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SIL, HIL, and Vehicle Fuel Economy Analysis of Pre-Transmission Parallel PHEV

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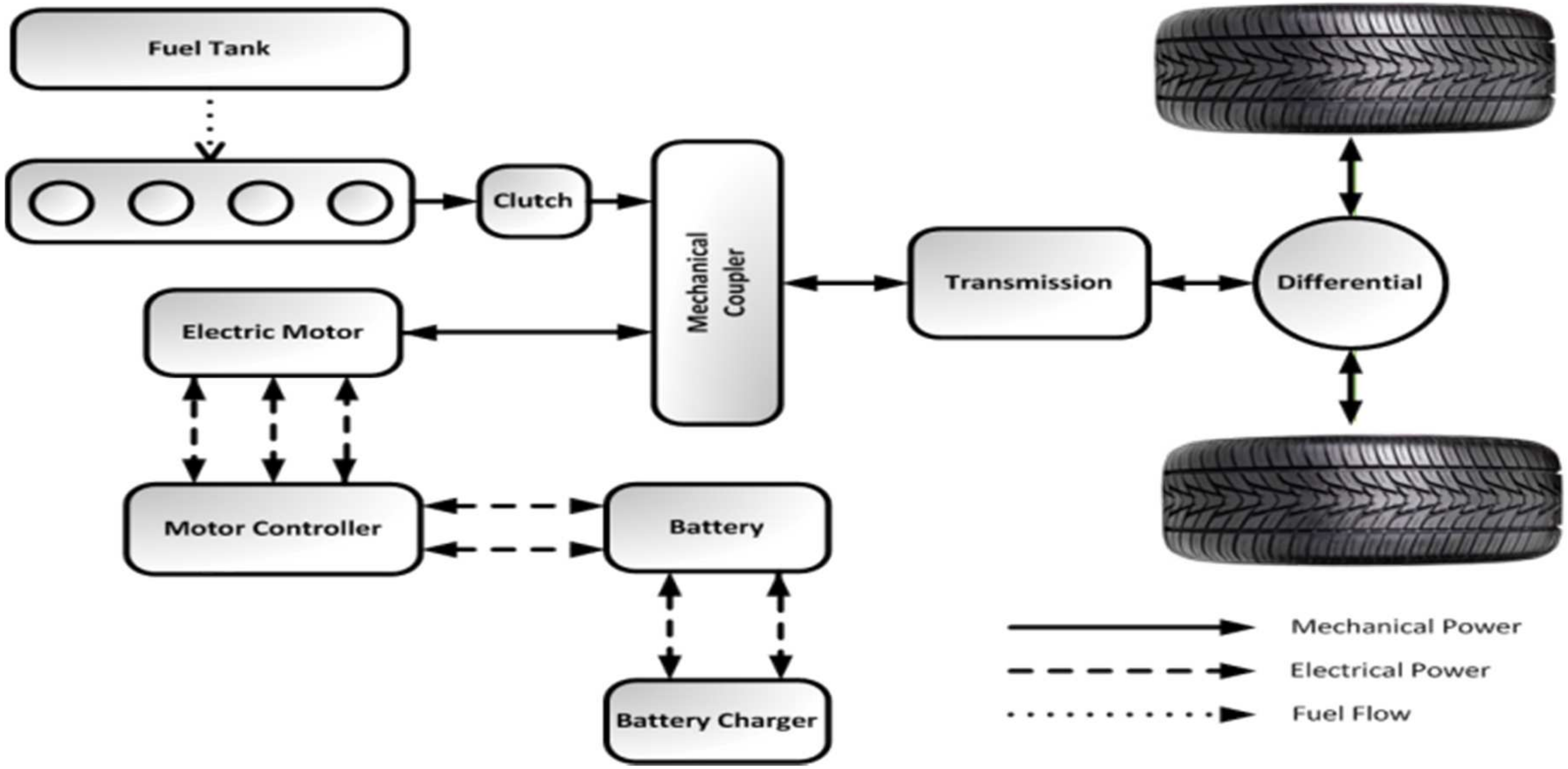
The Pre-Transmission Parallel PHEV



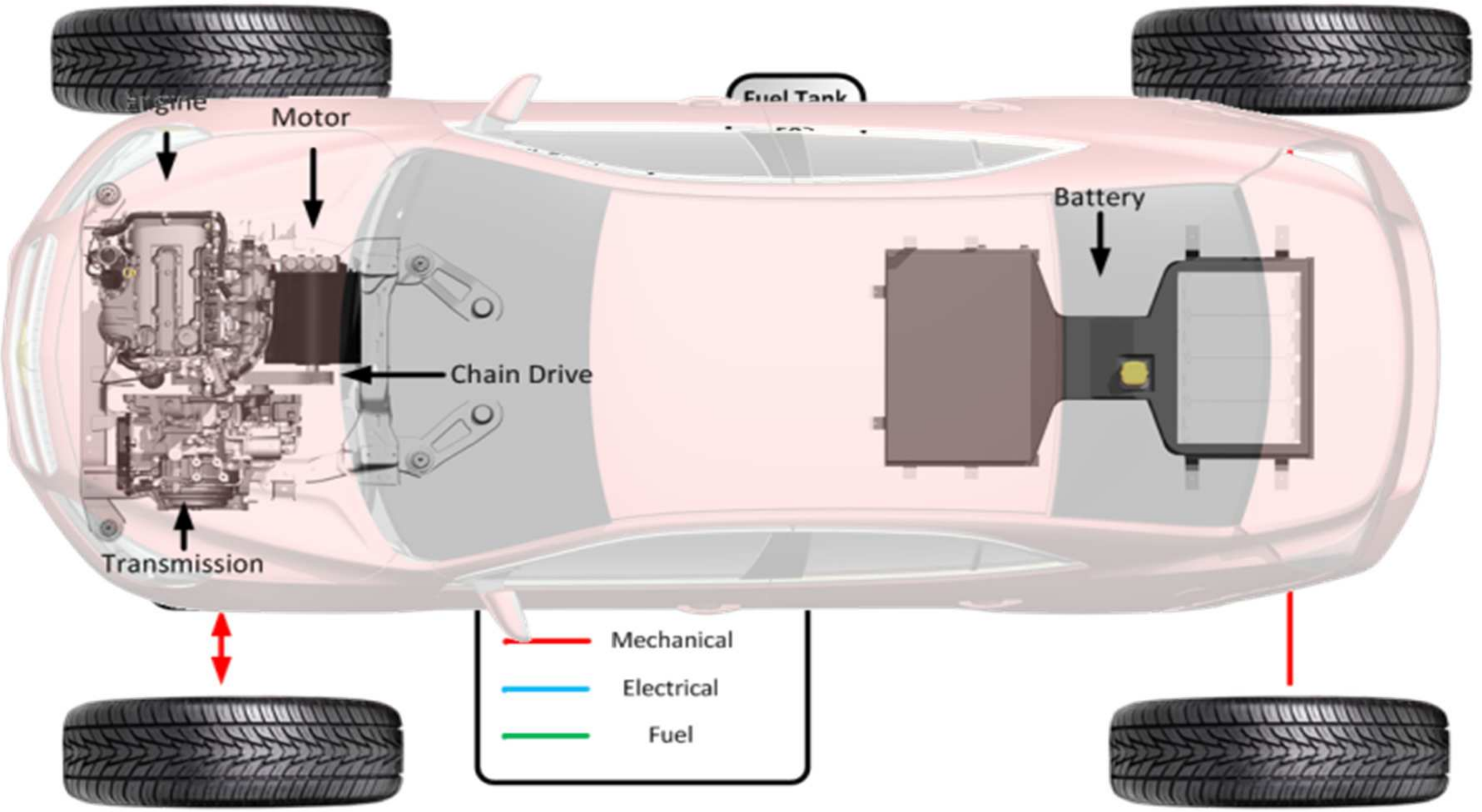
EcoCAR 2 Competition

- Redesign a stock GM vehicle as a hybrid
- IMPROVE efficiency and emissions
- MAINTAIN stock consumer features

Build a vehicle that achieves outstanding fuel economy and meets emissions standards, while maintaining or improving all other stock consumer features.

- Three-year competition, 15 Universities

The EcoCAR 2 Vehicle

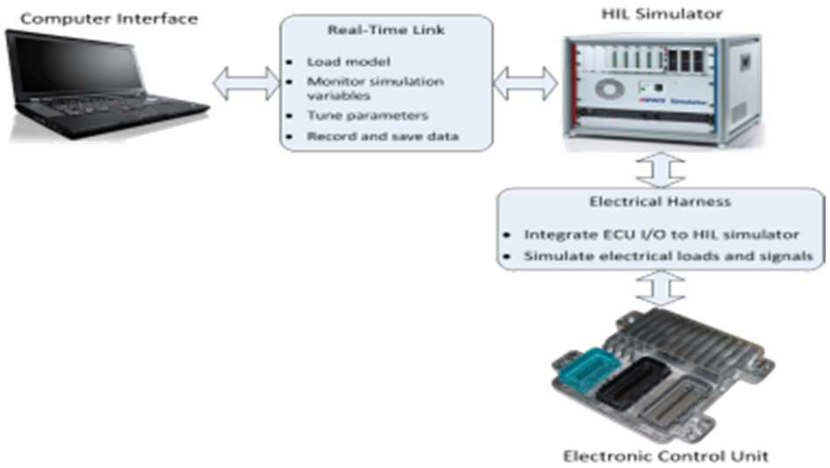


Vehicle Simulation

- Vehicle fuel consumption evaluated using:
  - Software-in-the-Loop (SIL) simulation
  - Hardware-in-the-Loop (HIL) simulation

- SIL simulation
  - Performed using a PC
  - No physical vehicle components required
  - Mathematical models represent vehicle components and dynamics
  - Matlab Simulink software

Hardware-in-the-Loop (HIL) Simulation



- Expands upon the capabilities of SIL simulation
  - Physical Input and Output (I/O)
  - Digital communication
    - Controller Area Network (CAN)
  - Provide inductive, capacitive, or resistive loads
- Real time simulation
- Reconfigurable hardware
  - Can be scaled to suit a variety of different requirements
  - Single or multiple processors

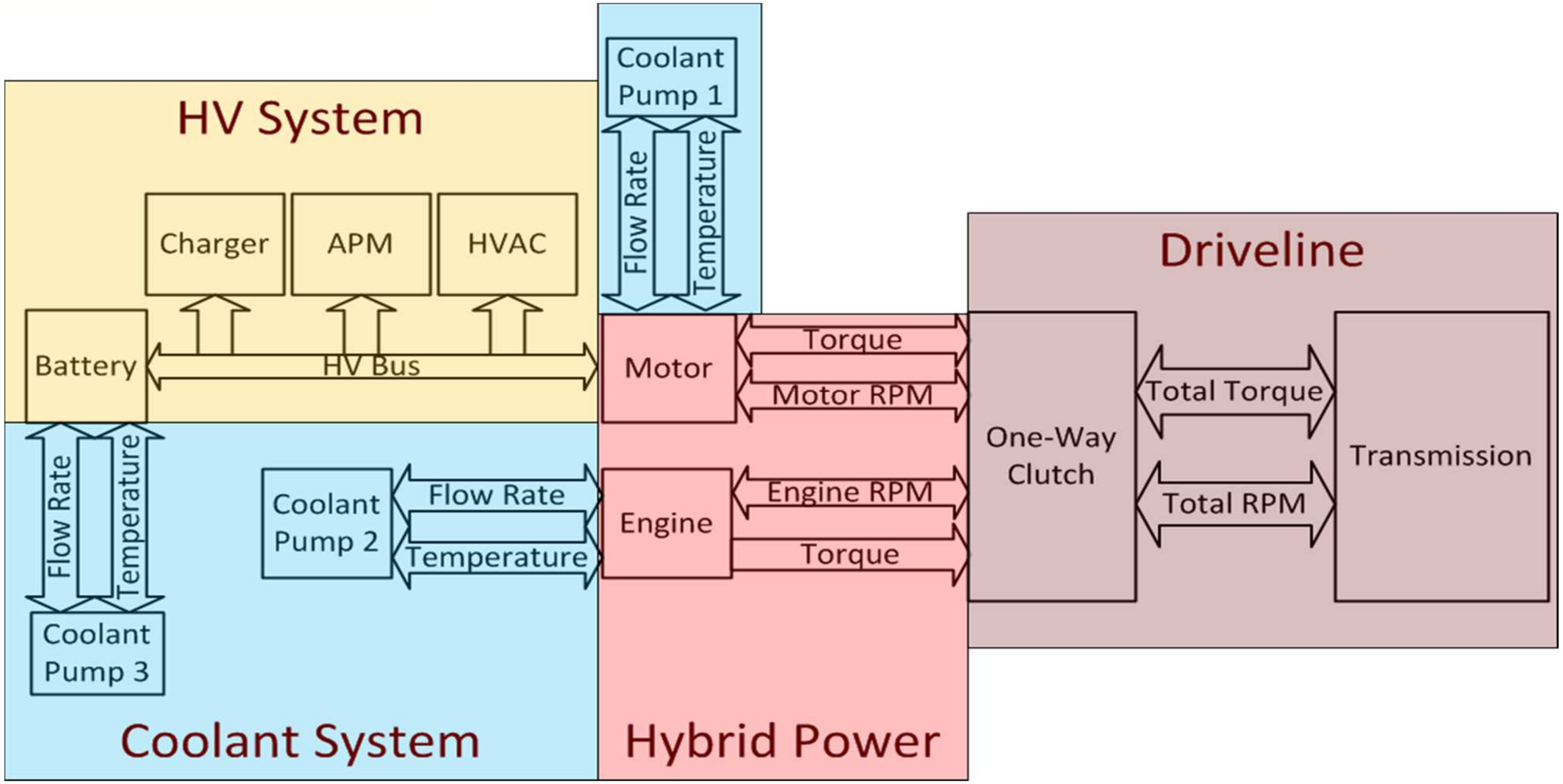
Vehicle and Component Modeling

- Accurate models are required to obtain accurate simulation results
  - Produce behavior representative of vehicle's anticipated response
  - Component physical characteristics
  - Component ECU behavior
- Combination of models from two sources
  - dSPACE Automotive Simulation Models (ASM)
  - MSU developed component models

Vehicle and Component Modeling Cont.

- ASM Models
  - Developed by dSPACE for a variety of common automotive systems
  - Engine, Battery, driveline, and vehicle dynamics
- MSU Models
  - Developed as part of the EcoCAR 2 competition
  - Electric motor, auxiliary power module (APM), battery charger, and coolant system

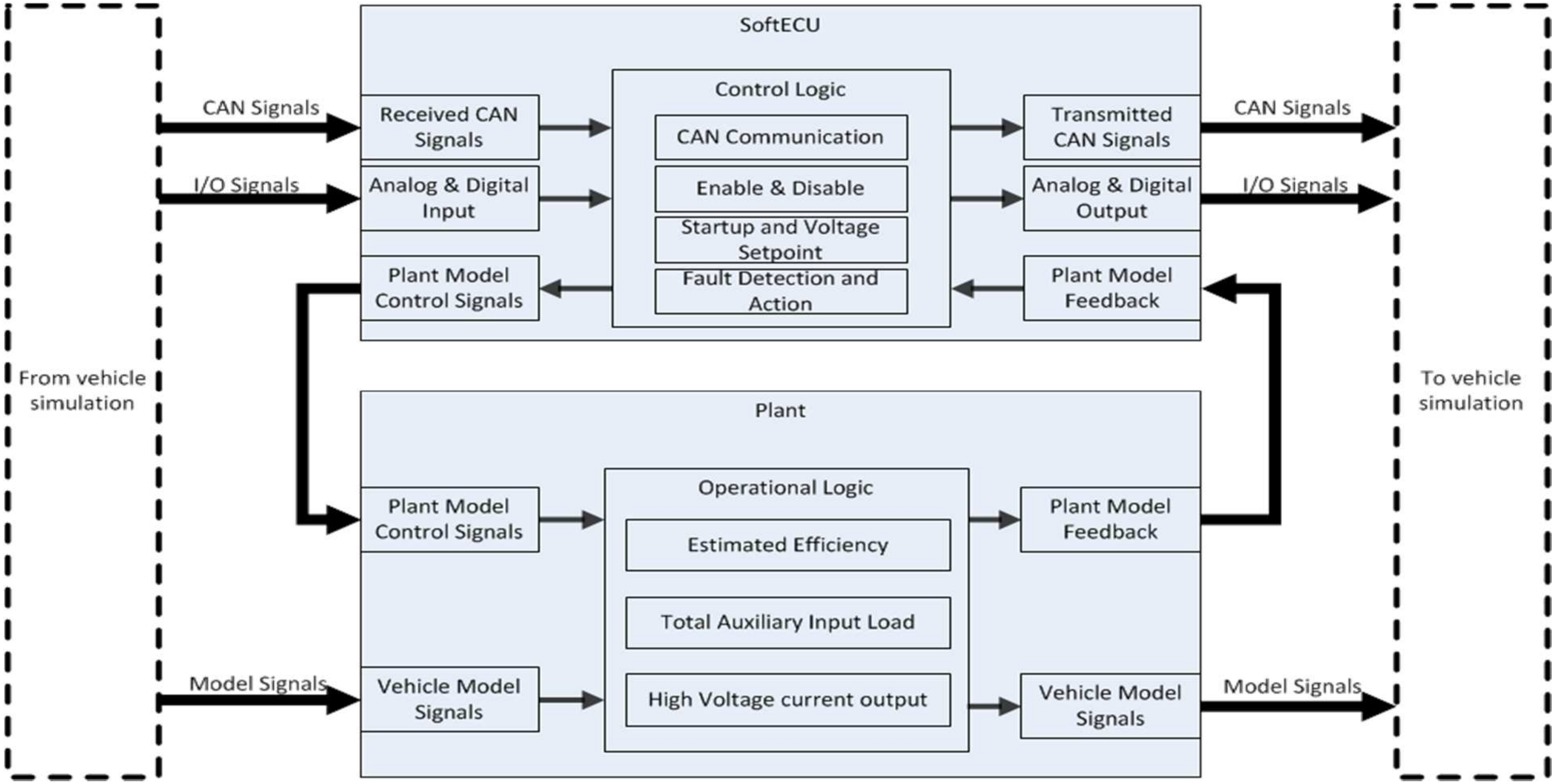
Vehicle and Component Modeling Cont.



Vehicle and Component Modeling Cont.

- Models separated into two sub-models
  - Plant model
  - Software electronic control unit (SoftECU)
- Plant models simulates the components physical characteristics
  - Engine torque and engine speed output
- SoftECUs simulate the components controller
  - Engine control module (ECM) fuel injector timing
  - ECM CAN communication

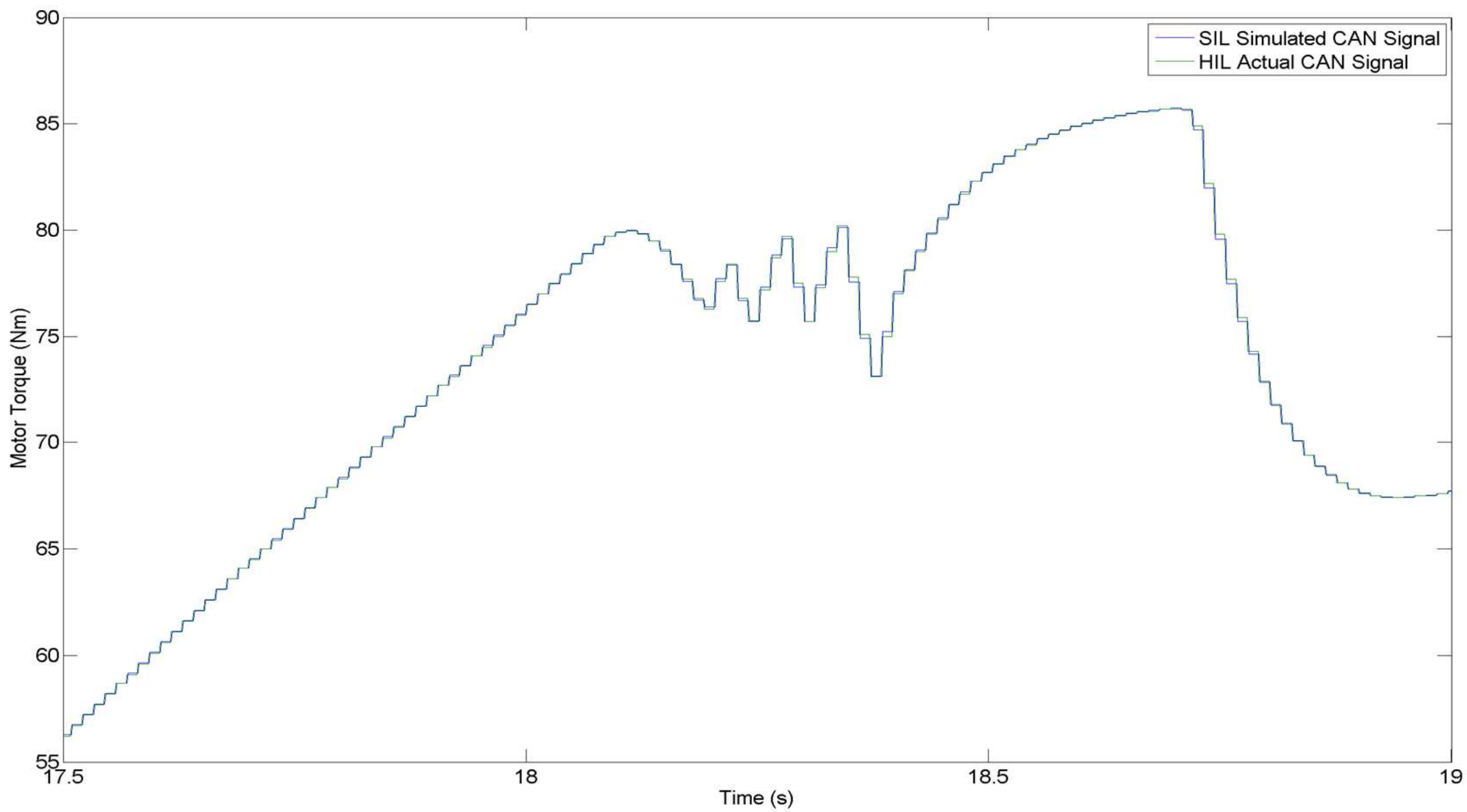
APM Model Overview



CAN Latency Simulation

- Some CAN messages transmitted periodically at a cyclic rate
  - Latency present in hardware in vehicle and on HIL simulator
  - Control algorithms may behave differently in SIL simulation than on hardware if this latency is not simulated
  - Developed vehicle model includes CAN latency simulation which replicates latency experienced on real hardware

CAN Latency Simulation Cont.



SIL Simulation Results

- Vehicle evaluation using SIL and 4 drive cycles:
  - HWFET
  - UDDS 505
  - US06 City
  - US06 Highway
- Charge Depletion (CD) and Charge Sustain (CS) results combined using method described in SAE Standard J1711

Drive Cycle Results		
Drive Cycle	CD Energy Consumption (Wh/km)	CS Fuel Consumption (L/100km)
HWFET	188.0	7.20
UDDS 505	238.1	8.73
US06 City	433.1	10.94
US06 Highway	218.3	7.47

Fuel Consumption Results			
CD Range (km)	Utility Factor	UF Fuel Consumption (L/100km)	UF Fuel Consumption (Lge/100km)
67.9	0.667	5.43	3.82

HIL Simulation Results

- HIL simulation results comparable to those obtained in SIL simulation

Drive Cycle Results		
Drive Cycle	CD Energy Consumption (Wh/km)	CS Fuel Consumption (L/100km)
HWFET	187.0	7.20
UDDS 505	238.9	9.33
US06 City	422.7	11.83
US06 Highway	220.4	7.43

Fuel Consumption Results			
CD Range (km)	Utility Factor	UF Fuel Consumption (L/100km)	UF Fuel Consumption (Lge/100km)
68.0	0.668	5.51	3.88

Conclusion

- SIL and HIL evaluation of a pre-transmission parallel PHEV
  - Combination of plant models and software ECUs to replicate vehicle dynamics and functionality
  - SIL simulation results match those obtained from HIL simulation
  - Vehicle evaluation currently being performed using a chassis dynamometer to validate SIL and HIL results

Questions?