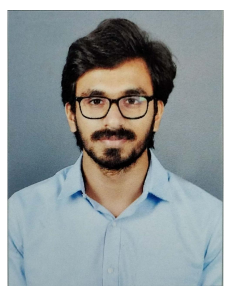
COURSE PROJECT REPORT

DEVELOPMENT OF HYBRID ELECTRIC VEHICLE (HEV) POWERTRAIN CONTROLLER USING STATEFLOW

Shivayogi Channappa Akki



A REPORT

Submitted for Distributed Embedded Control System

MASTER OF SCIENCE

In Mechatronics, Robotics, and Automation Engineering

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1 Introduction

The objective of the Course project is to develop a high-level controller using the concepts learned over the period of this course, model-based embedded control system design approach, for a configurable hybrid electric learning modules (CHELM). This high level controller is MotoTron Control System. Figure 1 shows the MotoTron Control System giving input signals to the engine and DC motor.

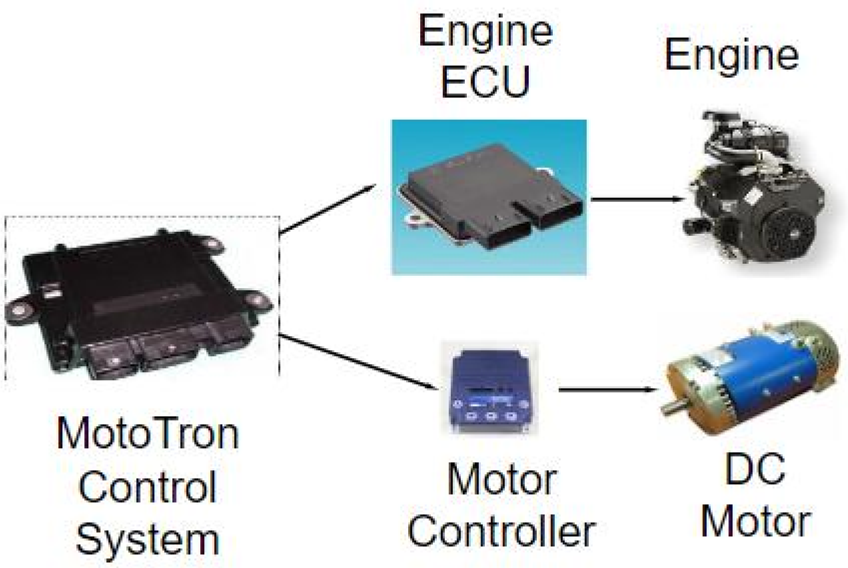


Figure 1. MotoTron Control System instructions

2 Building Model (Task 1)

The MotoTron control system designed consists of Sensor, Control and Actuator Module. While figure 2 shows the relationship between all input and output signals, Table 1 shows the all input and output signals and respective ECU pins.

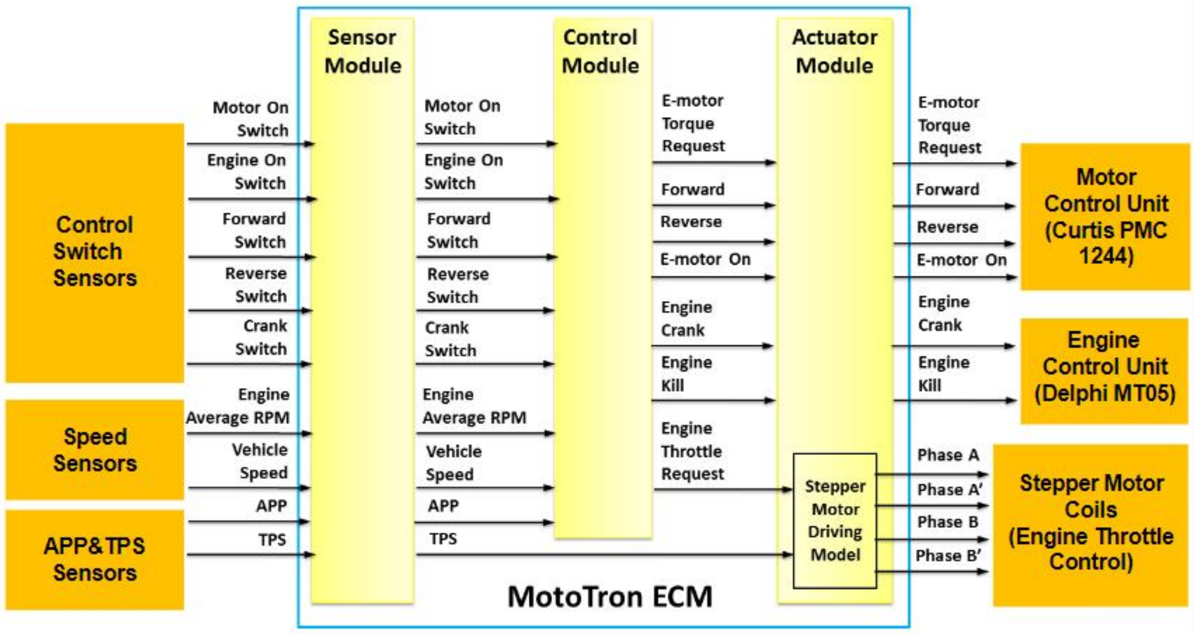


Figure 2. Overview of the MotoTron control system

Input Signal	ECU Pin	Output Signal	ECM Pin
Engine On Switch	AN5M	Engine Crank	LSD1
Motor On Switch	AN6M	Forward	LSD2
Forward Switch	AN7M	Reverse	LSD3
Reverse Switch	AN8M	E-motor On	LSD4
Crank Switch	AN9M	Engine Kill	LSD9
APP(PPS1)	AN1M	E-motor Torque Request	TACH
TPS	AN2M	Stepper Motor Driving Signals	Coil 1 – LSD 5 Coil 2 – LSD 6 Coil 3 – LSD 7 Coil 4 – LSD 8
Engine Average RPM	AN3M		
Vehicle Speed	AN4M		

Table 1. Input and Output Signals

Analog Inputs:

The following figures represent the Analog input models.

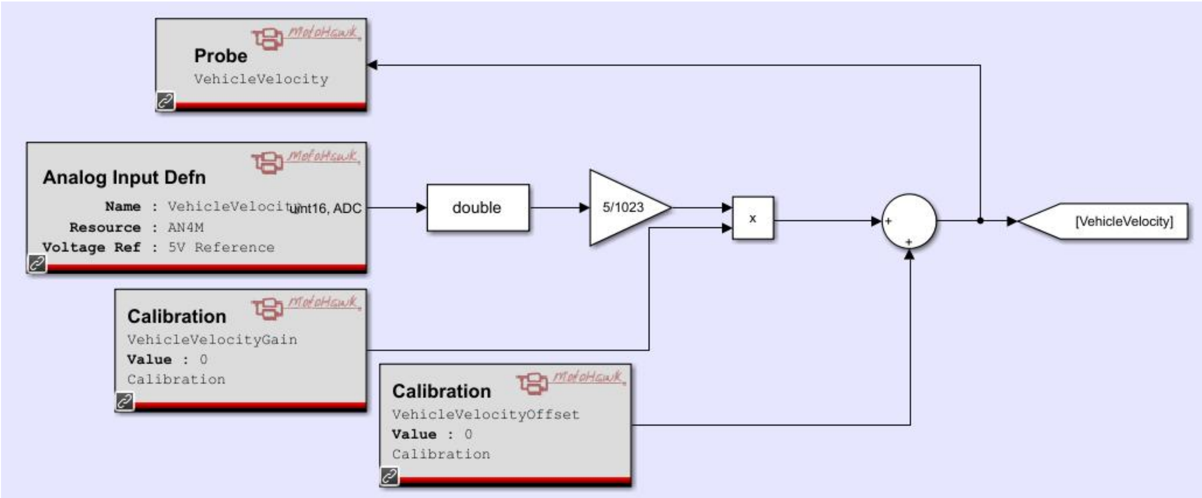


Figure 3. Vehicle Velocity Input block Calibration

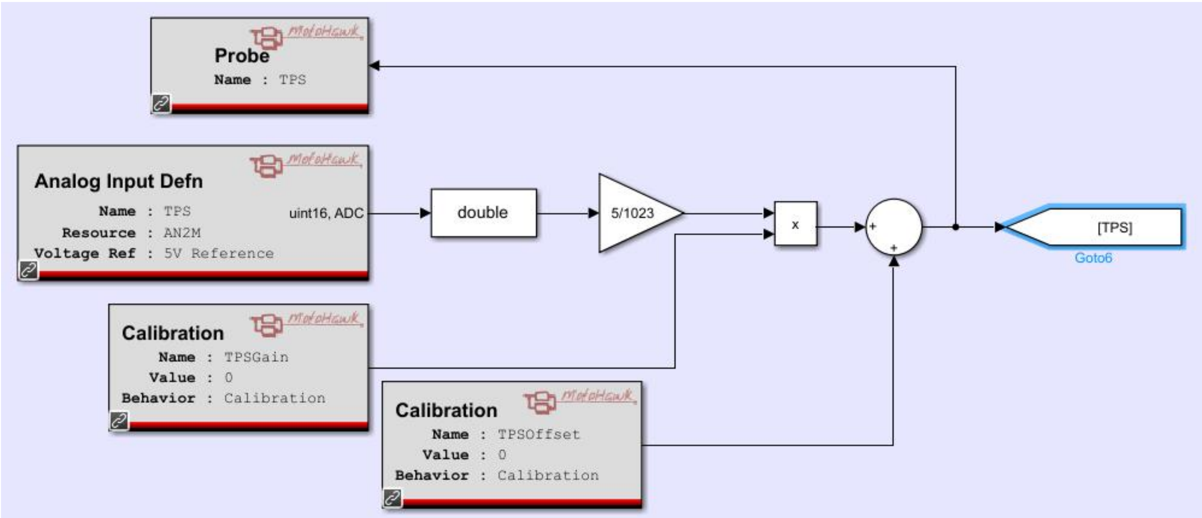


Figure 4. Throttle Position Sensor Input block Calibration

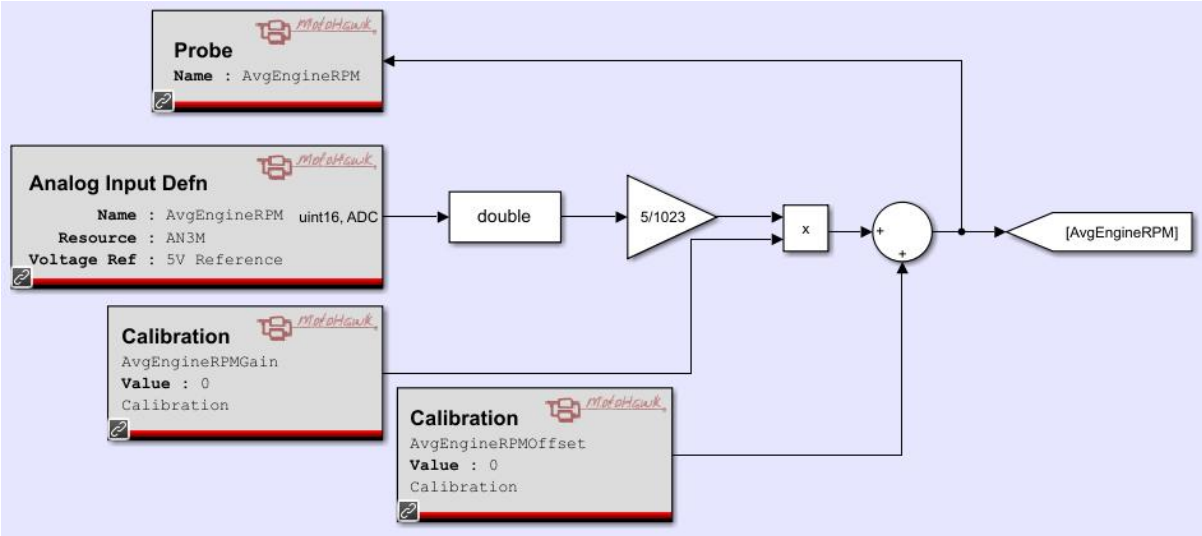


Figure 5. AvgEngineRPM Input block Calibration

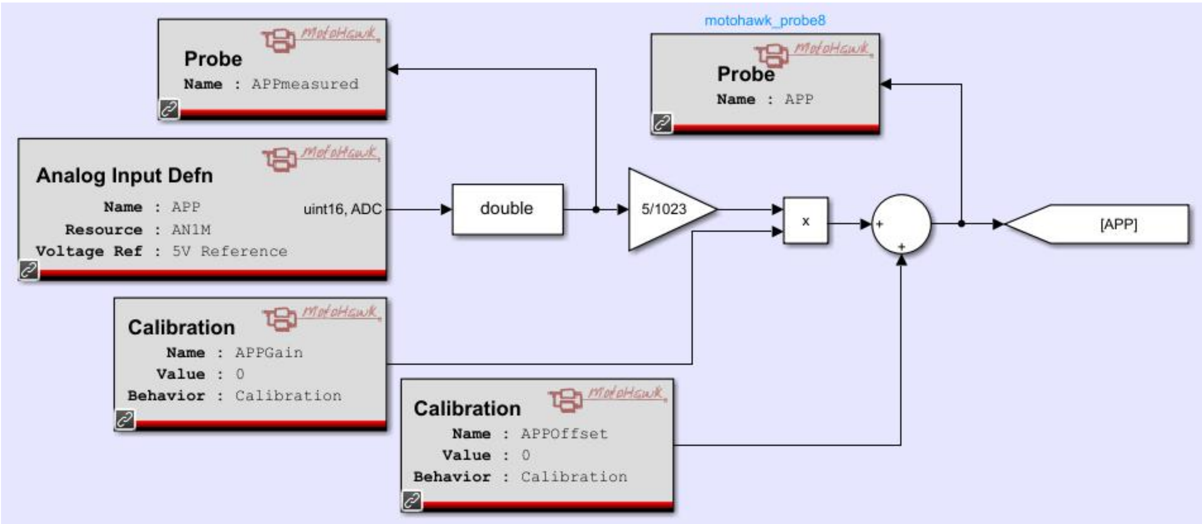


Figure 6. Acceleration Position Sensor Input block Calibration

Digital Input:

The following figures represent the Digital input models.

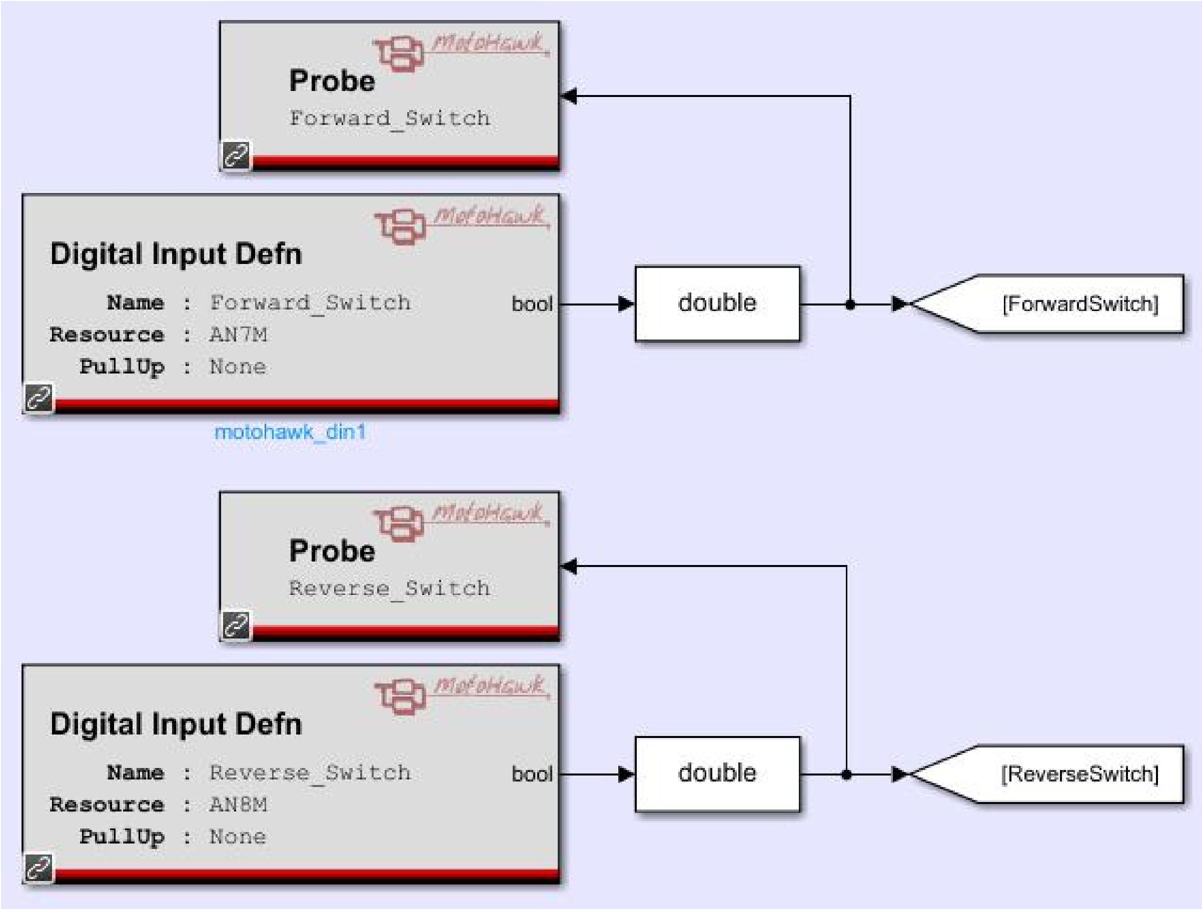


Figure 7. Forward and Reverse Switch Digital Input block

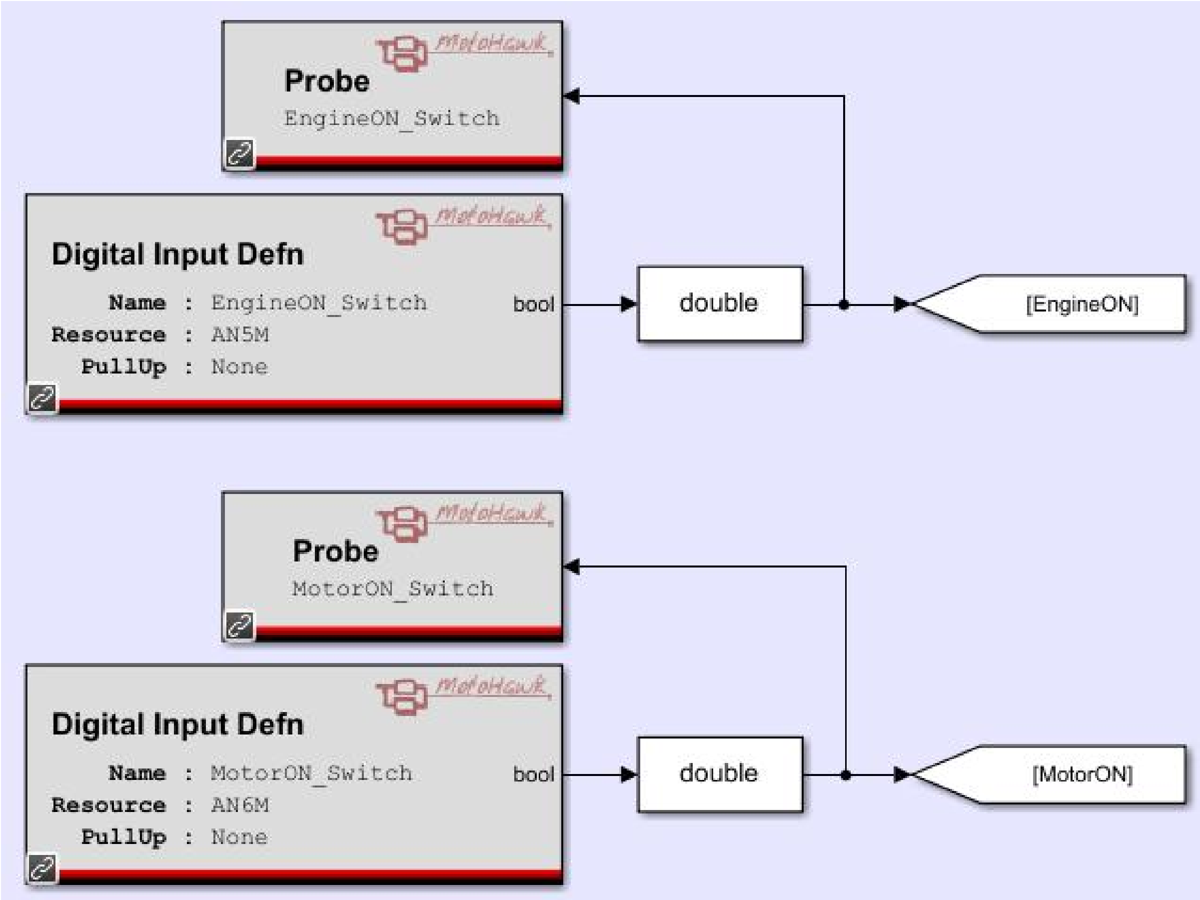


Figure 8. MotorOn and EngineOn Digital Input block

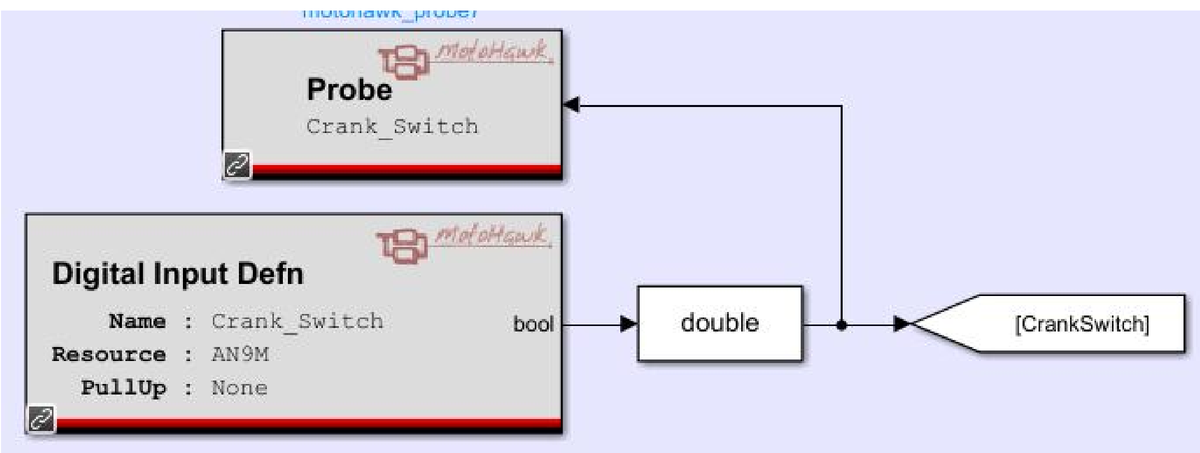


Figure 9. Crank Switch Digital Input block

Driving Mode Model

There are a total of 3 driving modes: Electric Solo Mode (1), Blending Mode (2) and Engine Solo Mode (3). As indicated by the name, in Mode 1 (Electric Solo Mode) the only source of driving force for the vehicle is E-motor. Similarly, Engine Solo Mode only uses the Engine and blending mode uses a combination of the both.

Input			Driving Mode Output		
Engine on Switch	**Motor On Switch**	**Vehicle Velocity**	**Electric Solo Mode (1)**	**Blending Mode (2)**	**Engine Solo Mode (3)**
True	False	V < 1 mph	False	False	True
False	True		True	False	False
False	False		False	True	False
True	True		Driving Mode will stay unchanged		
		V > 1 mph	Driving Mode will stay unchanged		

Table 2. Determine driving mode based on switch signals.

The Driving Mode Stateflow model has 3 input, EngineON, MotorON and VehicleVelocity. While Driving mode is the only output. Driving Mode is one of the most important signals since it is used in Engine Start/Stop model, E-motor Start/ Stop model and Torque Request model. Note that the Driving modes can only be changed when the velocity is less than 1mph (Figure 10).

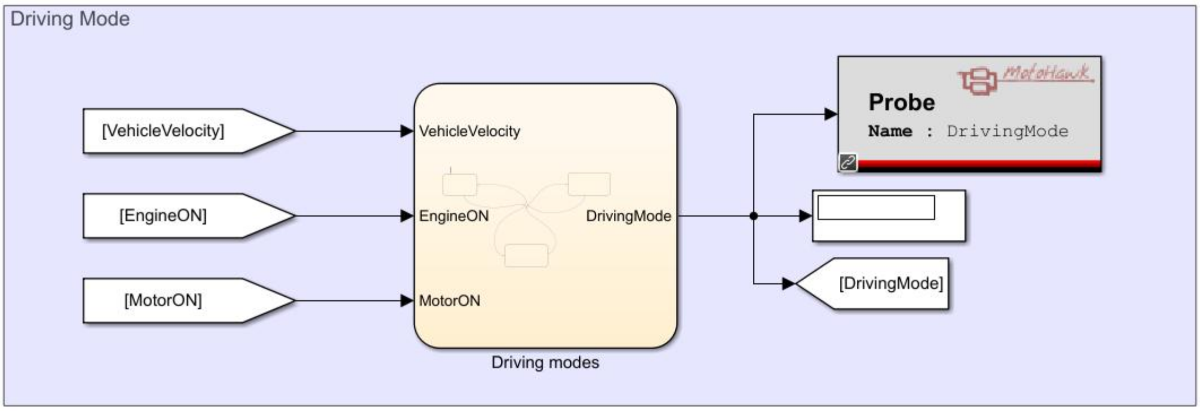


Figure 10. Driving Mode Stateflow model

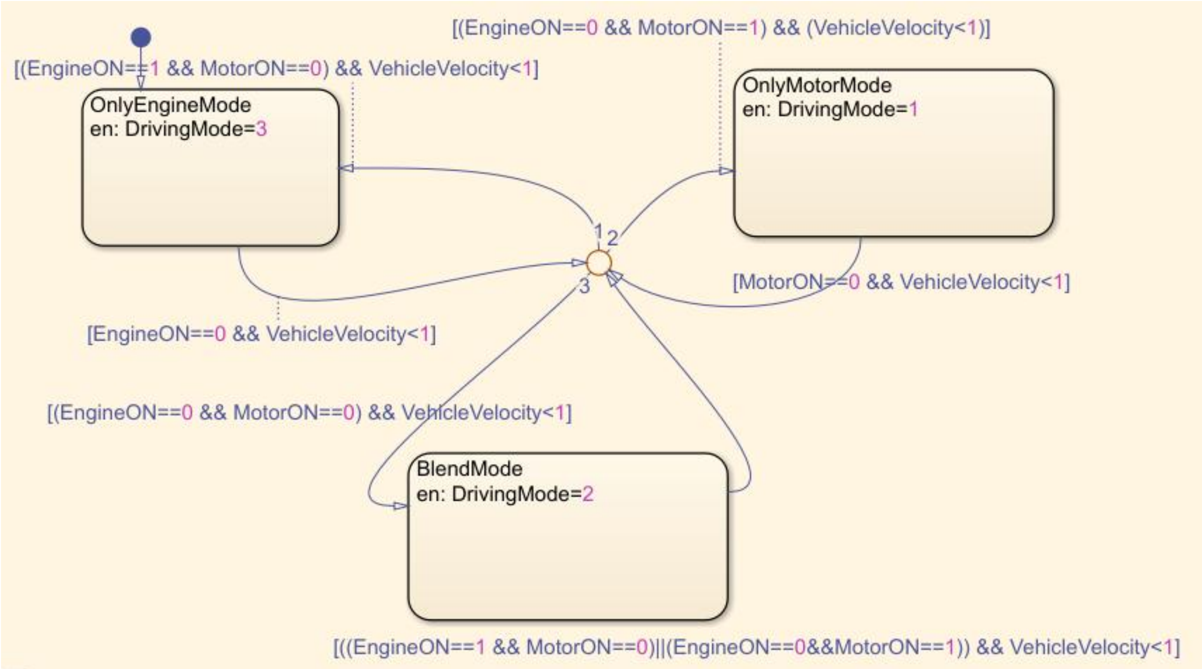


Figure 11. Driving Mode Stateflow logic

Blend Factor

This logic model is only applicable for the Blending Mode since the Motor torque request is dependent on it's motor blend factor and Engine torque request is dependent on it's respective engine blend factor. In Electric solo mode, Engine blend factor =0 and Motor blend factor is 1. Hence Motor torque request is equal to APP. In Engine solo Mode it is the other way around. Both blend factors are dependent on the VehicleVelocity and APP.

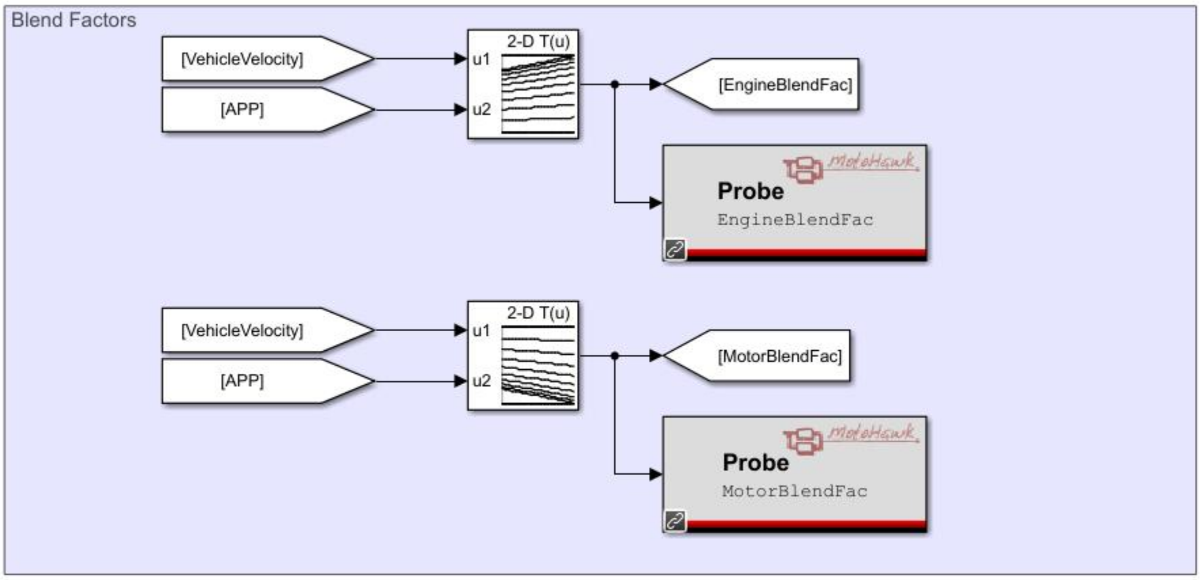


Figure 12. Blend Factor n-d look-up table

Engine State Logic

The Engine's initial Off state to Final On state is achieved in 5 states/steps. Engine Off state(1), Engine Crank state(2), Engine Warm-up state(3), Engine On state(4) and Engine State Fail State(5). Engine State Logic model is used to determine the current state of the engine.

Current state	Condition	Next state
Engine Off State (1) (default state)	Engine Crank=True Engine Kill=False Delay 1 sec.	Engine Crank State (2)
Engine Crank State (2)	Engine RPM>800 and Engine Crank Time>1.6 sec.	Engine Warm-up State (3)
	Engine Crank Time>2 sec and Engine RPM<=800.	Engine Start Fail State (5)
Engine Warm-up State (3)	Engine Warm-up time>3sec and Engine RPM >=500	Engine On State (4)
	Engine Warm-up time >3 sec and Engine RPM>=500	Engine Start Fail State (5)
Engine On State (4)	Engine RPM<50 or Engine Kill=True	Engine Off State (1)
Engine Start Fail State (5)	Delay 1 sec.	Engine Off State (1)

Table 3. The Conditions of Engine State Transitions

Engine State Logic model has 4 inputs and 1 output. The inputs are Time, Engine Crank, Engine Kill and AvgEngineRPM While the output is Engine State. Engine Off is the Default state, which transitions to Engine Crank state when Engine crank is ON and Engine kill is Off with a time delay of 1 sec. Engine crank state transitions to Engine Warm-up state when engine RPM is greater than 800 and Engine crank time is grater than 1.6 sec, but if the Engine RPM isn't greater than 800 Engine state 5 is achieved. From Engine state 3, Engine state 4 can be achieved when the Engine RMP is grater than or equal to 500 for more than 3 seconds, if not Engine start fail is achieved. Engine state 4 is Engine On position. To turn off the engine, Engine RMP should be brought to lower than 50 or Engine kill should be turned ON. From Engine state 5, it automatically transitions to Engine state 1 after 1 second.

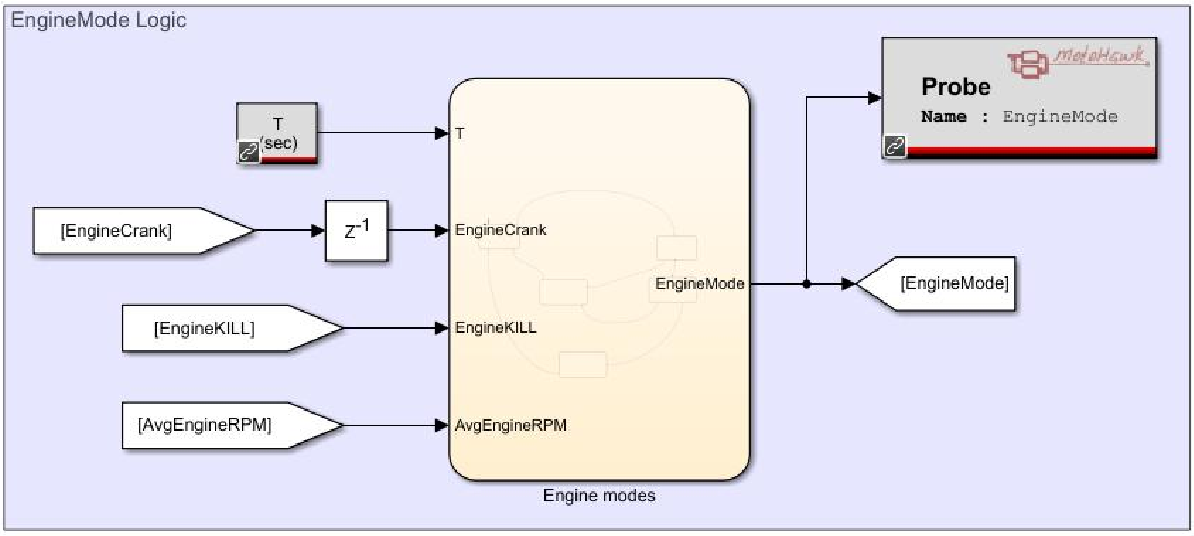


Figure 13. Engine State Stateflow model

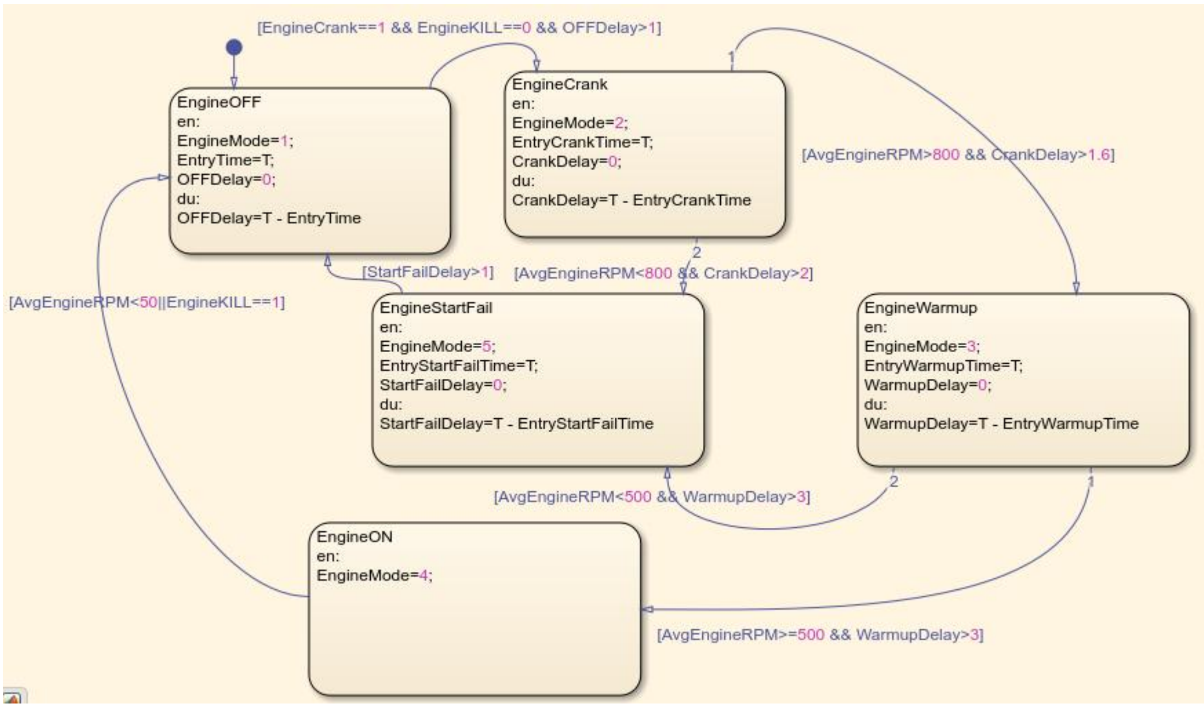


Figure 14. Engine State Stateflow logic

Engine Start/Stop Model

Engine Start/Stop model consists of 4 important outputs that control the Engine State. The outputs are Engine Kill, Engine Crank, Auto Crank and Manual Crank. Table 4 presents the Engine kill logic for different Driving modes and Engine Blend Factor Values. In Driving mode 1 and 3, Blend factor plays no role in determining the Engine Kill signal. Engine Kill is

True and False in Driving mode 1 and 3 respectively. In driving mode 2, Wngine kill is true only when Blend Factor is lesser than 0.01.

<table>
<tr><td rowspan="2">Conditions</td><td>Driving Mode</td><td>Electric solo mode (1)</td><td colspan="2">Blending mode (2)</td><td>Engine solo mode (3)</td></tr>
<tr><td>Engine Blend Factor</td><td>No impact</td><td>>0.01</td><td><0.01</td><td>No impact</td></tr>
<tr><td colspan="2">Engine Kill</td><td>True</td><td>False</td><td>True</td><td>False</td></tr>
</table>

Table 4. The impact of driving mode and engine blend factor on engine kill signal

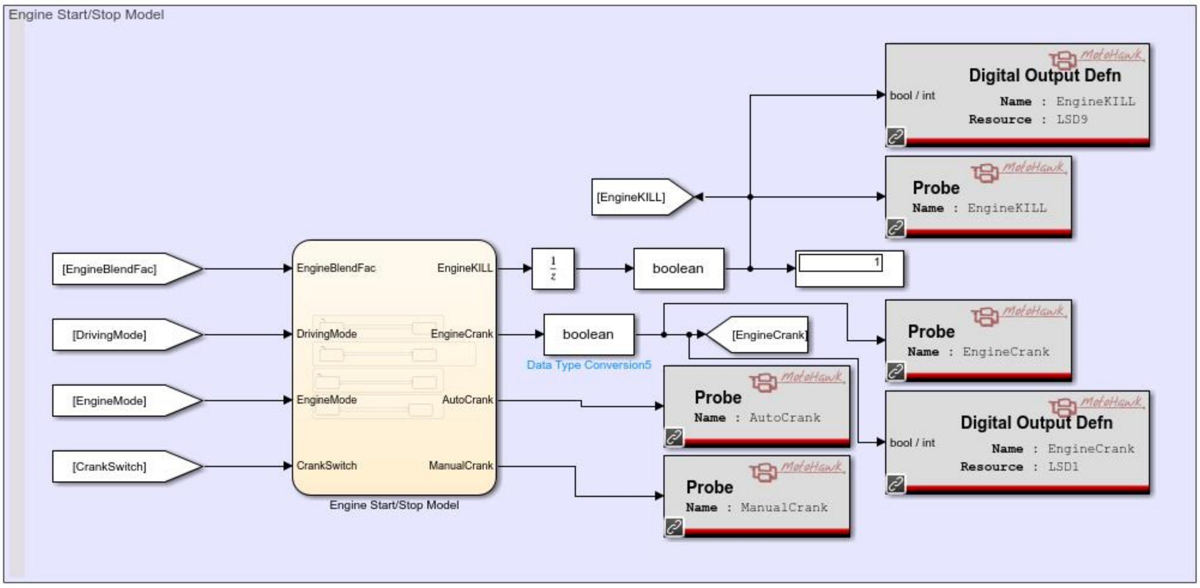


Figure 15. Engine Start/Stop Stateflow model

Table 5 explains the Manual Crank Logic. Manual Crank is only in Engine Solo mode when Crank switch is on and engine state is 1.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Manual Crank	False	False	True when the Crank Switch is True and the engine state is 1

Table 5. The logic of Manual Crank signal

Table 6 is the logic for Auto Crank. Auto crank is only true when in Driving mode 2 Engine state 1 with Blend Factor grater than 0.01.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)			Engine solo mode (3)
	Engine Blend Factor	Irrelevant	>0.01		<0.01	Irrelevant
	Engine State	Irrelevant	==1	==4	Irrelevant	Irrelevant
Automatic Crank		False	True	False	False	False

Table 6. The logic of Automatic Crank signal

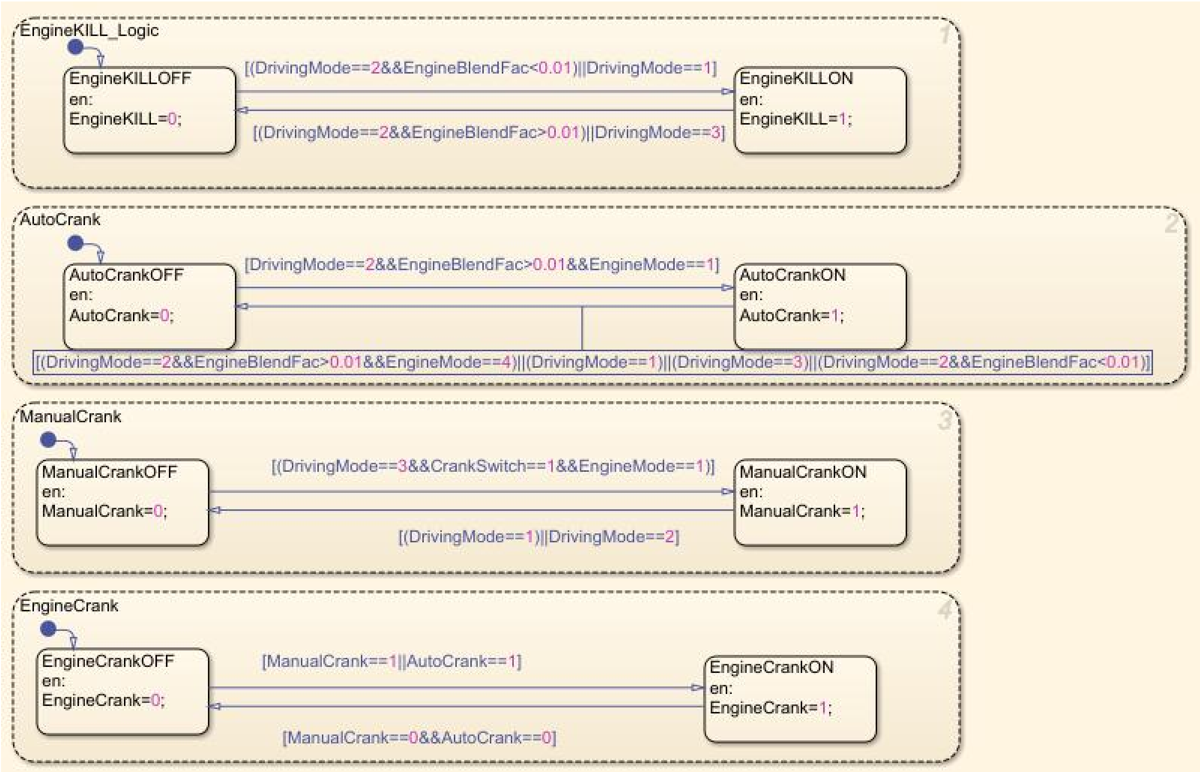


Figure 16. Engine Start/Stop Stateflow logic

Engine Torque request and Motor Torque request Model

Table 7 explains the working of Engine Throttle request in different Driving modes and Engine states. In Driving mode 1 and 3, Engine state has no effect on the Engine throttle request. EngineTR remains a constant value of 0 in Electric solo mode while it is equal to APP in the Engine solo mode. In blending mode, EngineTR stays constant at 7.5 and 0 in engine states 2 and 3, and 1 and 5 respectively. When the Engine is on, the EngineTR is APP times the EngineBlendFac.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)			Engine solo mode (3)
	Engine State	No impact	==2or==3	==1or==5	Engine On State	No impact
Engine throttle request		0	7.5	0	APP*(Engine Blend Factor)	APP

Table 7. The impact of engine state on engine throttle request

Table 8 explains the working on MotorTR in different Driving modes. Motor TR doesn't depend on the Engine state. MotorTR stays constant at 0 in Engine Solo mode and equals APP in Electric solo mode. While in blending mode, MotorTR is APP times the MotorBlendFac.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Motor torque request	APP	APP*(Motor Blend Factor)	0

Table 8. The impact of driving mode on motor torque request

EngineTR and Motor TR Stateflow Chart has 5 input and 2 outputs. The inputs being Engine Blend Factor, Driving Mode, Engine Mode, Motor Blend Factor, and APP, while the outputs are MotorTR and EngineTR.

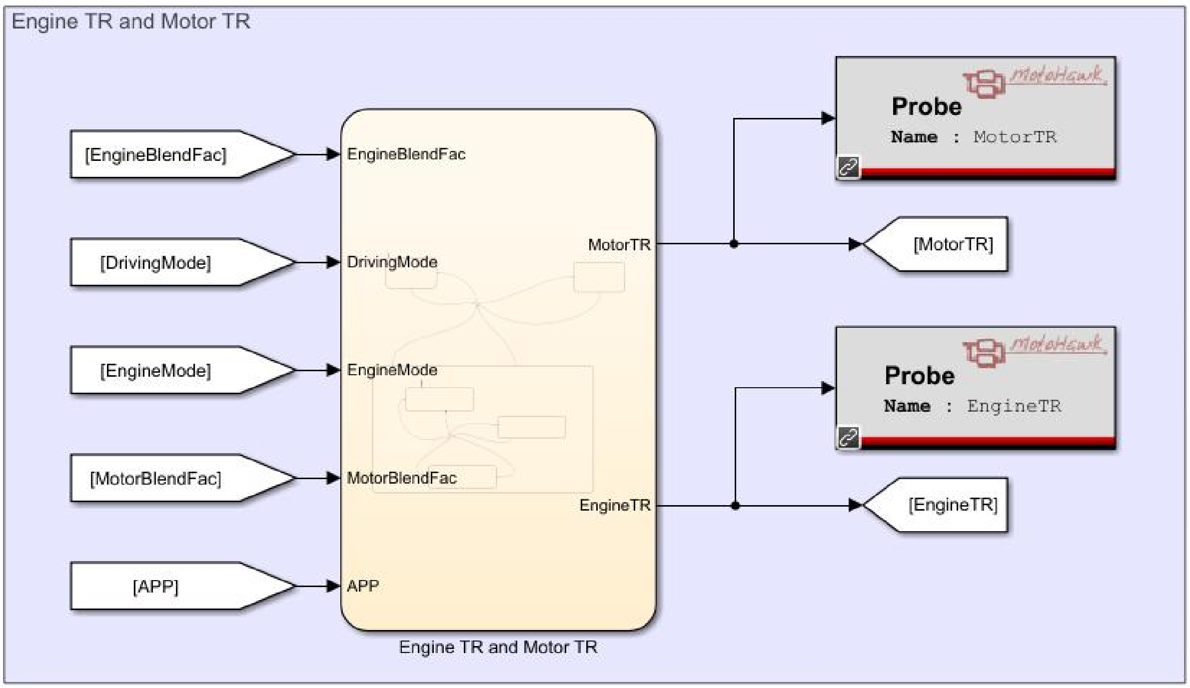


Figure 17. Engine Torque request and Motor Torque request Stateflow model

The Stateflow logic in figure 18 is a combination of the above 2 tables.

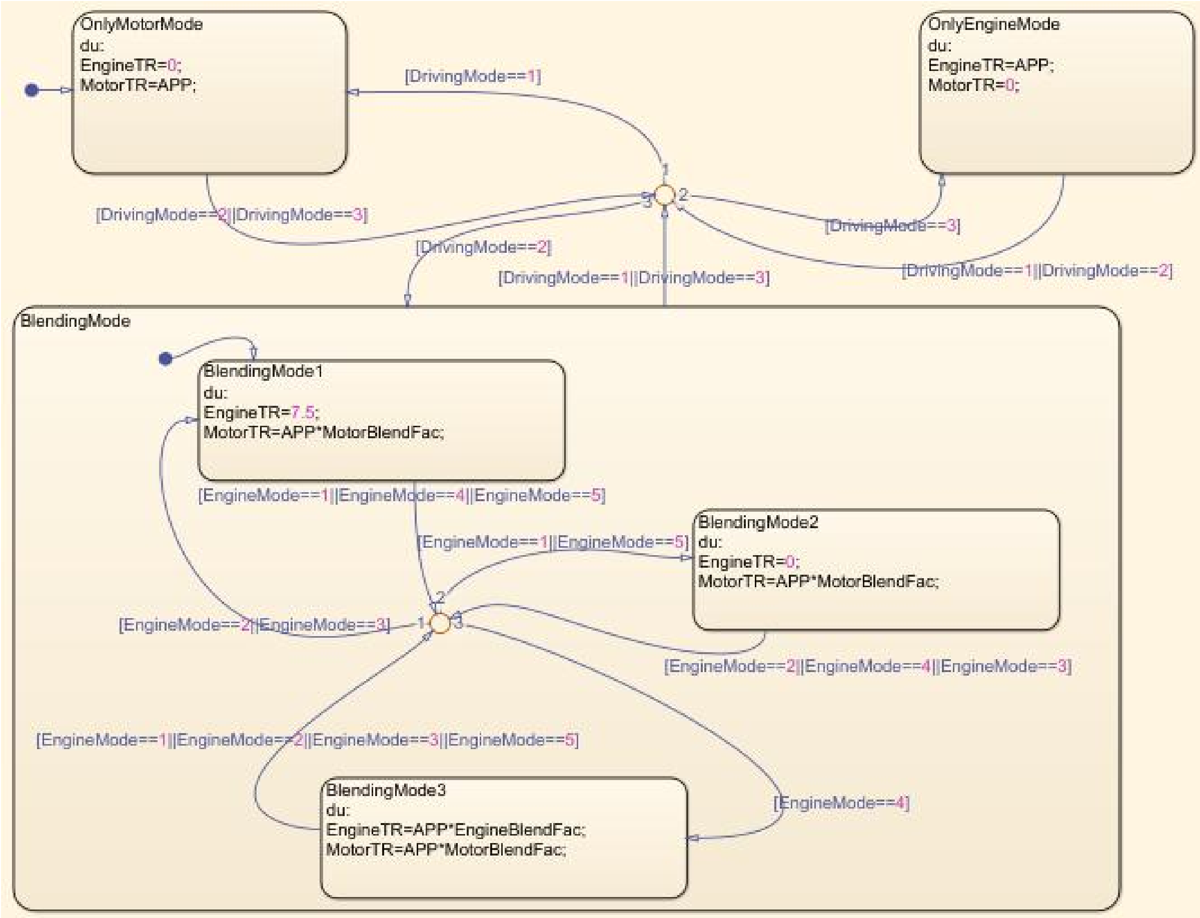


Figure 18. Engine Torque request and Motor Torque request Stateflow logic

E-motor Start/Stop Model

The E-motor Start/Stop model has 4 input signals and 3 output signals. The input signals being DrivingMode, ForwardSwitch, ReverseSwitch and MotorBlendFac, while the output signals are Motor, Forward and Reverse. Table 9 determines the Motor On and Motor Off signals. On the other hand, Table 10 and 11 determine the Forward and Reverse Logic.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)		Engine solo mode (3)
	Motor Blend Factor	Irrelevant	>0.01	<0.01	Irrelevant
E-motor On		True	True	False	False

Table 9. The logic of Motor On signal

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Forward signal	Forward Switch status	True	False

Table 10. The Forward Logic

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Reverse signal	Reverse Switch status	False	False

Table 11. The Reverse Logic

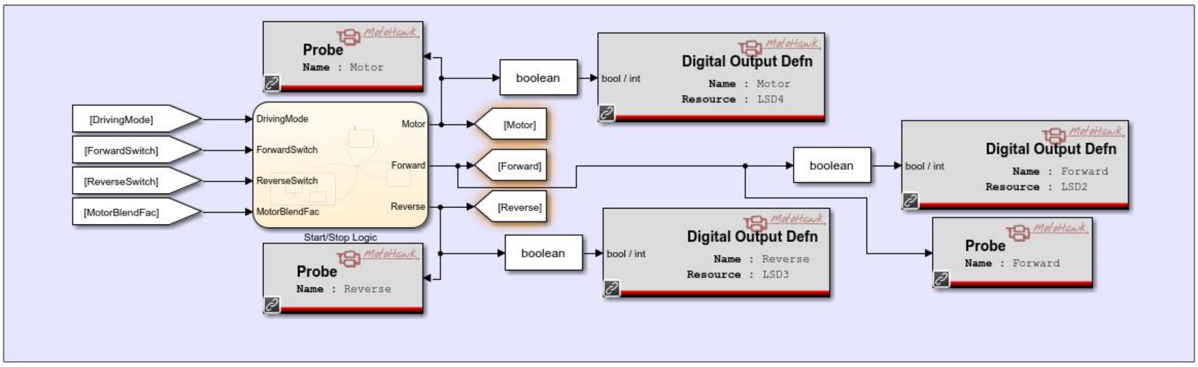


Figure 19. E-motor Start/Stop Stateflow model

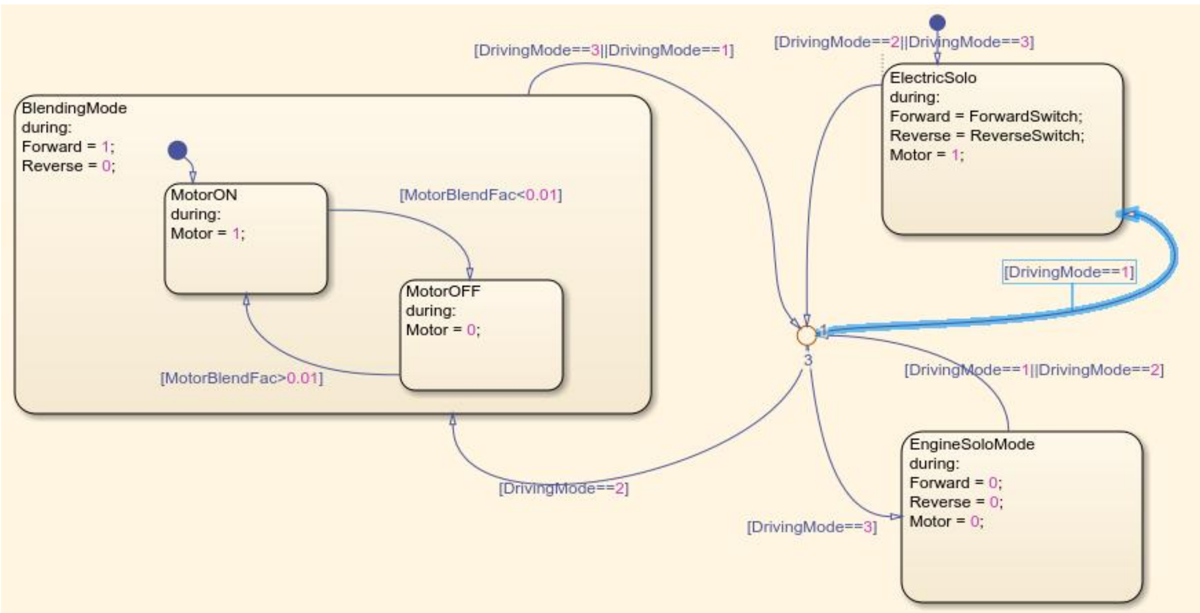
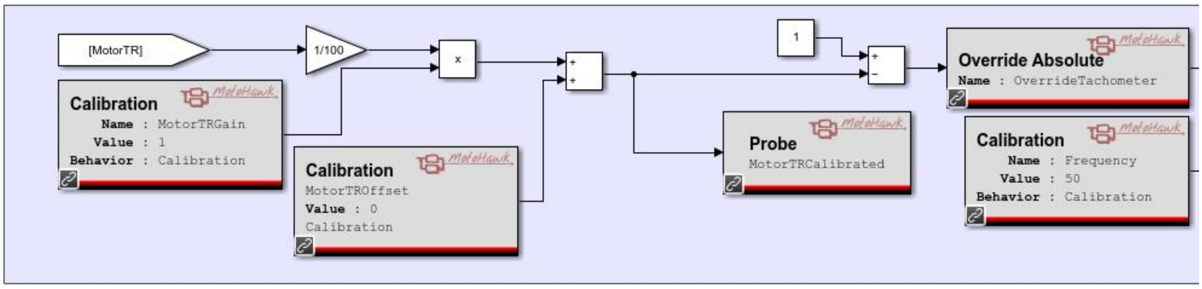
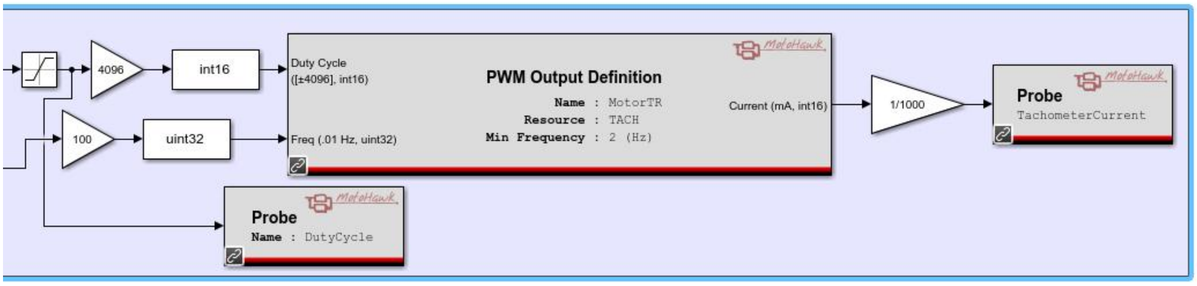


Figure 20. E-motor Start/Stop Stateflow logic

PWM DutyCylce Model

The motor is operated using the PWM output as duty cycle. MotorTR which ranges from 0 to 100 is multiplied by a gain of 0.01 to convert to 0-1 scale. The calibrated MotorTR is provided as input to the PWM block. The oscilloscope helps observe the PWM output. The motor rotation angle is 0-90 degrees and tachometer saturation limit is 0.9 to 0.95.





Stepper Motor Model

The stepper motor is a very key component. It is used to control the throttle opening of the engine. The stepper motor consists of 4 coils. The difference of Engine Throttle Request (ETR) and Throttle Position Sensor (TPS) determine the working of the stepper motor. Figure 21 represents the 4 bifilar, uni-polar coils. While Figure 22 determines the working of the stepper motor and it's direction. The clockwise and anti-clockwise direction is determined by the logic in Table12. Steps 1-2-3-4-5-6-7-8-1 spins in clockwise and steps 8-7-6-5-4-3-2-1-8 spins in anti-clockwise direction. Each step requires certain coils to be energized, while the others are not energized.

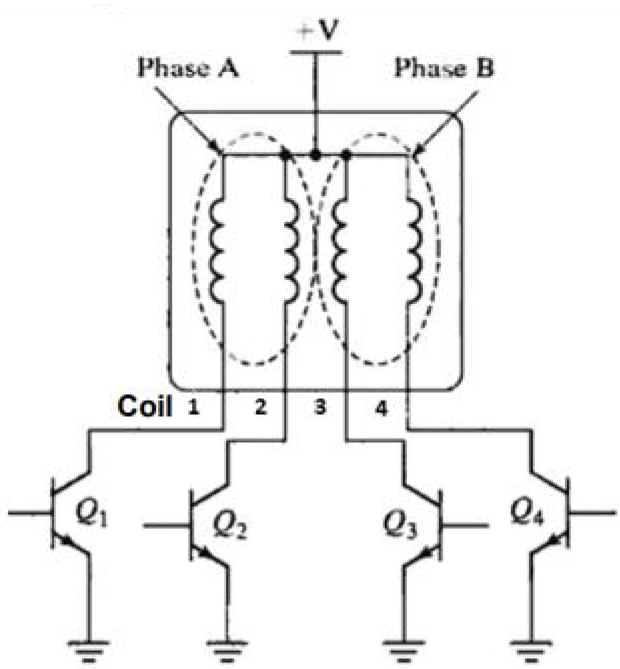


Figure 21. Uni-polar Stepper motor

Step	Q_1	Q_2	Q_3	Q_4
1	On	Off	On	Off
2	On	Off	Off	Off
3	On	Off	Off	On
4	Off	Off	Off	On
5	Off	On	Off	On
6	Off	On	Off	Off
7	Off	On	On	Off
8	Off	Off	On	Off
1	On	Off	On	Off

Table 12. The driving circuit and driving signals for half-step driving

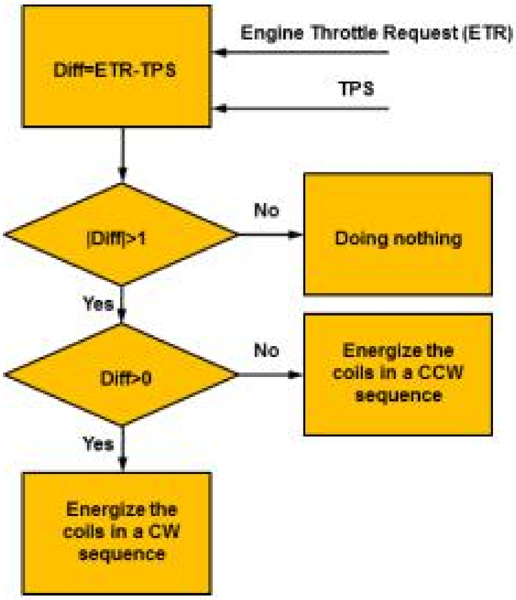


Figure 22. The flowchart for the determination of coil driving signals of the stepper motor

Engine Throttle Request minus Throttle Position Sensor equals the difference (Diff).

|Diff| < 1 = No change. (The motor continues to stay Off or On in it's previous direction.)

Diff > 0, leads to Stepper motor rotation in clockwise direction. Diff < 0, leads to Stepper motor rotation in anti-clockwise direction.

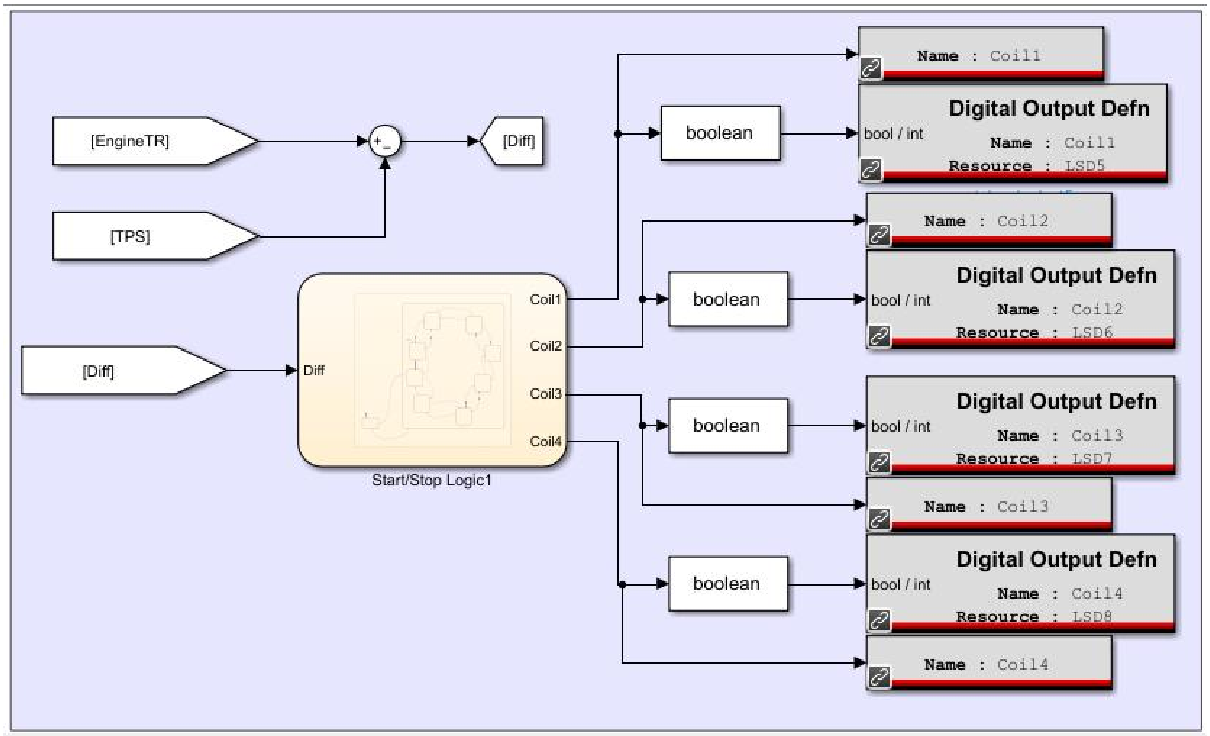


Figure 23. Stepper motor Stateflow model

Step 1 is the default transition state and with Diff grater than 0, execution occurs in the order of Step 1-2-3-4-5-6-7-8-1 and Diff lesser than 0 leads to Step 1-8-7-6-5-4-3-2-1.

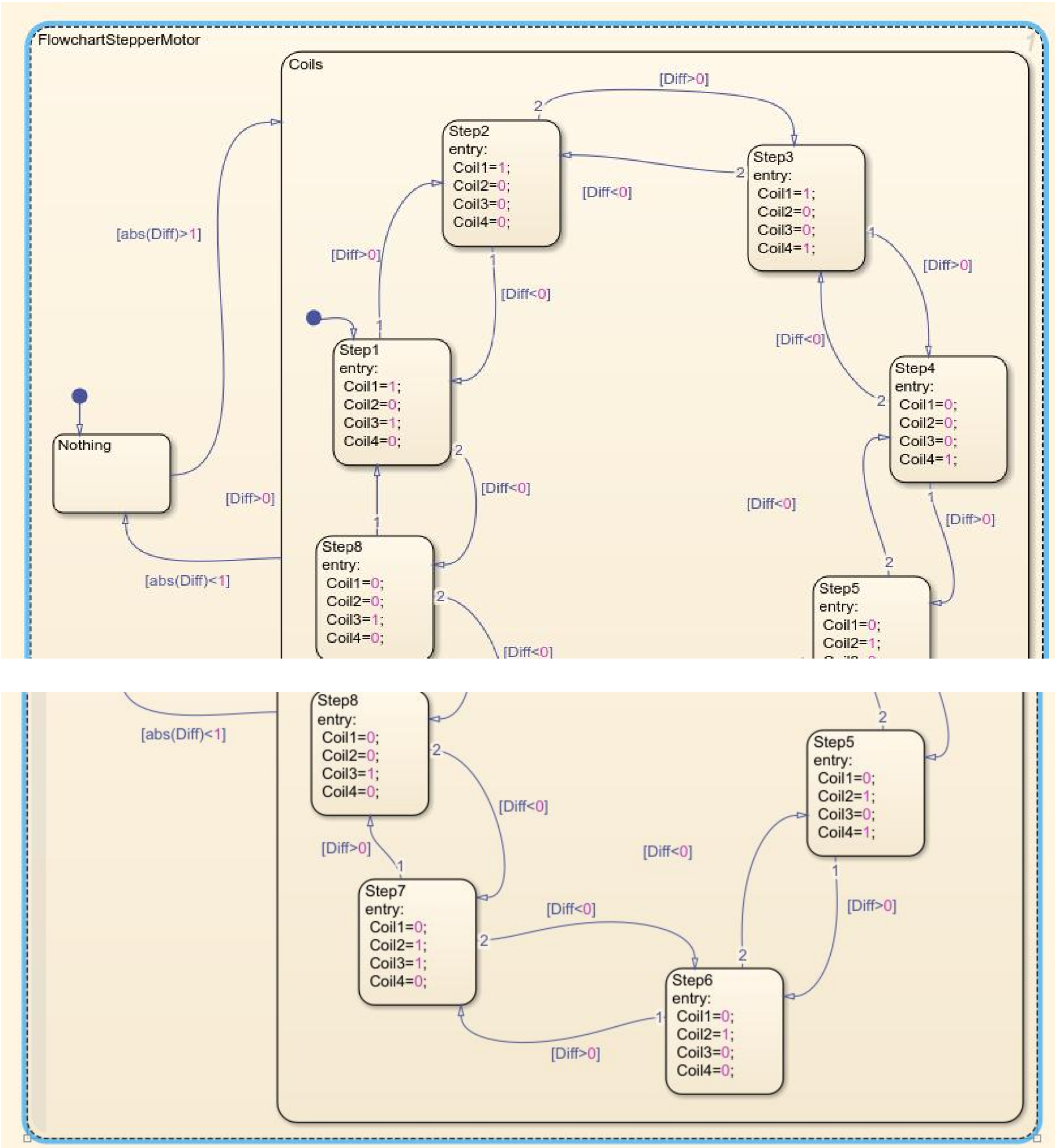


Figure 24. Stepper motor Stateflow logic

3 Calibration (Task 2)

As mentioned above, this project consists on 5 Digital inputs and 4 Analog inputs. The 5 Digital inputs are Boolean or ON and OFF switches. They are set by lifting the leaver all the way up and controlling the switch. Hence they do not require calibration.

On the other hand, Analog signals require calibration similar to all the previous labs performed. For example, in case of Acceleration Pedal Position, the count ranges from 0 to 1023 which is converted to 0 to 5 Volts, which is intern converted to 0 to 100 percent. While in the case of Average Engine RPM (AngEngineRPM), 0 to 5 Volts need to be calibrated to 10 to 3000 RPM. Similarly for Vehicle Velocity, 0 to 5 volts need to be converted to 0 to 19 MPH. The 2 figures below show the lowest and the highest value of analog inputs after calibration.

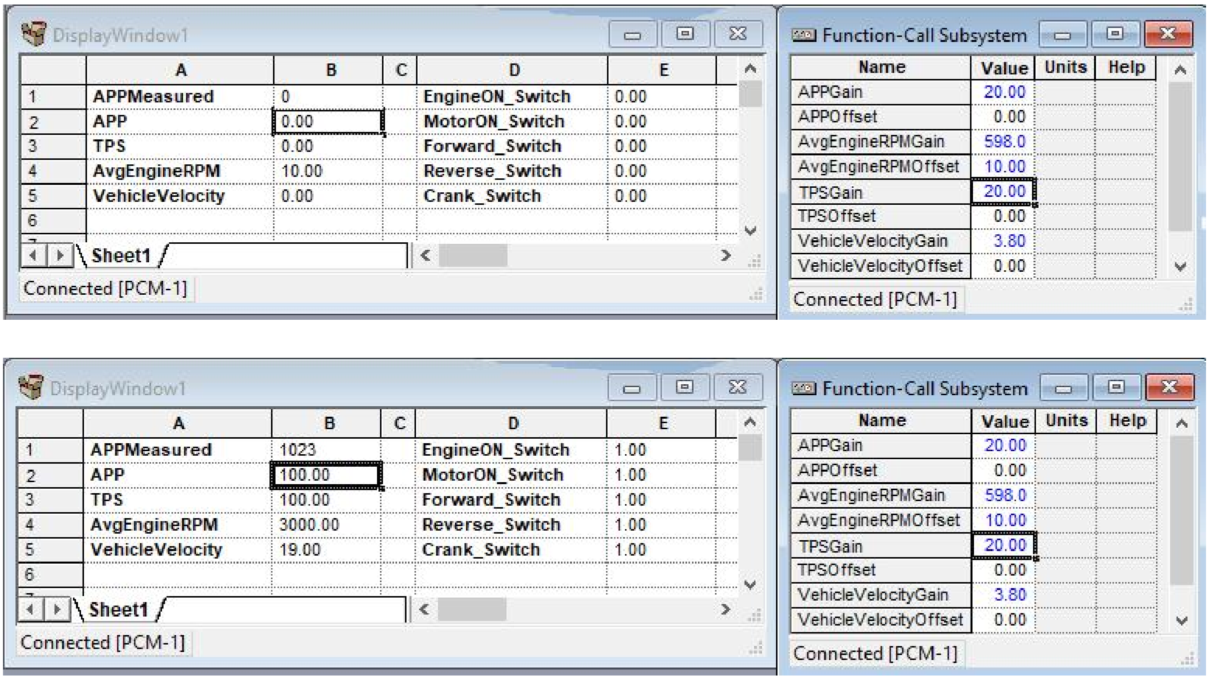


Figure 25. MotoTune Input Signals Calibration

- APP Calibration is shown below:

  $y = (G \times x) + O$

  where G is gain and O is offset.

  Two equations are formed,

  $0 = (G \times 0) + O$

  $100 = (G \times 5) + O$

  On solving, $G = 20$ and $O = 0$.

Experimentally verified, APP achieved good of calibration at $G = 20$ and $O = 0$.

- TPS Calibration is shown below:

  $y = (G \times x) + O$

  where G is gain and O is offset.

  Two equations are formed,

  $0 = (G \times 0) + O$

  $100 = (G \times 5) + O$

  On solving, $G = 20$ and $O = 0$.

  Experimentally verified, TPS achieved good of calibration at $G = 20$ and $O = 0$.

- AvgEngineRPM Calibration is shown below:

  $y = (G \times x) + O$

  where G is gain and O is offset.

  Two equations are formed,

  $10 = (G \times 0) + O$

  $3000 = (G \times 5) + O$

  On solving, $G = 598$ and $O = 10$.

Experimentally verified, AvgEngineRPM achieved good of calibration at $G = 598$ and $O = 10$.

- VehicleVelocity Calibration is shown below:

  $y = (G \times x) + O$

  where G is gain and O is offset.

  Two equations are formed,

  $0 = (G \times 0) + O$

  $19 = (G \times 5) + O$

  On solving, $G = 3.8$ and $O = 0$.

Experimentally verified, AvgEngineRPM achieved good of calibration at $G = 3.8$ and $O = 0$.

4 Validation of the Driving mode model (Task 3)

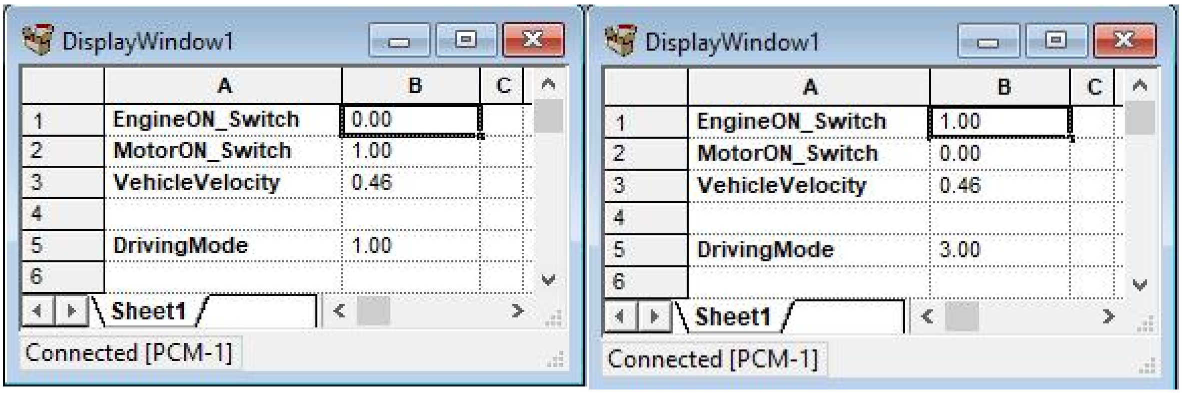


Figure 26. Driving Mode 1 and 3 Verification

As explained earlier, Driving mode is set to 1 (Electric Solo Mode) when the EngineON_Switch is Off and the MotorON_Switch is On and Velocity is less than 1 mph. Driving mode is set to 3 (Engine Solo Mode) when the EngineON_Switch is On and the MotorON_Switch is Off and Velocity is less than 1 mph.

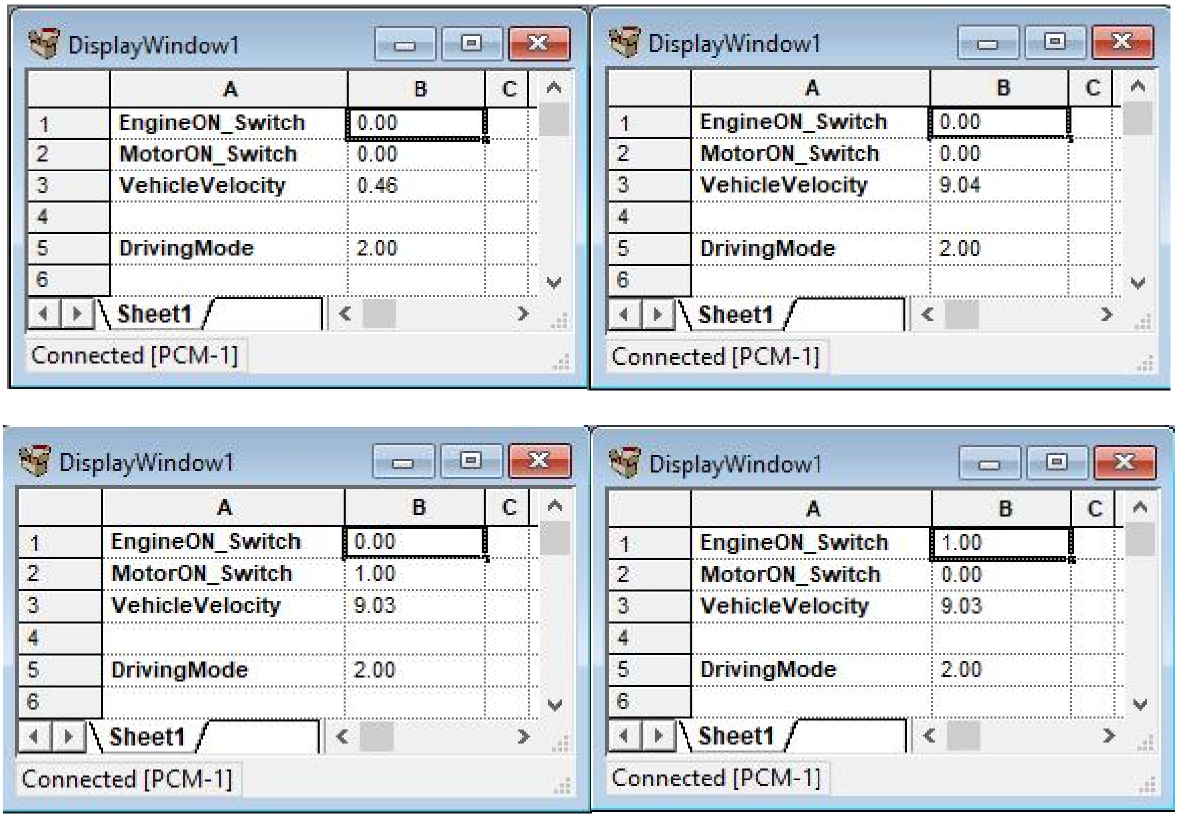
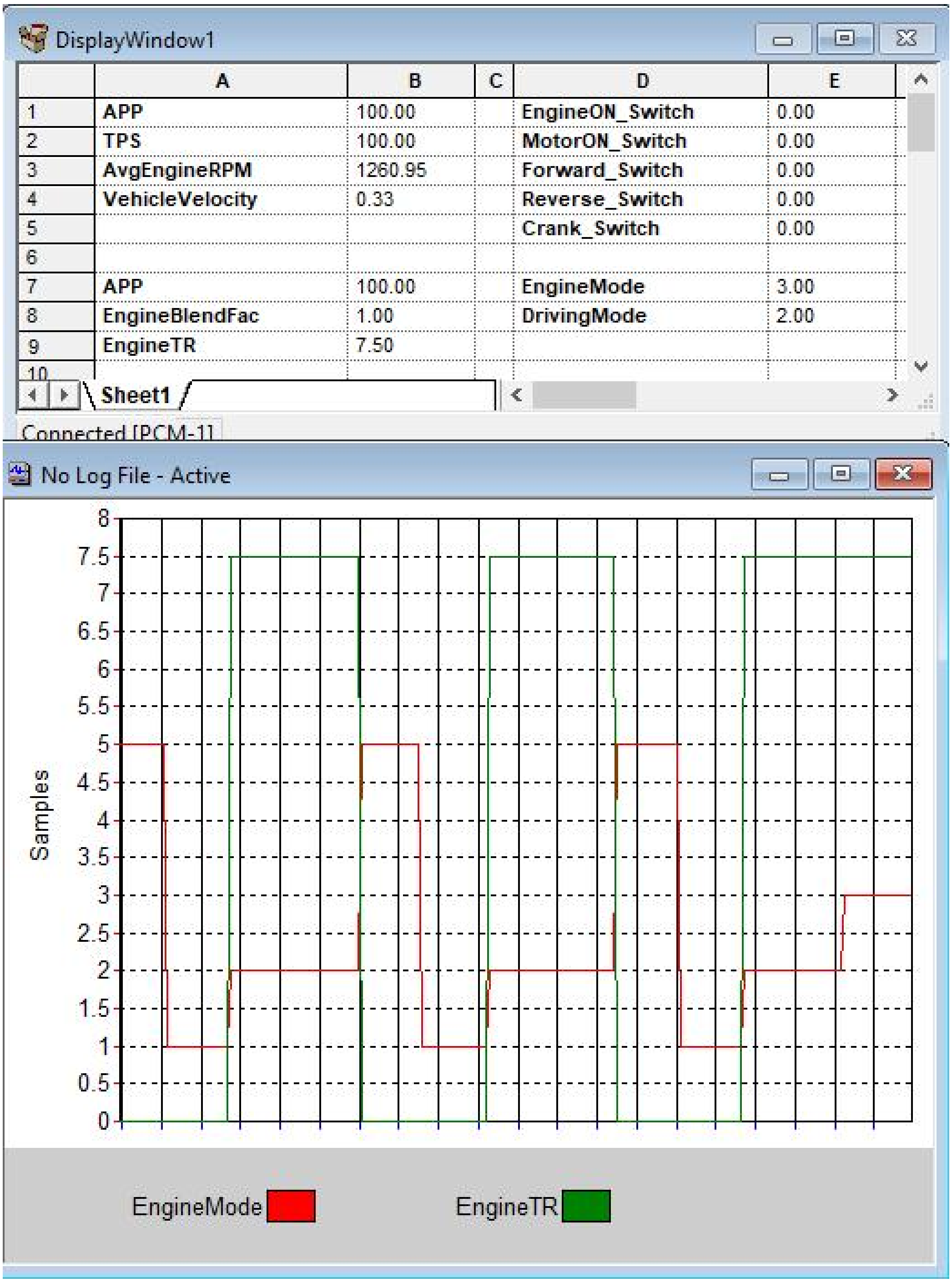


Figure 27. Driving Mode 2 Verification

Driving mode is set to 2 (Blending Mode) when the EngineON_Switch is Off and the MotorON_Switch is Off and Velocity is less than 1 mph. Once we are in Blending mode, increasing velocity did not effect the Driving mode (not even changing the Switches).

5 Validation of the Engine state logic model (Task 4)

There are a total of 5 Engine States with 3 possible transition paths. Path 1 being Engine state 1-2-3-4-1, path 2 being 1-2-3-5-1 and path 3 being 1-2-5-1. The below figures show verify these exact paths. These states or paths can be achieved by varying the values of Engine Kill, Engine Crank and Avg Engine RPM.



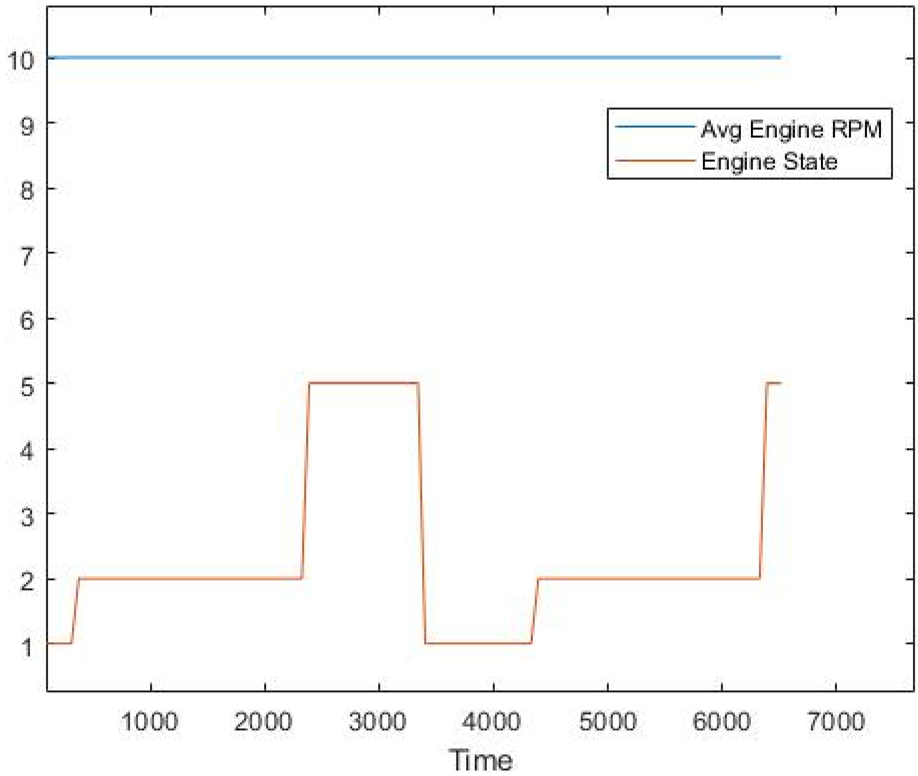
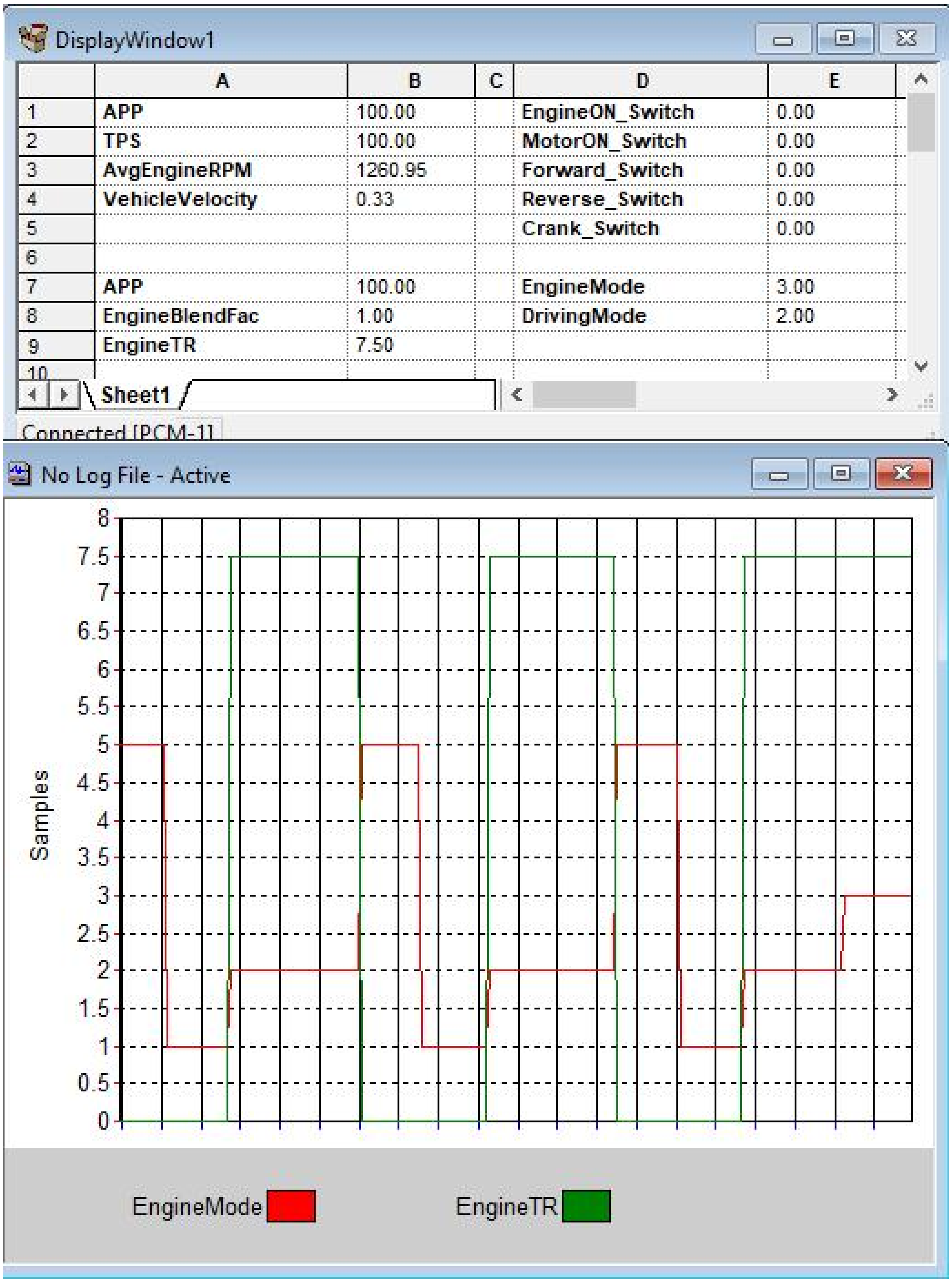


Figure 28. Engine State 1-2-5-1


DisplayWindow1
A
B
C
D
E
1 APP 100.00 EngineON_Switch 0.00
2 TPS 100.00 MotorON_Switch 0.00
3 AvgEngineRPM 1260.95 Forward_Switch 0.00
4 VehicleVelocity 0.33 Reverse_Switch 0.00
5 Crank_Switch 0.00
6
7 APP 100.00 EngineMode 3.00
8 EngineBlendFac 1.00 DrivingMode 2.00
9 EngineTR 7.50
10
Sheet1
Connected [PCM-1]
No Log File - Active
Samples
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
EngineMode
EngineTR

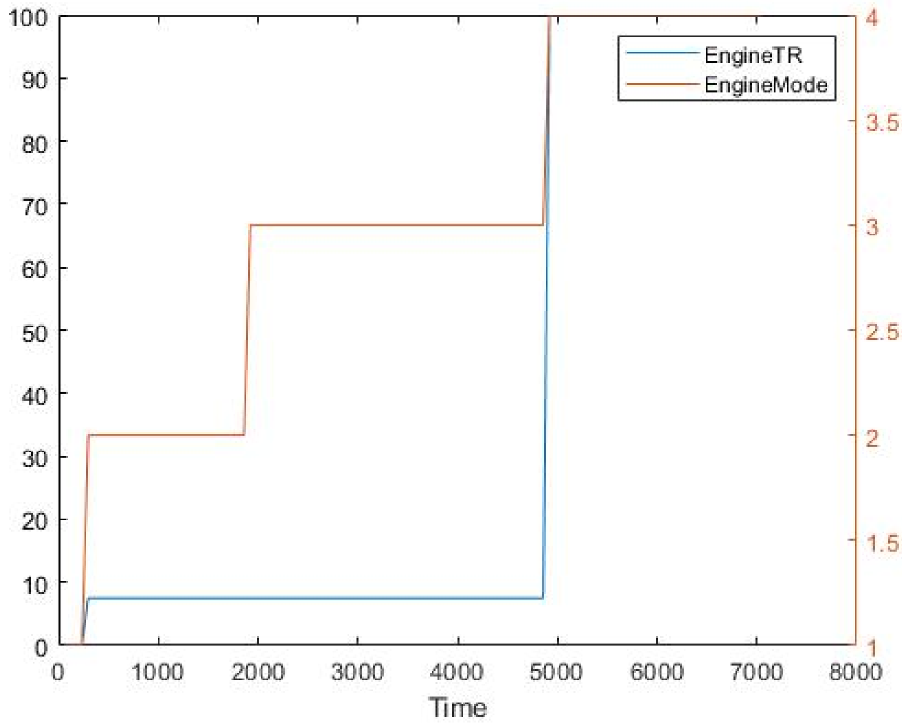


Figure 29. Engine State 1-2-3-4-1

6 Validation of the engine start/stop (Task 5)

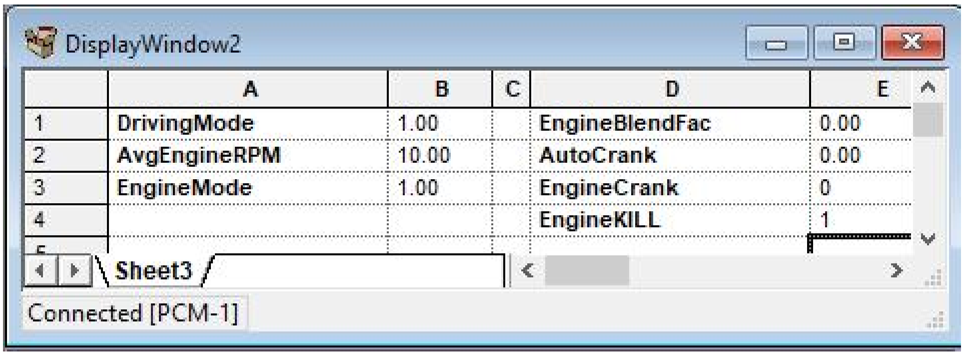
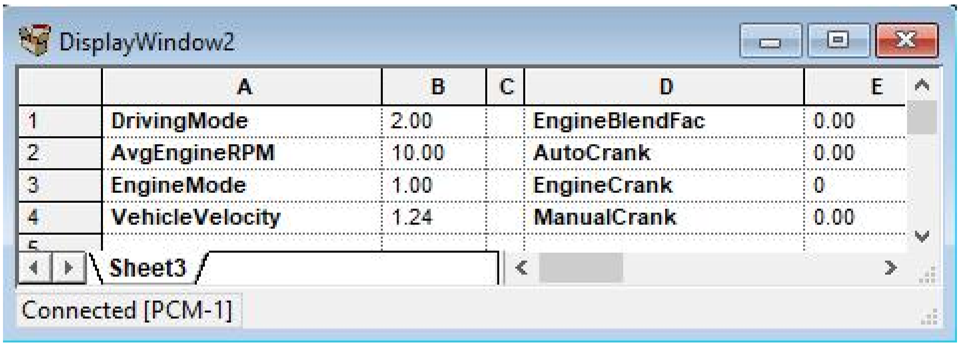
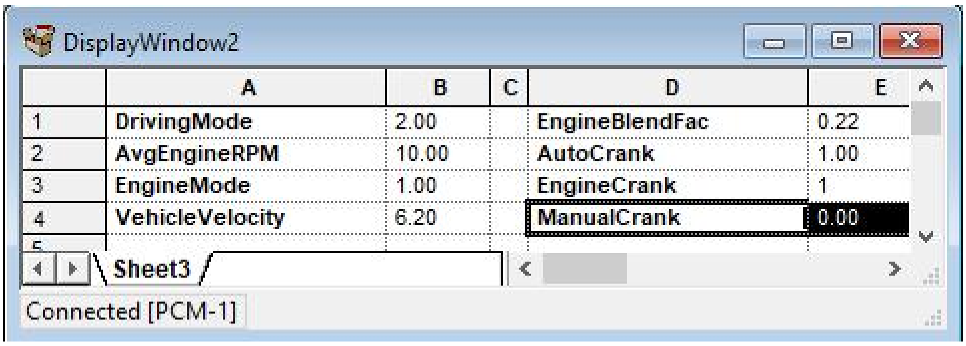


Figure 30. Driving mode 1 Engine Crank Off Verification

When in Driving mode 1 (Electric solo mode), Engine is Off and EngineKill is On.





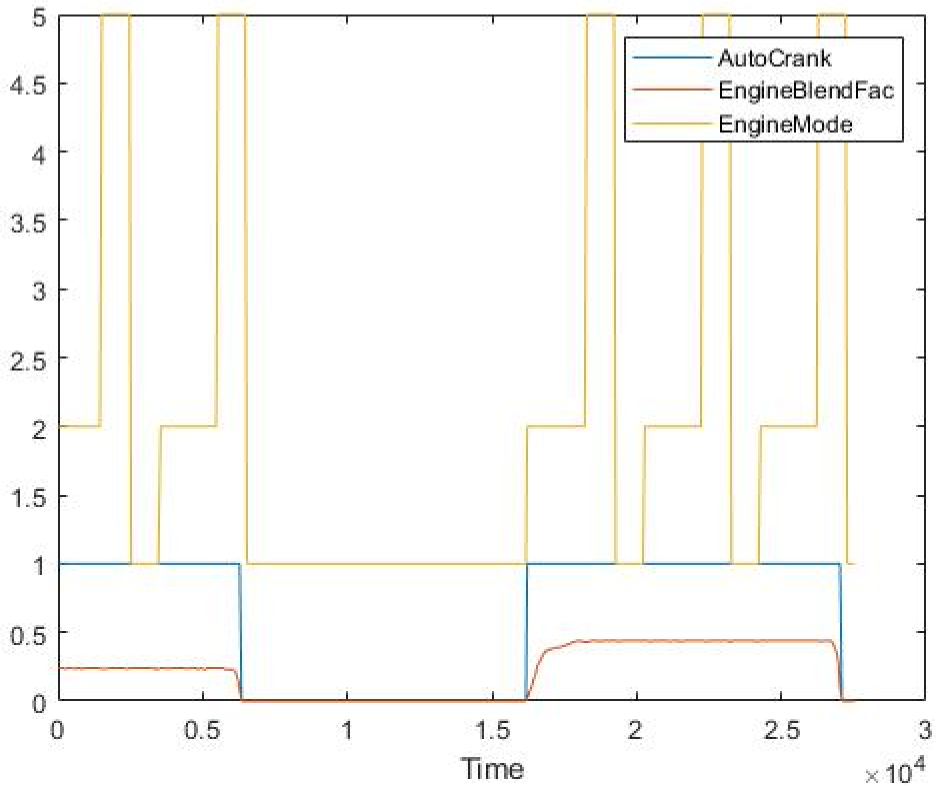


Figure 31. AutoCrank in Blending Mode

As represented in the figures above, Manual crank cannot be used in Blending mode, while Auto crank can be but only when blend factor is grater than 0.01.

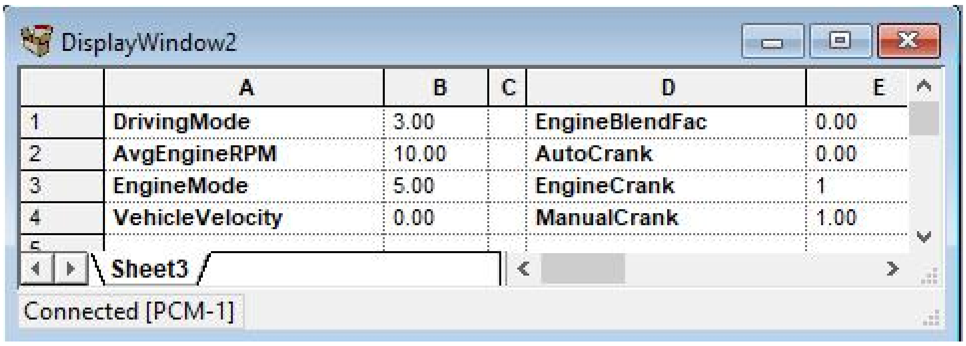
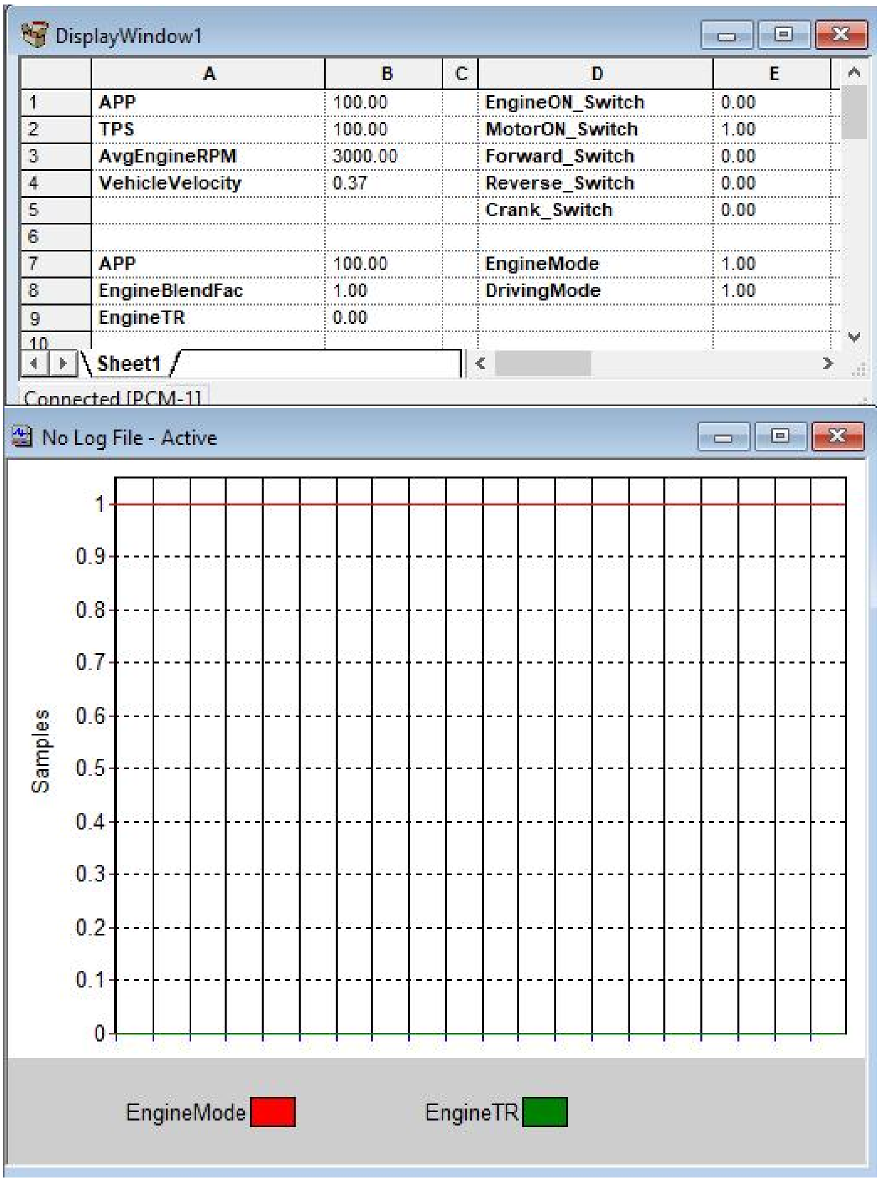


Figure 32. Manual Crank in Driving mode 3

Only manual crank can be used in the Engine solo mode.

7 Validation of Engine throttle request (Task 6)

The Figure below validates Engine Torque request for driving mode 1. As explained previously, EngineTR is 0 irrespective of the Engine State in Driving mode 1. The same thing can be noticed below.



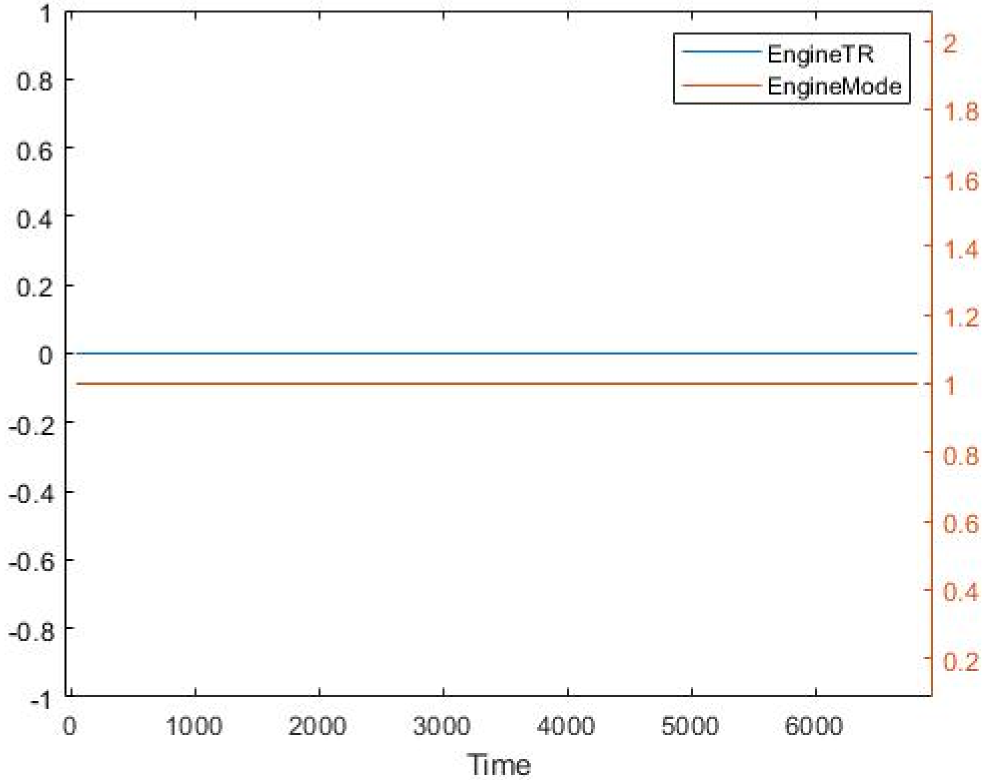
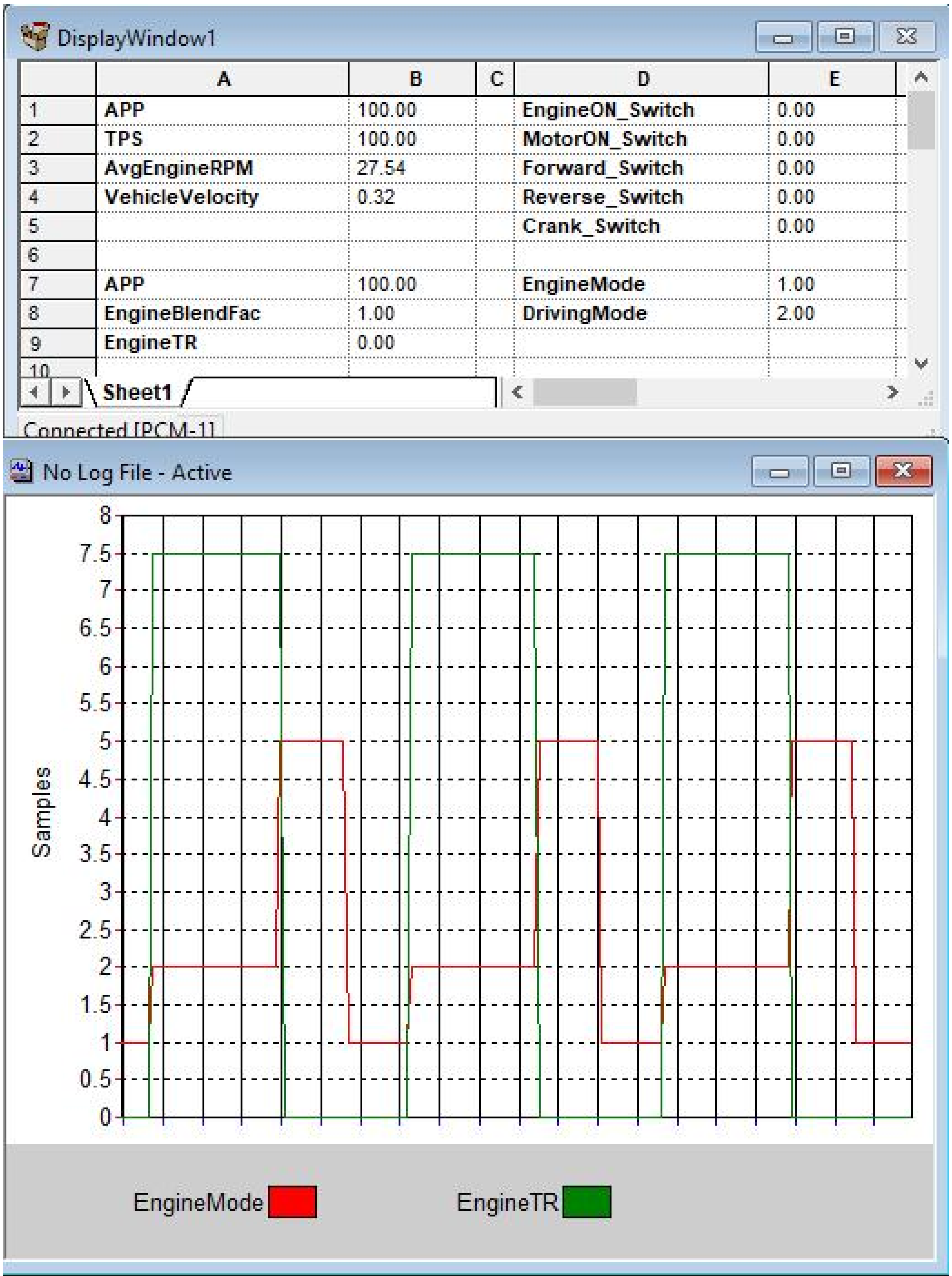


Figure 33. Engine TR Validation for Driving Mode 1

The Figures below validates Engine Torque request for driving mode 2. As explained previously, EngineTR is 7.5 in Engine State 2 and 3 in Driving mode 2. Also EngineTR is 0 in Engine State 1 and 5 in Driving mode 2. EngineTR is APP times EngineBlendFac in Engine State 4 in Driving mode 2. The same thing can be noticed below.


DisplayWindow1
A
B
C
D
E
1
APP
100.00
EngineON_Switch
0.00
2
TPS
100.00
MotorON_Switch
0.00
3
AvgEngineRPM
27.54
Forward_Switch
0.00
4
VehicleVelocity
0.32
Reverse_Switch
0.00
5
Crank_Switch
0.00
6
7
APP
100.00
EngineMode
1.00
8
EngineBlendFac
1.00
DrivingMode
2.00
9
EngineTR
0.00
10
Sheet1
Connected [PCM-1]
No Log File - Active
Samples
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
EngineMode
EngineTR

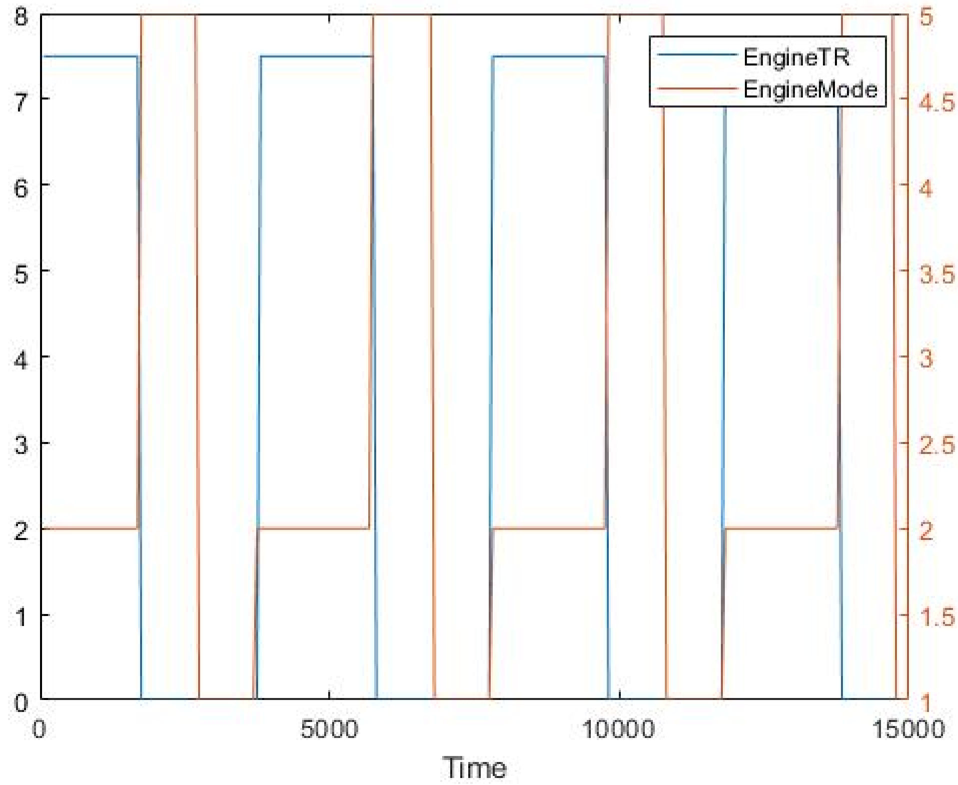
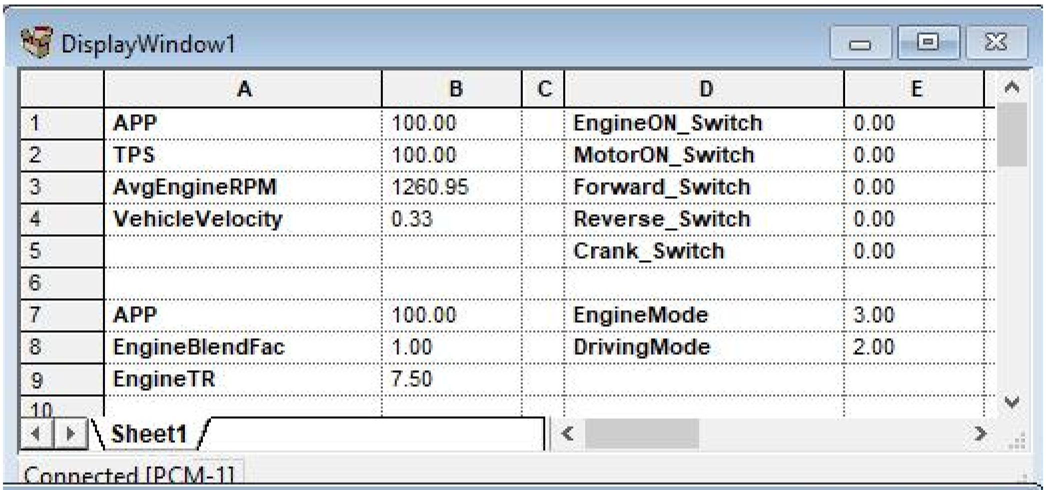


Figure 34. Engine TR Validation for Driving Mode 2 Engine state 1 and 5

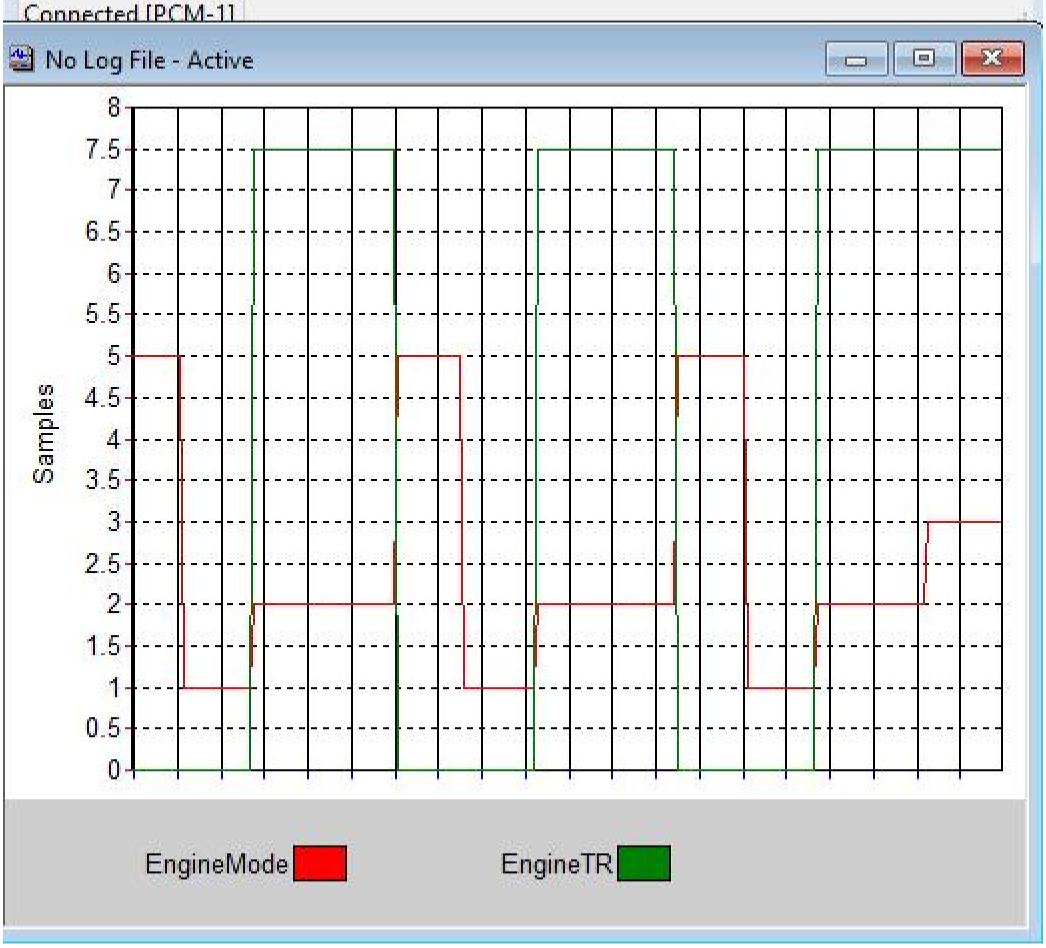


DisplayWindow1

	A	B	C	D	E
1	APP	100.00		EngineON_Switch	0.00
2	TPS	100.00		MotorON_Switch	0.00
3	AvgEngineRPM	1260.95		Forward_Switch	0.00
4	VehicleVelocity	0.33		Reverse_Switch	0.00
5				Crank_Switch	0.00
6					
7	APP	100.00		EngineMode	3.00
8	EngineBlendFac	1.00		DrivingMode	2.00
9	EngineTR	7.50			
10					

Sheet1

Connected [PCM-1]



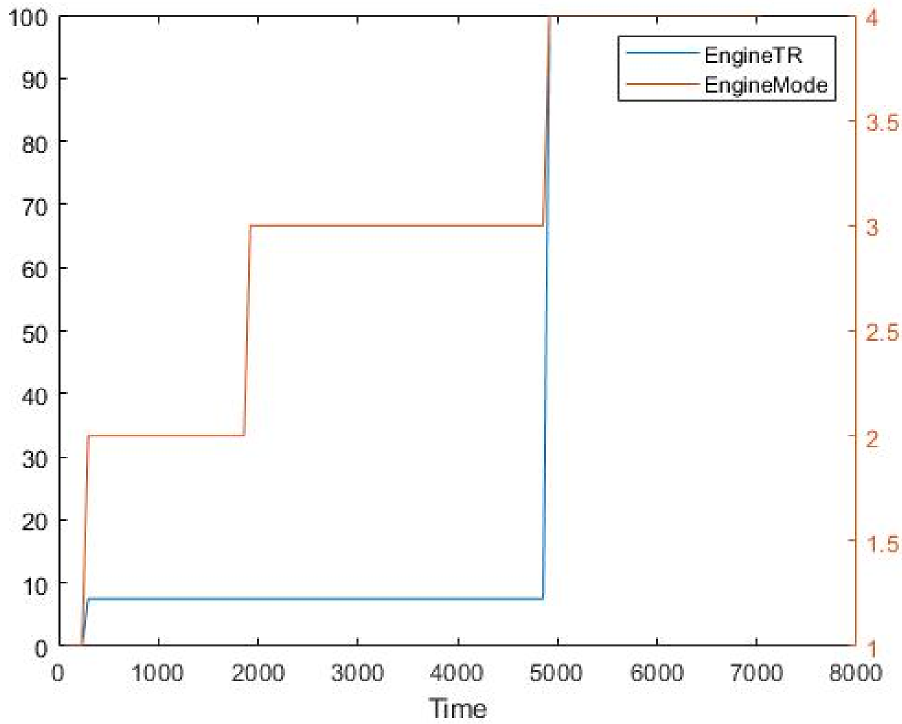
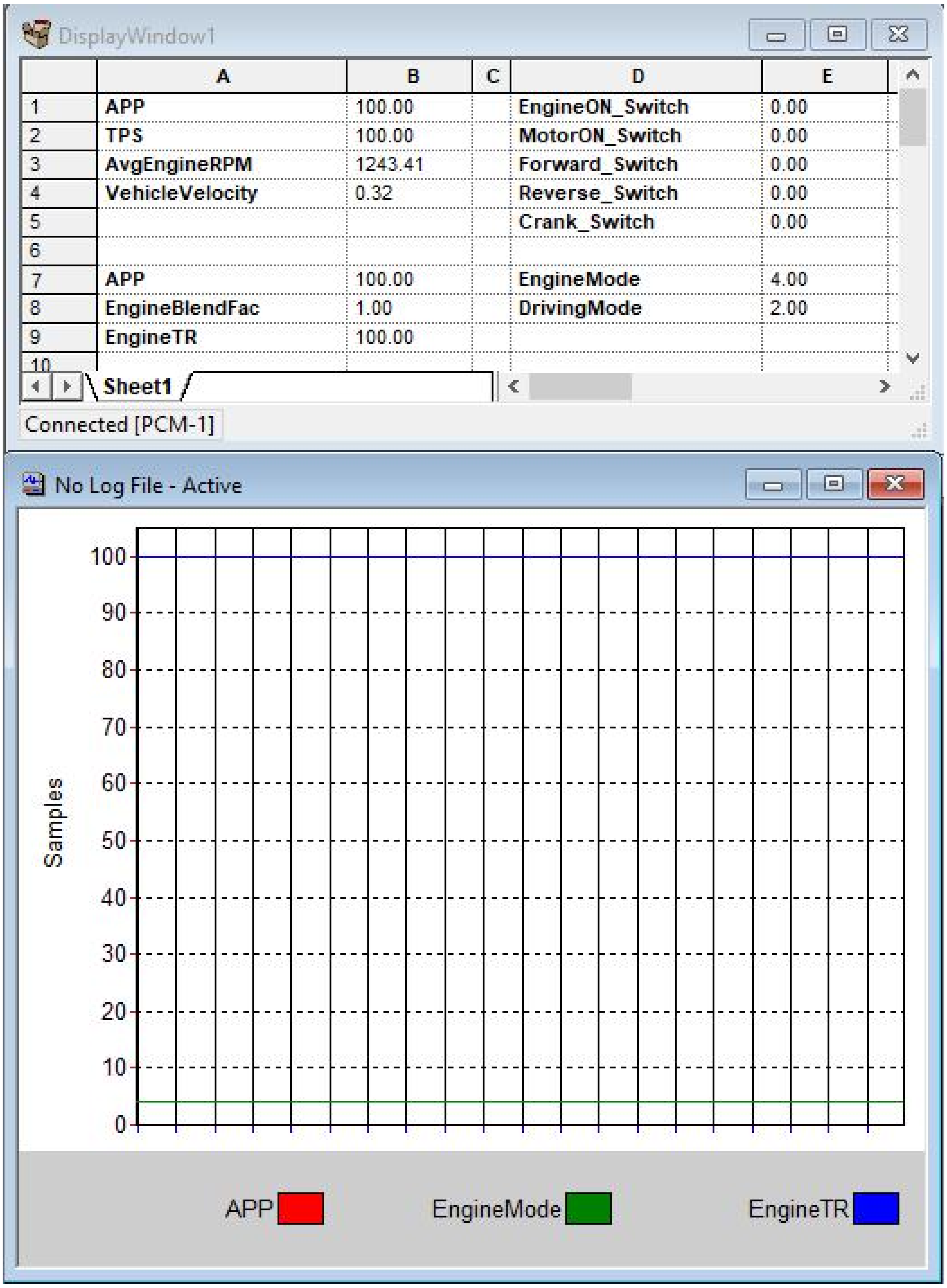


Figure 35. Engine TR Validation for Driving Mode 2 Engine state 2 and 3



DisplayWindow1
A
B
C
D
E
1 APP 100.00 EngineON_Switch 0.00
2 TPS 100.00 MotorON_Switch 0.00
3 AvgEngineRPM 1243.41 Forward_Switch 0.00
4 VehicleVelocity 0.32 Reverse_Switch 0.00
5 Crank_Switch 0.00
6
7 APP 100.00 EngineMode 4.00
8 EngineBlendFac 1.00 DrivingMode 2.00
9 EngineTR 100.00
10
Sheet1
Connected [PCM-1]
No Log File - Active
Samples
100
90
80
70
60
50
40
30
20
10
0
APP
EngineMode
EngineTR

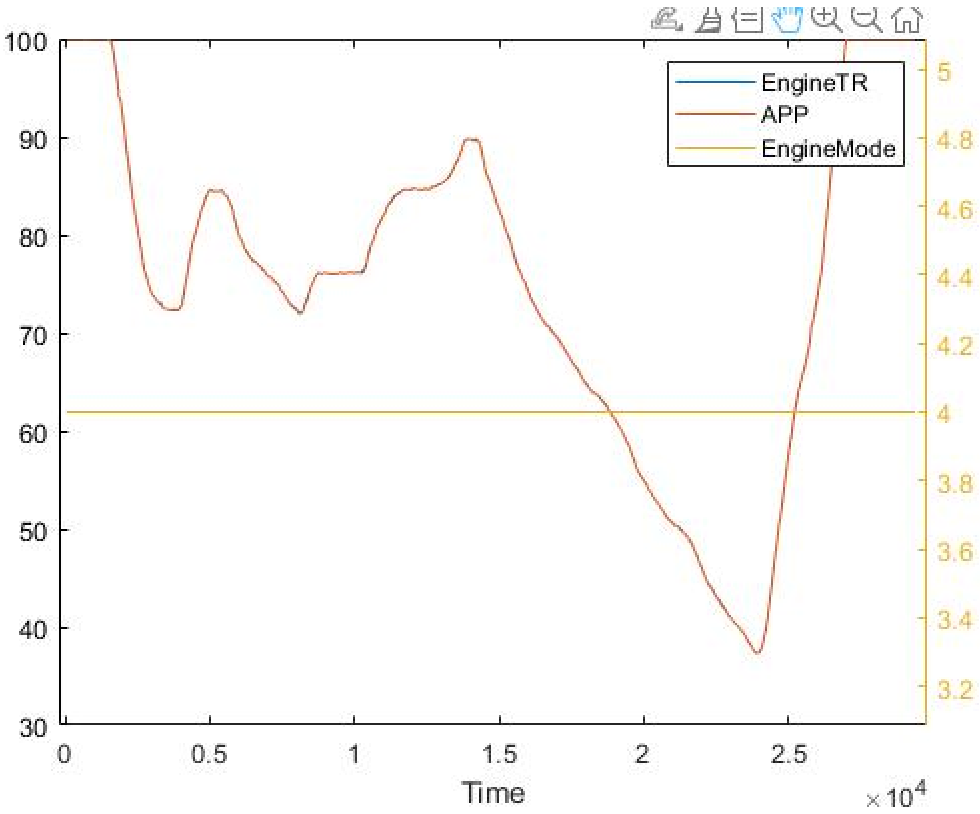
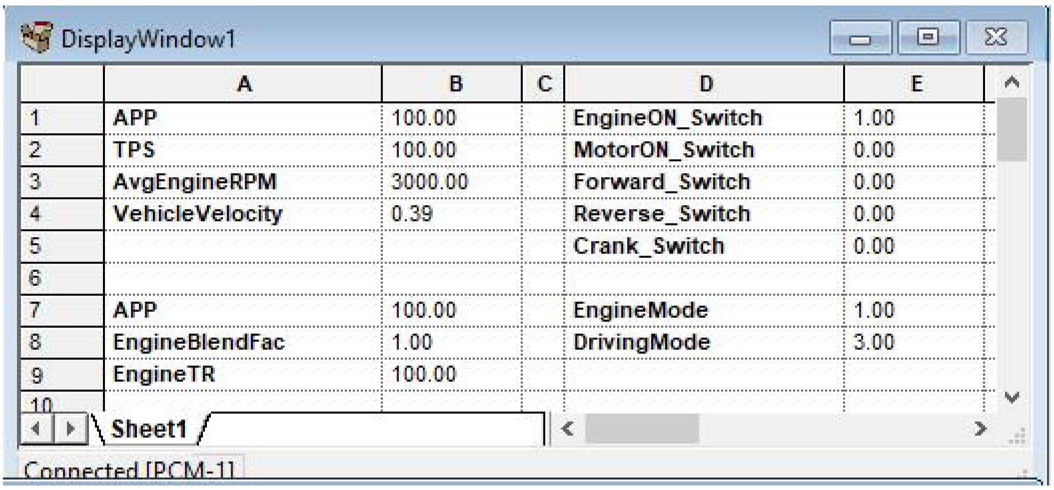


Figure 36. Engine TR Validation for Driving Mode 2 Engine state 4

The Figure below validates Engine Torque request for driving mode 3. As explained previously, EngineTR is equal to APP irrespective of the Engine State in Driving mode 3. The same thing can be noticed below.


DisplayWindow1

	A	B	C	D	E
1	APP	100.00		EngineON_Switch	1.00
2	TPS	100.00		MotorON_Switch	0.00
3	AvgEngineRPM	3000.00		Forward_Switch	0.00
4	VehicleVelocity	0.39		Reverse_Switch	0.00
5				Crank_Switch	0.00
6					
7	APP	100.00		EngineMode	1.00
8	EngineBlendFac	1.00		DrivingMode	3.00
9	EngineTR	100.00			
10					

Sheet1

Connected [PCM-1]

Figure 37. Engine TR Validation for Driving Mode 3

8 Validation of Motor Torque request (Task 7)

The Figures below validates Motor Torque request for all driving modes. As explained previously, MotorTR is equal to APP times MotorBlendFac irrespective of the Engine State or the Driving mode. The same thing can be noticed below for different combinations for Engine mode, Driving mode and blend factors.

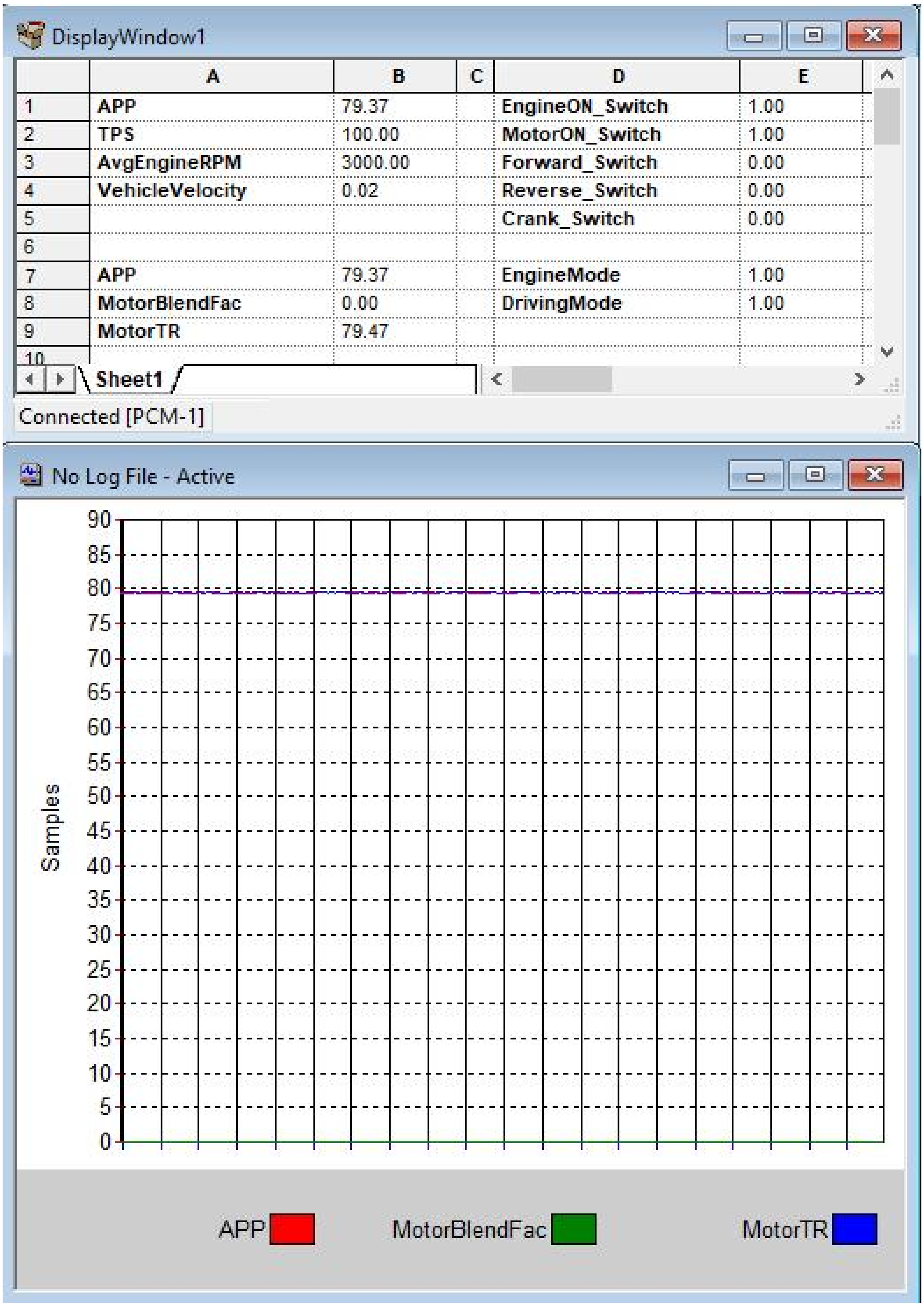


Figure 38. Motor TR Validation for Driving Mode 1

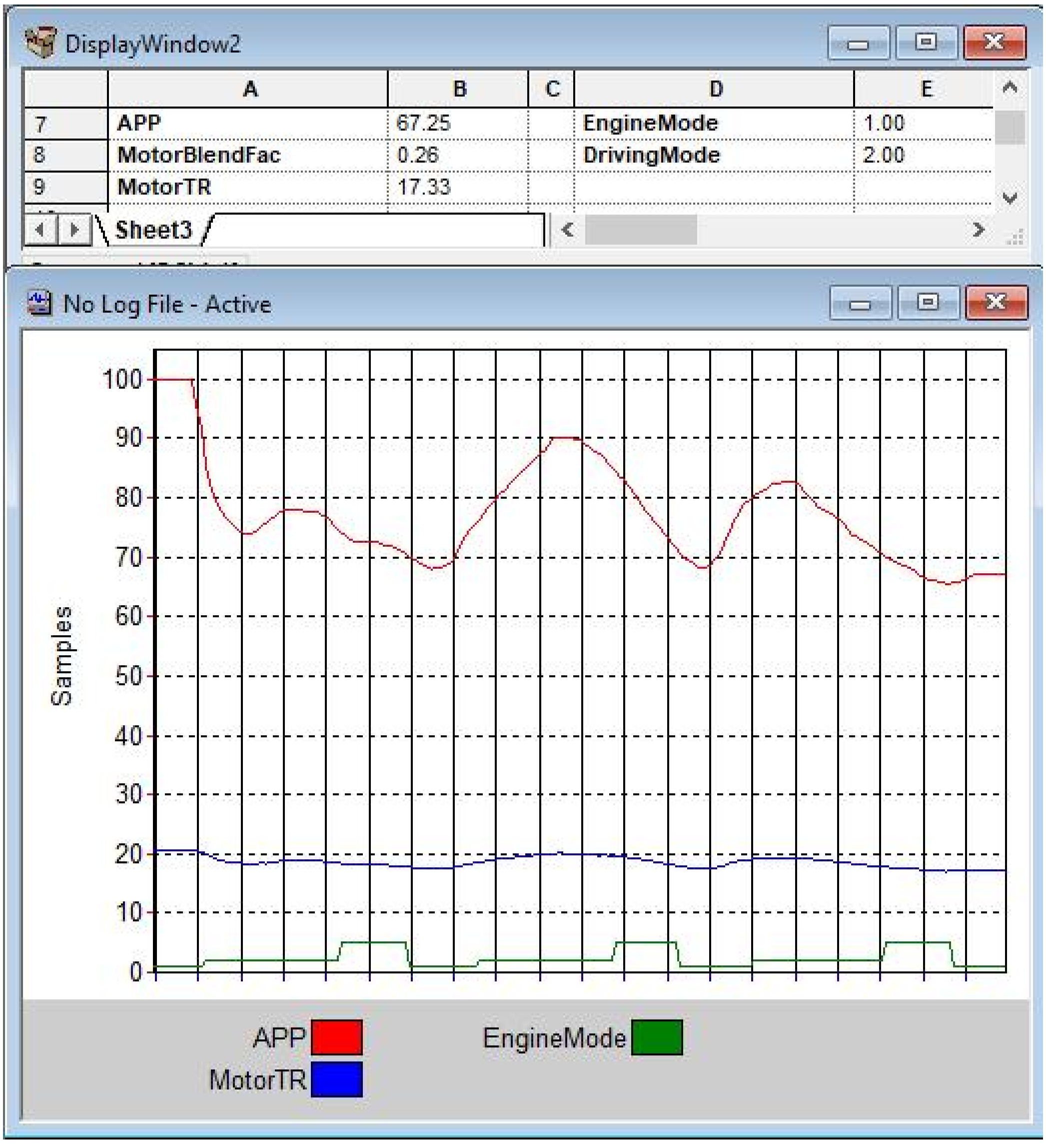


Figure 39. Motor TR Validation for Driving Mode 2 Engine Mode 1

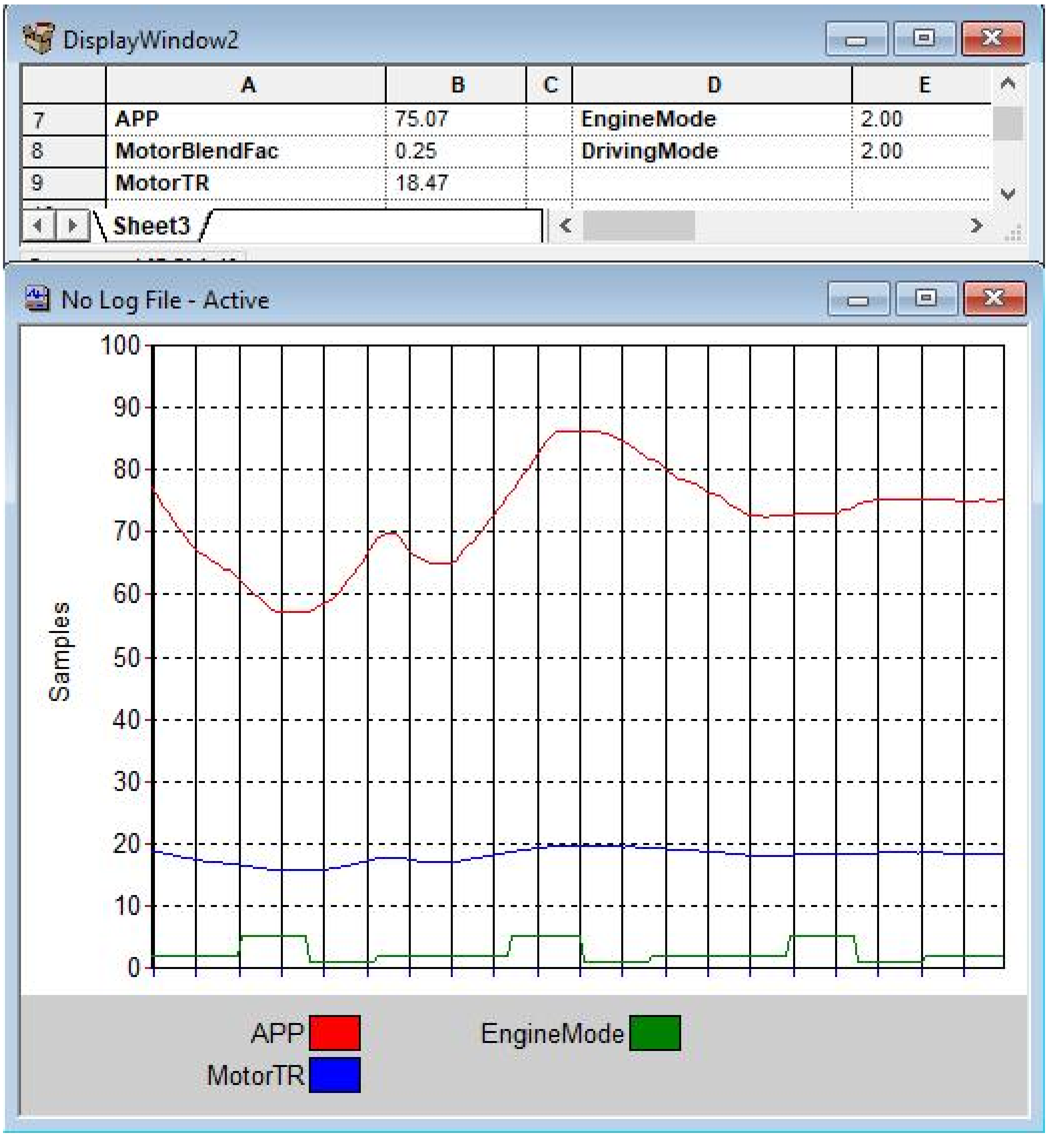


Figure 40. Motor TR Validation for Driving Mode 2 Engine Mode 2

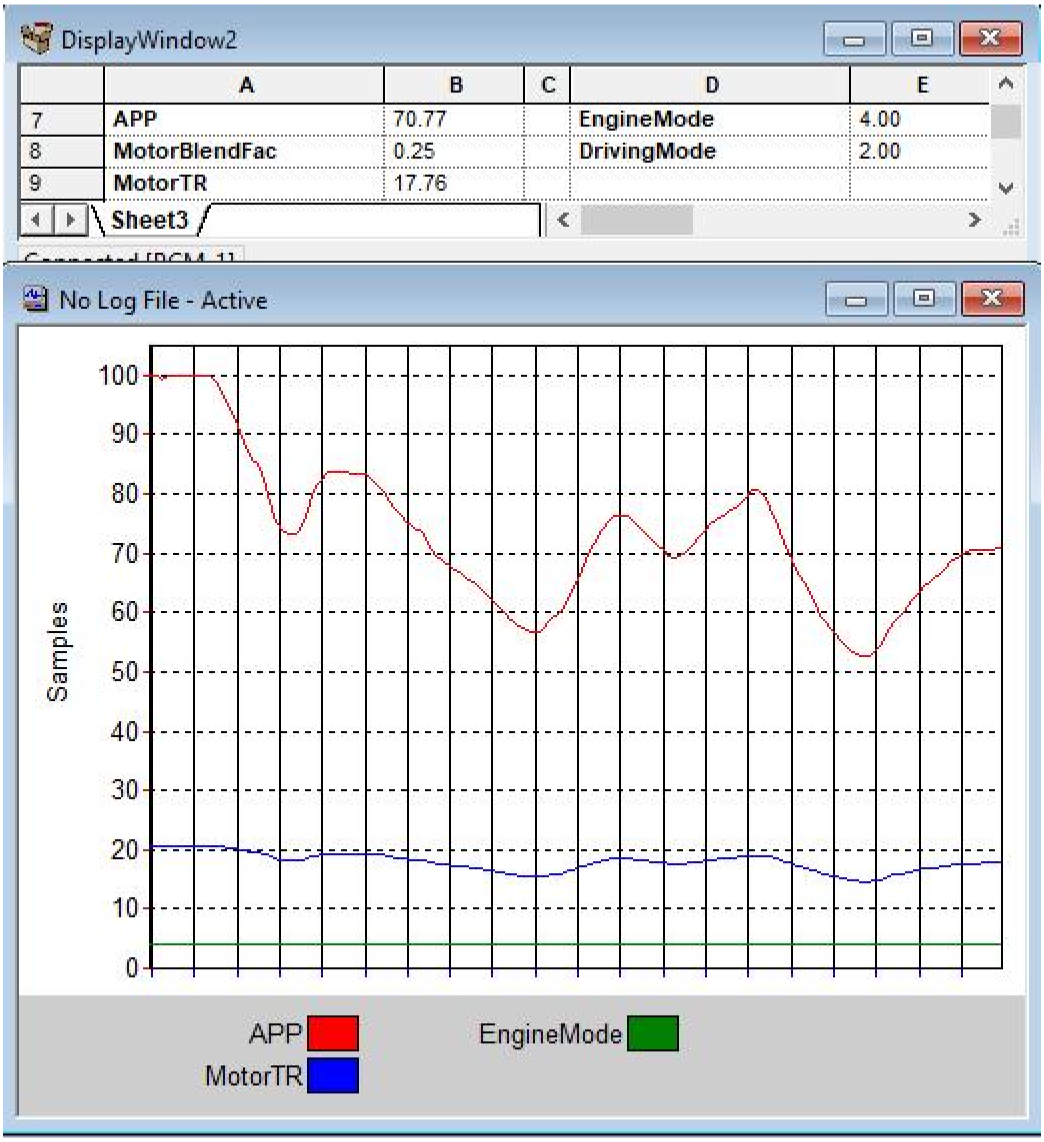


Figure 41. Motor TR Validation for Driving Mode 2 Engine Mode 4

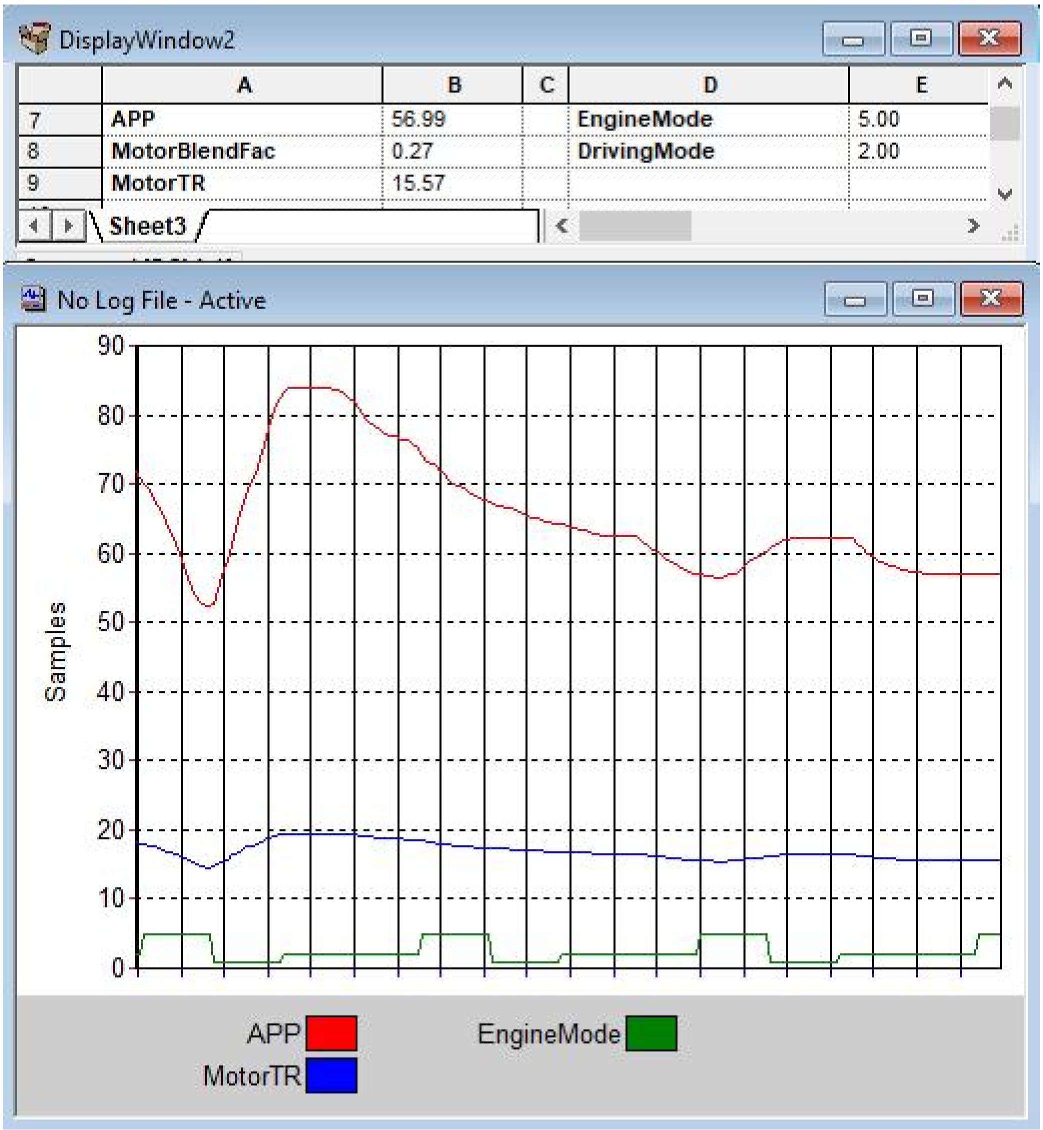


Figure 42. Motor TR Validation for Driving Mode 2 Engine Mode 5

The following figures show the desktop simulator connections for servo motor and oscilloscope. The yellow wire is connected to PWM Tacho pin, red is connected to 5V Power and brown to ground.

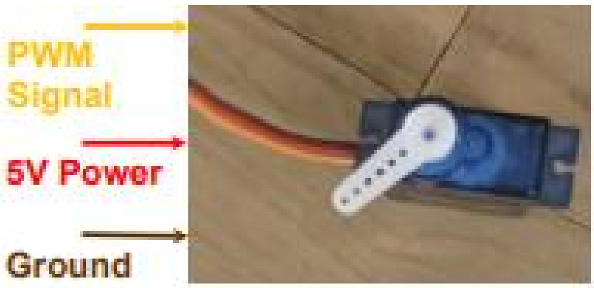


Figure 43. Servo Motor connections

The Table below is used for the MotorTR Calibration.

Calibration Value	Servo Rotation Angle (°)	Servo PWM Duty Cycle	Tachometer PMW Duty Cycle
Minimum E-motor Torque Request	0	0.05 (1ms/20ms)	0.95
Maximum E-motor Torque Request	90	0.1 (2ms/20ms)	0.90

Table 13. MotorTR Calibration

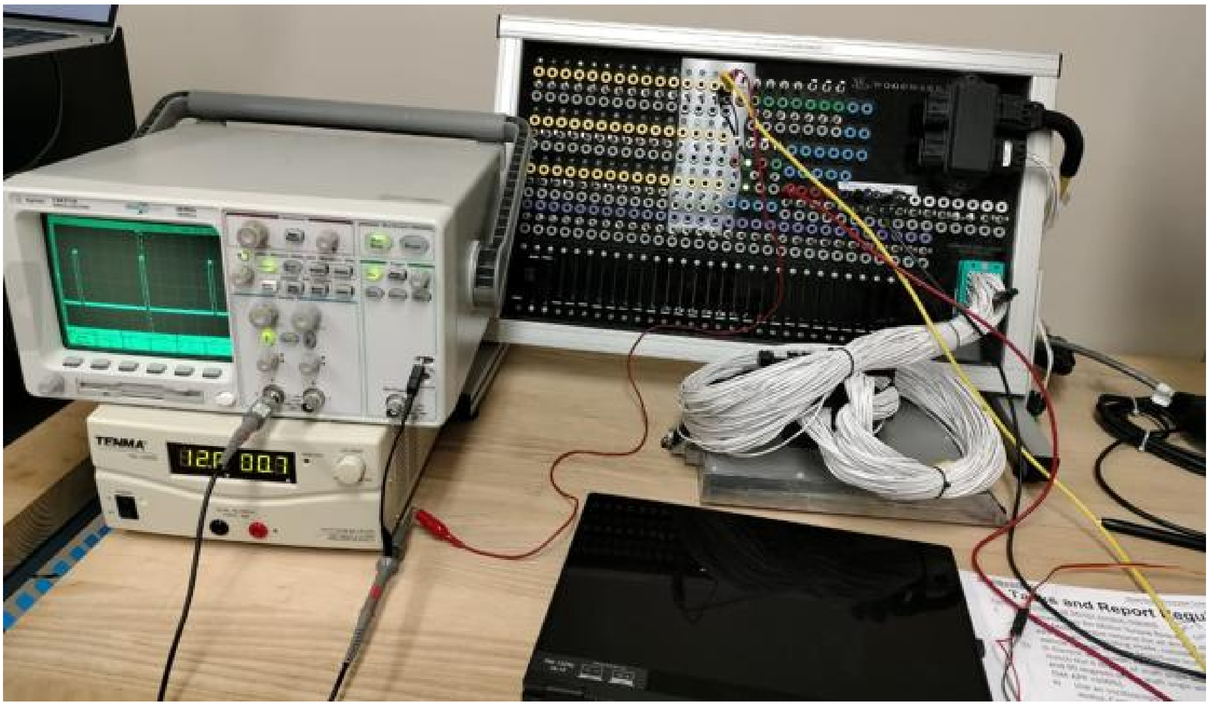


Figure 44. Servo and Oscilloscope Connections

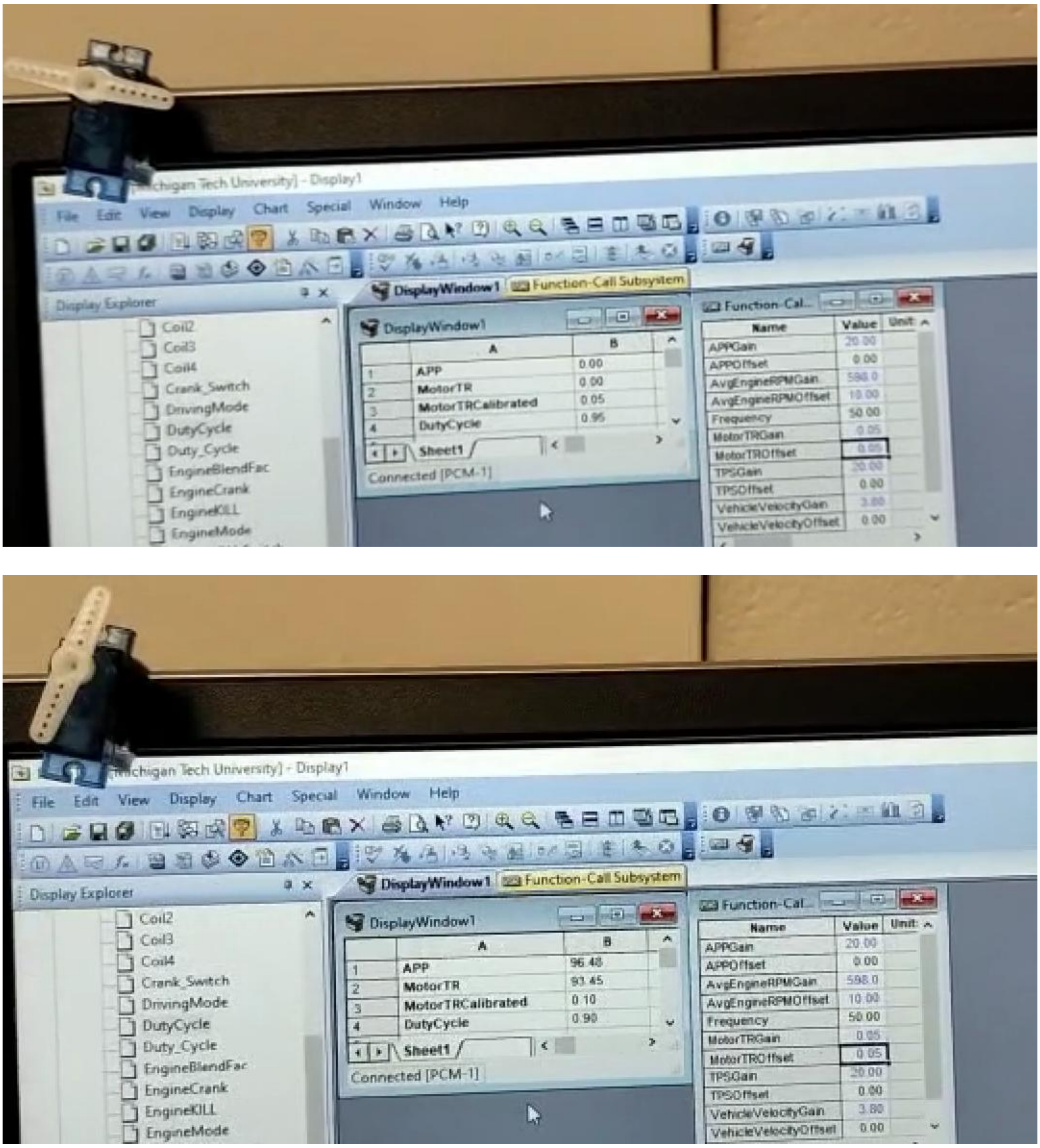
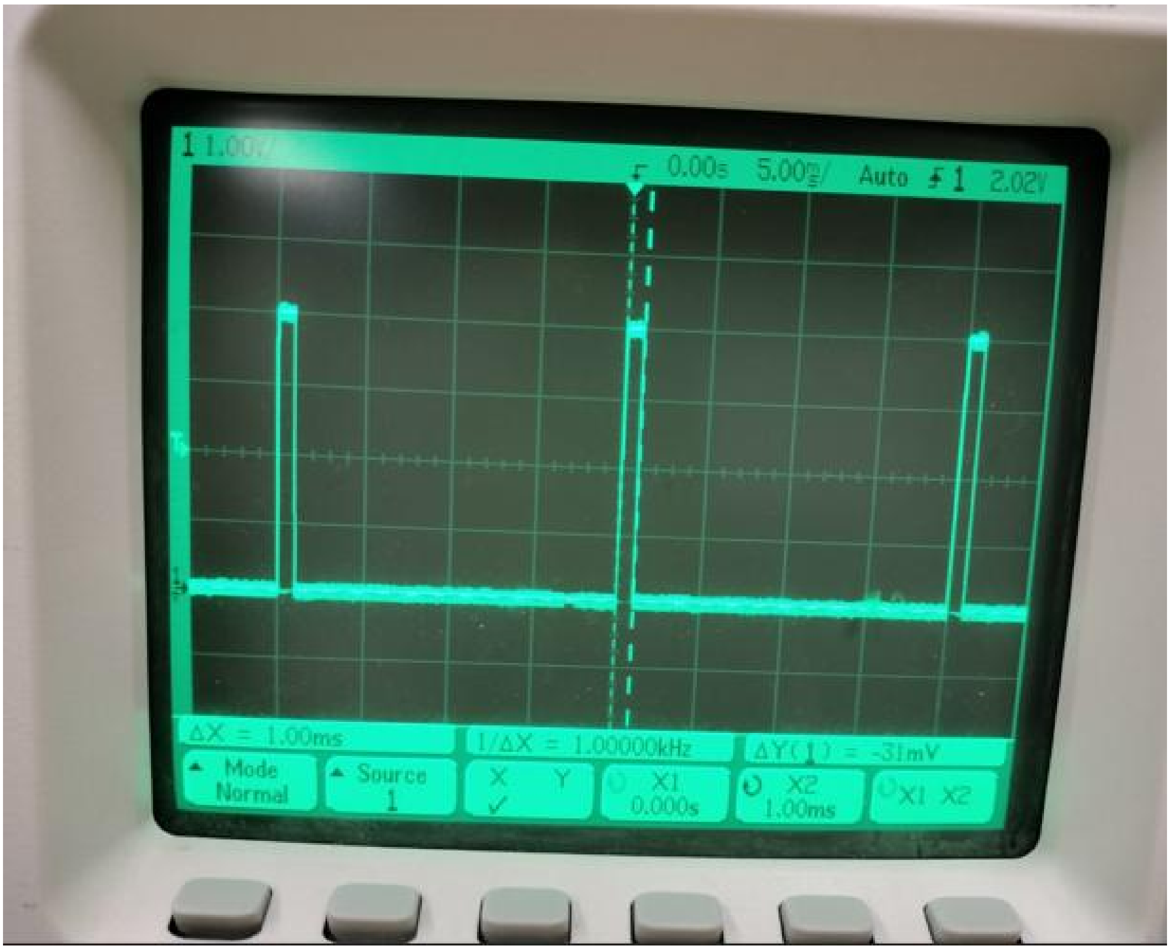


Figure 45. MotorTR calibration and change in duty cycle

Oscilloscope is used to show the change in the duty Cycle when the change in servo motor rotation angle. Please refer the Video for clear values and verification process.


1 1.00V/
0.00s 5.00ms/ Auto 1 2.02V
ΔX = 1.00ms
1/ΔX = 1.00000kHz
ΔY(1) = -31mV
Mode
Normal
Source
1
X Y
X1
0.000s
X2
1.00ms
X1 X2

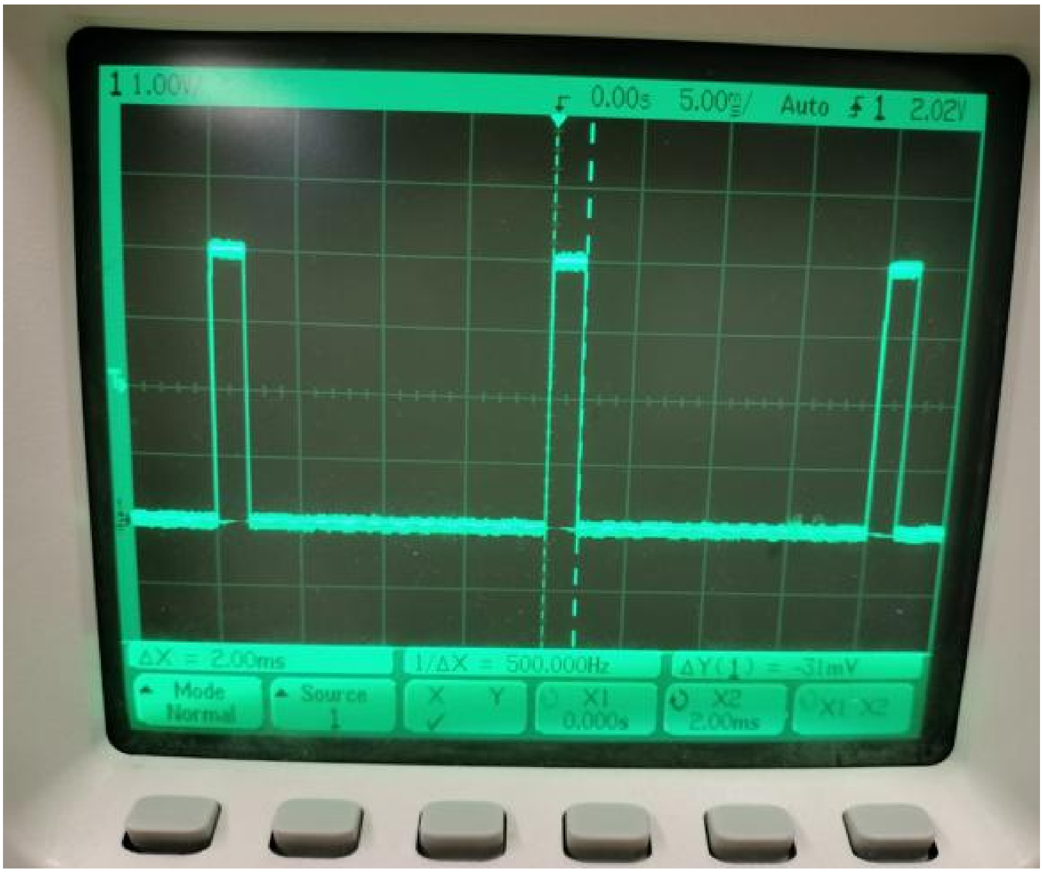


Figure 46. Oscilloscope Change in Duty cycle

9 Validation of E-motor start/stop model (Task 8)

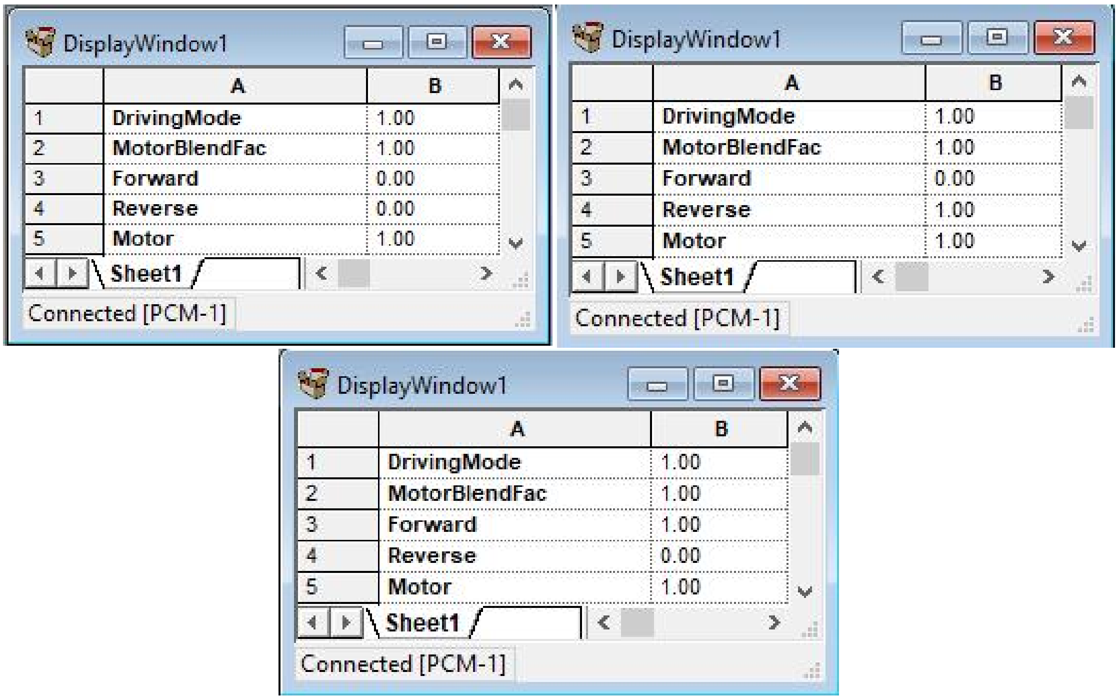


Figure 47. E-motor Start/Stop Validation for driving mode 1

In Electric Solo mode the Motor is always ON, but the direction changes based on the forward or reverse switch signal.

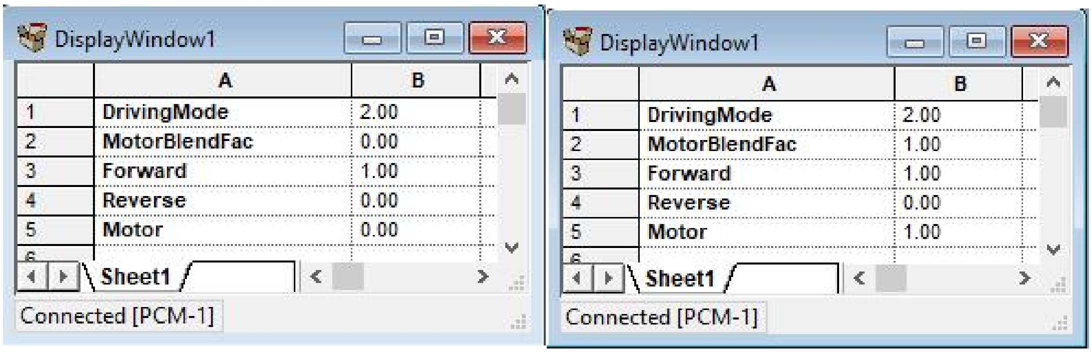


Figure 48. E-motor Start/Stop Validation for driving mode 2 with motor blend factor 0 and 1

In Blending mode the Motor is ON when motor blend factor is less than 0.01, but the direction is always forward.

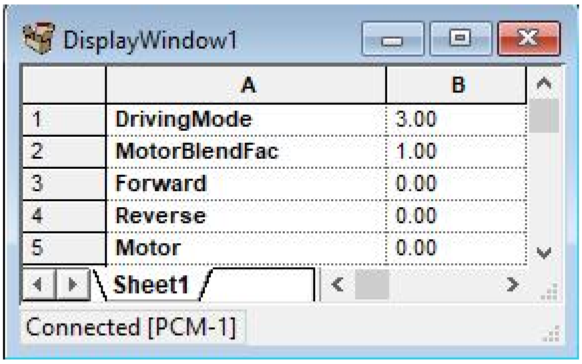


Figure 49. E-motor Start/Stop Validation for driving mode 3

In Engine Solo mode the Motor is always OFF. Since the motor is OFF, the direction will be OFF (0).

10 Validation of stepper motor driving model (Task 9)

The below Figure represents the connections for stepper motor. The stepper motor consists of 4 coils, 6 wires colored - Black, Yellow, Green, Red, White and Blue. The 4 coils are connected to LSD 5, 6,7 and 8 respectively. The +12 Volt wires are connected to XDRP pin.

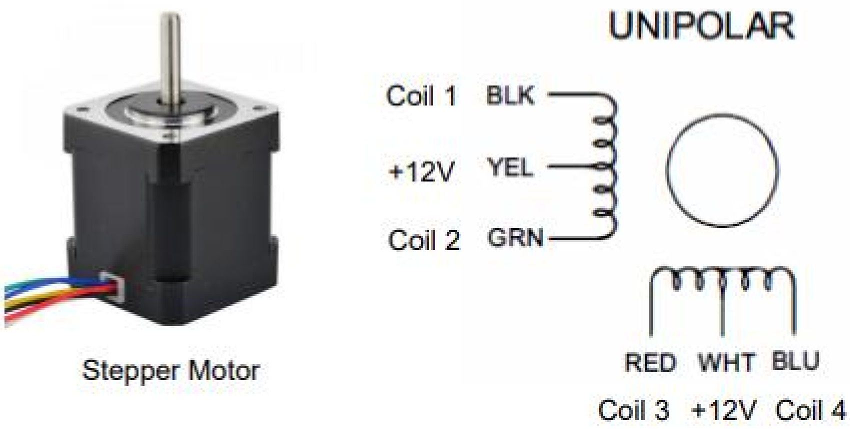


Figure 50. Stepper motor connections

The stepper motor rotates forward or backward direction based on the value of Diff, where Diff is Engine Torque Request minus TPS. The video submitted along with this report shows verification of forward and backward direction.

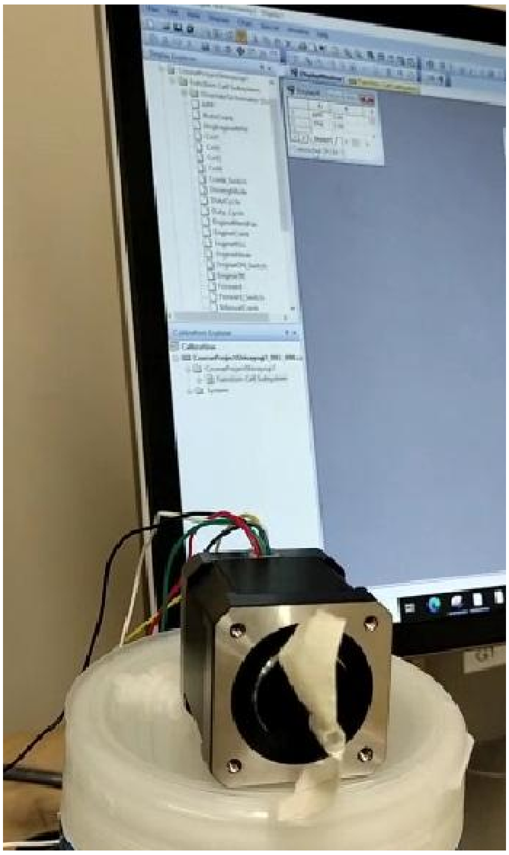


Figure 51. Stepper motor validation

11 Conclusion

The Configurable Hybrid Electric Learning Module(CHELM) was designed in Simulink and verified in Mototune. All 3 driving modes were tested for each task. Starting with Driving Modes, Blend factor look up tables, Engine States, Engine Start/Stop model, MotorTR and EngineTR model, E-motor Start/Stop module, and Stepper motor driving, a total of 7 models were created to work together and achieve the motor action with engine power, electric power or a combination of both. All tasks were verified with Mototune.

12 References

- MEEM 5750 Lecture Slides
- Motohawk