ✓ Either emergency stop switch is depressed
  - ✓ Inertial switch is triggered, i.e. in a crash (8 G's)
  - ✓ Loss of chassis ground reference or circuit isolation
  - ✓ 12V battery is disconnected
  - ✓ Severe under/overvoltage

HV Interlock Loop (HVIL)



ESS Safety

- Consolidated Pack
- 20 g lateral force
- Crush-resistant lid, easy to remove
- Catch Plate
- Lexan battery terminal covers
- HV bus bleed-down within 40 seconds
- Battery test connector



HV System Safety

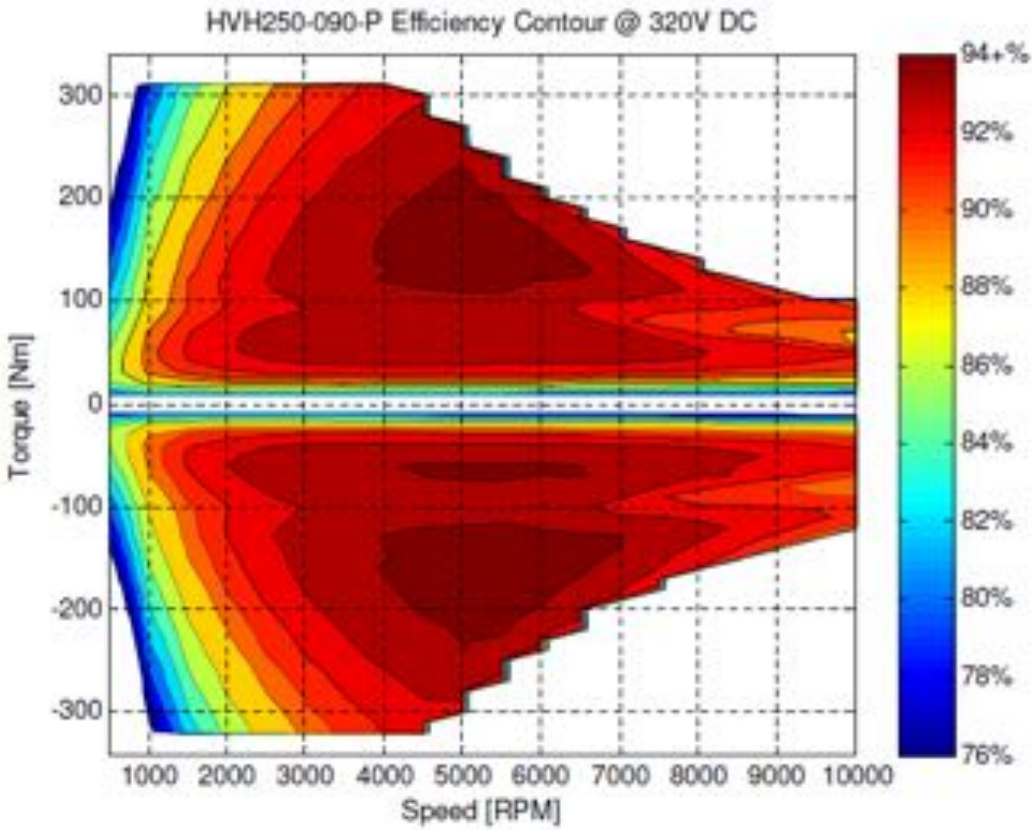
VTS

VTS

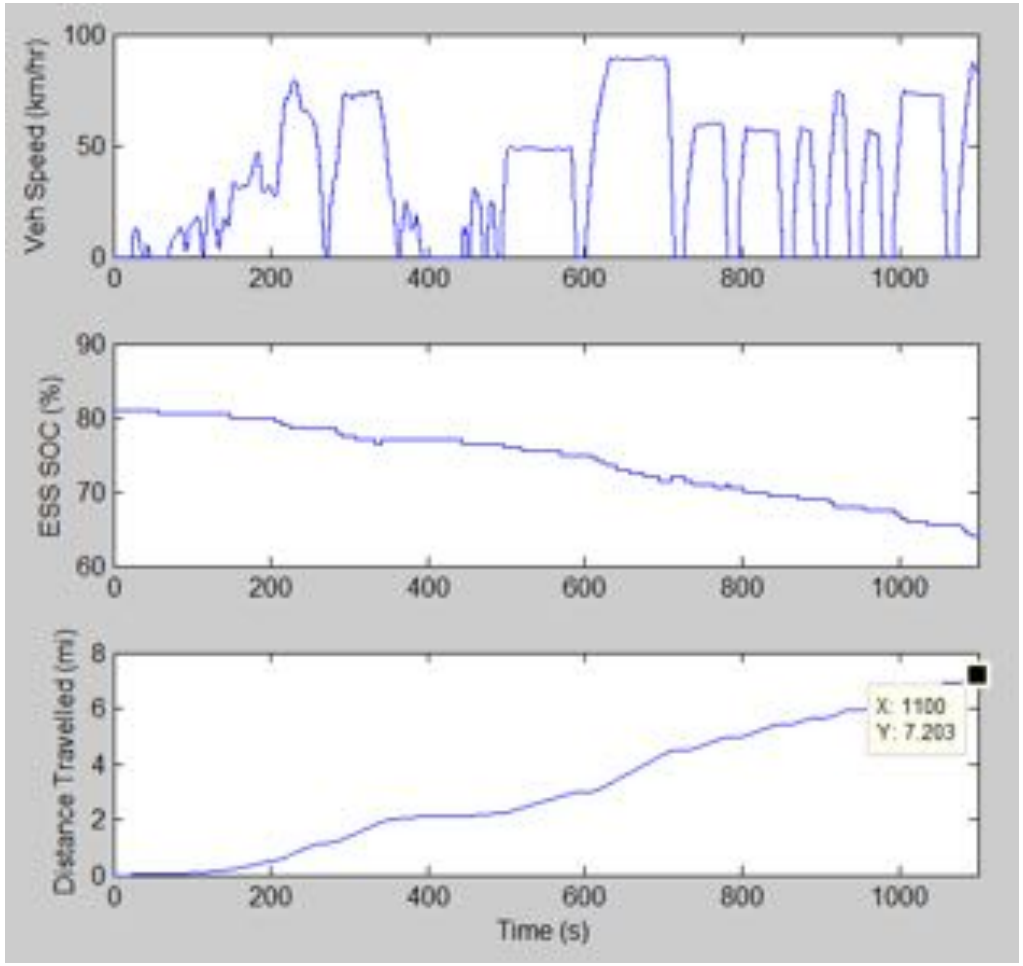
Specification	Production 2013 Malibu	Competition Target	Competition Requirement	UW EcoCAR2 VTS	UW EcoCAR2 Y3 Results	Percent Error*
Acceleration 0-60 mph	8.2 s	9.5 s	11.5 s	7	6.95	0.7%
Acceleration 50-70 mph (passing)	8.0 s	8.0 s	10.0 s	3.4	3.4	0.0%
Braking 60-0 mph	143.4 ft	143.4 ft (43.7 m)	180.0 ft (54.8 m)	143.4	130.88	9.6%
Highway Gradeability @ 20 min	10+% @ 60 mph	3.5% @ 60 mph	3.5% @ 60 mph	Pass	Pass	
Cargo Capacity	16.3 ft^3	16.3 ft^3	7 ft^3	Pass	Pass	
Passenger Capacity	5	>=4	2	5	2	
Mass	1589.6 kg	<2250 kg	<2250 kg	2160	2054	5.2%
Starting Time	<2 s	<2 s	<15 s	<2	P/F	
Ground Clearance	155 mm	155mm	>127 mm	pass	pass	
Vehicle Range	736 km	322 km [200 mi]	322 km [200 mi]	369 mi	tbd	
Charge-Depleting Range	N/A	N/A	N/A	47.6	47	-1.3%
Charge-Depleting Fuel Consumption	N/A	N/A	N/A	0		
Charge-Sustaining Fuel Consumption	787 Wh/km	N/A	N/A	619	tbd	
UF-Weighted Fuel Energy Consumption	787 Wh/km	634 Wh/km	N/A	215	tbd	
UF-Weighted AC Electric Energy Consumption	N/A	N/A	N/A	148	tbd	

*Percent error relative to original model

Motor and ESS Designs



CS Trigger (%)	EV Range (mi)
0	42.4
5	40.3
10	38.1
15	36.0
20	33.9



UW ECOCAR

Challenges

Challenges

- Space Claim / Packaging
- 12 V Loads
- Serviceability
- 99% production ready
- Troubleshooting
- Cooling
- DRBFM

UW ECOCAR

Knowledge Transfer

Methods of Knowledge Transfer

- Google Drive
- Customized team Wiki
- Lab fileserver
- Safety Binder
- Training sessions
- Lead training/dual leads
- Weekly meetings
- Recruiting young members
- Capstone projects

Questions?