DEPARTMENT OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY

POLYTECHNIC SCHOOL OF BASIC SCIENCES

MASTER'S IN AUTOMATION AND ROBOTICS ENGINEERING

THROTTLE BODY MODEL IN A HARDWARE-IN-THE-LOOP SYSTEM

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Outline

Hardware-in-the-Loop (HiL)

- Standard automotive validation practice.
- **Setup:** Bosch ECU connected to a real-time simulator (dSPACE).

Software Toolchain:

- **Configuration Desk:** Hardware mapping.
- **Control Desk:** User Interface/Dashboard.
- **INCA & CDA:** Calibration & Diagnostics.
- **Vector Tools:** CAN Bus monitoring.

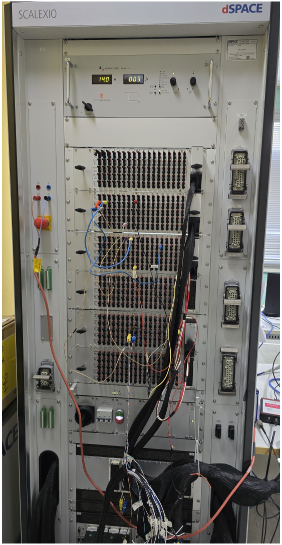


Figure: dSPACE Scalexio Rack

The Engine Control Module (ECM)

Device Overview:

- **Unit:** Bosch Engine Control Module utilized in the HiL setup.
- **Role:** Manages the air intake system by regulating the electronic throttle valve.

Control Strategy:

- **Actuation:** Drives the DC motor via an H-Bridge using two PWM signals ($Motor+$, $Motor-$).
- **Feedback Loop:** Continuously reads position from dual sensors (TPS1 & TPS2) to ensure precise tracking.

Safety & Diagnostics:

- Monitors for deviations between command and position.
- Manages the critical *Learning Phase* at startup.
- Triggers "Limp-Home" mode if faults (DTCs) are detected.

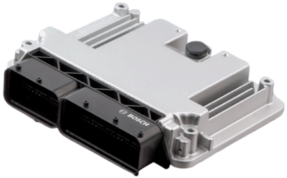


Figure: Bosch ECM

DS2680 & DS2671 Boards

The **DS2680 I/O Unit** is a MultiCompact I/O unit for the SCALEXIO system that provides all the I/O channels required for the hardware-in-the-loop simulation.

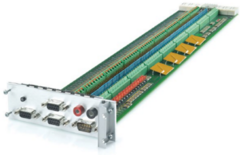


Figure: DS2680 Board Unit

Figure: DS2671 Board Unit

The **DS2671 Bus Board** is the interface between a SCALEXIO system and various bus systems. It has 4 multifunctional channels, each of which can support a bus system that is assigned to it by software.

Hardware Core: DS2680 I/O Unit

The **DS2680 Unit** is the main Board in Scalexio dSpace Simulator.

I/O Interfaces & Features

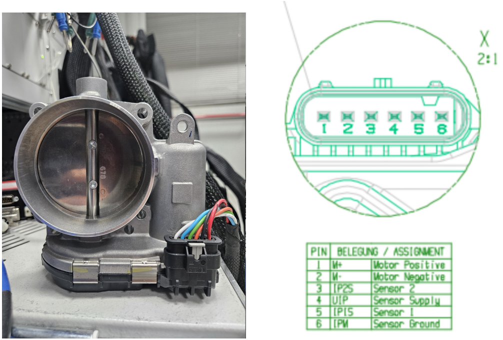
- **Analog I/O:** High-precision channels for sensors (Pressure, Pedal, 5V feed).
- **Digital I/O:** For PWM generation and measurement (Motor commands).
- **Resistance Channels:** Simulation of Resistance Sensors Signals (Ex: Temp Sensors).
- **Flexible Channels:** High-speed I/O measurement and generation (Current Signals).
- **Angular Simulation Channels:** Dedicated hardware for generating complex, angle-synchronous crankshaft and camshaft signals.
- **Failure Insertion Unit (FIU):**
  - Parametric capability to inject electrical faults.
  - Supported faults: *Open Circuit, Short to GND, Short to Battery*.

Electronic Throttle Control (ETC):

- Regulates airflow into the intake manifold.
- **Actuator:** DC Motor (H-Bridge driven).
- **Sensors:** Dual Potentiometers (TPS1 & TPS2) for redundancy.

Pinout (6 Wires):

1. Motor PWM Command Plus (+)
2. Motor PWM Command Minus (-)
3. Throttle Position Sensor 2 Signal
4. 5V Supply
5. Throttle Position Sensor 1 Signal
6. Sensor Signal Ground



PIN	BELEGUNG / ASSIGNMENT	
1	M+	Motor Positive
2	M-	Motor Negative
3	IP2S	Sensor 2
4	UIP	Sensor Supply
5	IP1S	Sensor 1
6	IPM	Sensor Ground

Figure: Real Component & Pinout

Motivation: Why Simulate?

- **Durability:** Avoiding mechanical failure (gears/springs) during intensive testing.
- **Repeatability:** Removing variations due to temperature/aging.
- **Flexibility:** Enabling simulation of "Ice Blockage" or specific end-stops.

Modeling Challenges:

- **Non-linear Dynamics:** Stick-slip friction and non-linear spring return.
- **ECM Diagnostics:** ECU triggers *Limp-Home* if Position $\neq$ Command.
- **Parameters:** Need for specific calibration (End-stops, Rise time).

Precise mapping between the ECU (Bosch) and Simulator (dSPACE).

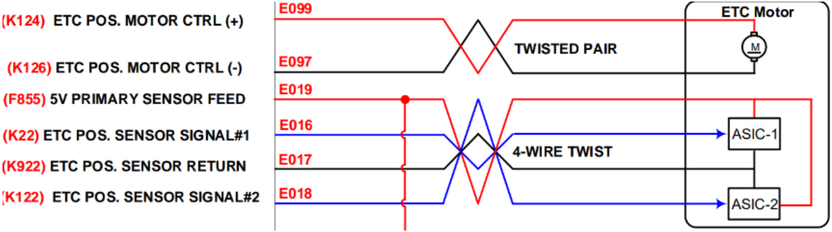


Figure: Electrical Schematic Overview

Mapping Strategy:

- **TPS 1 & 2:** Configured as *Analog Outputs* (with FIU enabled).
- **Motor +/-:** Configured as *Digital Inputs* to capture PWM Duty Cycle.
- **5V Feed:** *Analog Input* to monitor ECU reference.

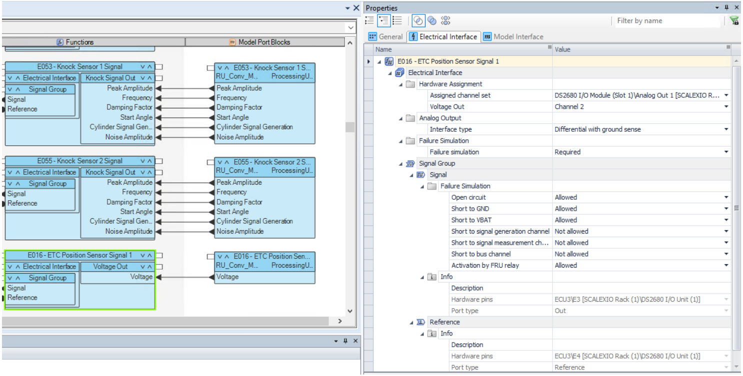


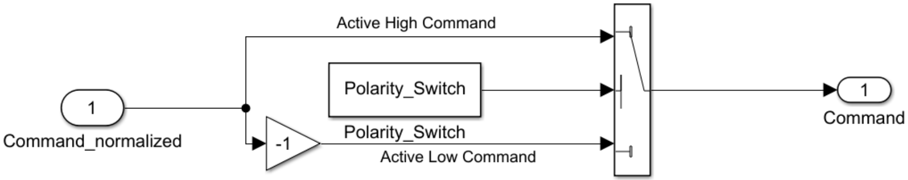
Figure: Configuration Desk Interface

Input Signal Processing

Processing the raw PWM from H-Bridge to a normalized command.

$$u(t) = \frac{DC_{+}(t) - DC_{-}(t)}{100} \cdot \text{PolaritySwitch} \quad (1)$$

- **Normalization:** Conversion to range $[-1, 1]$.
- **Polarity Switch:**
  - Value $= 1$: Normally Closed (Gasoline).
  - Value $= -1$: Normally Open (Diesel).
- Allows universal model application.



Approach: Modified First-Order Filter with Feedback.

$$\dot{y}(t) = \frac{1}{\tau} \cdot [K \cdot u(t) - K_{fb} \cdot y(t)] \tag{2}$$

The ECM controller is robust enough to handle this simplification over a full 2nd order mass-spring-damper.

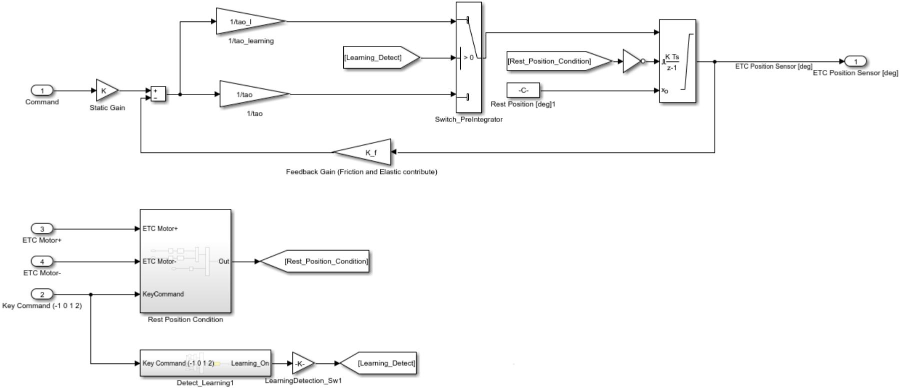
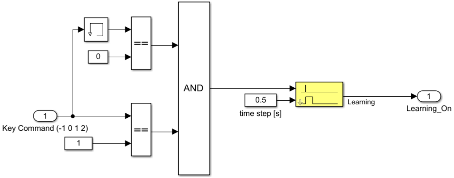


Figure: First Order Filter

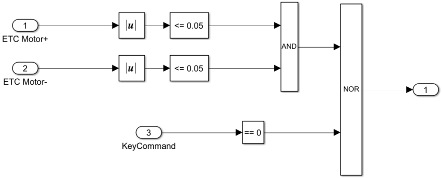
Learning Phase

- *Context:* ECU calibrates end-stops at Key-On.
- *Logic:* If `Detect_Learning` is TRUE, switch $\tau \longrightarrow \tau_{learning}$.
- *Goal:* Avoid Self-Learning DTC.



Rest Position

- *Context:* When de-energized, springs hold valve at $\approx 6.4°$.
- *Logic:* If no command from ECU, force integrator default to $6.4°$.
- *Goal:* Avoid Limp-Home Position DTC.



Physical Interface Generation:

- Conversion of Angle (*deg*) to Voltage (*V*) via Datasheet Maps.
- **Real/Sim Switch:** Allows real-time toggling between physical throttle feedback and model feedback for comparison.

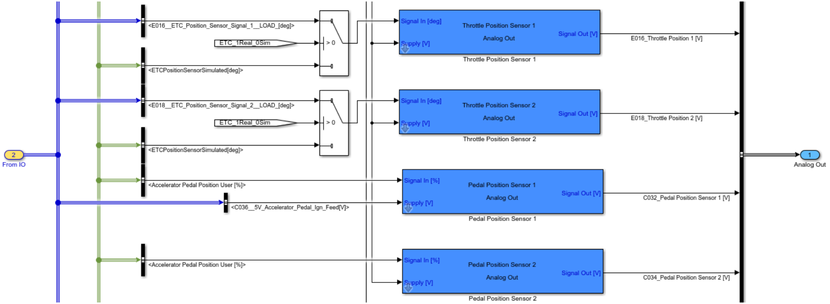


Figure: Hardware Interface Subsystem

The Problem: Open Load Faults

The ECU expects to drive a motor coil. Disconnecting the real throttle triggers "Open Load" errors, inhibiting commands. Simple resistors fail due to dynamic impedance.

Solution: DS5380 Load Module

- Programmable current sink (up to 300W).
- 3A per Volt control ratio.

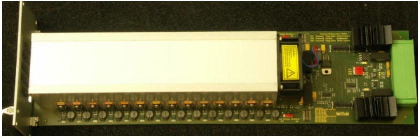


Figure: DS5380 Hardware

Implementation (RL Model):

- Simulated RL circuit calculates I_{motor} based on $V_{command}$.
- Model output drives DS5380 to draw precise current.

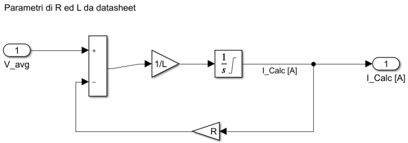


Figure: RL Circuit Model

Test Environment

Validation performed on a full **Jeep Wrangler** HiL simulator.

Tools:

- **Control Desk:** Real-time visualization.
- **INCA:** Calibration & Data log.
- **CAN Bus:** Network communication.

Tuned Parameters:

- $K = 12$
- $\tau = 0.06$
- $K_{fb} = 0.1$
- $\tau_{learn} = 0.04$

Test 1: Step Response (Bypass)

Objective: Evaluate transient behavior and settling time.

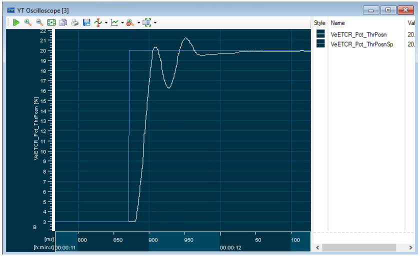


Figure: Real Component Step Response

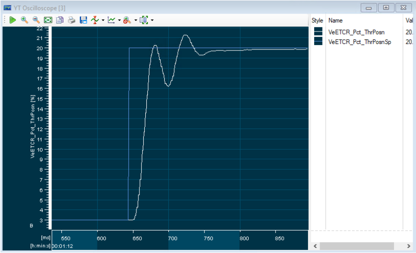


Figure: Simulated Step Response

$$
\begin{aligned}
t_r &= 20\,\text{ms} \\
S\% &= 7.6\% \\
t_s &= 115\,\text{ms} \\
e_\infty &< 1\%
\end{aligned}
$$

$$
\begin{aligned}
t_r &= 20\,\text{ms} \\
S\% &= 7.6\% \\
t_s &= 120\,\text{ms} \\
e_\infty &< 1\%
\end{aligned}
$$

Test 2: Train Pulse (Dynamic Tracking)

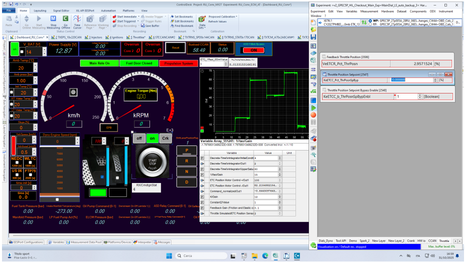


Figure: Real Component

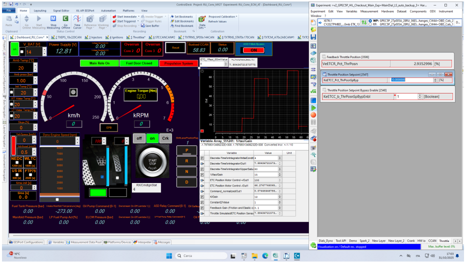


Figure: Simulated Model

Test 3: Learning Phase Validation

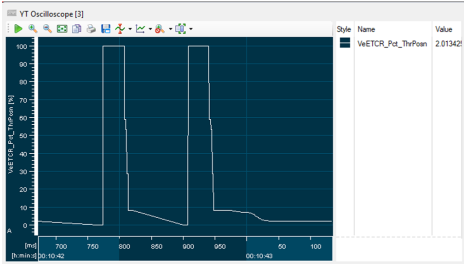


Figure: Real Learning Pattern

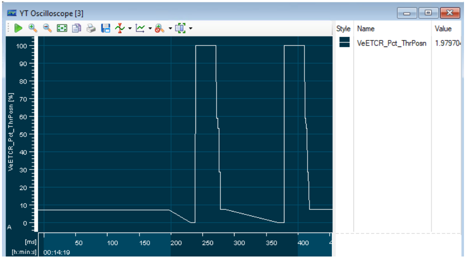


Figure: Simulated Learning Pattern

Model Validation

Zero Active DTCs in CDA, system ready for full vehicle simulation.

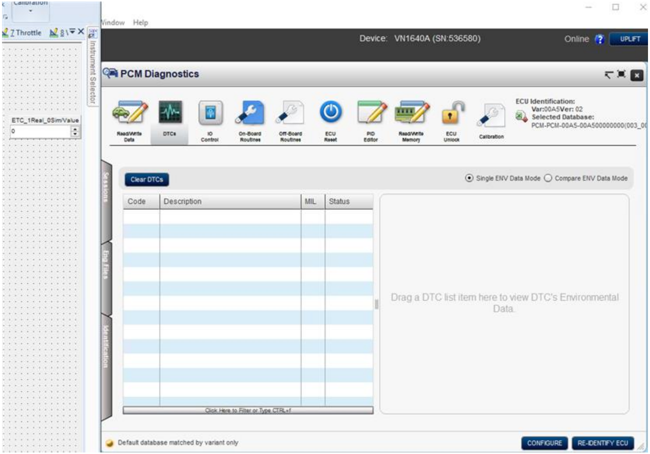


Figure: No DTC reported with Simulated Throttle Body

Achievements

1. **Interface:** Successful simulation of Throttle Body via DS2680 & Simulink Model.
2. **Electrical:** Solved Load Variable Behaviour issues via DS5380 + RL Model.
3. **Control:** Logic validated for critical Learning & Dis-Energized phase.

Operational Benefits:

- **Continuity:** Elimination of mechanical breakage downtime.
- **Repeatability:** Consistent behavior independent of age/temperature.
- **Advanced Testing:** Ability to simulate faults (Ice-blockage, Shorts) safely.

Enhancing physical realism for advanced control strategy testing.

1. **Second-Order Mechanical Model:**

$$J\ddot{\theta} + b\dot{\theta} + k(\theta - \theta_0) = T_{motor} - T_{friction}$$

   - Better representation of inertia and overshoot.

2. **Advanced Friction Modeling:**
   - Implementation of *Stribeck Curve*.
   - Simulation of "sticky valve" (stiction vs sliding).

3. **Aging Simulation:**
   - Real-time variation of stiffness (k) and friction (b).
   - Validation of ECU adaptive strategies over vehicle lifecycle.

Thank You for Your Attention