Lab 2: Group 17

SD2231 – Applied vehicle dynamics control

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Introduction

Nowadays, the vehicle manufactures are competing mainly at two fronts one being the technology and other being the cost. To stay in the market one need to produce a vehicle that has technology which is state of the art (example – ESC, Torque Vectoring, lane assist etc.) at a low cost. The problem with the technologies mentioned above is that they require expensive sensors if one is supposed to measure them directly. A solution to this problem is to use the existing and comparatively cheap sensors to 'estimate' the required vehicle states.

Through this assignment we would learn to develop body side slip estimators using wash-out filters and various types of Kalman filters.

Body Side Slip is defined as the sideways drift caused by the lateral velocity and is calculated as follows,

Task 1:

Build a Matlab/Simulink architecture that should include three body side-slip estimators; a model-based, integration of lateral acceleration based, and a washout filtered based. Illustrate your estimator architecture in the report and upload the files to bilda when handing in the report. Use the template file Init_for_washout_filter.m to load all the variables and vehicle parameters to the workspace.

The bicycle model based and integration based filters were made using the function block in Simulink. Whereas the wash-out filter was made using the outputs of the above filters & Simulink blocks.

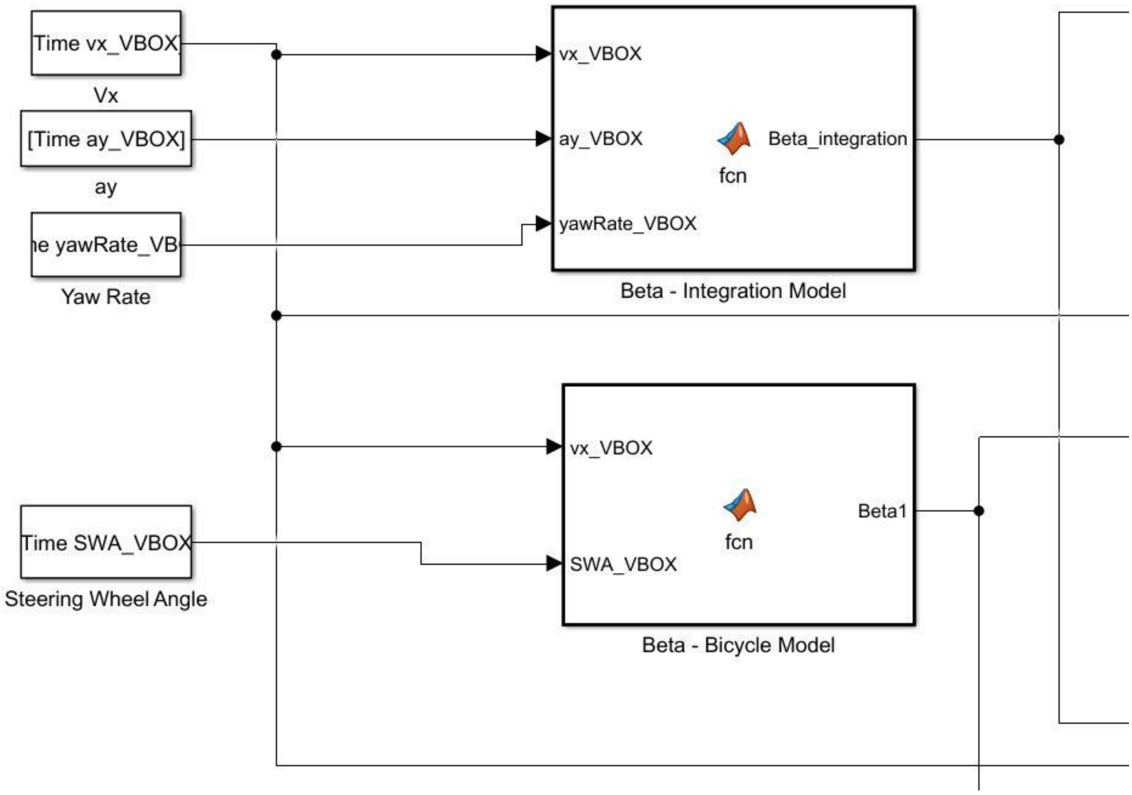

Figure 1 Body Side Slip by Bicycle model & Integration of Lateral Accleration

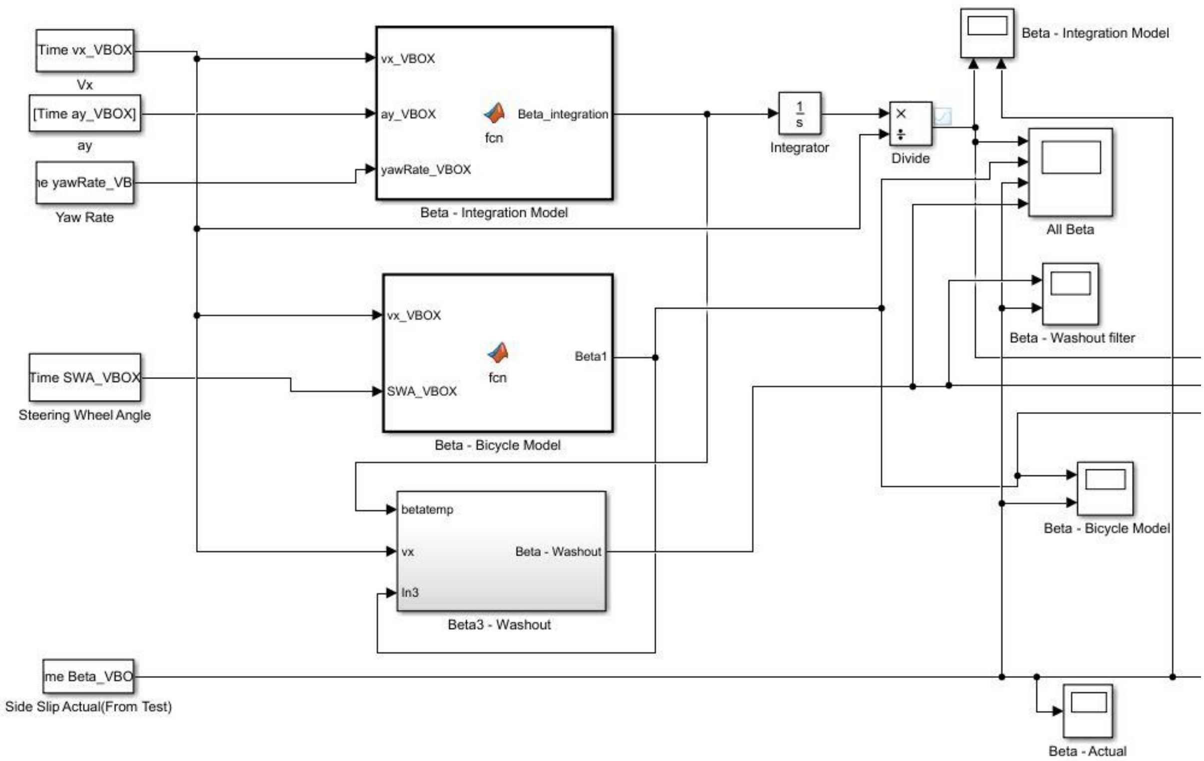

Figure 2 Implementation of Wash-out Filter

Correcting Errors:

The above developed system was run using the stand still file to check for errors in the measurements from the vbox.

It was noticed that for Standstill test, values of Steering Wheel angle, Longitudinal Velocity and Lateral Acceleration were not equal to Zero which should have been the case. Since the error values vary with time an attempt was made to make their mean values close to zero by adding/subtracting a constant.

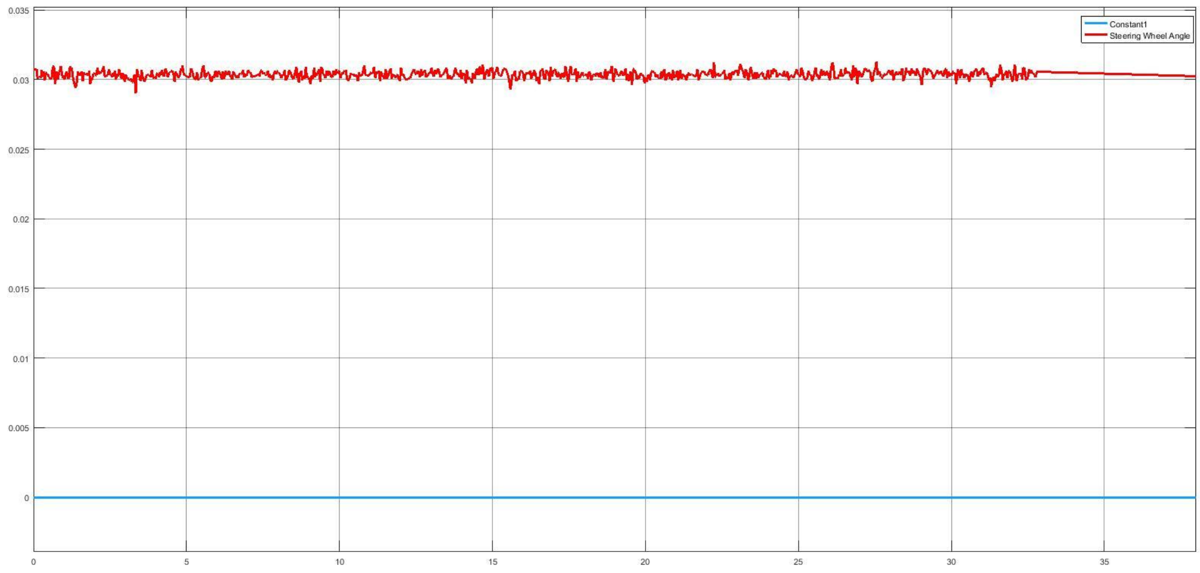

Figure 3 SWA - Error

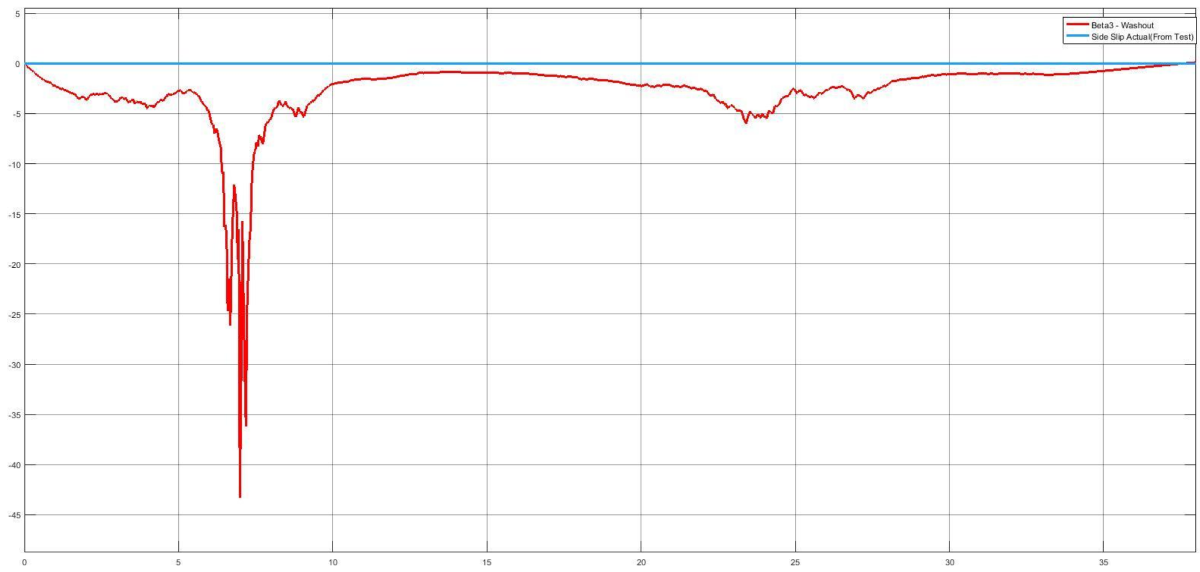

Figure 4 Beta Washout _ Standstill

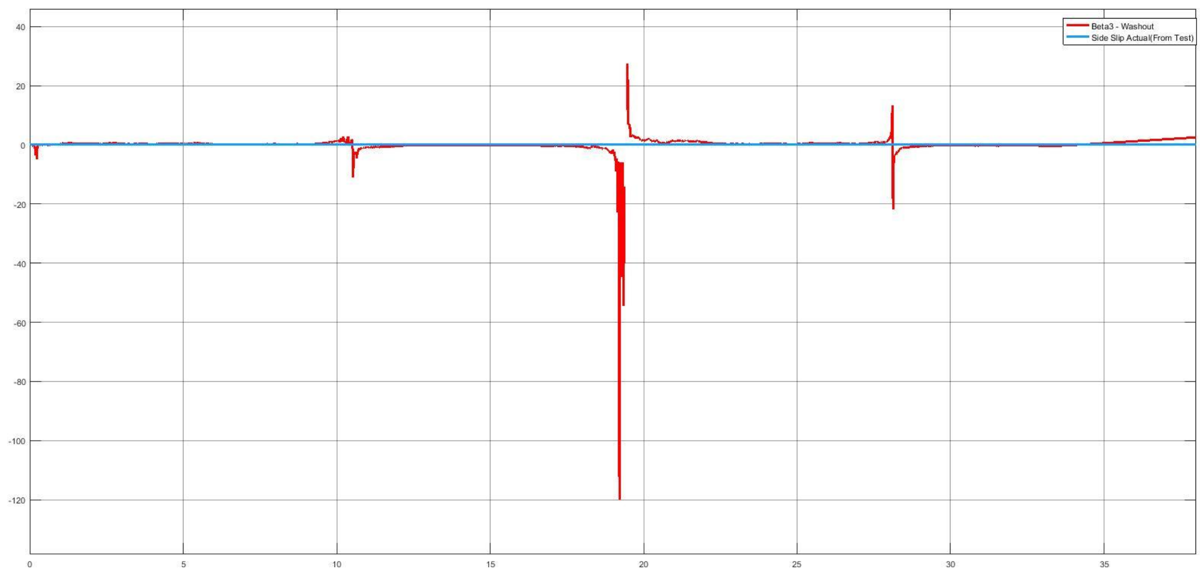

Figure 5 Beta Washout - StandStill - Corrected

Task 2

T Set and tune the vehicle parameters, see Appendix A for default values. Some vehicle parameters need tuning such as tyre parameters. The tuning is done by comparing results from your estimator design with the "truth" = body side-slip from reference measurement system (VBOX). All tasks in this section should be done by using one fix tuning (i.e. tuning should not be adapted for Tasks 3-9). Explain your tuning process. The vehicle parameters were inputted into the code and the tuneable parameters i.e. Front & Rear axle stiffness were tuned.

This was done by comparing the Side Slip from Bicycle model with the Actual Side Slip measure from VBOX. The difference between the actual and calculated was also plotted.

At first both stiffness we were tuned together i.e. keeping them equal, some initial 'extreme' values showed how the model behaves. At low values (= 50000 N/rad) the model under estimated the side slip values whereas for higher values (>100,000 N/rad) the model over-estimated the side slip. This showed that the ideal value lies somewhere between 50000 to 100000.

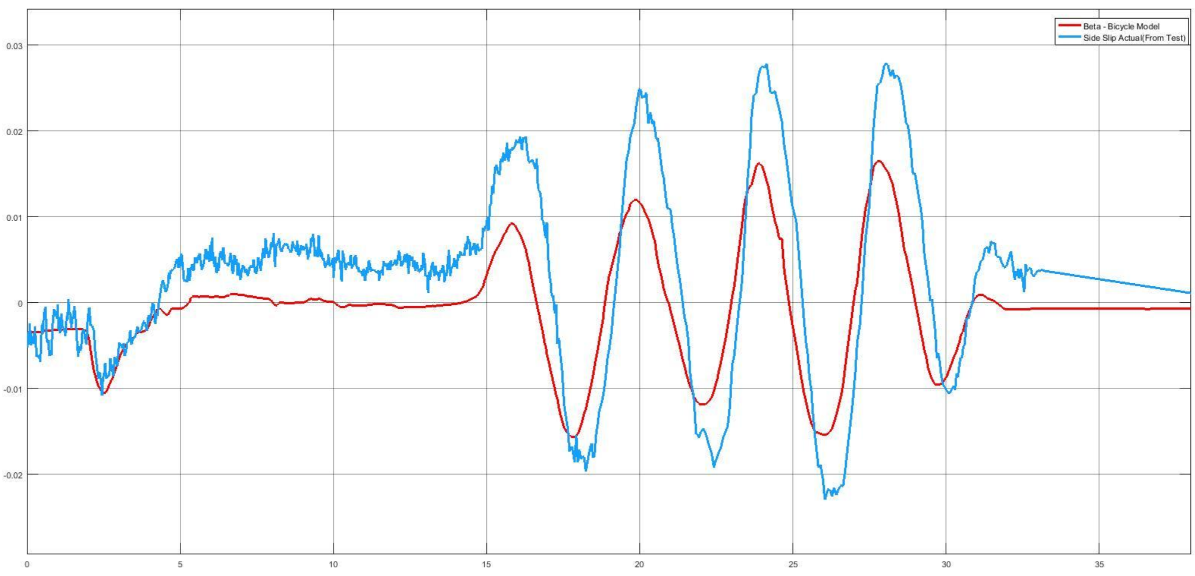

Figure 6 Under Estimated Body Silde Slip C12=C34=50,000 N/rad

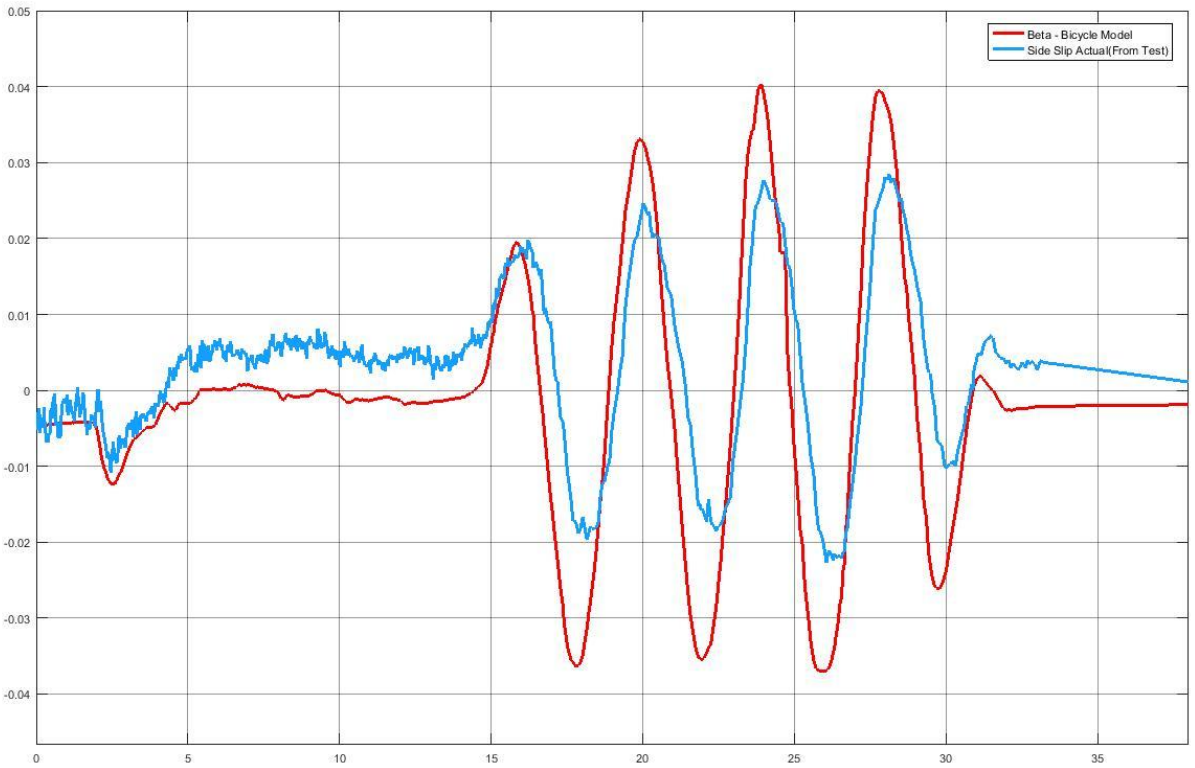

Figure 7 Over Estimated Body Silde Slip C12=C34=100,000 N/rad

Also, understeer gradient (Kus) for the Constant Radius Cornering (CRC) manoeuvre was calculated. The vehicle should understeer when the tires get saturated i.e. towards the end of the test.

As it can be seen from the figure below it is the case, if the Kus was negative towards the end of the test i.e. the vehicle in over steering instead then the balance of the front and rear axle stiffness would have been changed (making the front more stiff to neutralize the over steer. But since it wasn’t needed the front and rear axle stiffnesses were kept same (= 70000 N/rad).

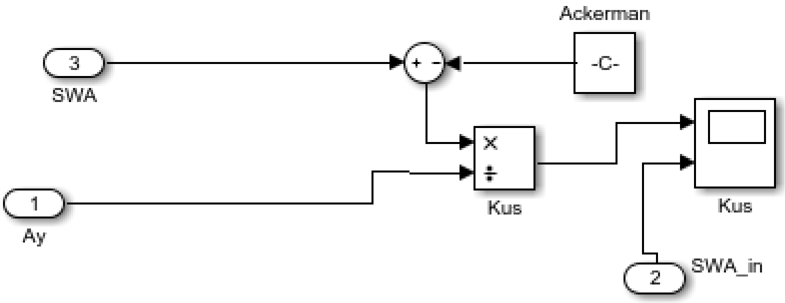

Figure 8 Calculating Understeer gradient

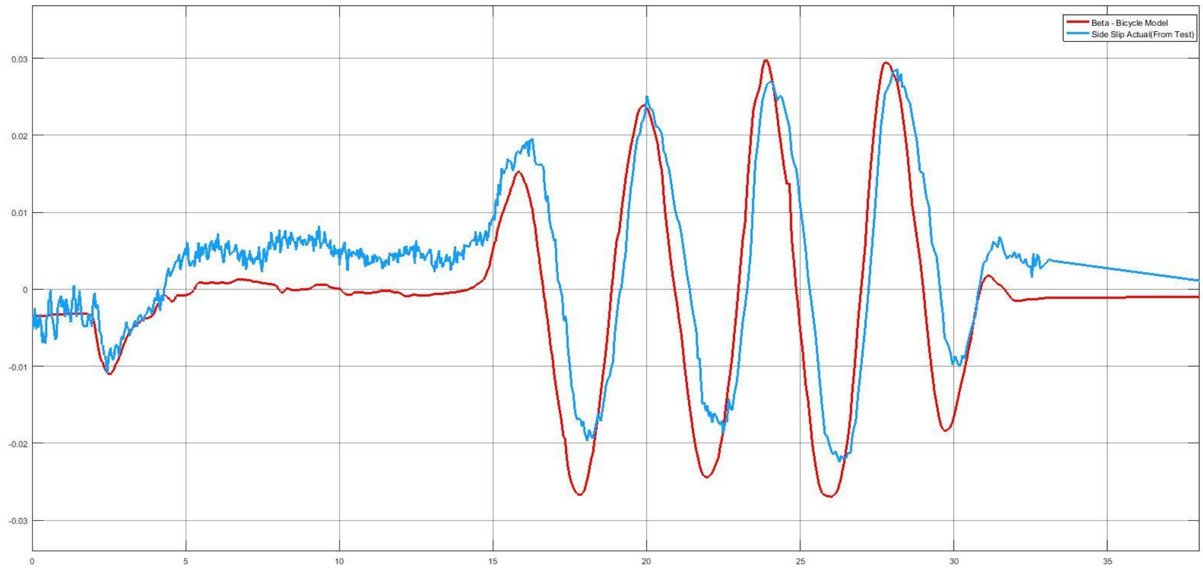

Figure 9 Tuned C12 & C34 = 100,000 N/rad

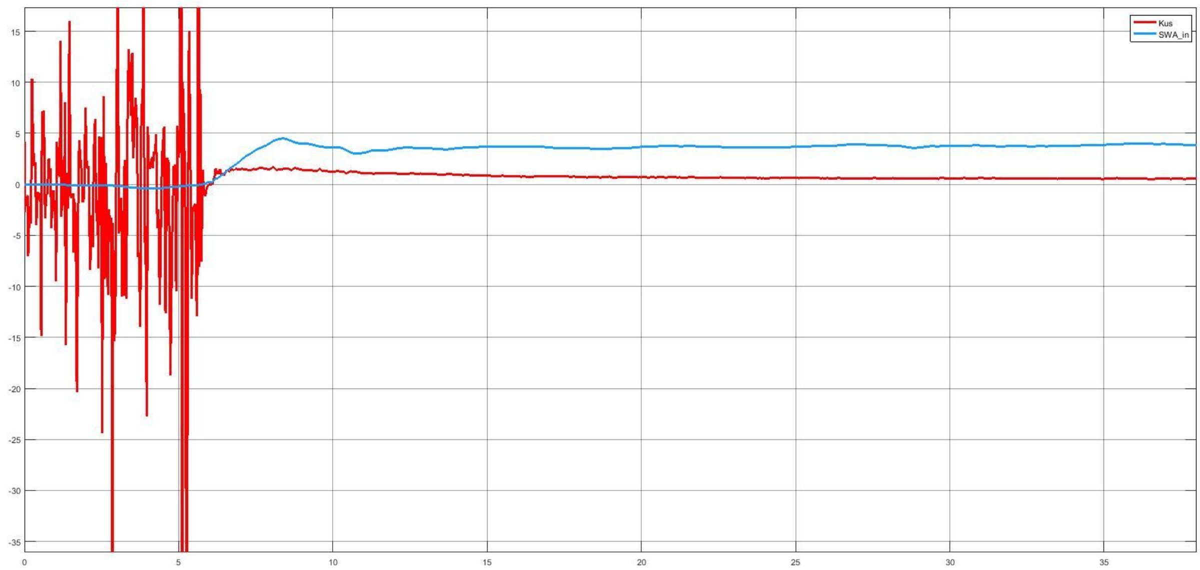

Figure 10 Under Steer Gradient & SWA for CRC (Note: vehicle is understeering after 10 seconds of event)

Task 3

Tune and find an appropriate value of the filter coefficient T in the wash-out filter. Motivate how you select your final tuning. You should find one value of T that is reasonably good for all tests scenarios.

The following was done to find the optimum value of T

For Slalom manoeuvre , T was changed from 0 to 50 with steps of 0.1 for the test and the mean and mode of error was calculated for each value of T

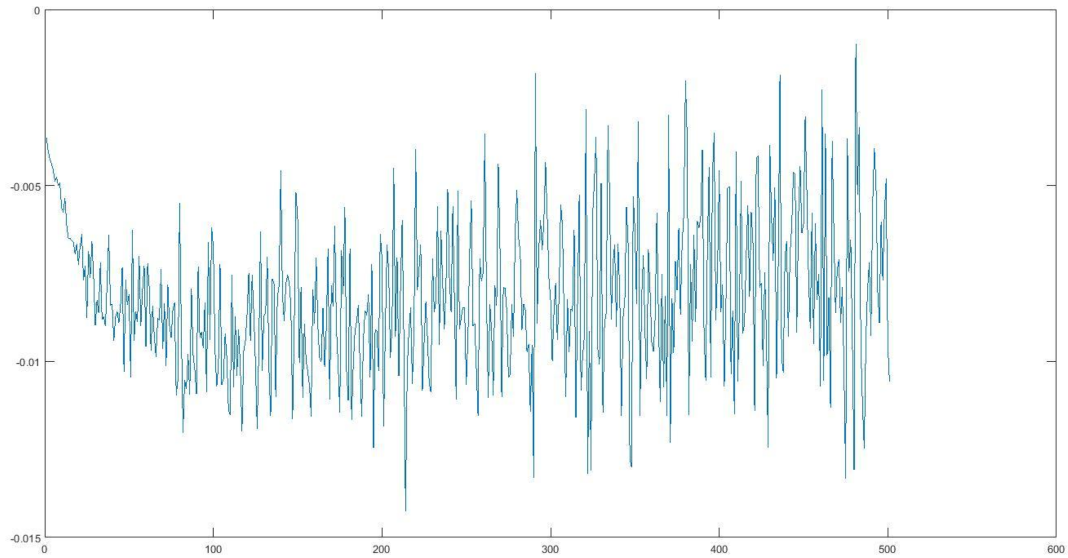

Figure 11 Mean of error for T = 0 to 50

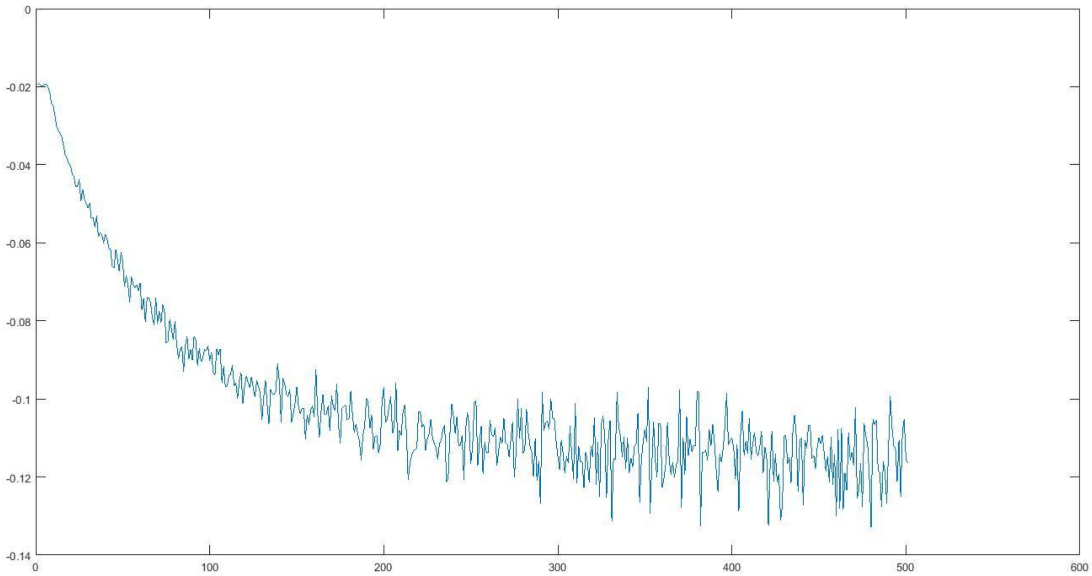

Figure 12 Mode of error for T = 0 to 50

As seen from the figures the Mode reduces with increase in value of T & although Mean doesn't give a reliable value as one big error may cause mean to increase. That is why mode was used, which shows the most reoccurring error (difference from measured side slip).

Now the loop was run with a step of 0.01 for T = 0 to 5 and then for T = 0 to 1 to find the value which gives least error.

The above result yielded T=0.47 as the optimum value.

The following figures show Body Side Slip & its error from VBOX SideSlip for different manoeuvres using the wash-out filter with T=0.47.

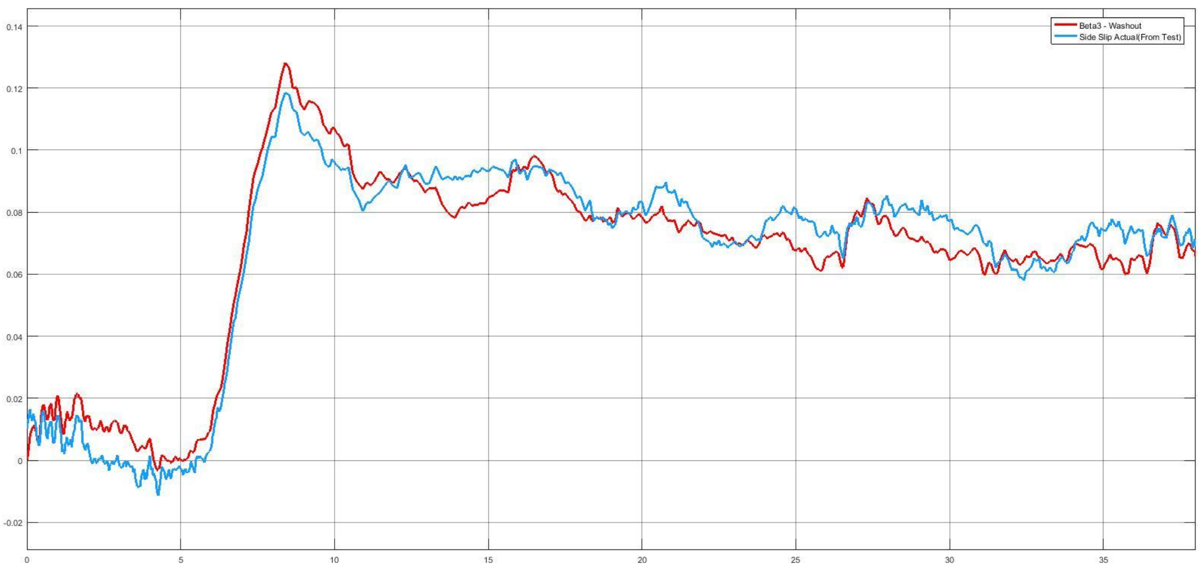

Figure 13 RC Actual & Wash-out Side Slip

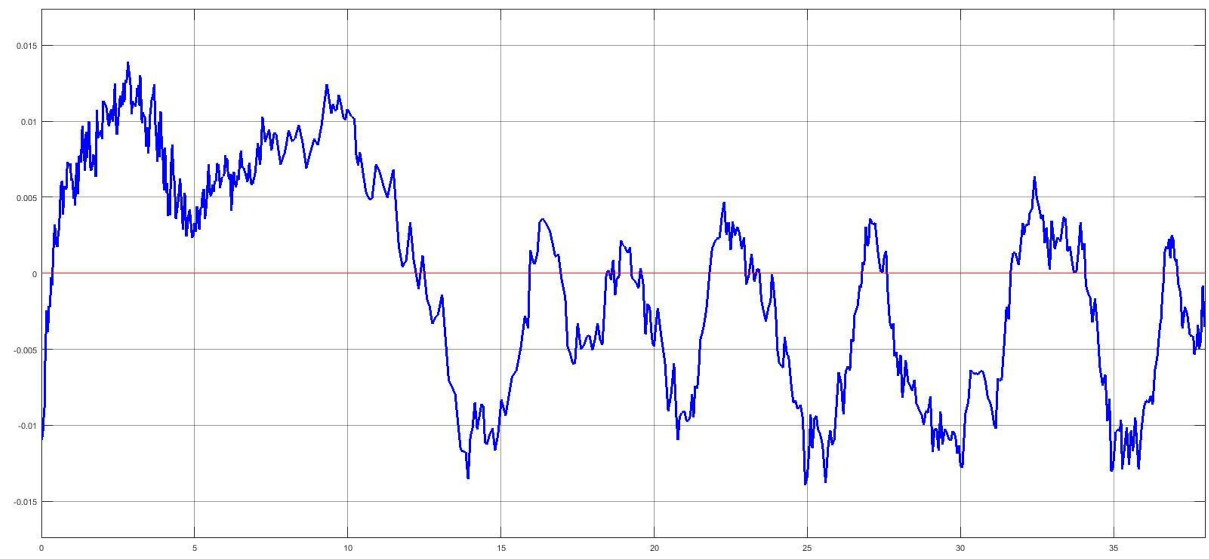

Figure 14 CRC Actual & Wash-out Side Slip Difference

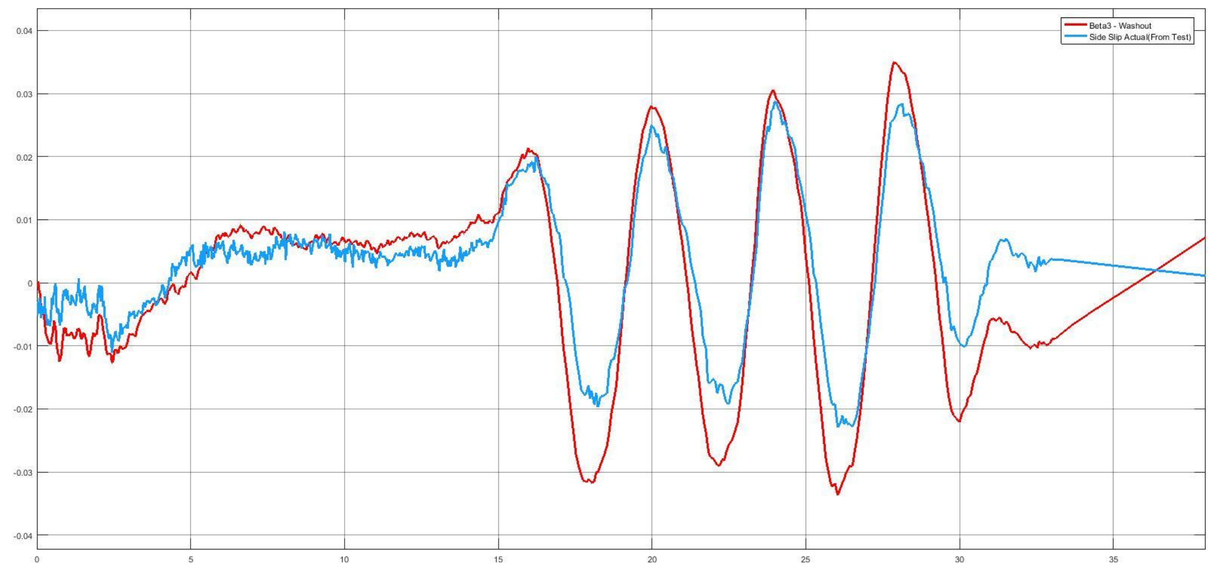

Figure 15 Slalom Actual & Wash-out Side Slip

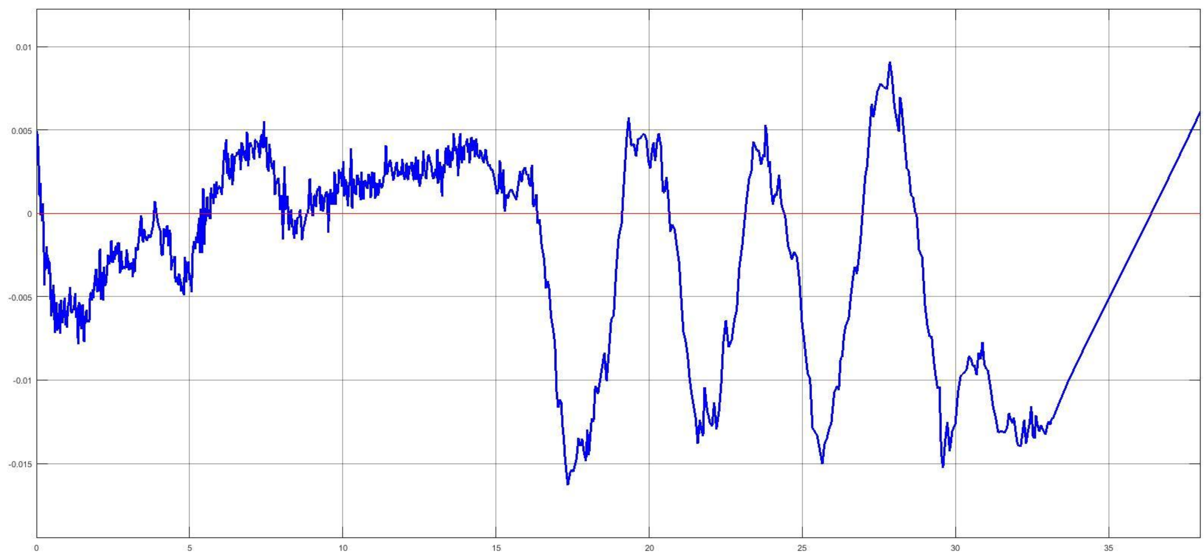

Figure 16 Slalom Actual & Wash-out Side Slip Difference

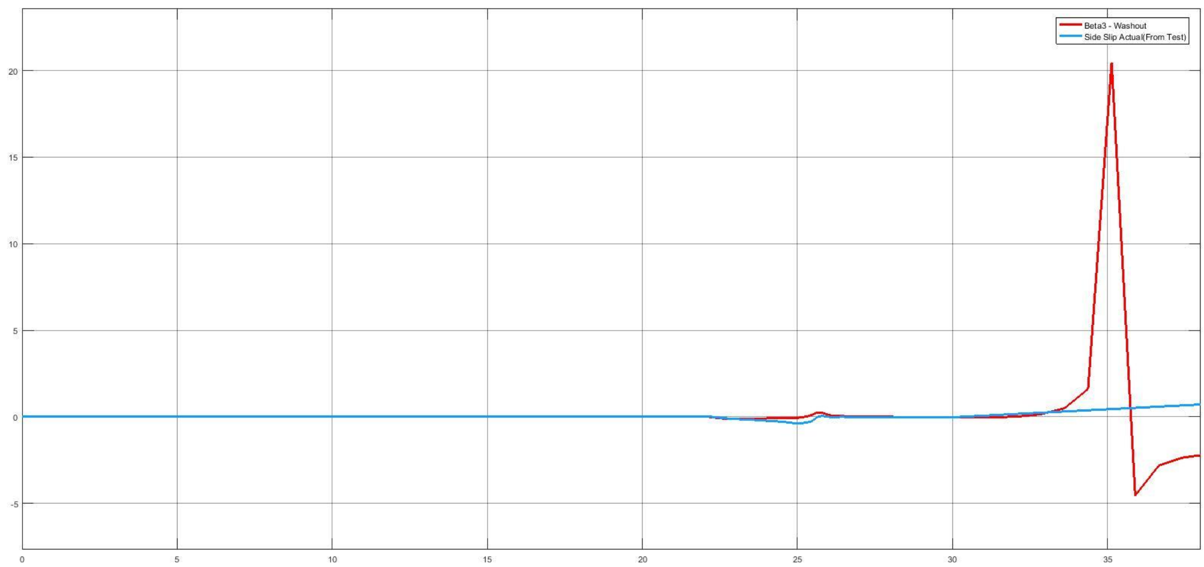

Figure 17 Step Steer Actual & Wash-out Side Slip

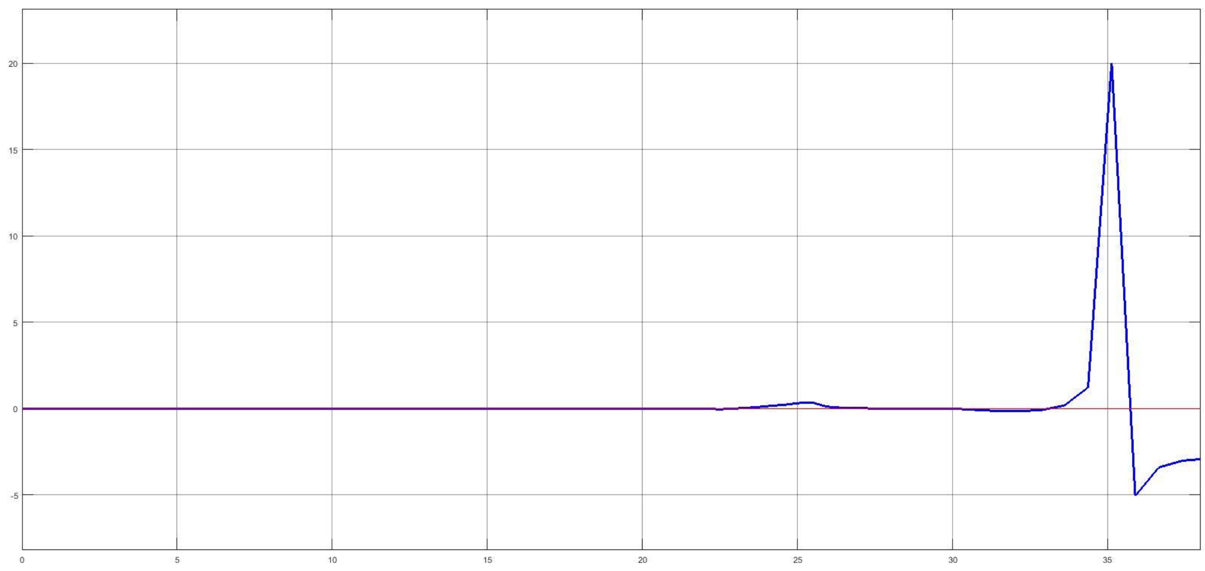

Figure 18 Step Steer Actual & Wash-out Side Slip Difference

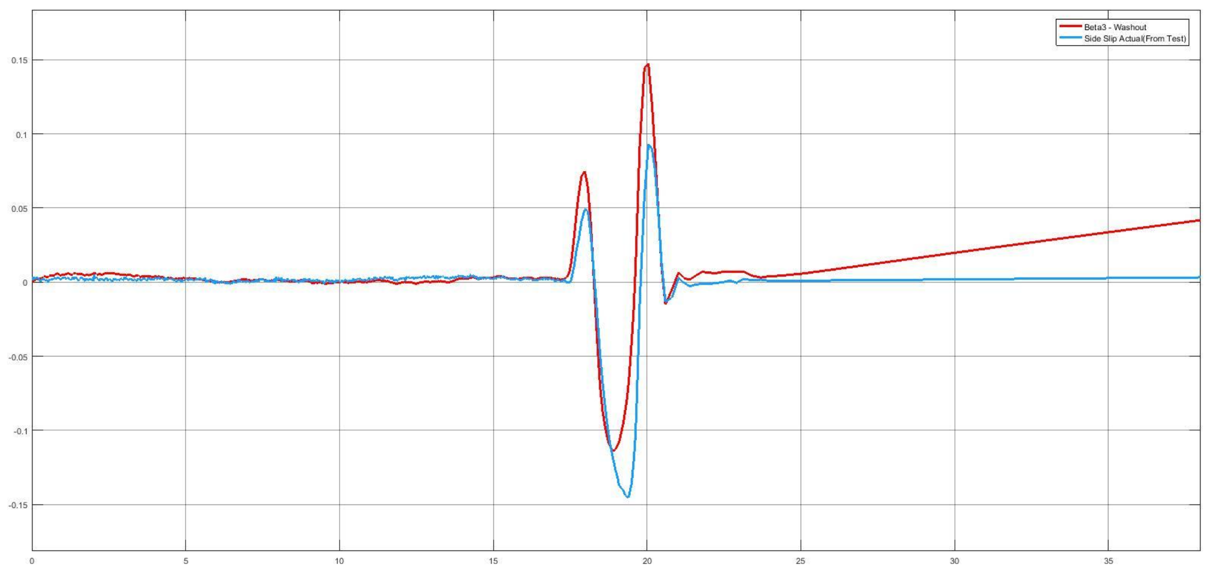

Figure 19 SWD Actual & Wash-out Side Slip

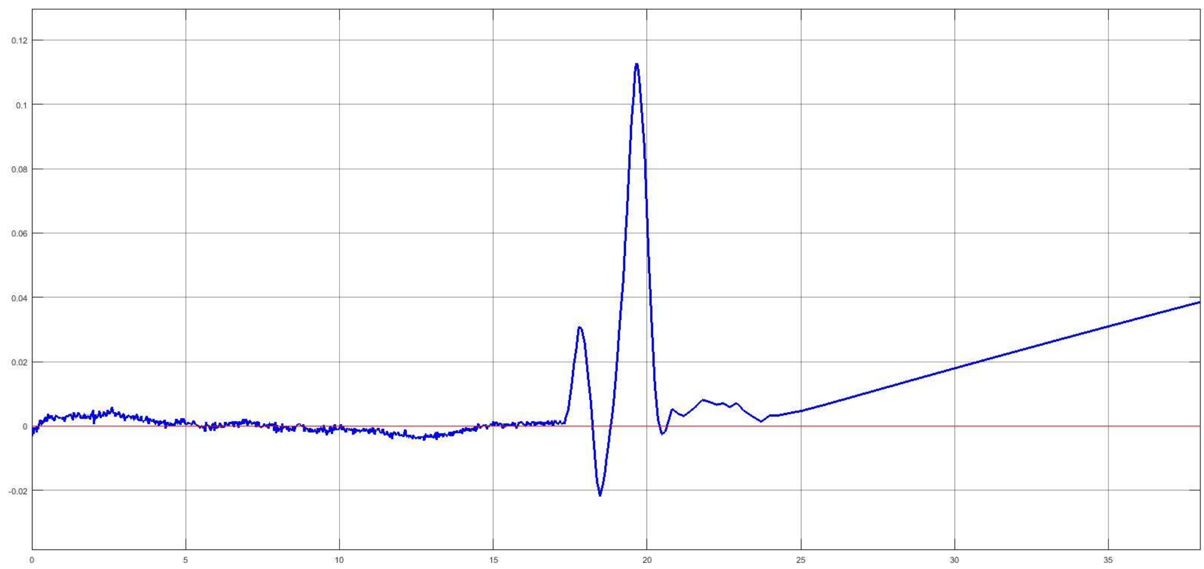

Figure 20 SWD Actual & Wash-out Side Slip Difference

Task 4

Evaluate the quality of the body side-slip estimates from the three estimators and for all the test drive scenarios described in section 2.2.1 by calculating the Mean Squared Error and Max error towards the reference (which is the side-slip from VBOX), use formulation given in section 2.4.1 and that is visible in the UKF_start.m template. Make a table with the resulting MSE, and Max error for each manoeuvre.

Using the formulation of calculating Mean Squared Error and Max Error given in UKF_start.m file the same were calculated by exporting the required data from Simulink to MatLab by using the 'to workspace' block. The following figure shows the same,

```
%        < TASK 4>

      Beta_VBOX_smooth=smooth(Beta_VBOX,0.01,'rlowess');
[e_beta_mean,e_beta_max,time_at_max,error] = errorCalc(bicycle.signals.values',Beta_VBOX_smooth);
[e_beta_mean1,e_beta_max1,time_at_max1,error1] = errorCalc(integration.signals.values',Beta_VBOX_smooth);
[e_beta_mean2,e_beta_max2,time_at_max2,error2] = errorCalc(washout.signals.values',Beta_VBOX_smooth);
disp(' ');
fprintf('The MSE of Beta estimation is: %d \n',e_beta_mean);
fprintf('The Max error of Beta estimation is: %d \n',e_beta_max)

%        < /TASK 4>
```

Figure 21 Calculating MSE & Max Error

The following table summarises the values of MSE & Max Error for each manoeuvre,

Table 1 Mean Squared & Max Errors

Step Steer		
	Mean Squared Error	Max Error
Body Side Slip Bicycle Model	0.0059	0.4082
Body Side Slip Integration Ay	10.2677	81.1175
Body Side Slip Wash-out Filter	0.6370	20.8538
CRC		
	Mean Squared Error	Max Error
Body Side Slip Bicycle Model	0.0022	0.1915
Body Side Slip Integration Ay	0.0098	0.2326
Body Side Slip Wash-out Filter	0.0018	0.1334
Slalom		
	Mean Squared Error	Max Error
Body Side Slip Bicycle Model	2.47 e-4	0.0557
Body Side Slip Integration Ay	0.0100	0.1977
Body Side Slip Wash-out Filter	3.04 e-4	0.0619
Sine with Dwell		
	Mean Squared Error	Max Error
Body Side Slip Bicycle Model	0.0010	0.2142
Body Side Slip Integration Ay	0.0064	0.7898
Body Side Slip Wash-out Filter	0.0013	0.2912

Task 5:

Investigate how the three estimators tend to drift over time, how their accuracy depends on steady-state or transient manoeuvres, how accuracy is depending on vehicle speed. Explain the reasons for the estimators' tendencies.

The following were observed,

- <u>Estimator Drift over Time:</u>

  The estimators tend to drift over time especially the integration estimator (and hence the washout filter) due to the accumulation of errors over time.

- <u>Accuracy for Steady State & Transient manoeuvres:</u>

  It was observed that the accuracy of body side slip from bicycle model and wash-out filter performed very well for all for all manoeuvres with body side slip from bicycle model being better than wash-out filter in most cases. Whereas the based body side slip from integration model did not perform well for transient manoeuvres especially High Speed Step Steer.

- Accuracy Depending on Vehicle Speed:

Task 6:

Summaries under which circumstances it is difficult to estimate body-side slip

The following circumstances were identified for which body side slip calculations become difficult:

- When longitudinal velocity is very small as compared to the lateral velocity, this special case arises when the vehicle is drifting, performing donuts, etc.
- Another problem arises when there is a rapid change in the Steering wheel input like in case of fish hook manoeuvre or in our case high speed step steer. In these cases the input changes from left to right to left very quickly, this results the estimator to first under estimate and then overestimate the body side slip.

Extra Task 1.1:

Let the filter coefficient T be dependent on whether the vehicle is under a transient motion. The less transient, the more weight should be put on the model-based term of Equation (13). Hint: Let T be a linear function of the vehicle's yaw acceleration. Show your design and the improvement in accuracy.

Yaw acceleration was calculated by differentiating the yaw rate from the VBOX. It was noticed that the yaw acceleration in greater than 1 for transient manoeuvres, therefore a simple logic was made using the switch block which switched the value of T to 0.1 for transient (high yaw acceleration) from original value of 0.47 . The logic can be seen in the following figure,

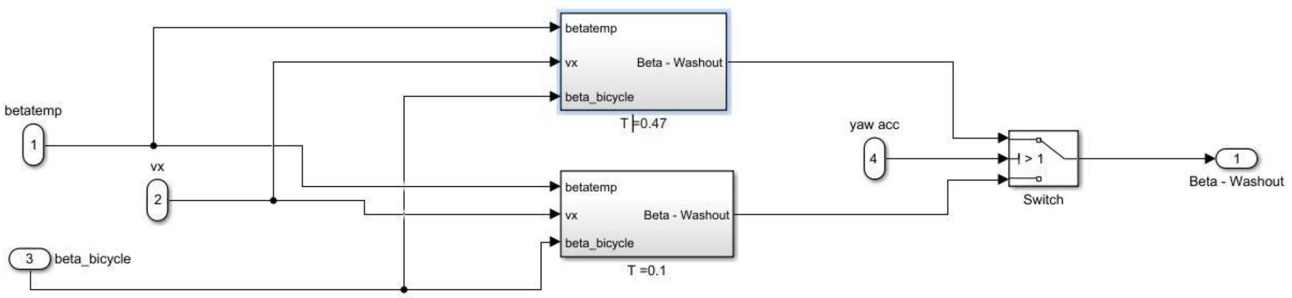

Figure 22 Switching T on basis of Yaw Acceleration

The difference can be seen for the high speed Step Steer manoeuvre in the following figures,

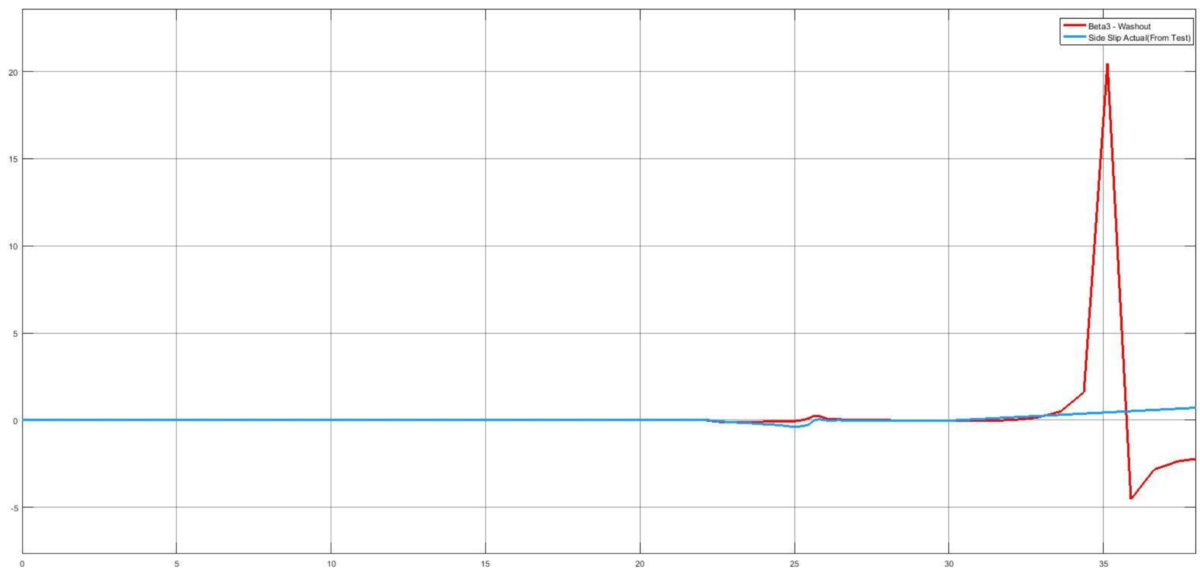

Figure 23 Beta Actual & Beta Washout for Step steer

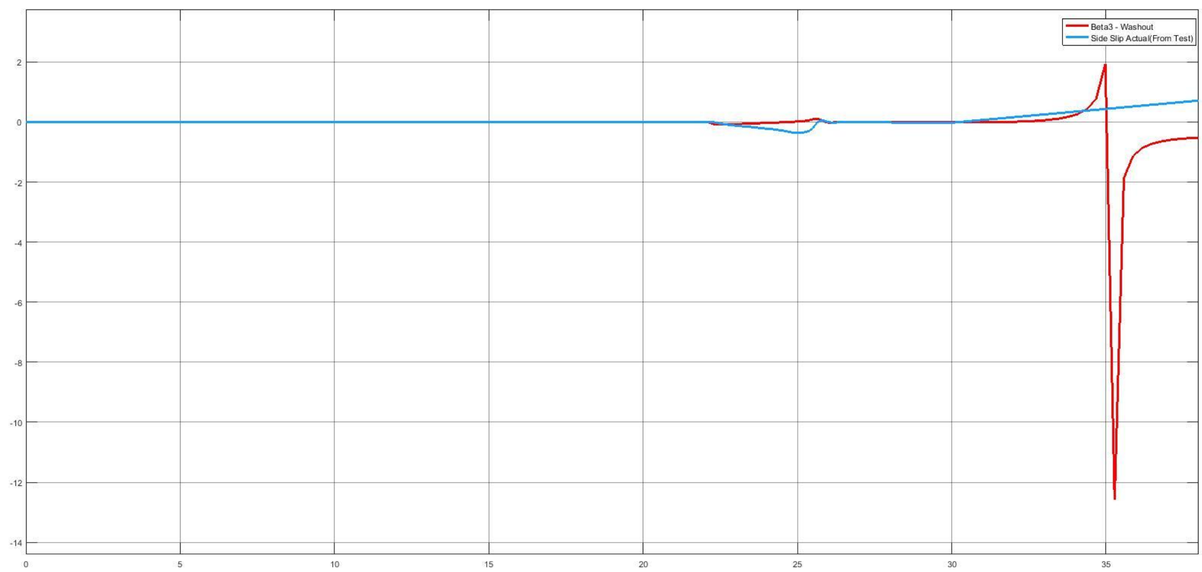

Figure 24 Beta Actual & Beta Washout for Step steer with Switching T

Extra Task 1.2:

Suggest, describe or show improvements that could make the wash-out filter even better

The wash-out filter according to us can be made better by,

- Using a more sophiscated switching algorithm (compared to extra Task1.1)
- The error due to Body side slip calculated by integration is too high at times, if the equation can be made such that it gives more realistic values then it will improve the wash-out filter.
- The Kroll term in integration body side slip is a constant if it can be taken from VBOX the results would be better.

Task 7:

If you study the simple Kalman Filter implementation in Section 2.1.6.1 what would you do in order to be able to use this filter in a vehicle given the input data that you have given for this exercise? You cannot change type of Kalman Filter but you can use logics and steady state vehicle kinematic models.

With the present given vehicle inputs, the state transition matrix A, B and C will change. Moreover, in the example given we are measuring the angle directly with (a_y/a_z) which cannot be done for our vehicle inputs. For vehicle measurement we measure a_y using the vehicle dynamics equations.

Furthermore, we use the equations from (37) to (43) to build our state space model. In the state space model given in the example, there are only two state-space variables $f1$ and $f2$ while with the vehicle model, we will use three state variables v_x, v_y, and $\dot{\psi}$.

The error calculation for the example is simplified by assuming only one measurement unit, while error in the vehicle dynamics model depends on all other measured units as well. So the covariances are different in both cases.

The filter in the example will only work for low dynamics motions, so it needs to alter the measurement equations to account for high velocity and accelerations.

Task 8:

Study your equations, will we have problem with observability for some values of the variables?

The inputs to the model is the measured values from vbox so it depends on how smooth is the stream of data from the logger. If the data is not made smooth like the value of v_y and v_x, and v_x goes zero for certain points, the value of side slip reaches infinity.
Similarly if v_y is too small or unreadable, the slip estimation becomes difficult.

Task 9:

Show for the four manoeuvres how the UKF differs from the model-based, integration of lateral acceleration based, and washout filtered based designs. Use the same tuned values of cornering stiffness as you did for the model based estimation.

We plotted the MSE and Max errors for all the manoeuvres to check the closeness of the model from the actual reading. The errors are plotted in the table below.

Table 2 Meam Squared & max Error compared compared to UKF Filter

Step Steer		
Body Side Slip	Mean Squared Error	Max Error
Bicycle Model	0.0059	0.4082
Integration Ay	10.2677	81.1175
Wash-out Filter	0.6370	20.8538
UKF Filter	3.125722e-03	2.463321e-01
CRC		
	Mean Squared Error	Max Error
Bicycle Model	0.0022	0.1915
Integration Ay	0.0098	0.2326
Wash-out Filter	0.0018	0.1334
UKF Filter	1.448970e-03	1.241410e-01
Slalom		
	Mean Squared Error	Max Error
Bicycle Model	2.47 e-4	0.0557
Integration Ay	0.0100	0.1977
Wash-out Filter	3.04 e-4	0.0619
UKF Filter	1.019074e-04	2.532150e-02
Sine with Dwell		
	Mean Squared Error	Max Error
Bicycle Model	0.0010	0.2142
Integration Ay	0.0064	0.7898
Wash-out Filter	0.0013	0.2912
UKF Filter	4.882202e-04	1.294527e-01

We can clearly see the difference in errors for UKF is the minimum for most of the cases which suggests us that UKF gives the best performance in all the manoeuvres. Moreover, we plot the graphs for all the manoeuvres showing all the slide slips: from Bicycle model, from Integration Model, from Washout Filter, from UKF and the actual side slip from VBOX Measurement.

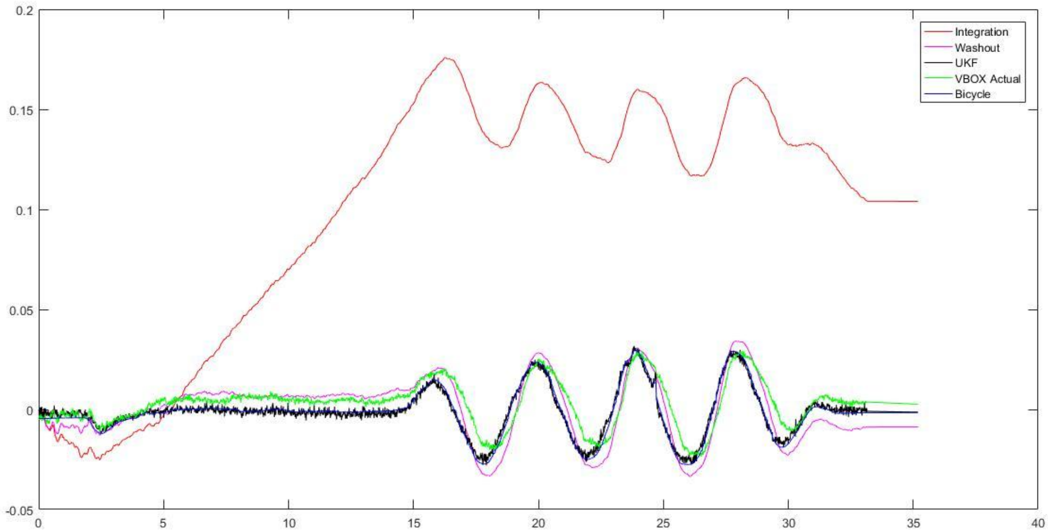

Figure 25 Slalom Test (Side Slip v/s Time)

In the first figure which shows the slalom test, UKF shows the closest resemblance to the actual filter and the integration model does not fit the model at all. Washout and Bicycle models are close but their error is bigger than UKF.

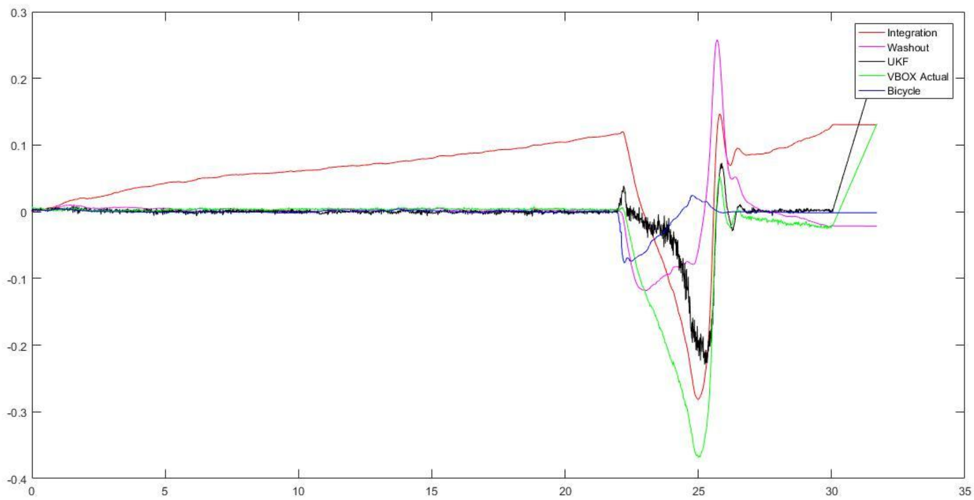

Figure 26 Step Steer Left Test (Side Slip v/s Time)

In this second figure, a step steer test side slip angle is plotted and we can see the integration model does better than UKF for a small part of the graph from 22 sec to 26 sec but UKF fits best overall.

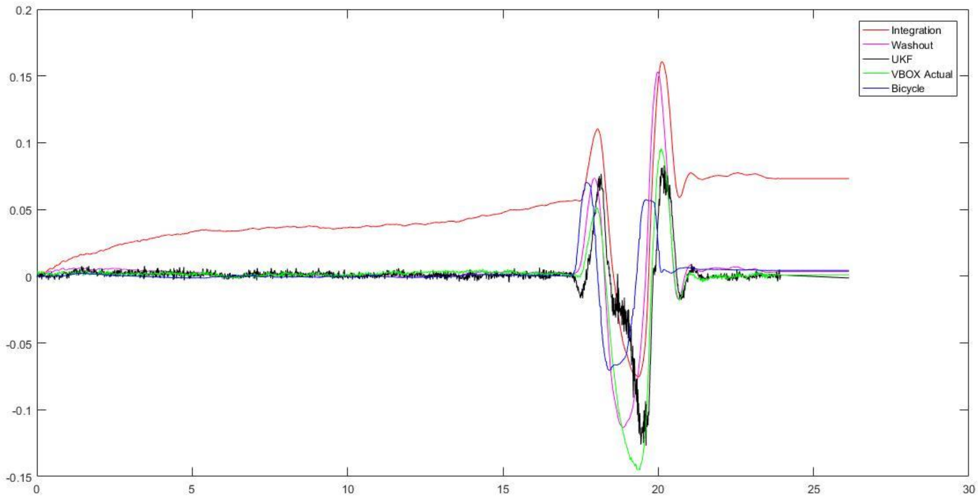

Figure 27 Sine With Dwell Test (Side Slip v/s Time)

In the third figure, We can see for sine with dwell, a washout filter performs equally good as a UKF since there is a trade-off between the two. The washout is good for t=17s to 19s while the UKF fits better for 18s to 25sec while we can see the rest of the graph is similar for Washout and UKF filters. Integration filter as usual does not fits well to the actual slide slip readings.

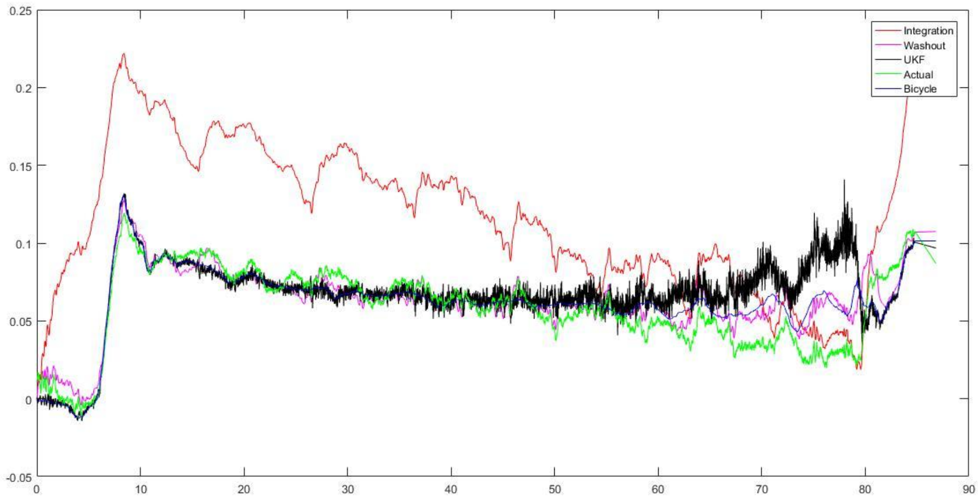

Figure 28 Circle Test (Side Slip v/s Time)

In figure 27, the circle test readings are quite different from the other three tests. Here we can see that the UKF does not fits for the later part of the experiments from t=60sec onwards. A washout filter much closely resembles the actual reading for most part of the graph.