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Development and Testing of AMT Control Strategy Using Model Based Design Method

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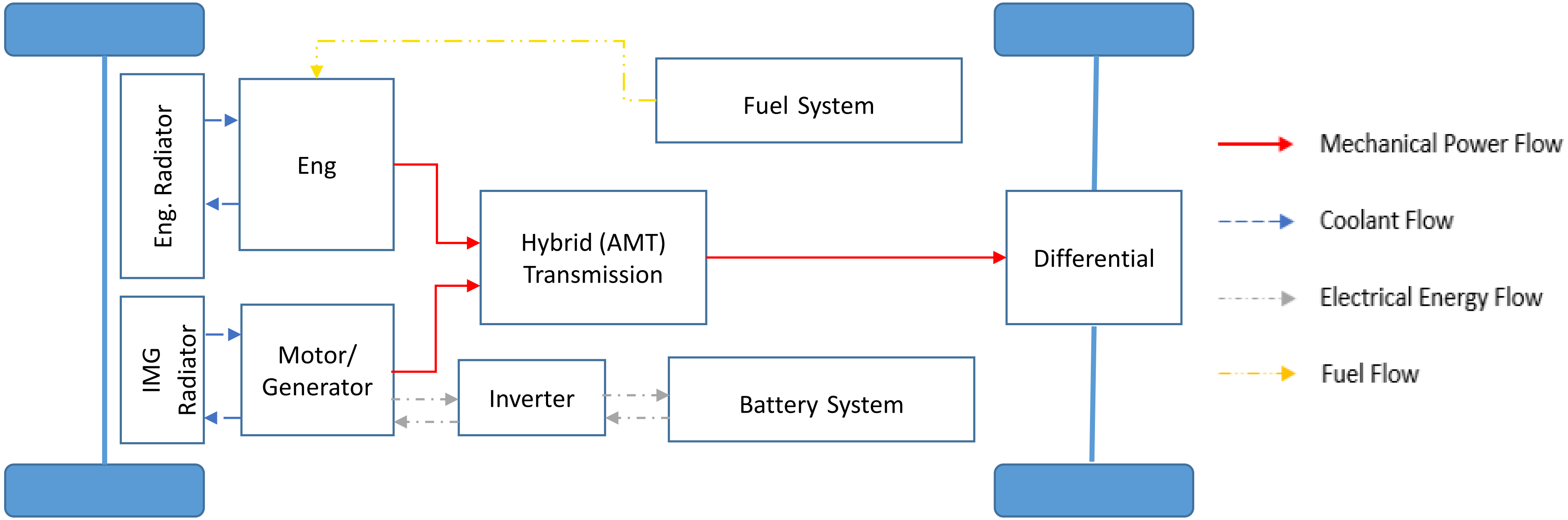
Introduction: Background and Target

Parallel Hybrid Concept:



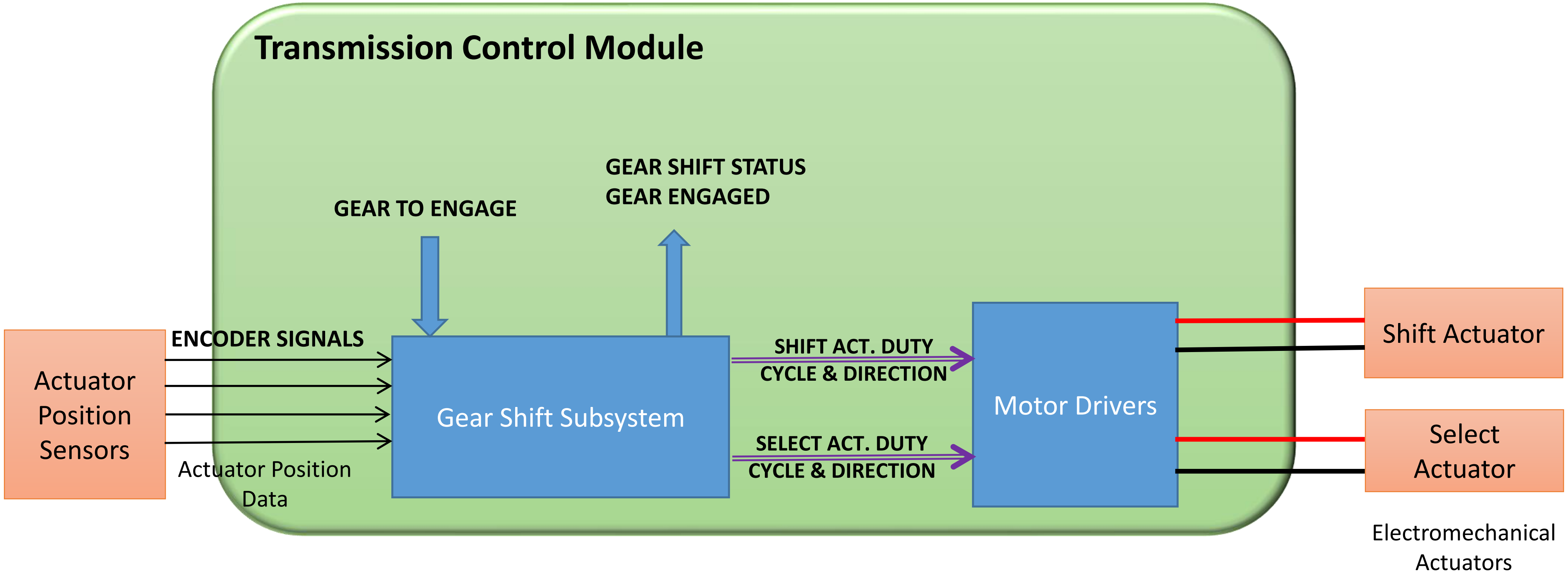
Target: Development of Transmission Control Submodule for a parallel hybrid prototype

Transmission Control Module

- The main function of the transmission control unit is to control the hybrid transmission(refer fig. in slide above) and the gear shift mechanism for the multi-speed gearbox which is a part of hybrid transmission.
- The gearshift mechanism consists of two electromechanical actuators for selection of gear rail (1-2, 3-4, 5-6) henceforth called '**Select Actuator**' and for shifting from neutral into a gear henceforth called '**Shift Actuator**'.
- It executes the following tasks:
  - Gear shift strategy (decide when to shift gear)
  - Gear shift execution (drive/control actuators)
  - Power split mechanism lock/unlock
  - Motor control for synchronization while shifting gears
- For this presentation we focus on a subsystem of TCM, which drives and controls actuators to execute gear shift

Gear Shift Subsystem Block Diagram

- The block diagram below shows a subsystem from the transmission control module
- We are going to focus our attention on this subsystem for the rest of presentation
- A brief overview of system requirements is given in the slide below



Scope of Work

We followed a proprietary '5 Level Model Based Development V Model' framework for product development, testing and validation

Following activities are carried out:

- Requirements: Definition and Management
- Proof of Concept/Model Development using Model Based Design tools, MATLAB, Simulink and Stateflow
- Model in Loop Testing
- Rapid Prototyping
- Hardware in Loop Testing

System Requirements: A Brief Overview

Following is a list of some of the system requirements.

- System should be able to drive and control actuators to engage desired gear
- System should inform about status of gear shift i.e. gear shift in progress/completed
- Feedback about gear engaged eg. 1,2,3 etc
- Shift time constraint eg. Shift within ‘X’ secs.
- Position accuracy of actuators should be within tolerance
- Repeatability
- Other diagnostic and error ‘flag’ requirements

Example:

*When the system completes a gearshift(refer section ‘Terminology’ above for definition of ‘gearshift complete’), the function shall set the value of output signal **Gear_Shift_Status** equal to 1.*

Control System Design

- Top Down approach was used for system design
- Top level system model was created using empty ‘shells’ for subsystems
- Subsystems are interfaced using buses
- Buses are defined using bus objects
- Bus objects allowed better control and traceability
- Bus objects are under revision control
- Simulink Projects helped in organizing files and setting up workspace
- For version control we used Simulink’s built in source control tools

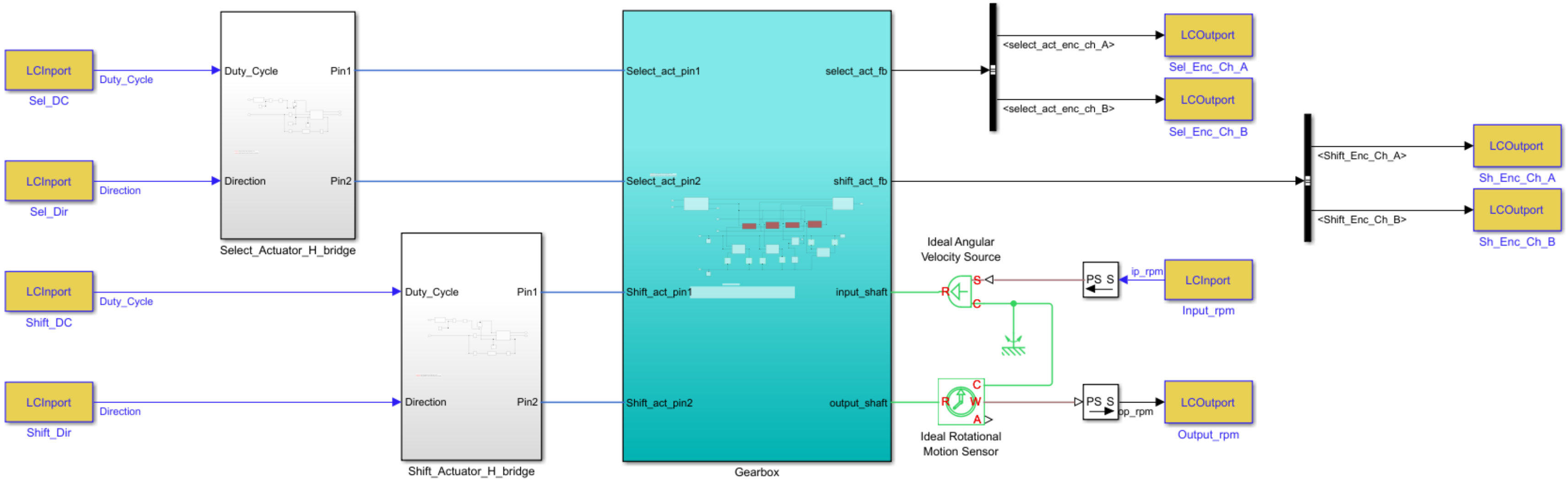
Plant Model

Plant model of a seven speed manual transmission was created

Plant Model was created using Simscape and Simscape Driveline toolboxes in Simulink

Simscape greatly simplified modeling process because:

- It allows use of physical components instead of modeling based on governing equations
- Connections are bi-directional



Plant Model (continued..)

The following components/effects were modeled:

- Electromechanical actuators with encoders
- Shift linkages, shift fork, shift sleeve, detent mechanism
- Synchronizers, dog clutch, gear pair

- Custom components also created for plant model in Simscape with support from Mathworks team
- In the model, the force to be applied by the shift actuator for synchronization was a function the inertias in the system, synchronizer parameters and the speed difference between input and output gears
- The current drawn by the actuator is proportional to the force required for synchronization

LABCAR: Hardware-in-Loop System (HIL)

- LABCAR is the HIL system for automotive ECUs developed by ETAS GmbH
- We have used this system for our HIL testing activities
- LABCAR architecture consists of the following system components#:
  - Real-time simulation target, model configuration, signal I/O cards, operator interface, extensions
- LABCAR supports MALTAB, Simulink and Simulink Coder
- Simulink coder generates code for model using Simscape components. Code for Simscape blocks generated separately.
- LABCAR uses its own Target Language Compiler (TLC). However Simscape code does not pass through TLC.
- Simscape pre-compiled libraries are not used by LABCAR
- Hence, static runtime libraries needed by code generated by Simscape need to be compiled during code generation

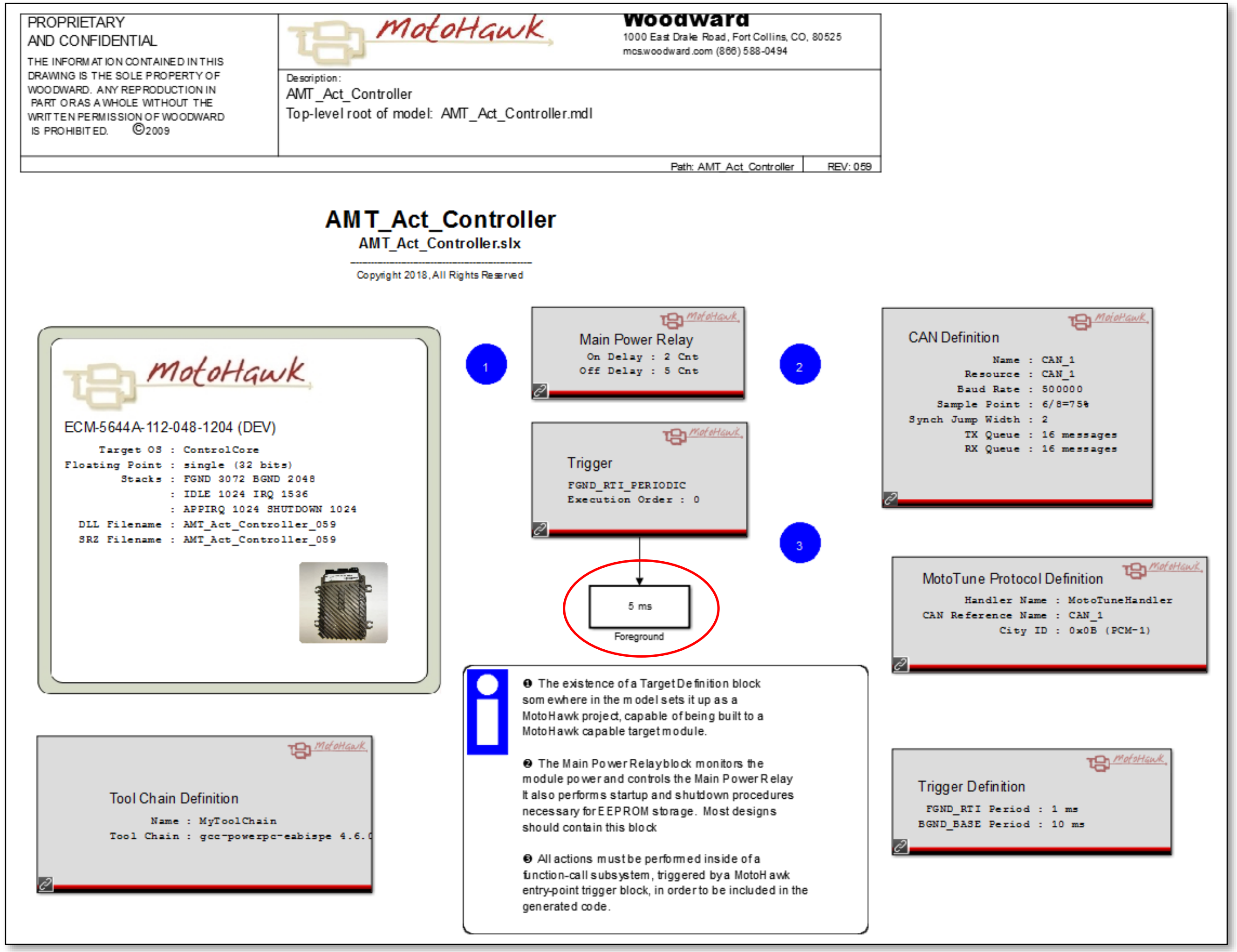
: LABCAR Component Overview HIL Systems: https://www.etas.com/en/products/solutions_labcar_component_overview.php

Rapid Prototyping

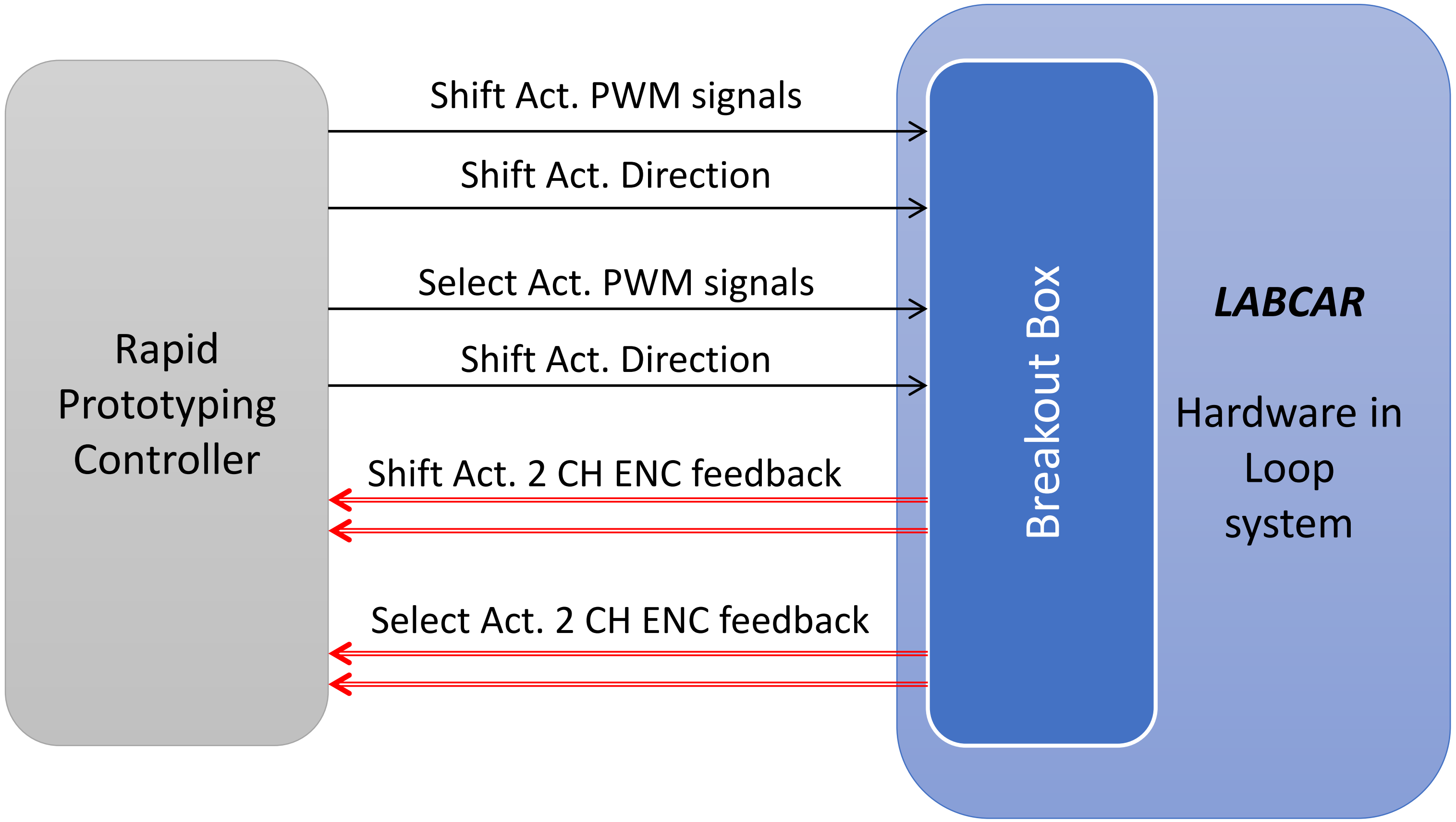
- The control strategy developed for the gear shift subsystem is deployed on MotoHawk Controller
- MotoHawk Controller is an embedded control module developed by Woodward Inc. for automotive applications[#].
- MotoHawk is an application development tool built on top of Matlab and Simulink.
  - It is used to program MotoHawk Controllers
  - It leverages the powerful capabilities of Simulink to develop and deploy application software on MotoHawk Controllers
  - It has its own library of components which can be accessed through Simulink Library Browser
- MotoTune is the application used for calibrating the controller

: MotoHawk Control Solutions: https://www.woodward.com/WorkArea/DownloadAsset.aspx?id=2147484104

Rapid Prototyping: MotoHawk Interface



System Layout for HIL Testing



Verification and Validation (V&V) Test Plan

- Verification and Validation was carried out as per a prescribed framework
- Following activities were carried out

Stage/Level in V Model	Tests Carried Out
Model Development	Requirement Traceability Consistency Checks Check compliance to MAAB guidelines
MIL Testing	Functionality tests using test cases generated through DOE Model Coverage, Decision Coverage Formal Verification using Simulink Design Verifier
SIL Testing	Functionality tests
HIL Testing	Functionality tests Test to verify compliance to set targets of shift time, shift accuracy, repeatability, fault detection etc.

Requirement Traceability and Consistency Check

Requirements Traceability Report for Gearshift_Controller_Submodule

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Chapter 1. Model Information for "Gearshift_Controller_Submodule"

Requirements Traceability Report for Gearshift_Controller_Submodule

Requirements Consistency Checking

- **Identify requirement links with missing documents**
  Passed
- **Identify requirement links that specify invalid locations within documents**
  Passed
- **Identify selection-based links having description fields that do not match their requirements document text**
  Passed
- **Identify requirement links with path type inconsistent with preferences**
  Passed

V&V: Model Coverage

- Model Coverage checked using Simulink Design Verifier
- Detailed report gives instances where certain combinations have not occurred.
- Using state flow debugger we identify root cause of coverage issue and modify the model
- Following is a snapshot from the Model Coverage Report

Summary

Model Hierarchy/Complexity		Test 1 Decision	Condition	MCDC	Execution
1. Gearshift_Controller_Submodule	78	74%	78%	50%	100%
2. . . . GearShiftActuatorController	77	74%	78%	50%	100%
3. . . . . . . Gear_Shift_Act_Logic	76	74%	77%	49%	100%
4. . . . . SF: GearShiftActuatorController/Gear_Shift_Act_Logic	75	74%	77%	49%	100%

Recalibration, Fault Detection and HIL Testing

- Repeatability in actuator displacement is ensured by recalibrating the displacement encoders.
- System recalibrates itself during operation
- Software has routines to detect faults in actuation system
- HIL tests were carried out to verify functionality of system
- HIL testing was also done to verify compliance to
    - set targets of shift time,
    - shift accuracy, repeatability,

Mathworks Tools in Development Process

- Mathworks has built an ecosystem of tools around Model Based Product Development Process
- Mathworks tools were used in all stages of product development including
  - Requirements linking, traceability and consistency check using Simulink Requirements
  - Project management and revision control
  - Controller and plant model development using Simulink, Stateflow and Simscape
  - Model-in-loop testing
  - V&V activities like checking against standards, checking against errors, proving properties etc.
  - Model and Code optimization by doing code coverage and decision coverage tests
- These tools provided clear visibility, helped reduce development time, helped develop robust and optimized code, allowed collaboration on development activities etc.
- Mathworks tools integrate seamlessly with third party tools while retaining most of their functionality

THANK YOU!