Vehicle Dynamics Project

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Modelling of vehicle using linear and non-linear models

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Submitted to:

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Content

Vehicle Dynamics

To model the Dynamic characteristics of the vehicle the following Equations were Used:

$$m(\dot{V}_x - rV_y) = F_{xf}\cos\delta_f - F_{yf}\sin\delta_f + F_{xr}$$
$$m(\dot{V}_y + rV_x) = F_{xf}\sin\delta_f + F_{yf}\cos\delta_f + F_{yr}$$
$$I_{zz}\dot{r} = a(F_{xf}\sin\delta_f + F_{yf}\cos\delta_f) - bF_{yr}$$

Where m is the mass of the vehicle, V_x is the velocity in x, r is angular velocity, V_y is velocity in y,F_{xf} is force on front wheel in x direction, δ_f is the wheel angle, F_{yf} is the force on front tyre in y direction , F_{xr} is the force on rear tire in x direction, I_{zz} is the moment of Inertia of the vehicle about zz-axis, a is the distance of front axle from center of gravity and b is the distance of rear axle from CG.

To determine the F_{xf}, F_{xr}, F_{yf}, F_{yr} two types of tire models are used which is described in later section.

Tire Modeling

Two approaches were used to model tire behavior, namely, Linear tire model and non-linear tire(or Sine model).

Linear tire model

Linear tire model is a simple way of modelling tire behavior, following equations depicts the behavior of linear tire model. These equations were used to model linear vehicle model.

$$F_{yf} = C_{\alpha f}\alpha_f = C_{\alpha f}\left(\delta_f - \frac{V_y + \dot{\psi}a}{V_x}\right)$$
$$F_{yr} = C_{\alpha r}\alpha_r = C_{\alpha r}\left(\delta_r - \frac{V_y - \dot{\psi}b}{V_x}\right)$$

$$F_{xf} = Q_f / R_{fe}$$
$$F_{xr} = Q_r / R_{re}$$

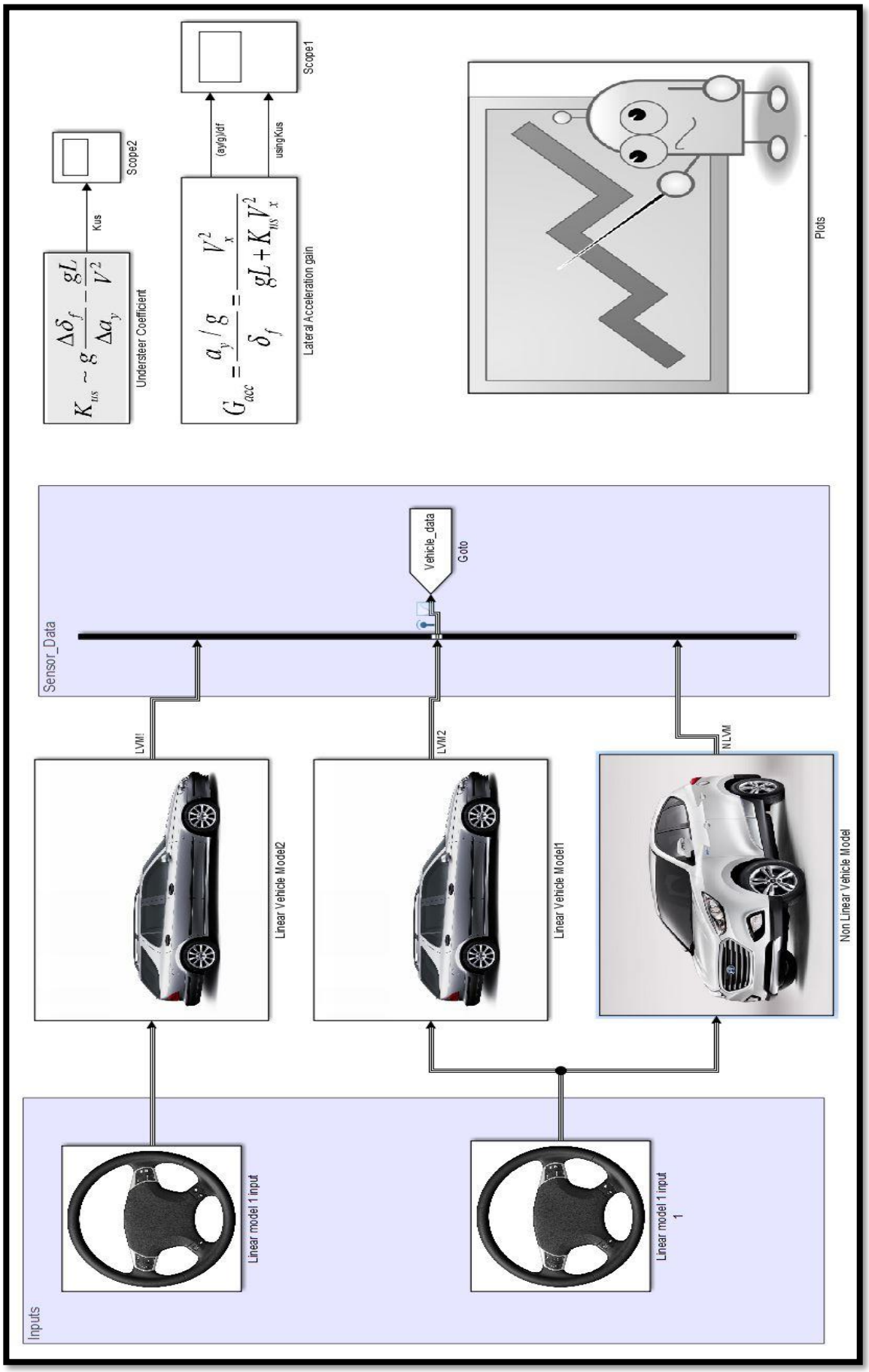
Non-linear tire model

There are many models available for modeling nonlinear tire behavior, here we have used the sine model, here are the Equations for this model

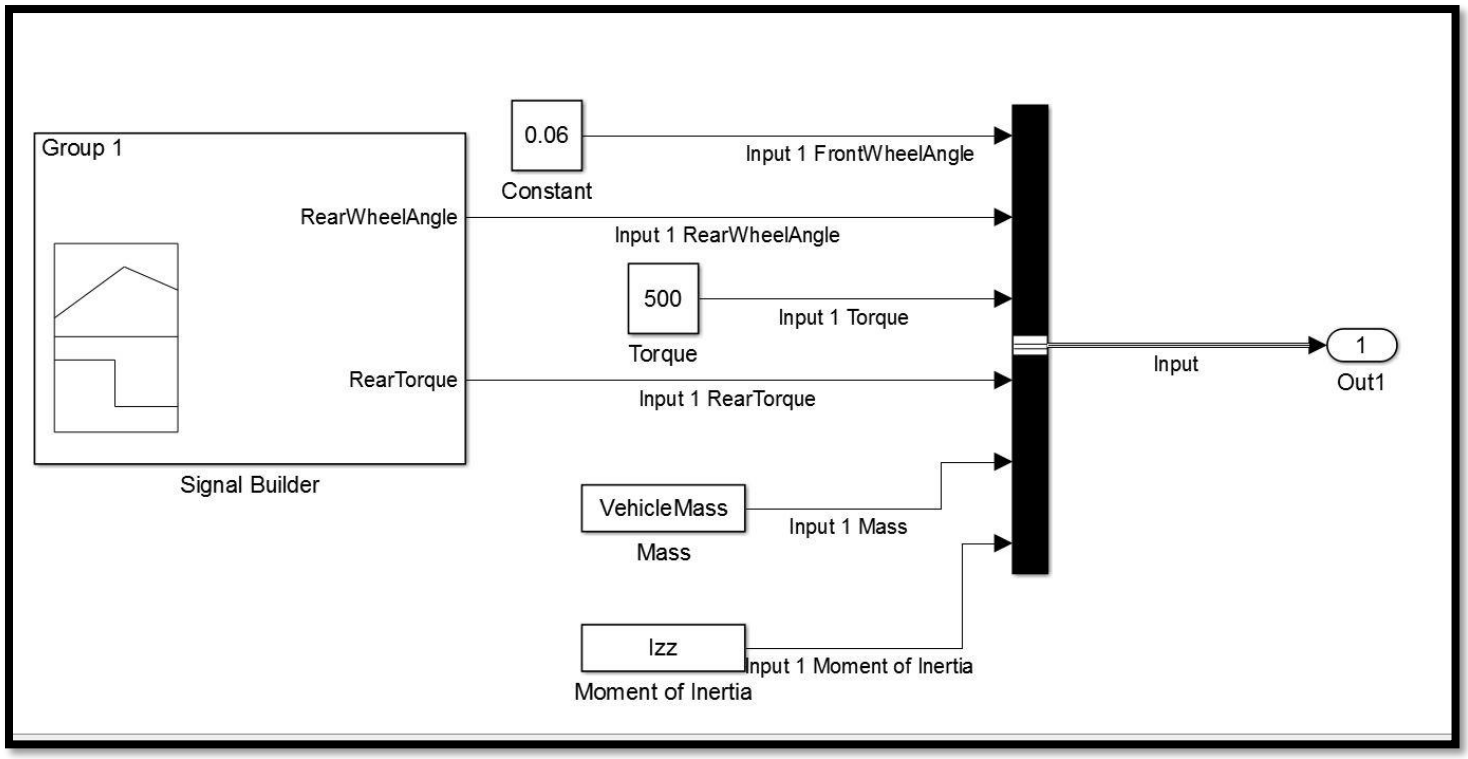
$$F_y(\alpha) = A \sin\left[B \arctan\left(\frac{C_\alpha}{AB} \alpha \right) \right]$$

$$A = F_y^{\max} = \mu F_z$$

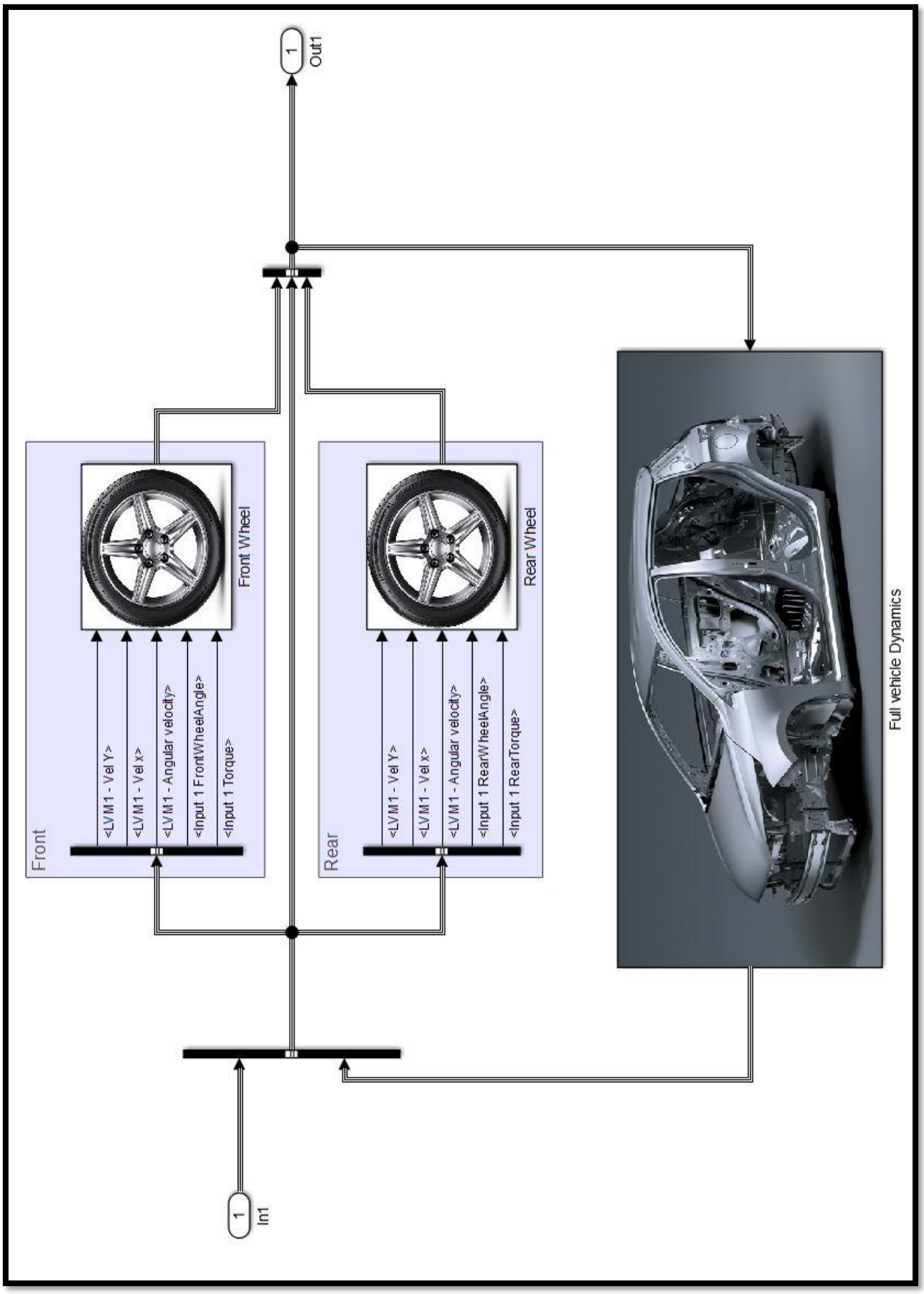
Implementation –



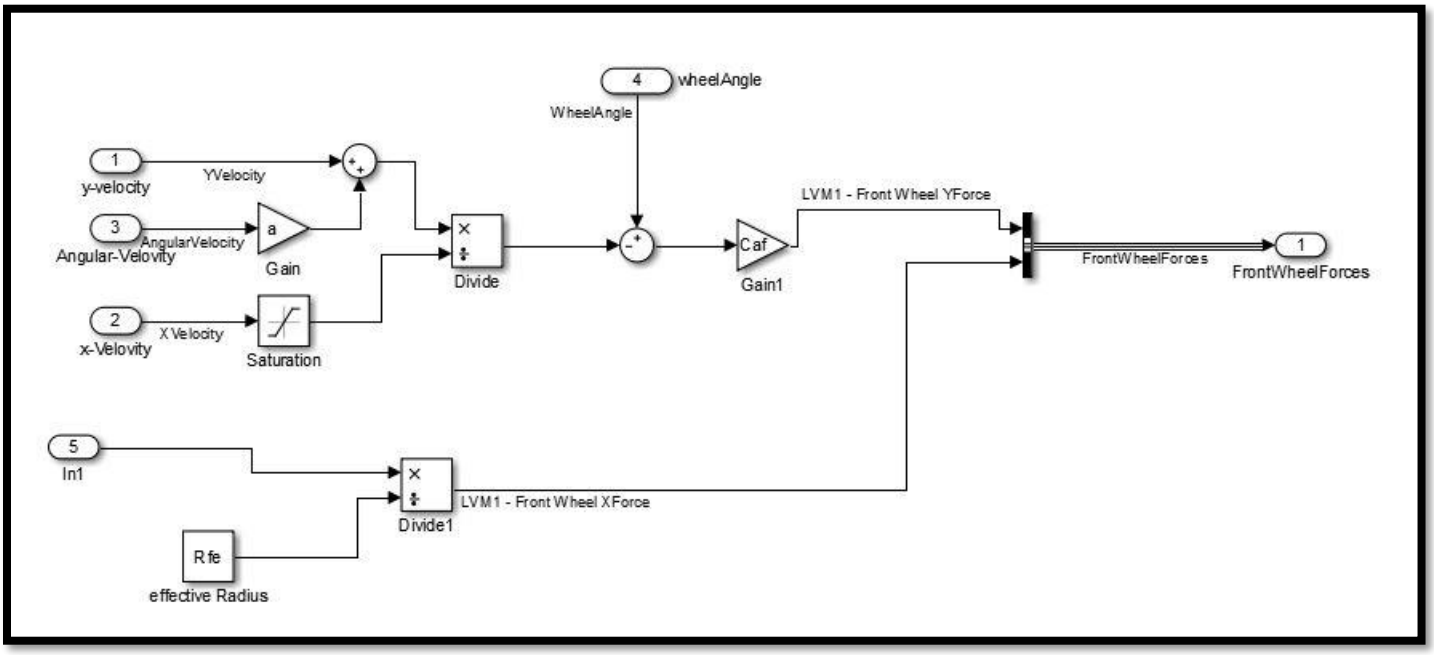
Inputs


Group 1
RearWheelAngle
RearTorque
Signal Builder
0.06
Constant
Input 1 FrontWheelAngle
Input 1 RearWheelAngle
500
Torque
Input 1 Torque
Input 1 RearTorque
VehicleMass
Mass
Input 1 Mass
Izz
Moment of Inertia
Input 1 Moment of Inertia
Input
1
Out1

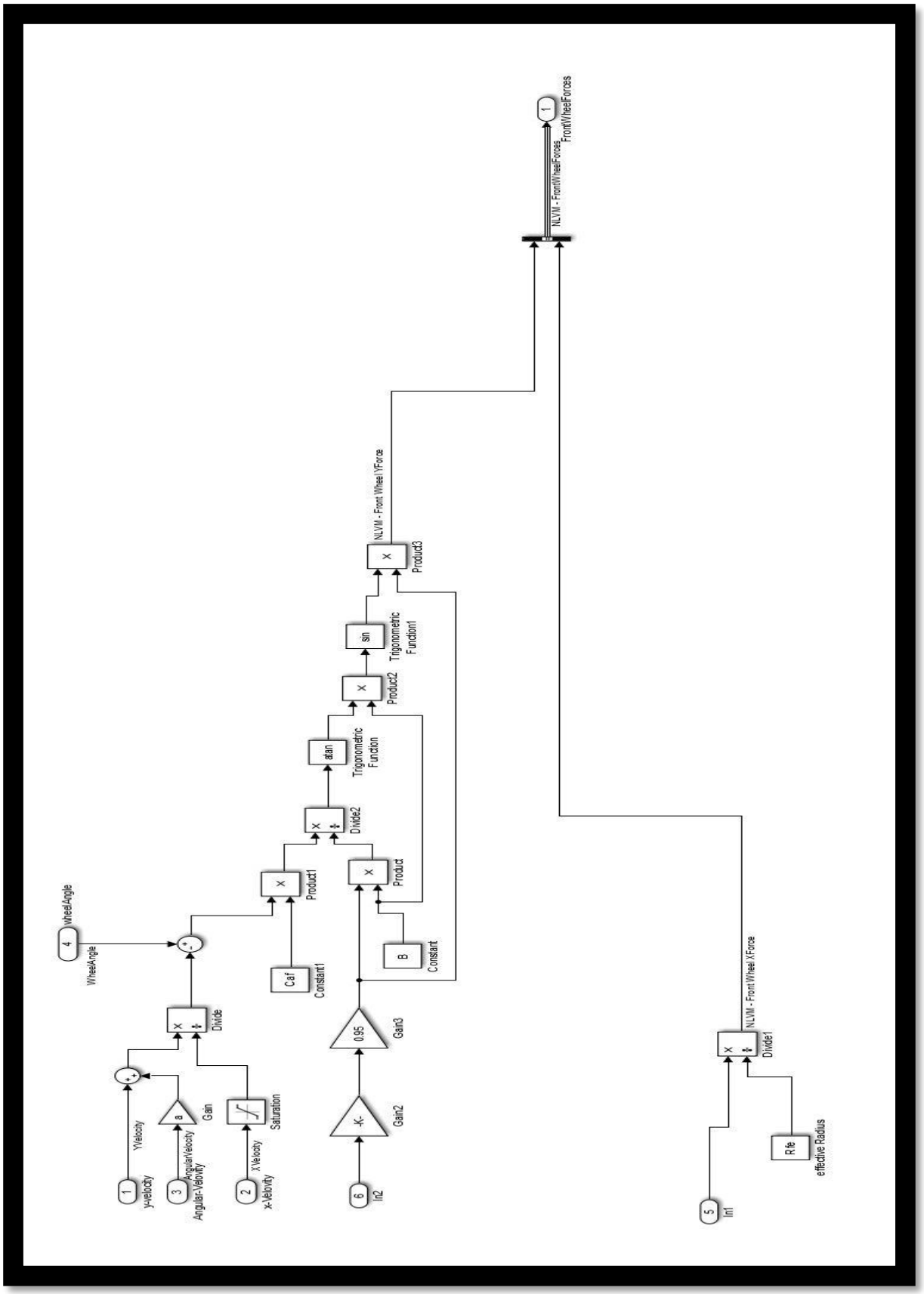
Vehicle Model



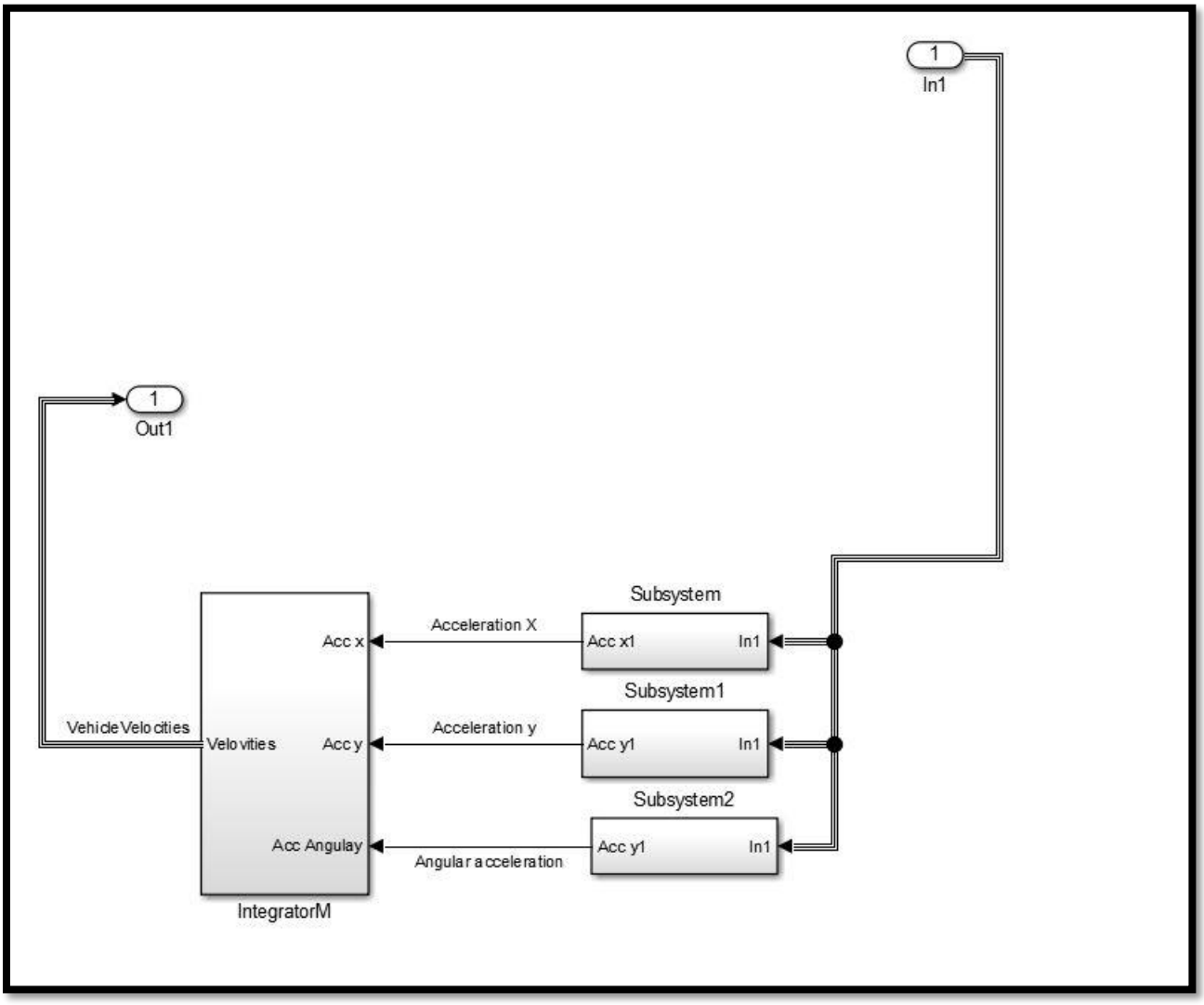
Inside Front Tire Model



Inside non-linear tire Model

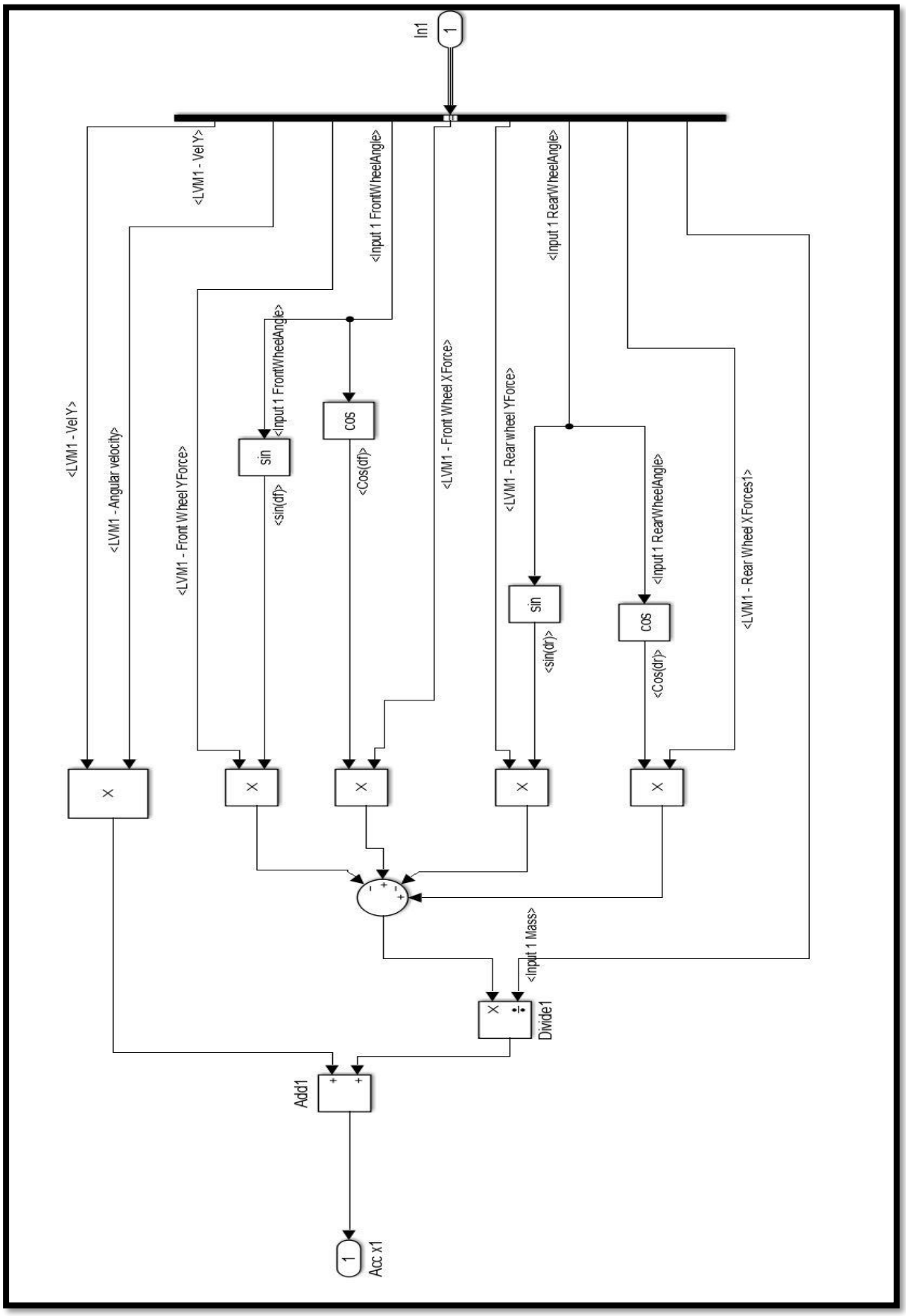


Inside Full Vehicle Dynamics Block

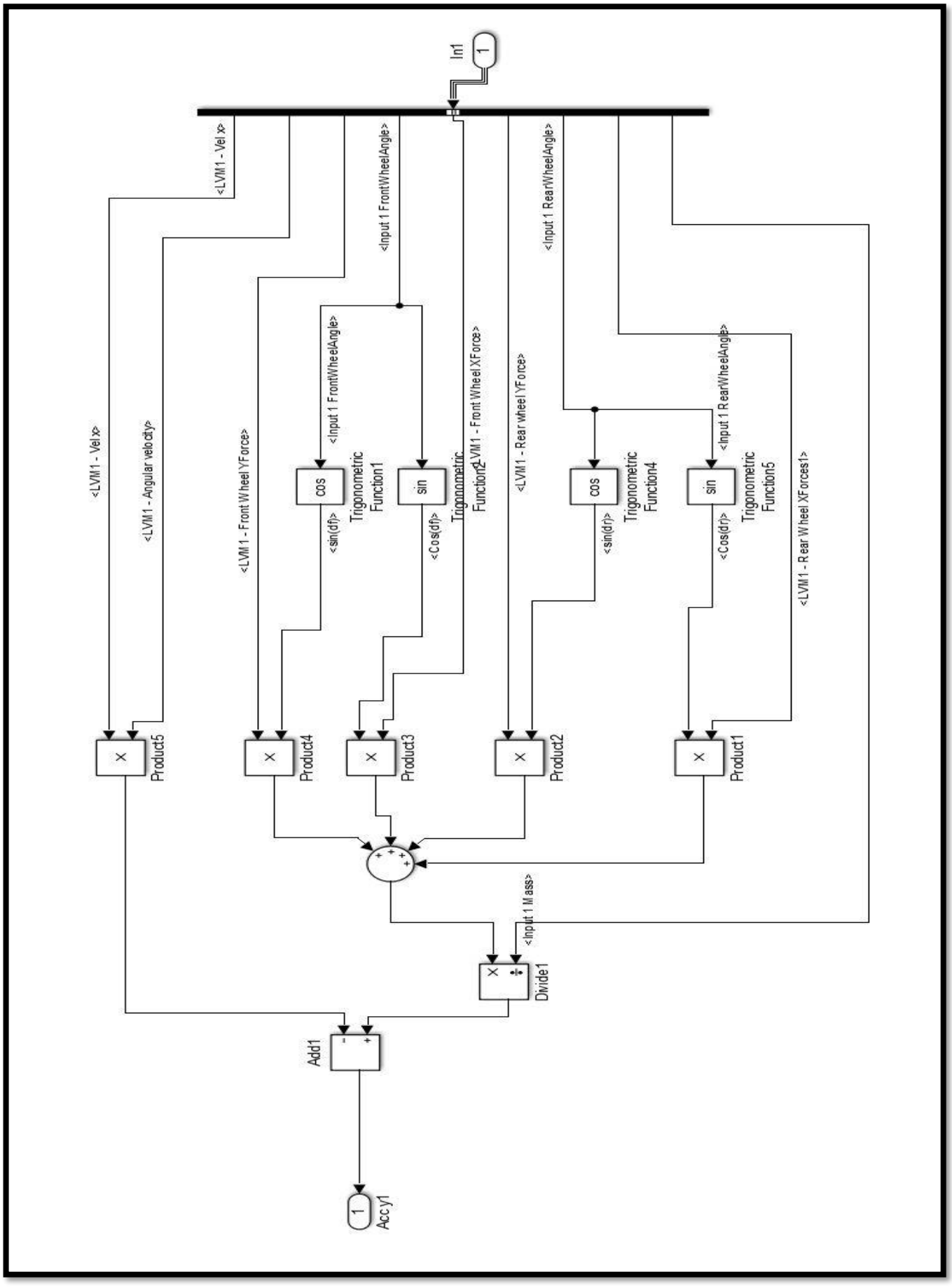


Acceleration calculation

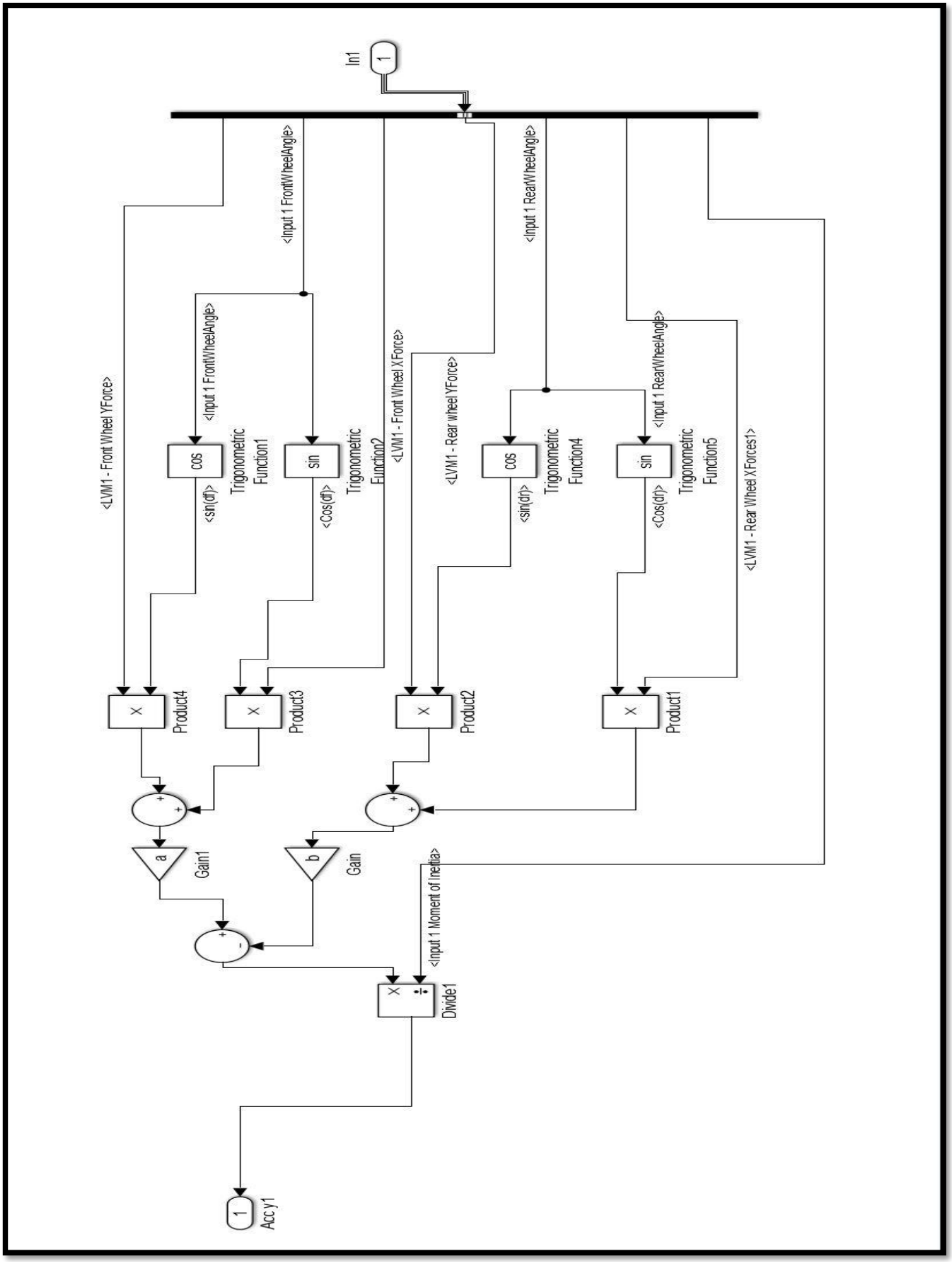
X



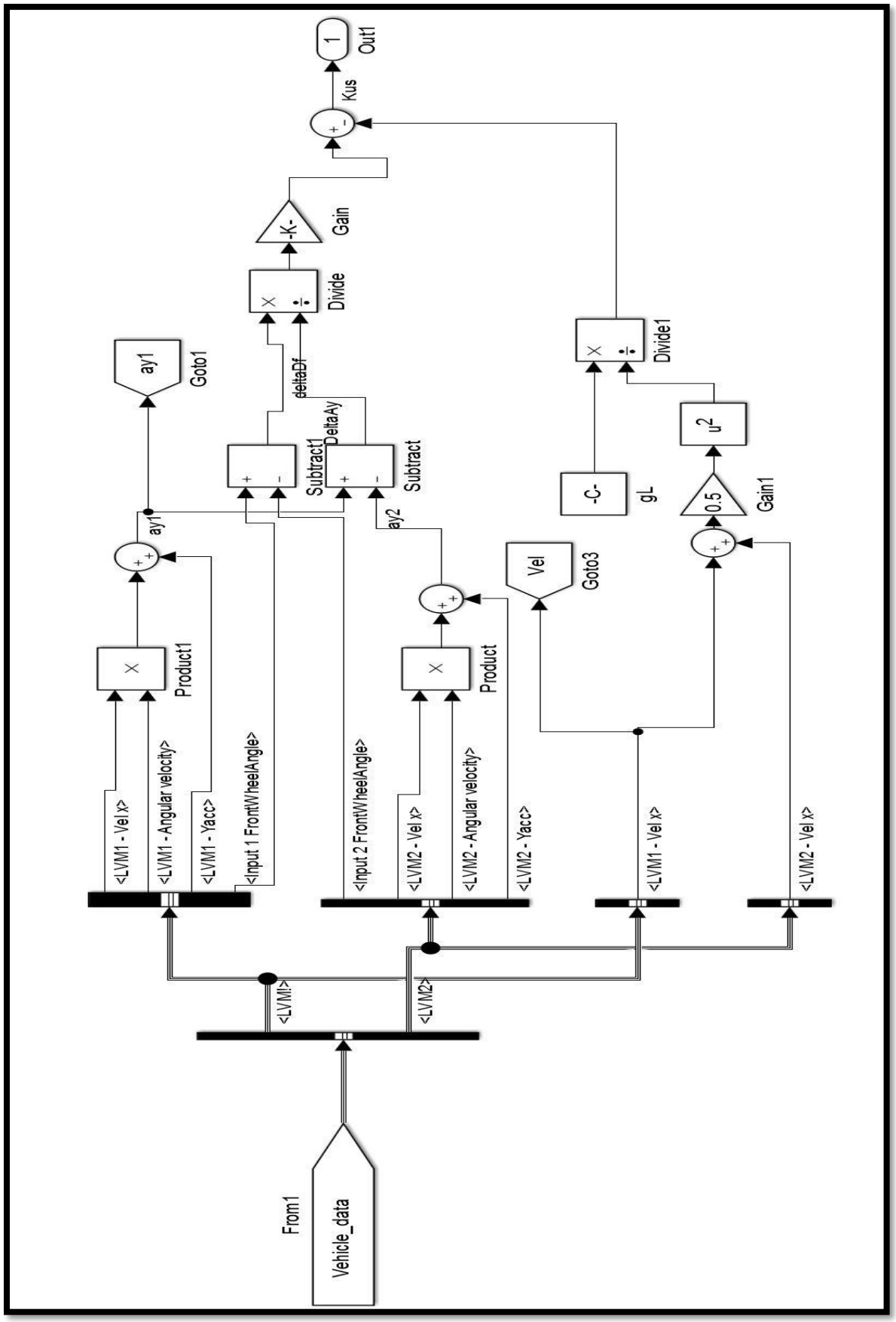
Y


In1
1
<LVM1 - Vel x>
<Input 1 FrontWheelAngle>
<Input 1 RearWheelAngle>
<LVM1 - Vel x>
<LVM1 - Angular velocity>
<LVM1 - Front Wheel YForce>
<Input 1 FrontWheelAngle>
cos
Trigonometric Function1
<sin(df)>
sin
Trigonometric Function2
<Cos(df)>
<LVM1 - Front Wheel XForce>
<LVM1 - Rear wheel YForce>
<Input 1 RearWheelAngle>
cos
Trigonometric Function4
<sin(dr)>
<Input 1 RearWheelAngle>
sin
Trigonometric Function5
<Cos(dr)>
<LVM1 - Rear Wheel XForces1>
Product5
Product4
Product3
Product2
Product1
<Input 1 Mass>
Divide1
Add1
1
Accy1

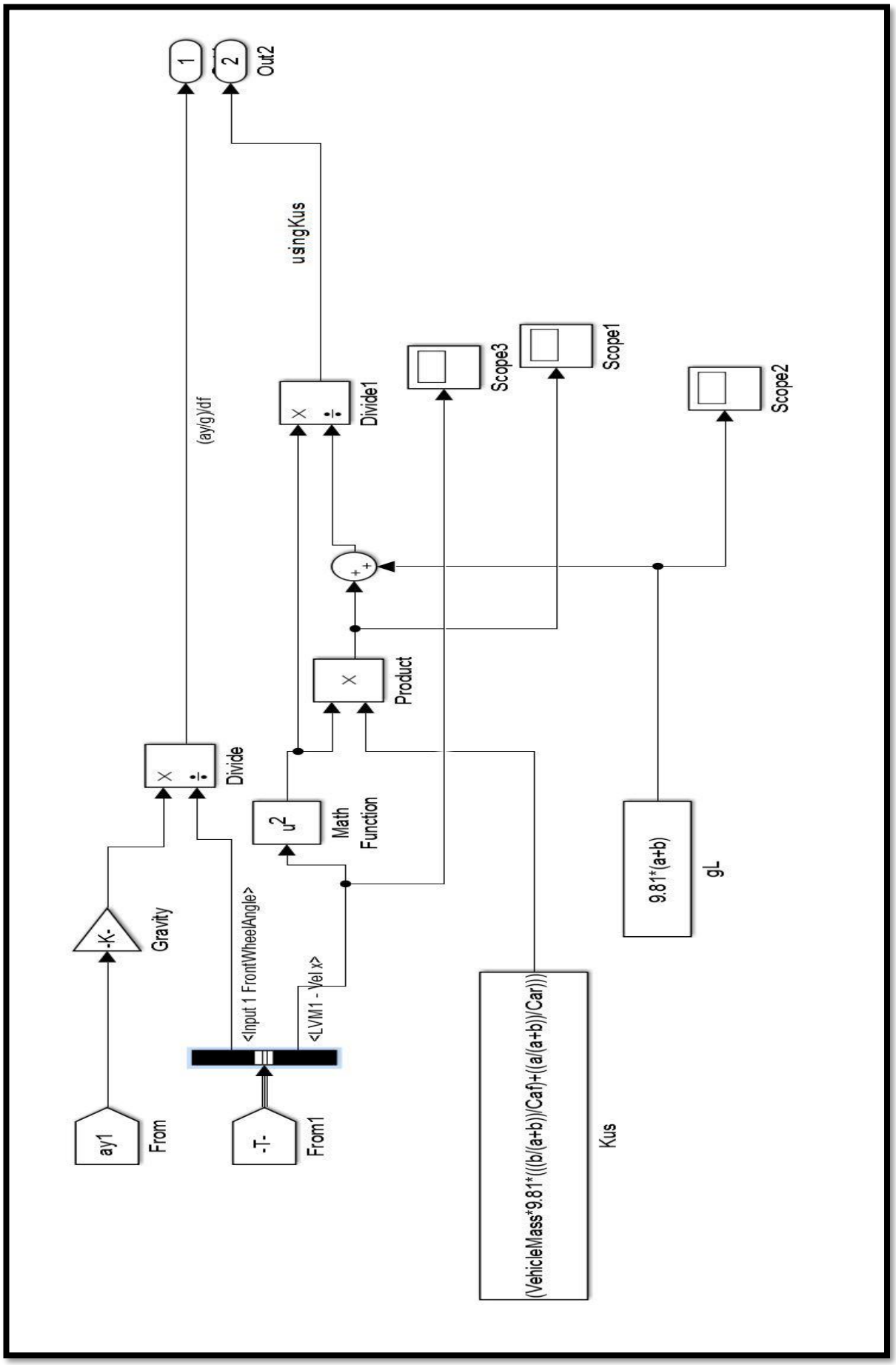
Angular Acceleration



Kus


From1
Vehicle_data
<LVM>
<LVM1>
<LVM2>
<LVM1 - Vel x>
<LVM1 - Angular velocity>
<LVM1 - Yacc>
<Input 1 FrontWheelAngle>
Product1
ay1
Goto1
<Input 2 FrontWheelAngle>
<LVM2 - Vel x>
<LVM2 - Angular velocity>
<LVM2 - Yacc>
Product
ay2
Vel
Goto3
Subtract1
Subtract
DeltaAy
deltaDf
Divide
-K-
Gain
Kus
1
Out1
-C-
gL
Divide1
<LVM1 - Vel x>
u^2
0.5
Gain1
<LVM2 - Vel x>

Lateral Acceleration gain

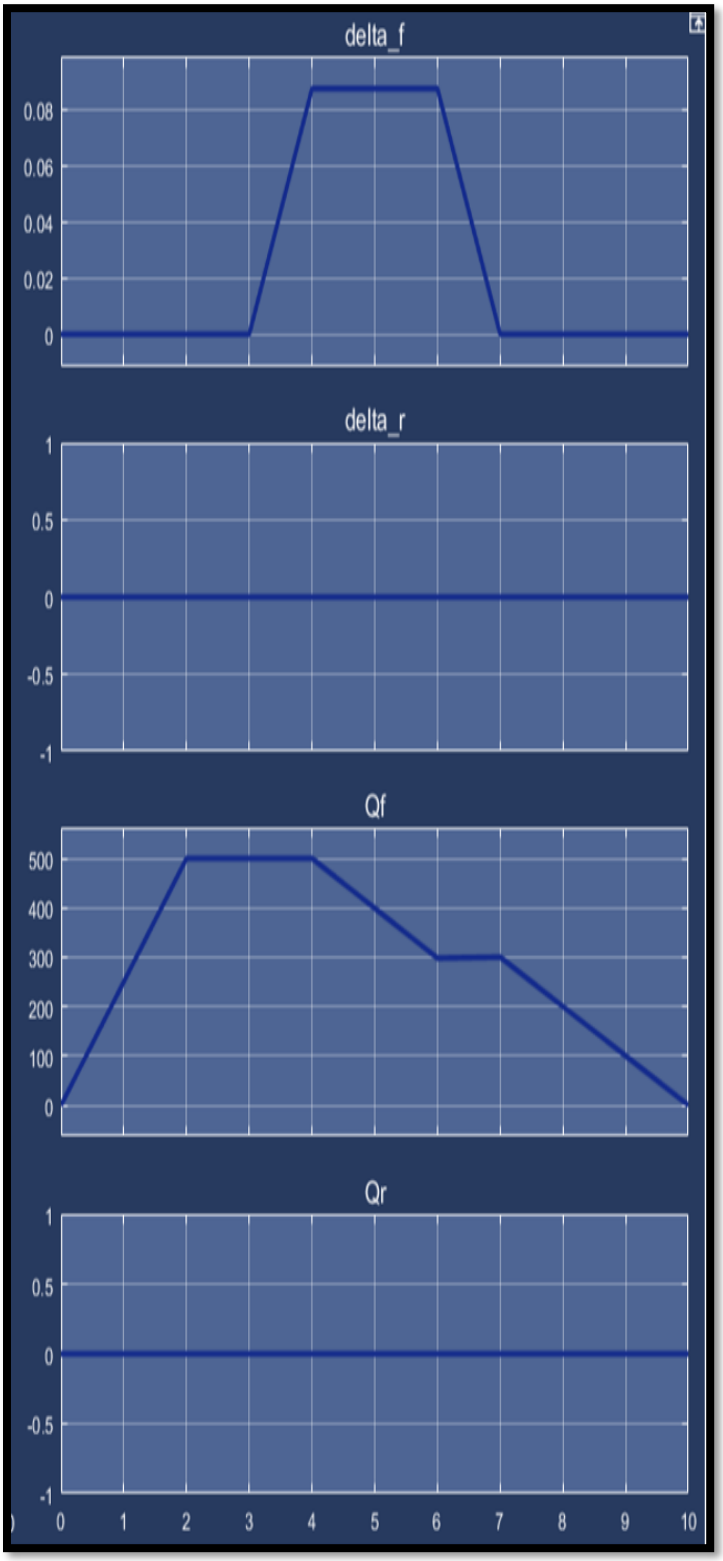


Result and Analysis

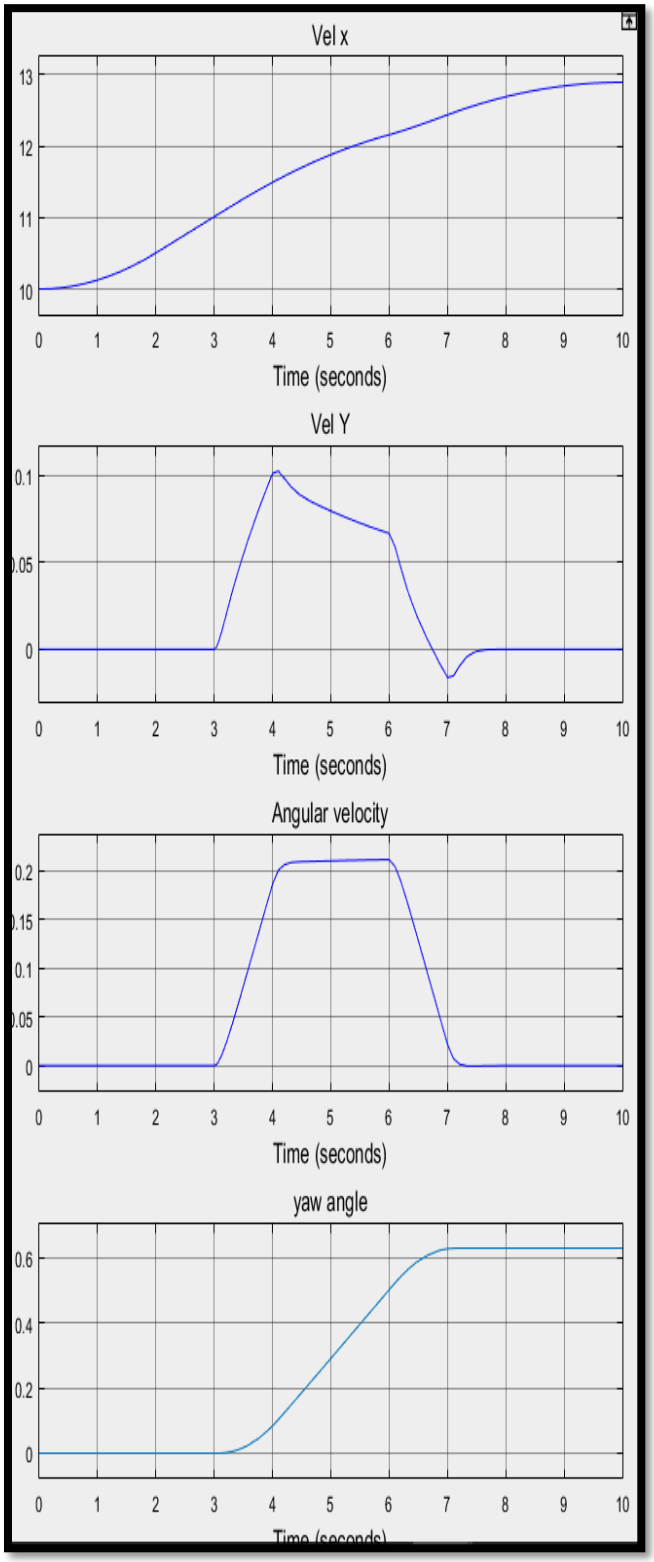
Baseline Validation

For Baseline validation, the output acquired is same as expected hence the validation was approved

Inputs:



Outputs:

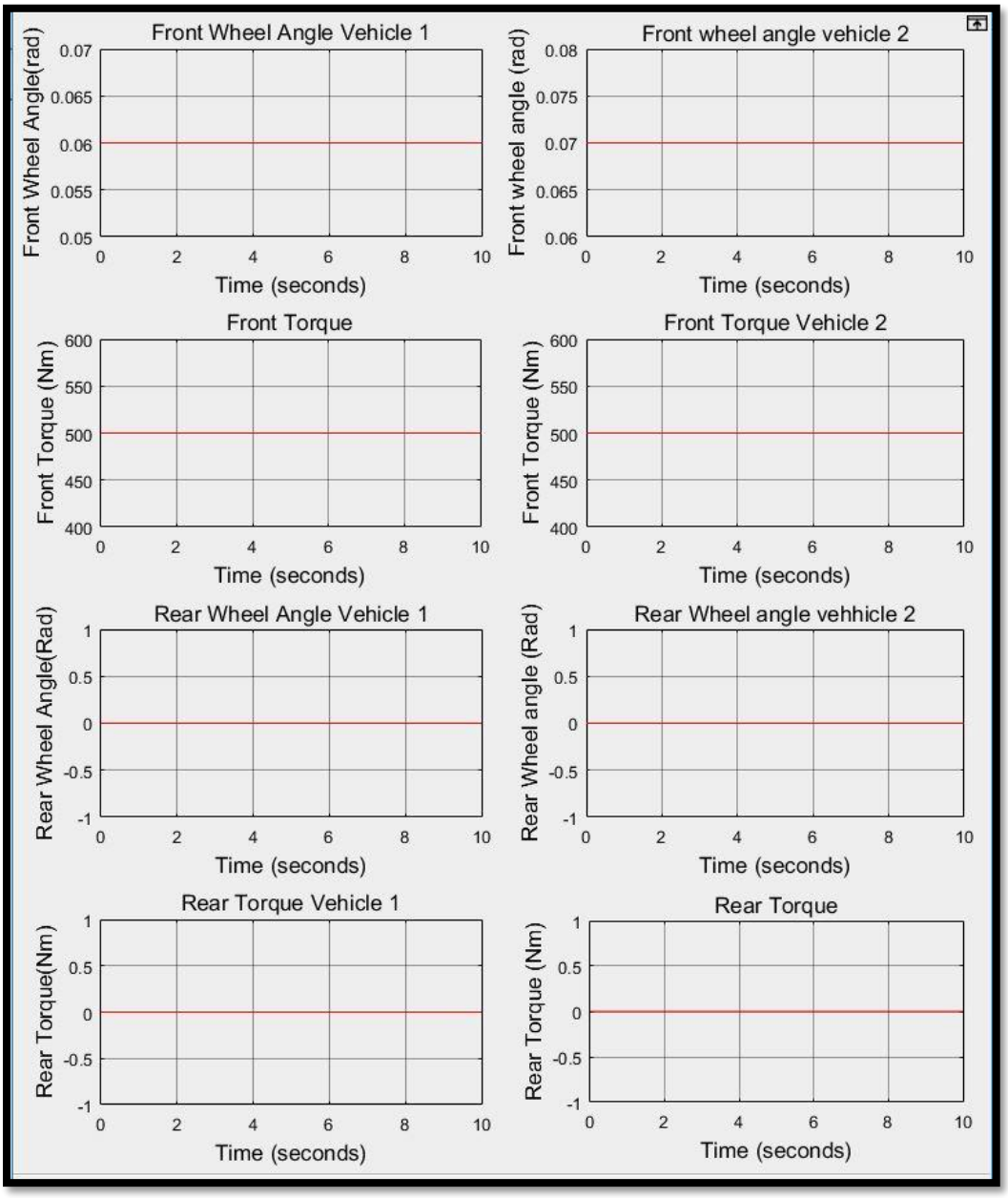


Understeer Coefficient:

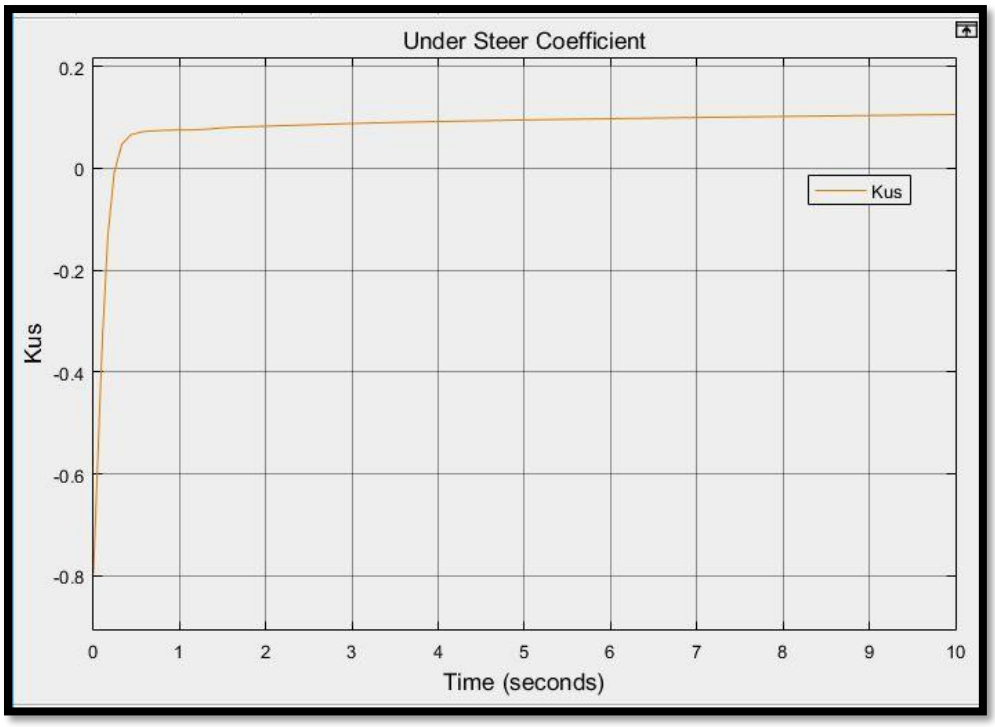
To find the understeer coefficient constant velocity test was used under which the understeer coefficient can be determined using following formula

$$K_{us} \sim g\frac{\Delta\delta_f}{\Delta a_y} - \frac{gL}{V^2}$$

Inputs



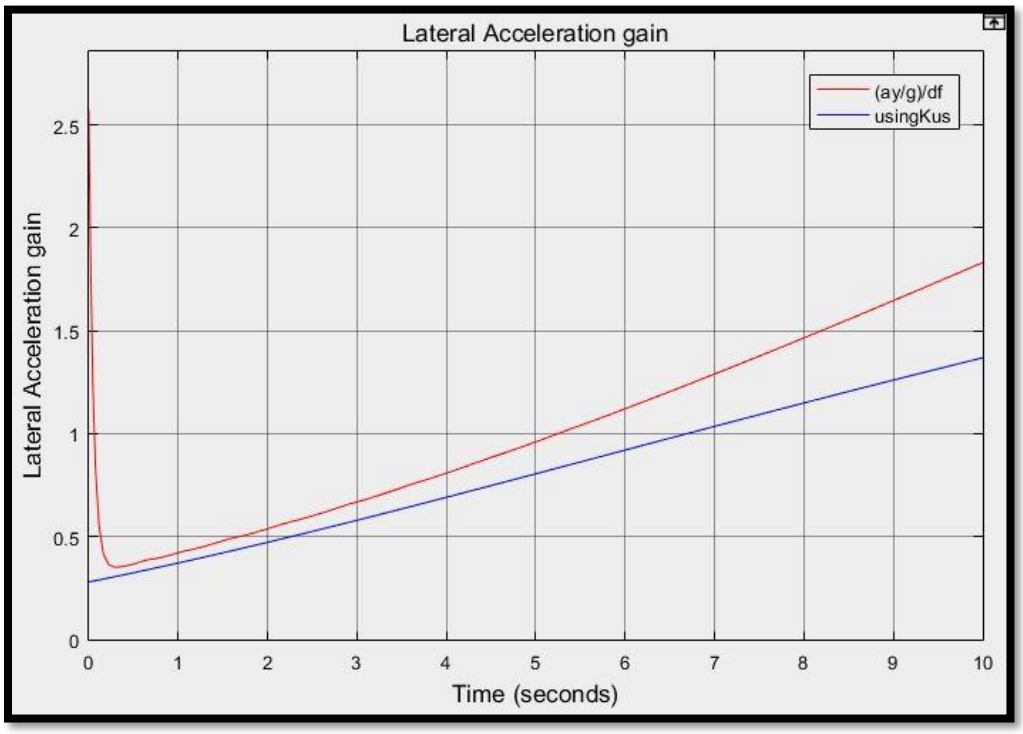
And the following plot was obtained:



Lateral Acceleration gain

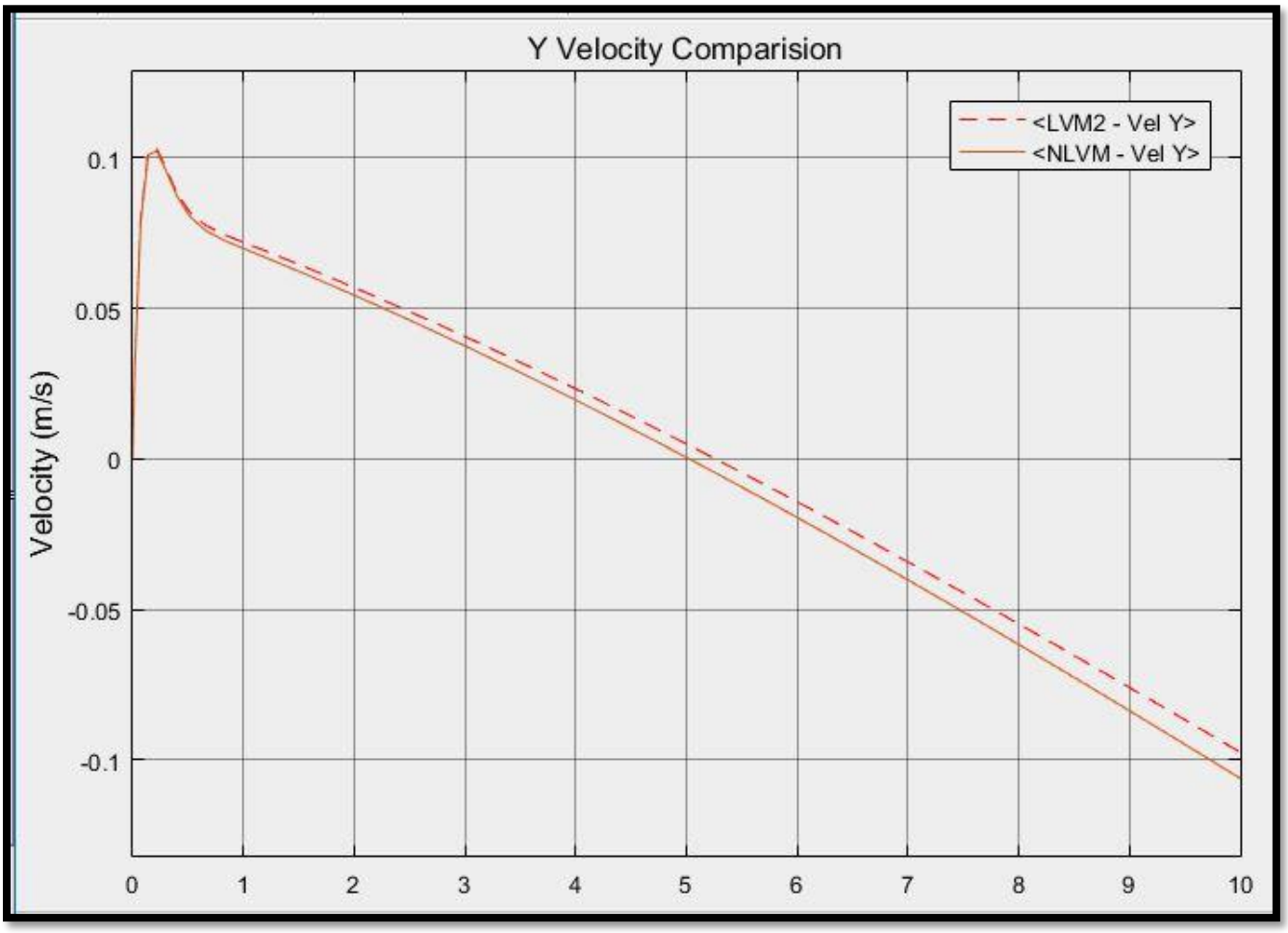
Lateral Acceleration gain was calculated using the following two formulas the values obtained were similar at lower values of Vy and alfa.

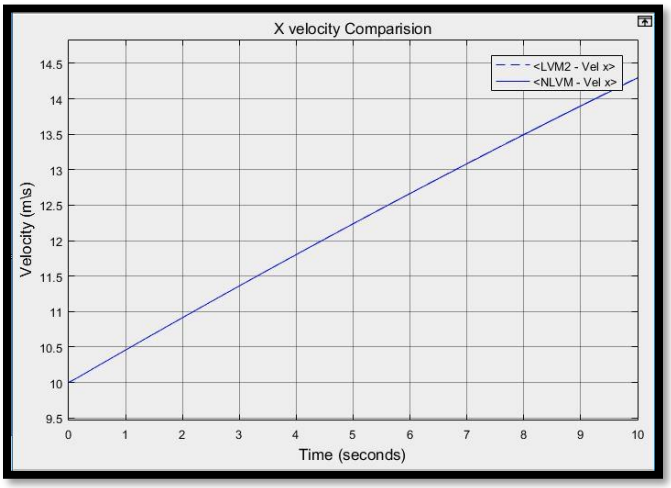
$$G_{acc} = \frac{a_y / g}{\delta_f} = \frac{V_x^2}{gL + K_{us} V_x^2}$$

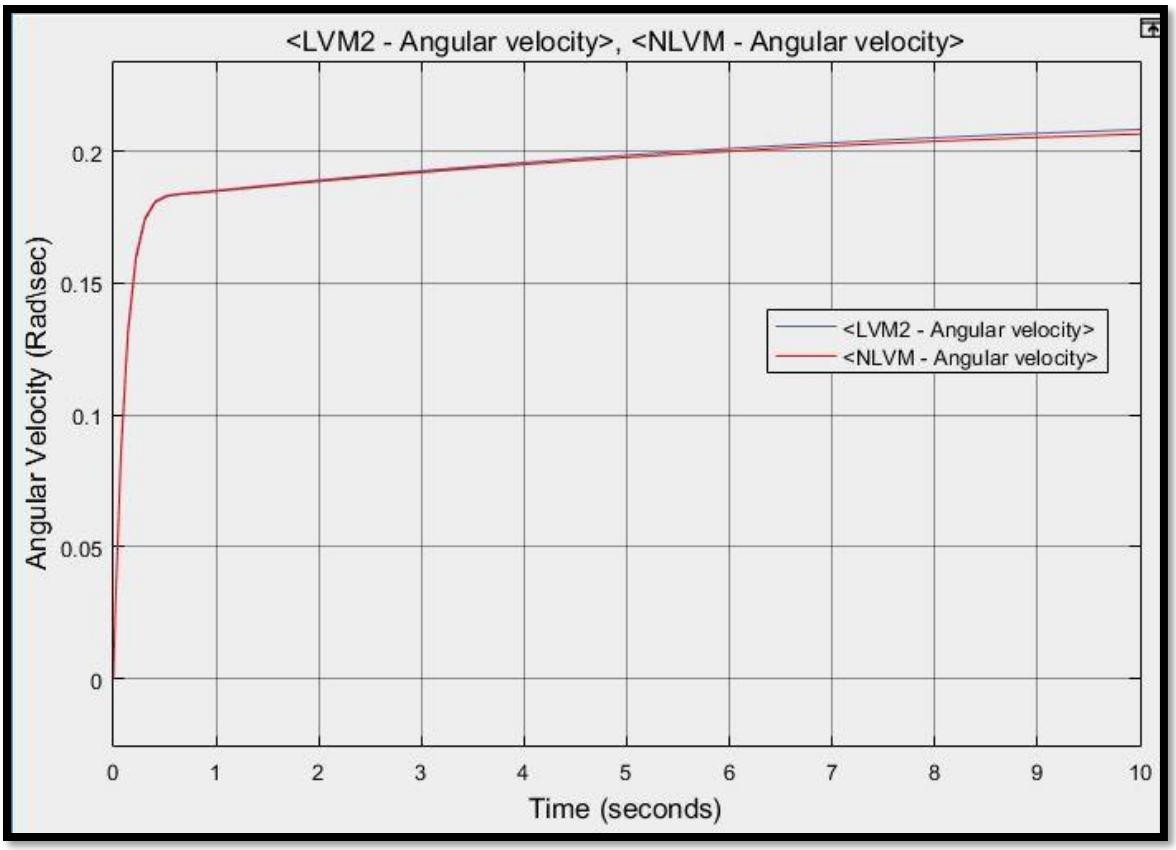


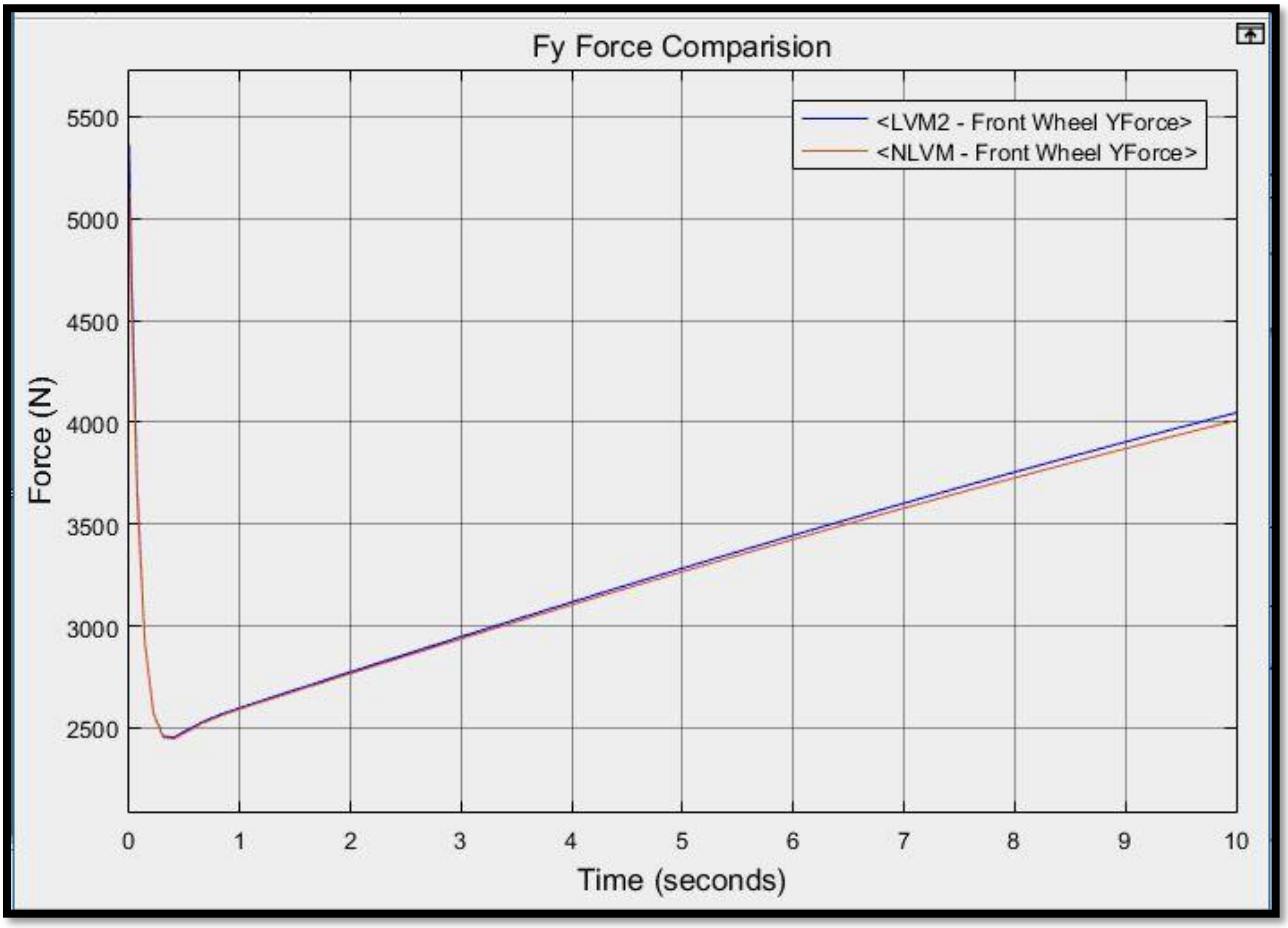
Comparison of Linear and nonlinear model

After the above modelling and testing the model was found to be satisfactory and then the comparison of results obtained by linear and nonlinear model was done although the initial values obtained by both the model are similar but with increasing values of velocity in y and alfa the linear model drifts away from the nonlinear model hence showing the lack of accuracy in linear model at higher slip angles






<LVM2 - Angular velocity>, <NLVM - Angular velocity>
Angular Velocity (Rad\sec)
Time (seconds)
<LVM2 - Angular velocity>
<NLVM - Angular velocity>
0
0.05
0.1
0.15
0.2
0
1
2
3
4
5
6
7
8
9
10


Fy Force Comparision
Force (N)
Time (seconds)
<LVM2 - Front Wheel YForce>
<NLVM - Front Wheel YForce>
2500
3000
3500
4000
4500
5000
5500
0
1
2
3
4
5
6
7
8
9
10

References:

- Gillespie, T.D., Fundamentals of Vehicle Dynamics, Society of Automotive Engineers, 1992.
- Wong, J.Y., Theory of Ground Vehicles, Wiley-Interscience, 2001.
- Pacejka, H.B. and Besselink, I., Tire and Vehicle Dynamics, Butterworth-Heinemann, 2012.