Week 3
Problem 3: ABS

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Introduction

ABS is an acronym for Antilock Braking System. As the name suggests it is a safety, anti-skid braking system used on most of the modern day vehicles such as aircrafts, on land vehicles like cars, bikes, trucks and buses.

The basic principle of operation of an ABS is an amalgamation of threshold braking and cadence braking. It operates by preventing the wheels from locking up during braking, thereby maintaining tractive contact with the road surface. One of the major advantages of an ABS is that it operates at a much faster rate and more efficiently compared to both human reaction and previously available braking systems. Although ABS generally offers improved vehicle control and decreases stopping distance on dry and some slippery surfaces yet on loose gravel or snow covered surfaces it may significantly improve braking distance, while still improving steering control.

There are four major components of an ABS and they are wheel speed sensors or encoders, valves, pump and controller. A wheel speed sensor determines the acceleration or deceleration of the wheel with the help of either Hall sensor or a toothed wheel and an electromagnetic coil. The valves are used to maintain the pressure in the master cylinder by varying its positions. The pump is used to restore the pressure of the hydraulic brakes after the valves have released it. The controller is an electronic control unit type unit in the car which receives information from each of the wheel speed sensors. If a wheel loses traction the signal is sent to the controller. The controller will then limit the brake force and activates the ABS modulator which actuates the braking valve on and off.

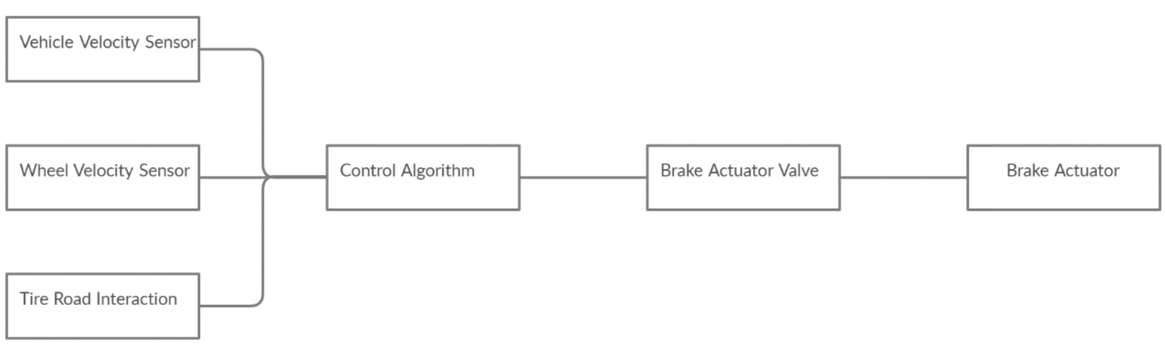

Fig. 1: Block Diagram of ABS

There are different schemes associated with ABS depending upon the type of brakes in use. They can be differentiated depending upon the number of channels i.e. based on the number of valves that are individually controlled and the number of wheel speed sensors. Based on the above parameters there are mainly five configurations present till date and they are as follows. Four channel four sensor ABS here, there are individual valves and sensors associated with each wheel and thus, the maximum brake force can be applied since each wheel is monitored individually. Three channel four sensor ABS here, there are speed sensors associated with each of the individual wheels but there is a common valve present for both of the rear wheels. Three channel three sensor ABS here, there are individual wheel speed sensors and valves associated with each of the front wheels but there is a common wheel speed sensor and valve associated with the rear wheels. Two channel four sensor ABS here, there are individual wheel speed sensors associated with each of the individual wheels but there is a common valve present for both of the front and rear wheels respectively. One channel one sensor ABS here, there is a common valve present for both of the rear wheels and a wheel speed sensor present on the rear axle. Its functioning is similar to the operation of the rear end of a three channel system.

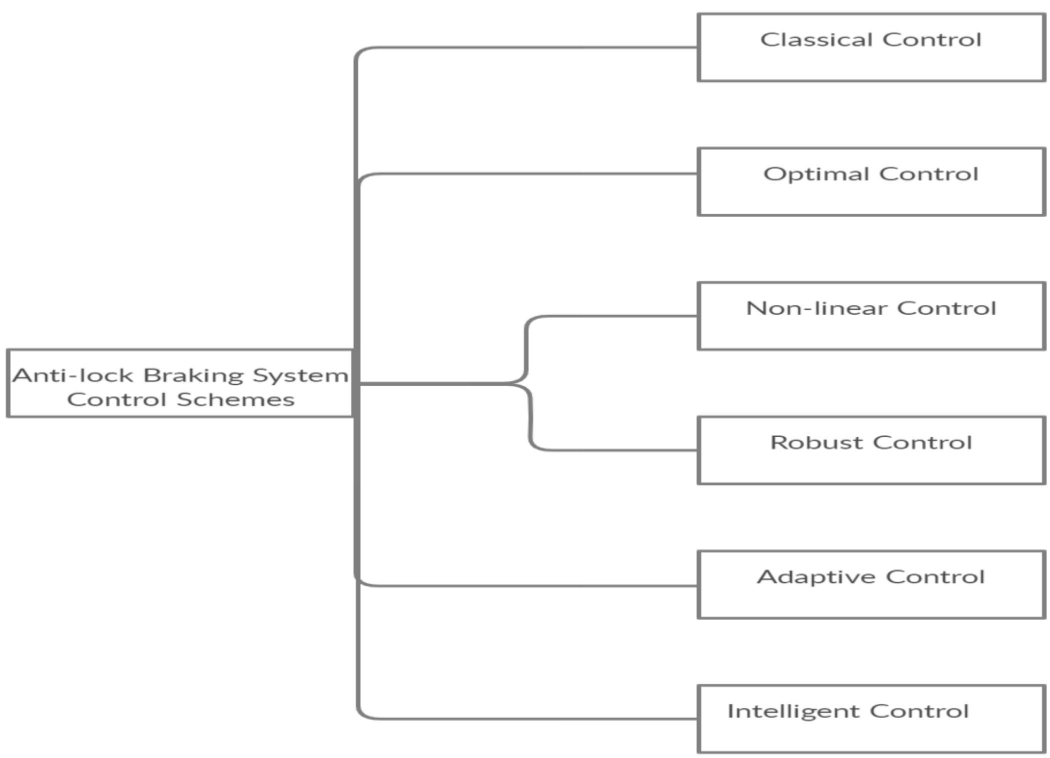

Fig. 2: Control Schemes of ABS

Objective

To develop a simple model for an anti-lock braking system and to simulate the dynamic behavior of a vehicle under hard braking conditions.

Analysis and Physics

Analyzing the model for a single wheel and the model can be replicated a number of times to create a model for a multi- wheel vehicle.

The wheel rotates with an initial velocity corresponding to the vehicle speed before the brakes are applied.

Two separate integrators are used to compute wheel speed and vehicle speed and the two speeds are used to calculate slip, which is determined by

$$\text{Slip } s = 1 - \omega_w/\omega_v \text{, where } \omega_v = V_v / R_r$$

Where s = slip

ω_w = wheel angular velocity

ω_v = vehicle angular velocity

V_V = vehicle linear velocity

R_r = wheel radius

From the above equation it is evident that when $\omega_w=\omega_v$ slip is zero and when $\omega_w = 0$ slip is equal to one.

A desirable slip value is 0.2, which means that the number of wheel revolutions equals 0.8 times the number of revolutions under non-braking conditions with the same vehicle velocity. This maximizes the adhesion between the tire and road to minimize the stopping distance with the available friction.

Modeling

The co-efficient of friction μ, is an empirical function of slip known as the μ-slip curve. The μ-slip curves have been created using MATLAB variables that were brought into the block diagram using a SIMULINK lookup table. The model multiplies the friction co-efficient μ, by the weight on the wheel m*g/4, to yield the frictional force Ff, acting on the circumference of the tire. Ff is divided by the vehicle mass to give the vehicle deceleration, which the model integrates to obtain the vehicle velocity.

An ideal anti-lock braking controller that uses bang bang control based upon the error between actual slip and desired slip has been used. The desired slip has been set to the value of slip at which the μ-slip curve reaches a peak value, this being the optimum value for minimum braking distance.

By subtracting slip from desired slip, and feeding this signal into a bang-bang control, the model controls the rate of change of brake pressure. This on/off rate passes through a first-order lag that represents the delay associated with the hydraulic lines of the brake system. The model then integrates the filtered rate to yield the actual brake pressure. The resulting signal, multiplied by the piston area and radius with respect to the wheel (Kf), is the brake torque applied to the wheel. The model also multiplies the frictional force on the wheel by the wheel radius, Rr, to give the accelerating torque of the road surface on the wheel. The brake torque is subtracted to give the net torque on the wheel. Dividing the net torque by the wheel rotational inertia, I, yields the wheel acceleration, which is then integrated to provide wheel velocity.

In order to prevent wheel speed and vehicle speed from going negative, limited integrators are used in this model.

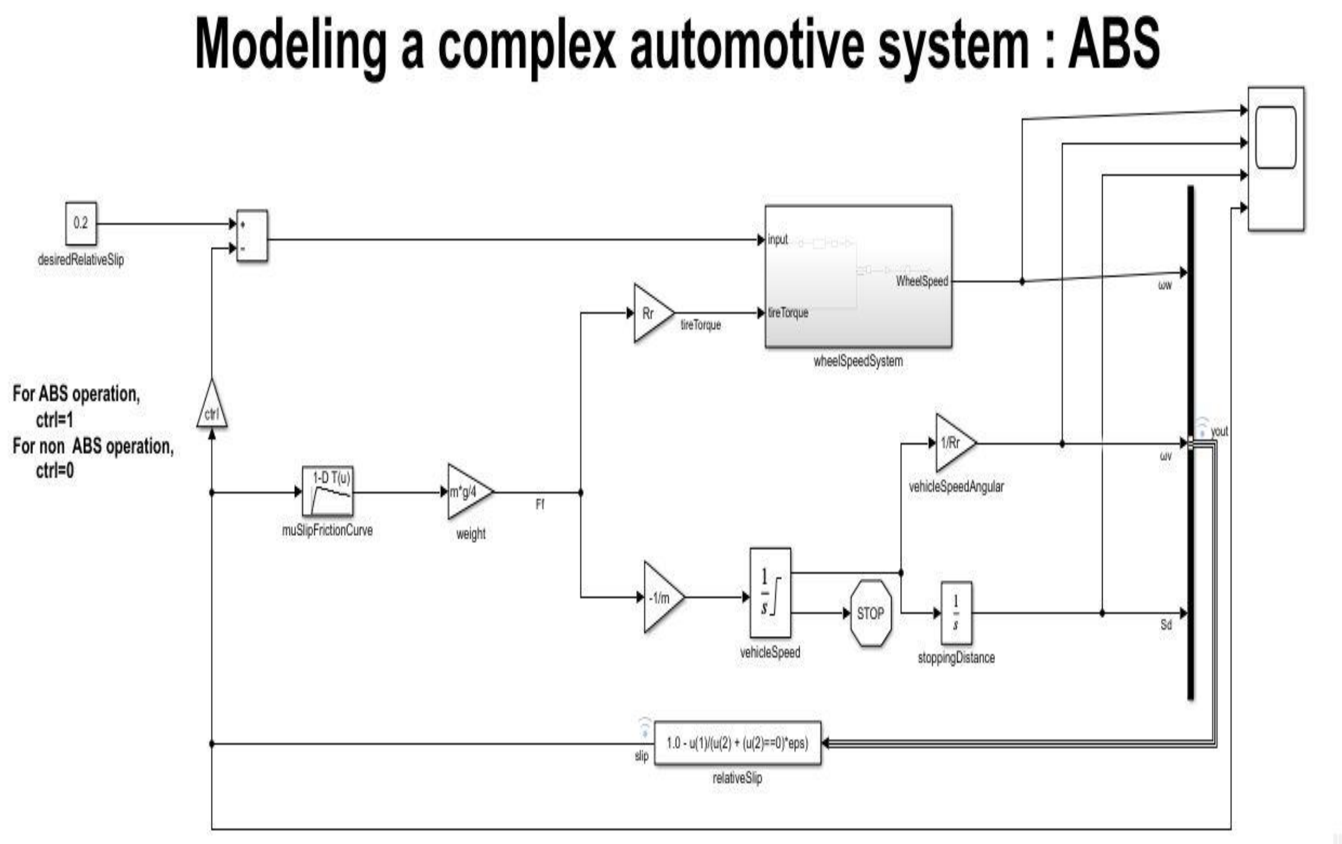

Fig. 3: SIMULINK diagram for modeling of an ABS

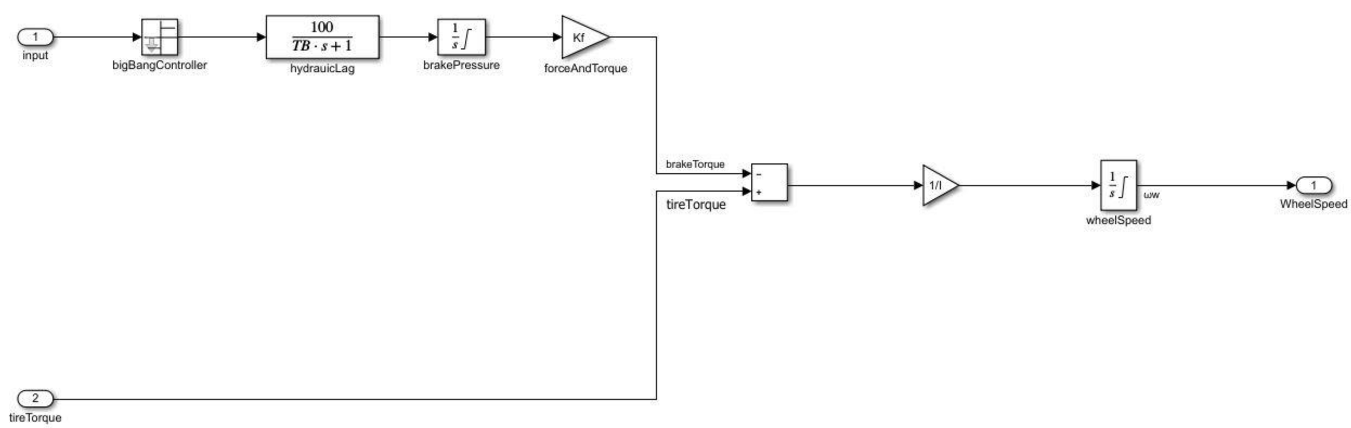

Fig. 4: SIMULINK sub-system for wheel speed control

Results

Results without ABS:

1. Wheel speed:

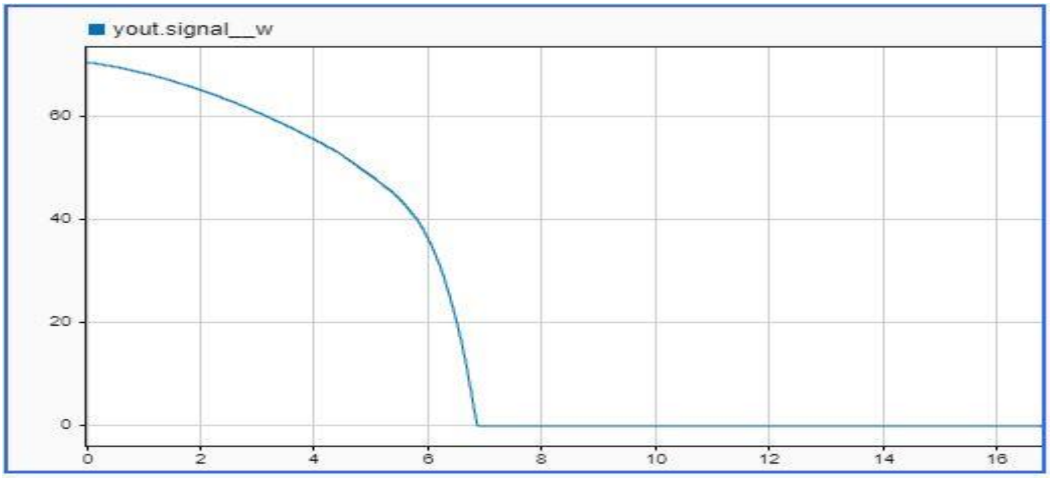

Fig. 5: Wheel speed: Speed (rad/sec) VS Time (sec)

2. Vehicle speed:

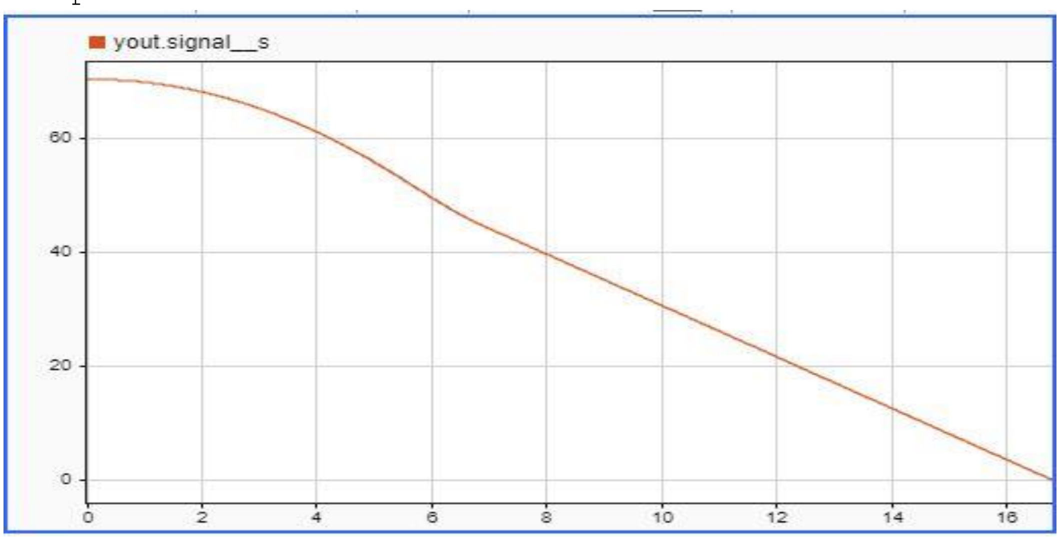

Fig. 6: Vehicle speed: Speed (rad/sec) VS Time(sec)

3. Stopping distance:

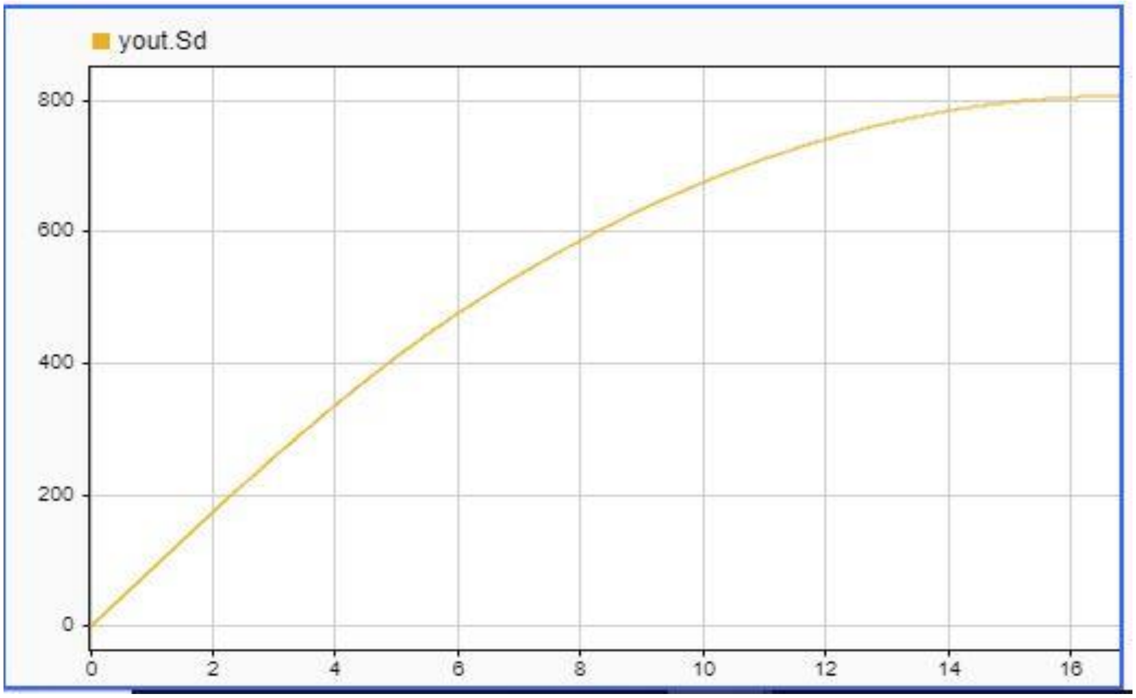

Fig. 7: Stopping distance:
Stopping distance(feet) VS Slip time(sec)

4. Slip:

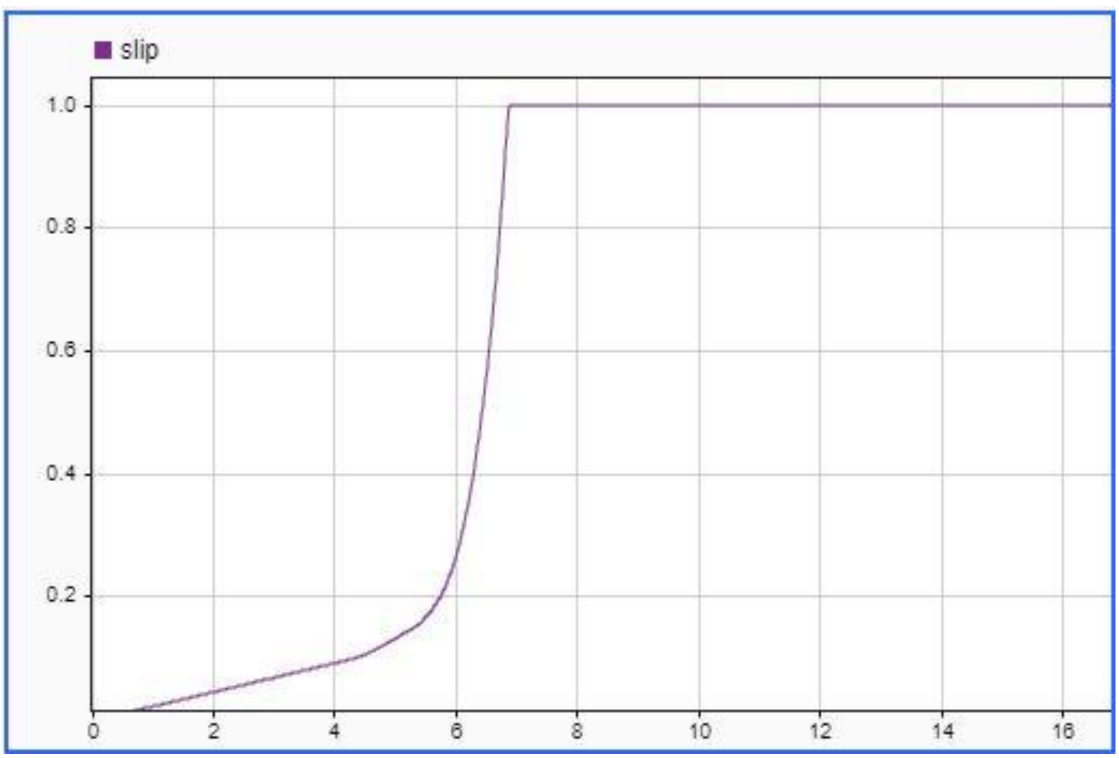

Fig. 8: Slip: Normalized relative slip VS Time(sec)

Results with ABS:

1. Wheel speed:

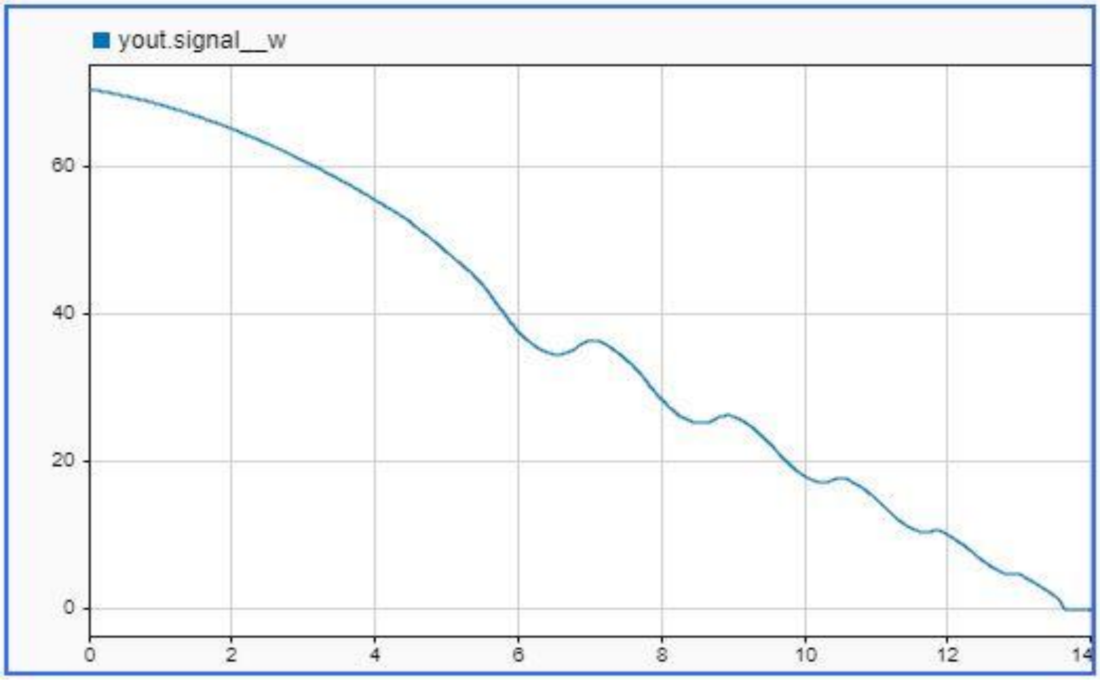

Fig. 9: Wheel speed: Speed(rad/sec) VS Time(sec)

2. Vehicle speed:

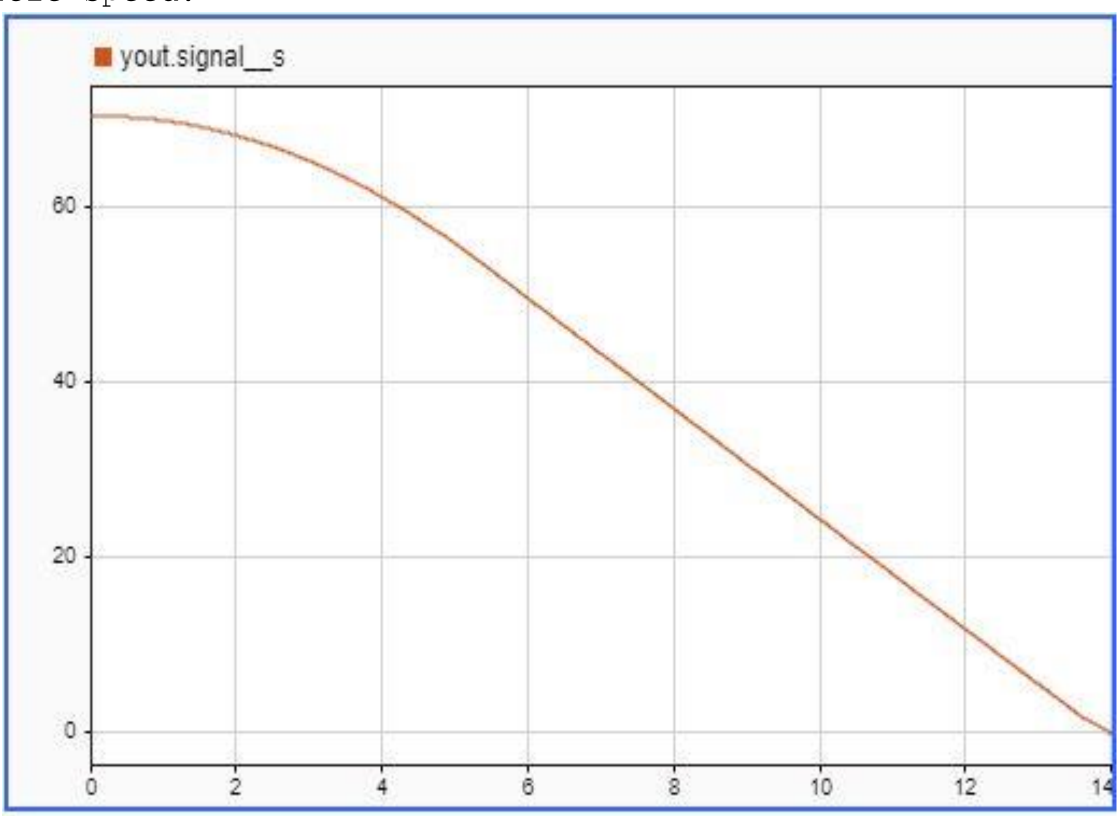

Fig. 10: Vehicle speed: Speed(rad/sec) VS Time(sec)

3. Stopping distance: Stopping distance(feet) VS Slip time(sec)

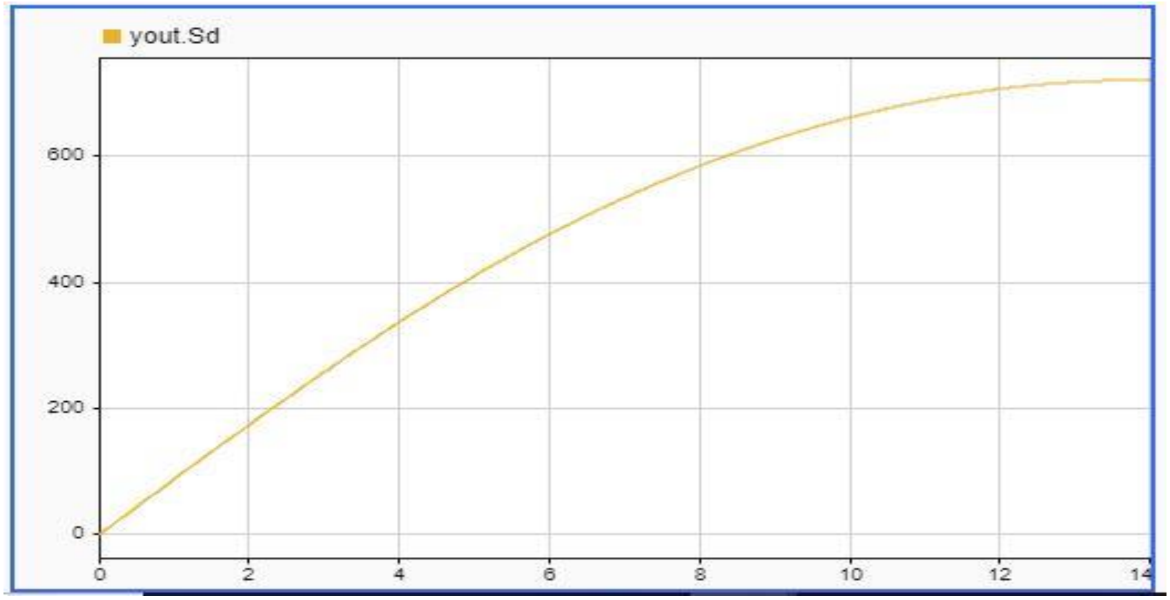

Fig. 11: Stopping distance:
Stopping distance(feet) VS Slip time(sec)

4. Slip: Normalized relative slip VS Time(sec)

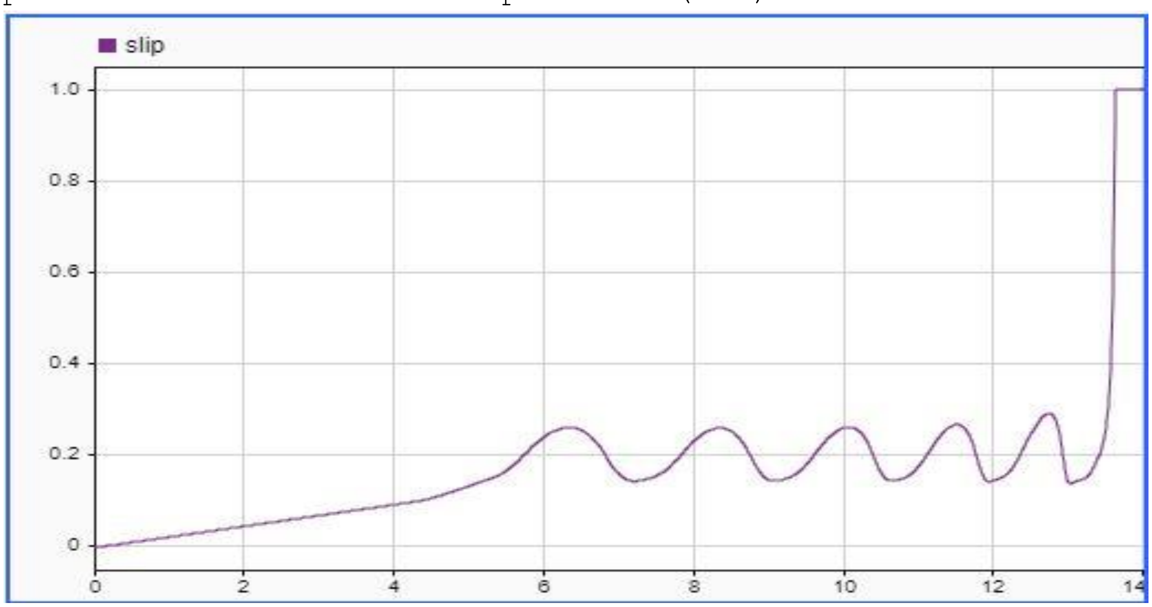

Fig. 12: Slip: Normalized relative slip VS Time(sec)

Comparing results with and without ABS:

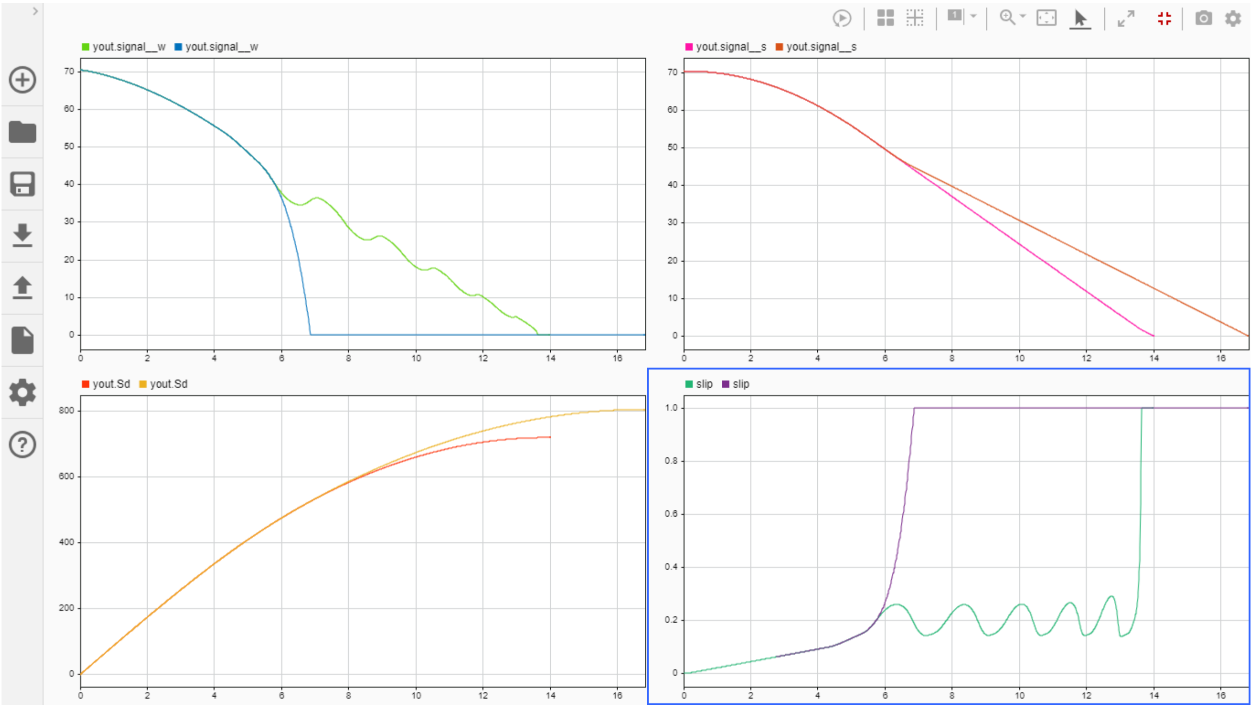

Fig. 13: Comparing results with and without ABS

Figure: Clockwise from selected figure

i. Slip: Normalized relative slip VS Time(sec)- Purple (without ABS) Green (with ABS)

ii. Stopping distance: Stopping distance(feet) VS Slip time(sec) Orange (without ABS) Red (with ABS)

iii. Wheel speed: Speed(rad/sec) VS Time(sec) Blue (without ABS) Green (with ABS)

iv. Vehicle speed: Speed(rad/sec) VS Time(sec) Orange (without ABS) Pink (with ABS)

Conclusion

Fig. 9, fig 10 and fig. 12 clearly shows that wheel angular velocity stays below vehicle angular velocity, without locking up, with vehicle speed going to zero in less than 15 seconds.

Fig. 5, fig 6 and fig. 8 clearly shows that when slip has been disconnected from the feedback from the controller then it results in maximum braking and it has been observed that the wheel locks up in about 7 seconds and the braking, from that point on, is applied in a less-than-optimal part of the slip curve. That is, when slip = 1, as seen in Figure 8, the tire is skidding so much on the pavement that the friction force between the two has dropped off.

From fig. 13(Stopping distance) it is evident that without ABS the vehicle skids about an extra 100 feet, taking about 3 seconds longer to come to a stop.

MATLAB and SIMULINK Skills:-

i. Callbacks: InitFcn*
   g=32.18;
   v0=88;
   Rr=15/12;
   Kf=1;
   m=50;
   PBmax=1500;
   TB=0.01;
   I=5;
   slip=(0:.05:1.0);
   mu=[0 .4 .8 .97 1.0 .98 .96 .94 .92 .9 .88 .855 .83 .81 .79 .77 .75 .73 .72 .71 .7];
ii. Data inspector:
   Output signal (yout) and slip has been logged and the data inspector results have been displayed above.
iii. Solver selection strategy:
   Solver: ode45
   Max step size: 0.01
iv. MATLAB function block:
   Relative slip expression: 1.0 – u(1)/(u(2)+(u(2)==0)*eps)
v. Look up table:
   1-D lookup table:
   Table data: mu
   Breakpoints 1: slip

References:

[1] https://en.wikipedia.org/wiki/Anti-lock_braking_system
[2] https://in.mathworks.com/help/simulink/automotiveapplications.html