ANTI LOCK BRAKING SYSTEM
MODELLING AND DEVELOPMENT

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Introduction

- ABS prevents locking of wheels during braking

- During severe braking or on slippery surfaces, wheels approach lockup. At that time, ABS takes over

- ABS modulates the brake line pressure independent of the pedal force, to bring the wheel speed back to the slip level range that is necessary for optimal braking performance.
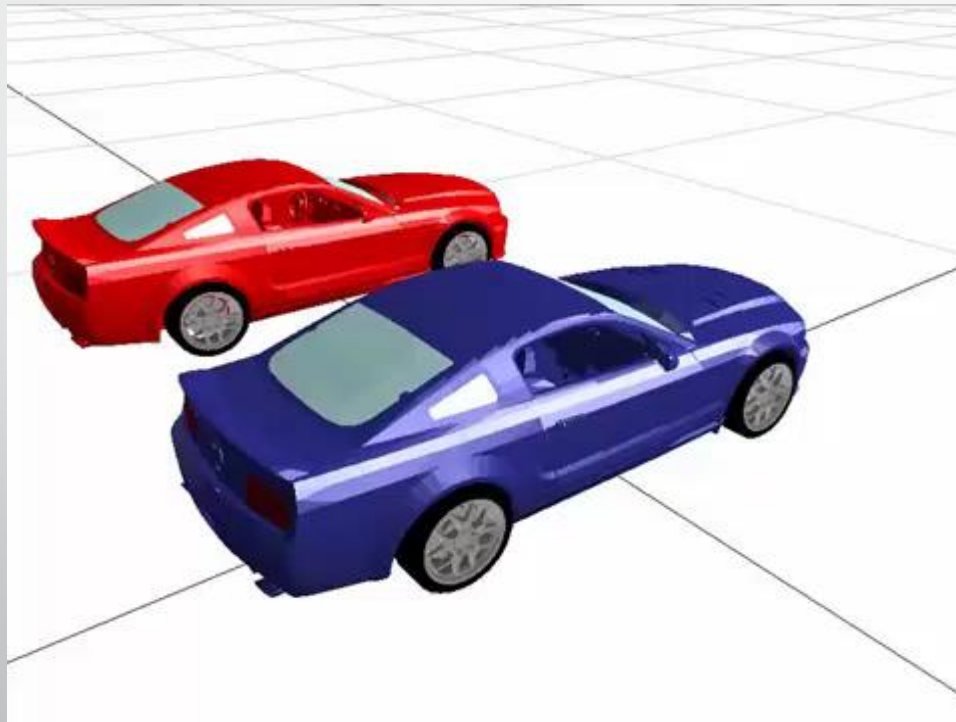
Video Courtesy: Maplesoft
Software Used: Maple Sim

Motivation

- Though Anti lock Braking System has already been implemented in sophisticated cars , still the technology is considered as a cutting edge.

- As far as automotive industry is concerned ABS technology is most recent development in enhancing passenger safety and accident avoidance.

  - A 2004 Australian study by Monash University Accident Research Centre found that ABS

    - Reduced the risk of multiple vehicle crashes by 18 percent,

    - Reduced the risk of run-off-road crashes by 35 percent.

- That is why , we felt it is important as well as challenging to study
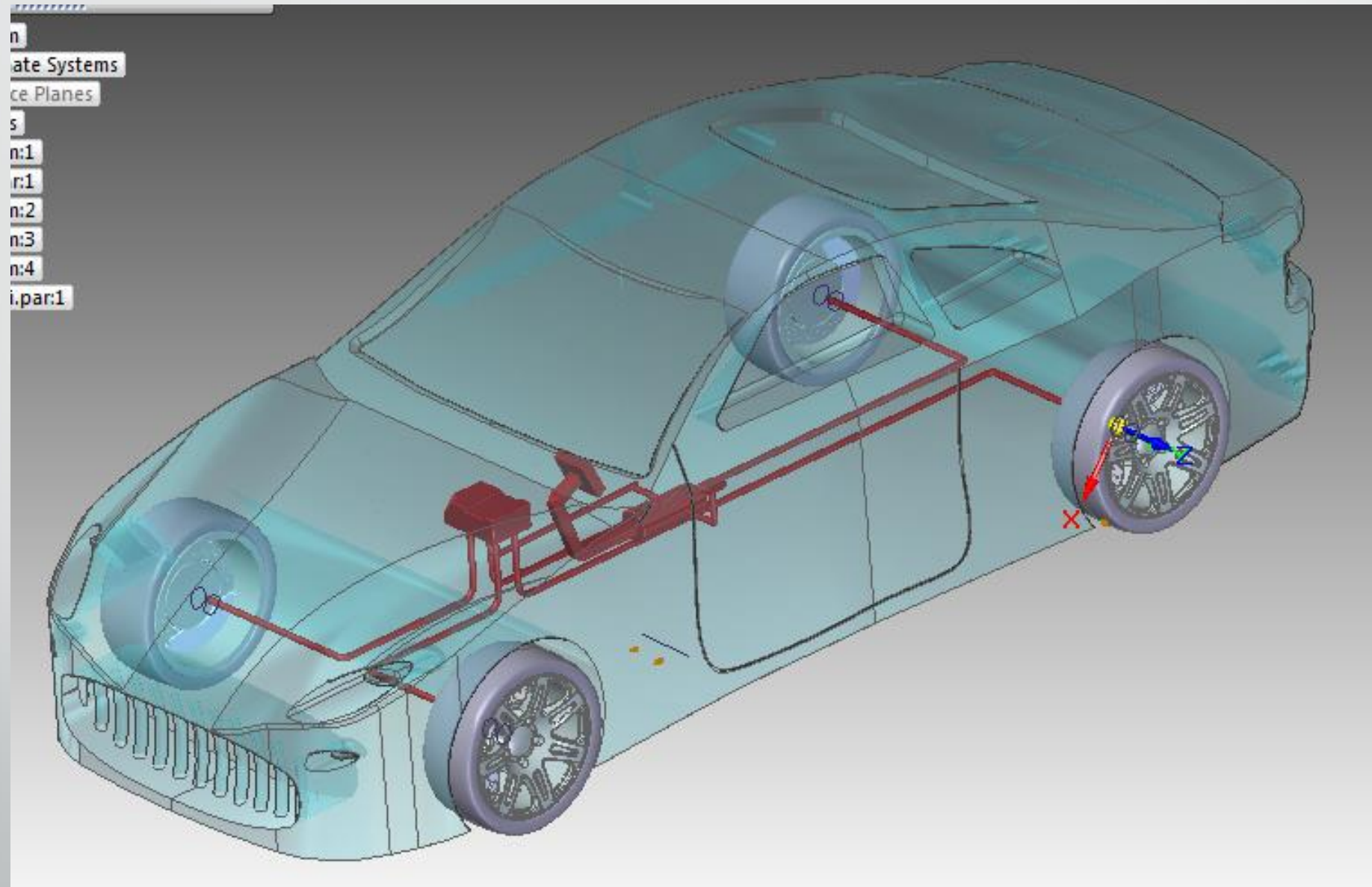
Project Outline

- Car Model
- Brake System model
- How ABS works ??
- Mathematical model
- System model
- Results
- Discussion
- Conclusion
- References

CAR MODEL

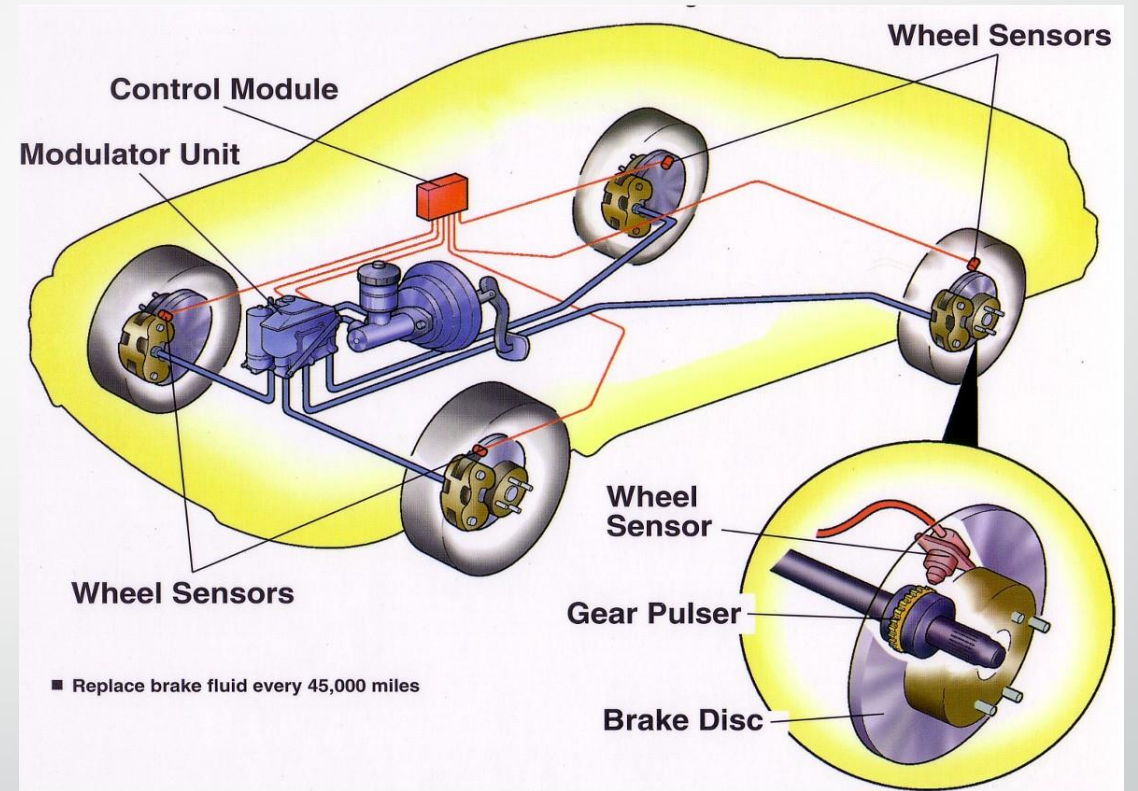- Maserati GranTurismo !!
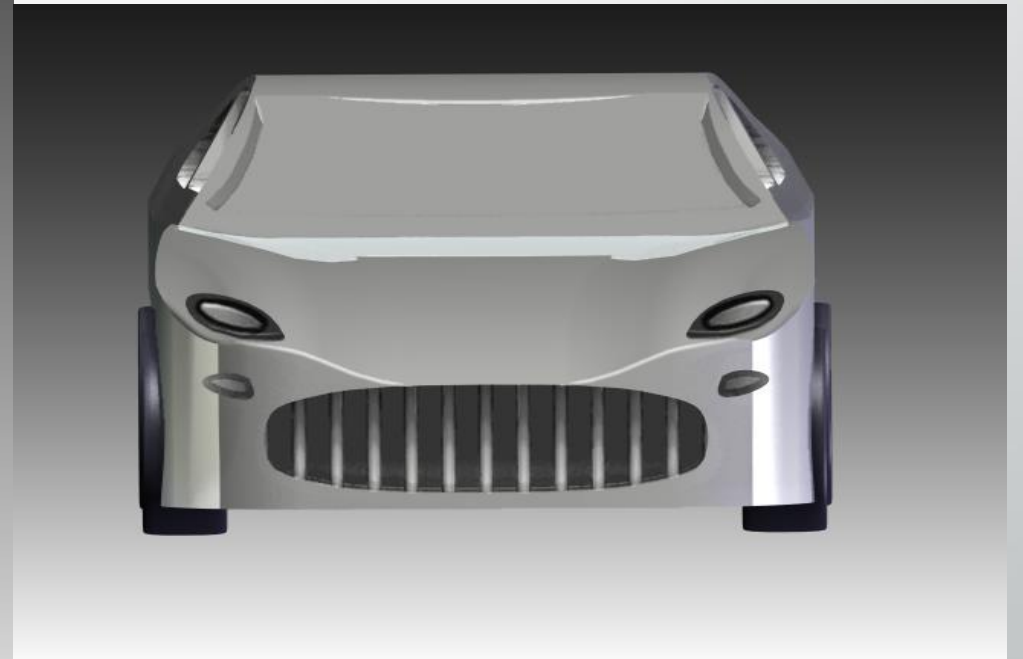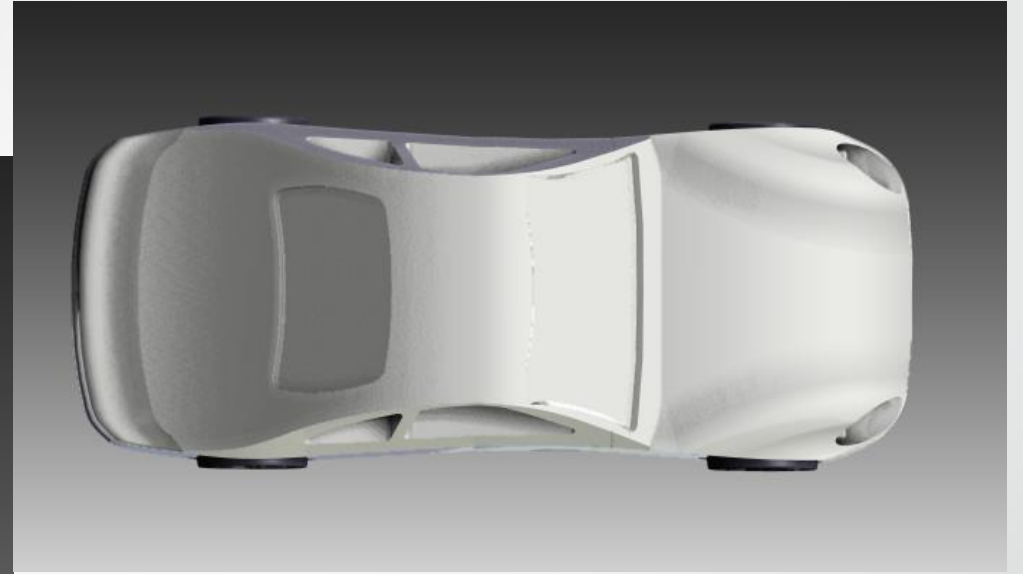
Brake Model

How ABS works

- ABS consists of –
  - Wheel speed sensors
  - Controller unit
  - Hydraulic modulator Unit
  - Braking device

How ABS works - Subsystems

- Wheel Speed Sensors
  - Electro-magnetic or Hall-effect pulse pickups with toothed wheels mounted directly on the rotating components of the drivetrain or wheel hubs.
  - As the wheel turns the toothed wheel (pulse ring) generates an AC voltage at the wheel-speed sensor.
  - The voltage frequency is directly proportional to the wheel's rotational speed.
- Electronic Controller Unit
  - The electronic control unit receives, amplifies and filters the sensor signals for calculating the wheel rotational speed and acceleration.
  - ABS is usually implemented here.
  - ECU assists the vehicle operator to prevent wheel lockup by regulating the wheel slip.
- Hydraulic Unit
  - The hydraulic pressure modulator is an electro-hydraulic device for reducing, holding, and restoring the pressure of the wheel brakes by manipulating the solenoid valves in the hydraulic brake system.
  - Hydraulic unit actuates the brakes by increasing the hydraulic pressure or bypassing the pedal force to reduce the braking power.
  - Depending on the design, this device may include a pump, motor assembly, accumulator and reservoir

How ABS works

- When a wheel lockup is detected or eminent, ECU commands HCU to release the brake pressure to allow the wheel velocity to increase and the wheel slip to decrease.

- Once the wheel velocity spins up, ECU re-applies the brake pressure to confine the wheel slip to a predetermined value or interval.

- HCU Controls hydraulic brake pressure to each disc brake caliper or wheel cylinder based on input from the system sensors, thereby controlling wheel speed.

Objectives of ABS

- 1. To reduce stopping distances

  - The distance to stop is a function of the mass of the vehicle, the initial velocity, and the braking force.

  - By maximizing the braking force the stopping distance will be minimized if all other factors remain constant.

  - However, on all types of surfaces, to a greater or lesser extent, there exists a peak in fiction coefficient.

  - It follows that by keeping all of the wheels of a vehicle near the peak, an antilock system can attain maximum fictional force and, therefore, minimum stopping distance.

Objectives of ABS

- 2. Stability

- Although decelerating and stopping vehicles constitutes a fundamental purpose of braking systems, maximum friction force may not be desirable in all cases

- For example not if the vehicle is on a so-called p-split surface (asphalt and ice, for example), such that significantly more braking force is obtainable on one side of the vehicle than on the other side.

- Applying maximum braking force on both sides will result in a yaw moment that will tend to pull the vehicle to the high friction side and contribute to vehicle instability, and forces the operator to make excessive steering corrections to counteract the yaw moment.

- If an antilock system can maintain the slip of both rear wheels at the level where the lower of the two friction coefficients peaks, then lateral force is reasonably high, though not maximized.

- This contributes to stability

Objectives of ABS

- 3.Steerability

- Good peak frictional force control is necessary in order to achieve satisfactory lateral forces and, therefore, satisfactory steerability.

- Steerability while braking is important not only for minor course corrections but also for the possibility of steering around an obstacle.

- Tire characteristics play an important role in the braking and steering response of a vehicle. For ABS-equipped vehicles the tire performance is of critical significance.

- All braking and steering forces must be generated within the small tire contact patch between the vehicle and the road.

- Tire traction forces as well as side forces can only be produced when a difference exists between the speed of the tire circumference and the speed of the vehicle relative to the road surface.

Mathematical Model

- Quarter vehicle/Single wheel model

- Brake torque and friction force

- Two DOF model – Vx and ω

- Equations of Motion

- $ma_x = -\mu\, F_N$

- $J\omega = \mu R F_N - T_b$

- Slip Ratio = $\lambda = \dfrac{V_x - \omega R}{V_x}$

- Slip rate = $\dot{\lambda} = \dfrac{\dot{V}_x(1-\lambda) - R\dot{\omega}}{V_x}$
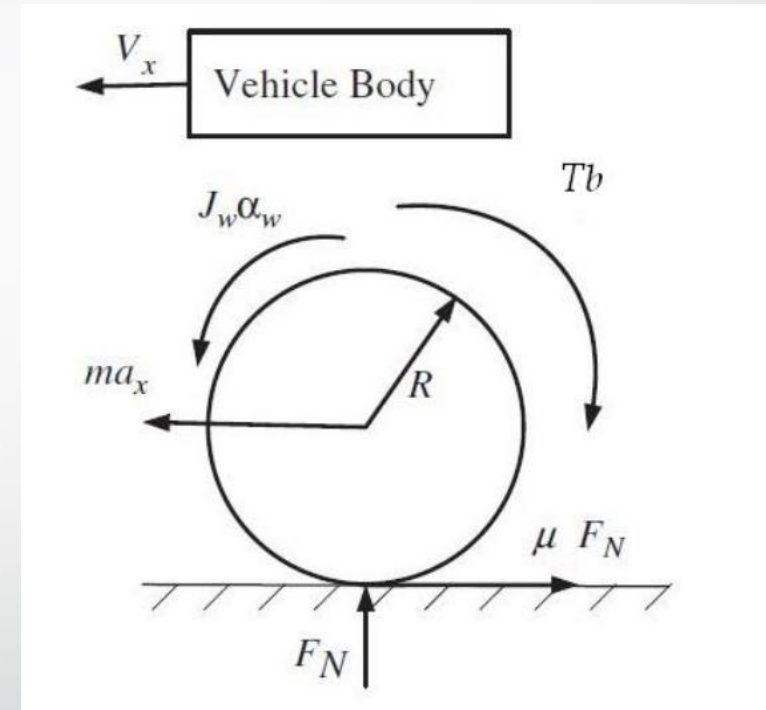
Mathematical Model

- State Space representation

- State Variables are

  - $x_1 = S_x\ ,x_2 = V_x\ ,x_3 = \lambda$

- State Space Equations are –

  - $\dot{x}_1 = x_2$

  - $\dot{x}_2 = \dfrac{-\mu F_N}{m}$

  - $\dot{x}_3 = \dfrac{-\mu F_N}{x_2}\left(\dfrac{1-x_3}{m}+\dfrac{R^2}{J_w}\right)+\dfrac{R}{J_w*x_2}T_b$

Mathematical Model

- If the wheel velocity is zero (ω=0), the wheel slip will equal to 1 (λ=1). It means that the wheel is locked. However, if v = ωr, the wheel slip will equal to zero (λ=0). It is usually called free rolling.

- The longitudinal coefficient (μ) of friction between tyre and road is a nonlinear function of the wheel slip (λ).
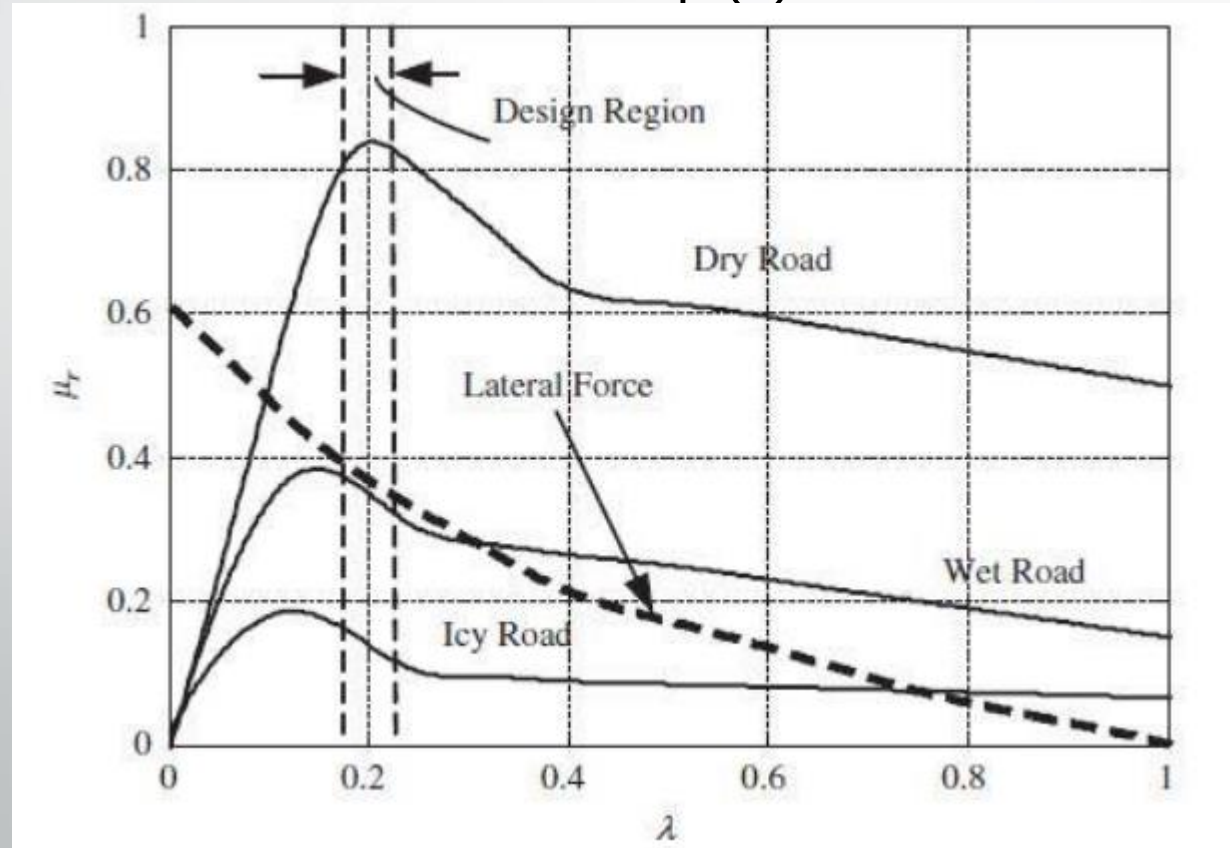
Mathematical Model

- When the vehicle is under perfectly braking maneuver, for a small applied braking torque, the wheel velocity starts to decrease and the wheel slip starts to increase from zero.

- Now if slip is less than 0.2 , then with the rise of slip , frictional coefficient also increases which is resulting in the rise of frictional force and consequently wheel velocity increases, resulting in the decrease of slip.

- But for a hard braking torque, the wheel slip may go straightly to a large number, which causes the μ to pass its peak point and reach somewhere in the decreasing part of the μ-slip curve, where with the rise of slip, frictional force decreases and consequently wheel velocity decreases constantly.

- If the brake torque is not reduced quickly at this point, the reduction of the road friction force will lead to a rapid increase of the wheel slip and eventually to a wheel lockup.

- Ideally ABS tries to maintain wheel slip at the peak of μ-slip curve, so that maximum friction force and consequently minimum vehicle stopping distance can be achieved.

- However maintaining wheel slip at the peak of μ-slip curve is always very difficult, as peak of the μ-slip curve does change with the varying surface and varying vehicle velocity.

Mathematical Model

- The friction coefficient can vary in a very wide range, depending on factors like:

  - Road surface conditions (dry or wet)

  - Tire side-slip angle

  - Tire brand (summer tire, winter tire)

  - Vehicle speed

  - The slip ratio between the tire and the road.

- Friction model :

- $\mu(\lambda, V_x) = [c_1 (1 - e^{c_2\lambda}) - c_3\lambda]e^{-c_4 V_x}$

Control System

- A feedback control system is a closed loop control system in which a sensor monitors the output (slip ratio) and feeds data to the controller which adjusts the control (brake pressure modulator) as necessary to maintain the desired system output (match the wheel slip ratio to the reference value of slip ratio).
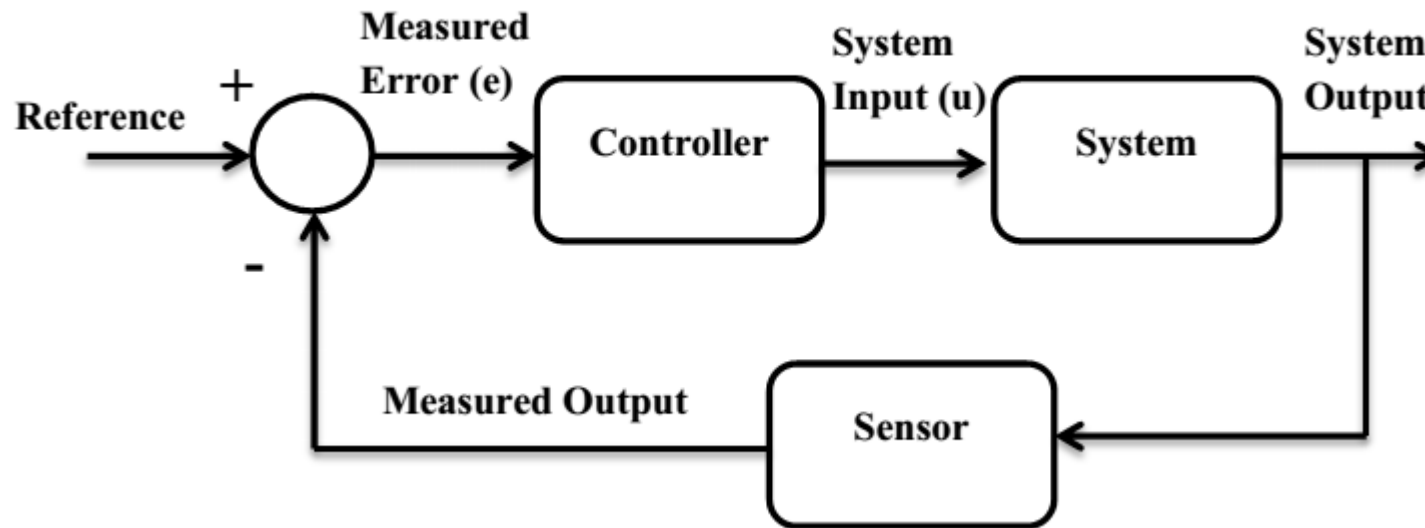
Control System

- Feedback controller used are :

- P Controller

- PD Controller

- PI Controller

- PID controller

- $u = K_p e + K_I \int e \, dt + K_D \dfrac{de}{dt}$
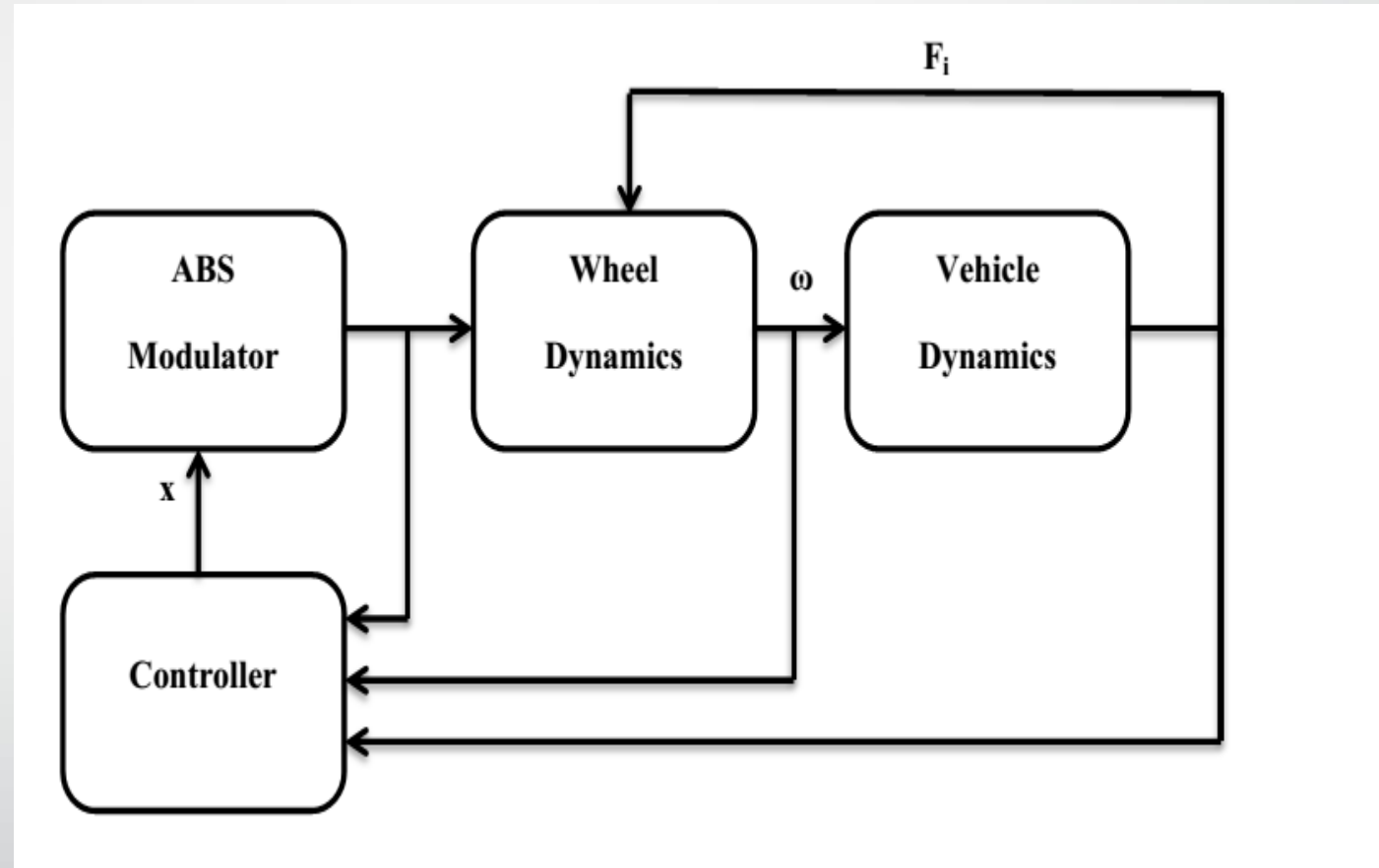
System model using Simulink
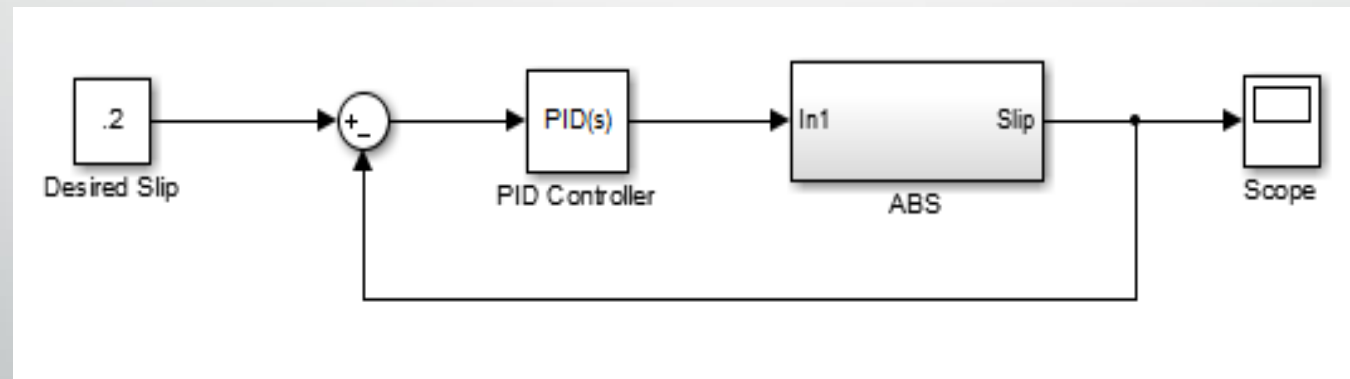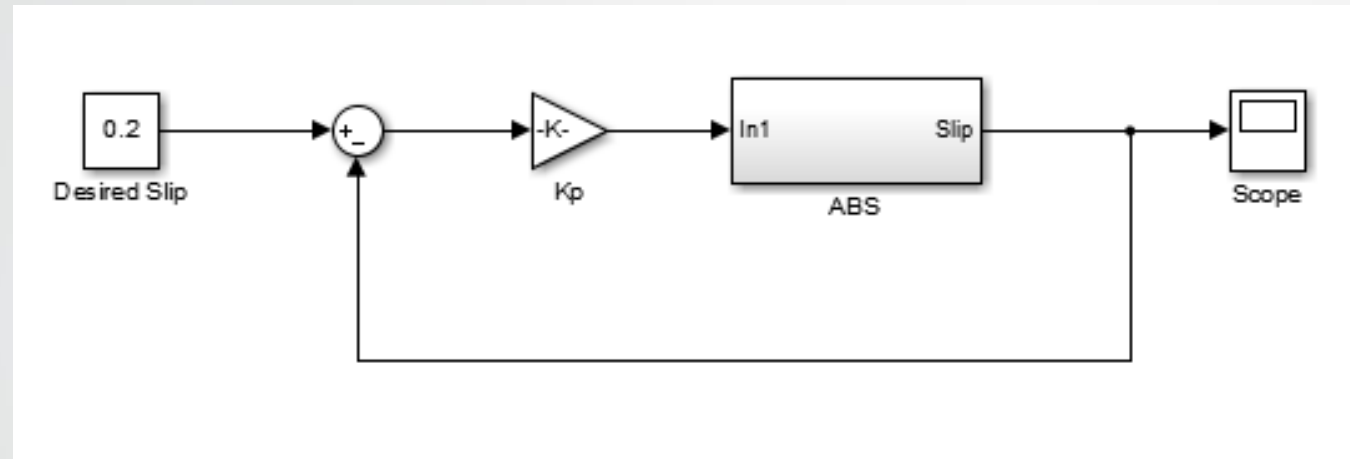
ABS model
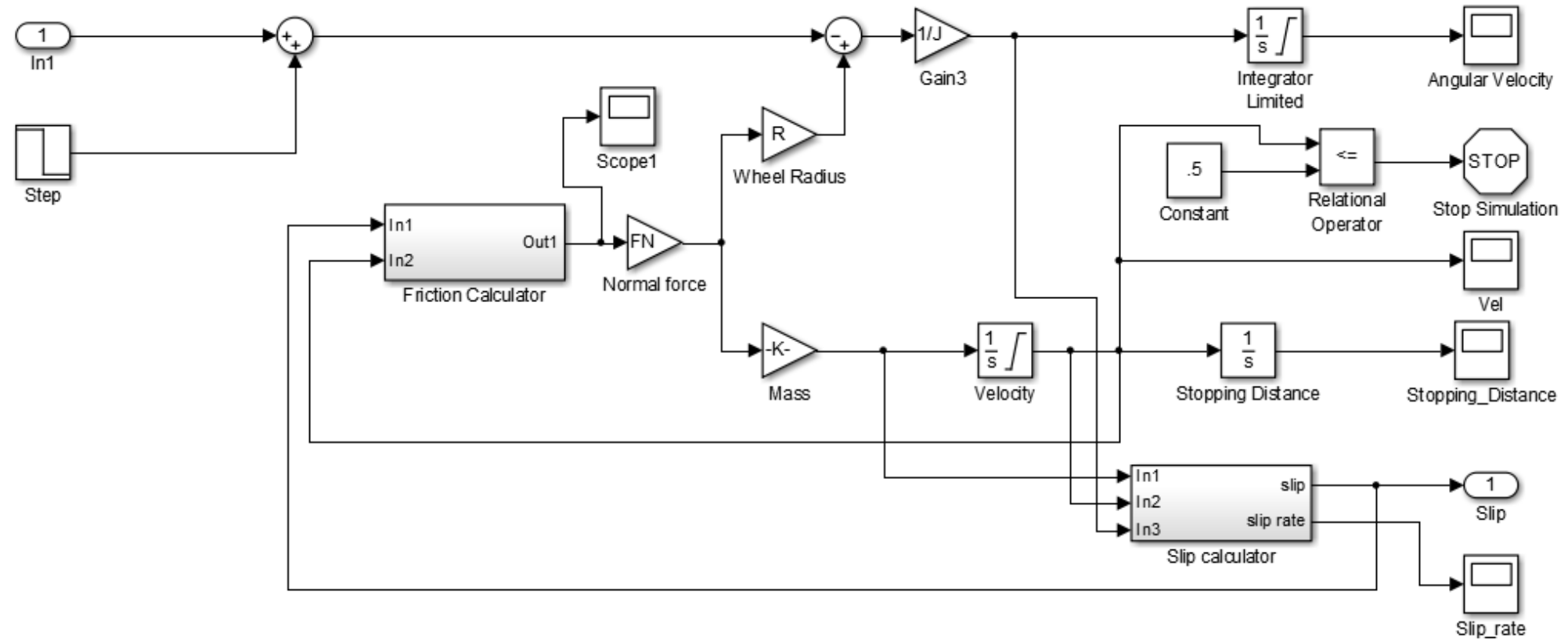
Slip Calculator
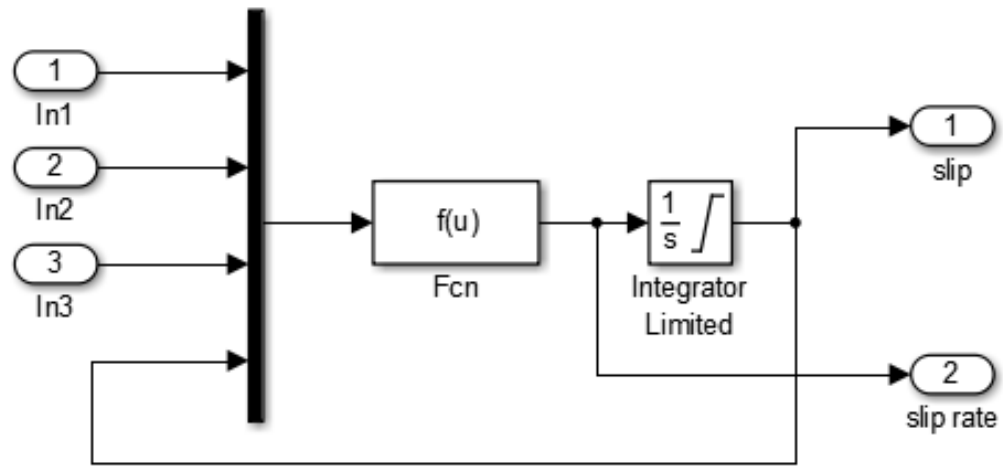
$$(u(1)*(1-u(4))-(R*u(3)))/(u(2) + (u(2)==0)*eps)$$

Friction Calculator
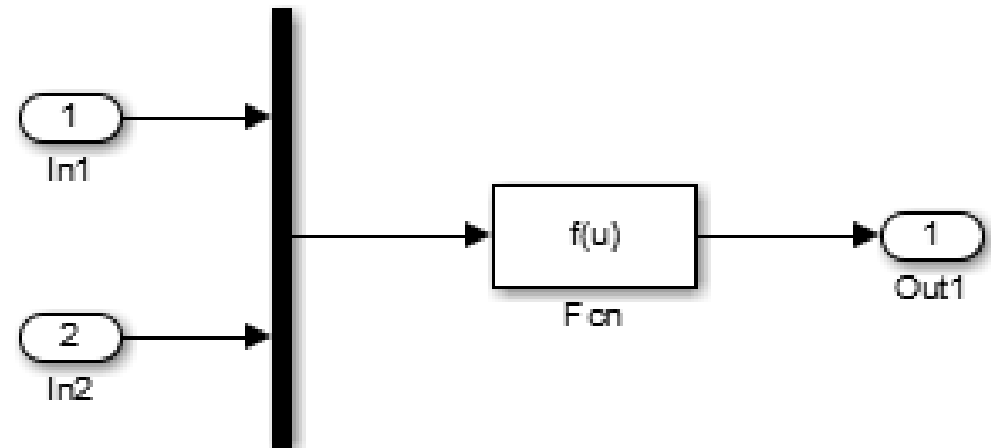
$$[c_1 (1 - e^{c_2 u(1)}) - c_3 u(1)]e^{-c_4 u(2)}$$

Parameters

- R =0.352

- m=493

- J=1.13

- g=9.81

- Tb=1500

- c1=1.2801

- c2=23.99

- c3=0.52

- c4=0.03

- FN =m*g

- Vo=(5*96.5606)/18

- Wo=Vo/R

Results

- Open loop model

- Angular velocity vs. time
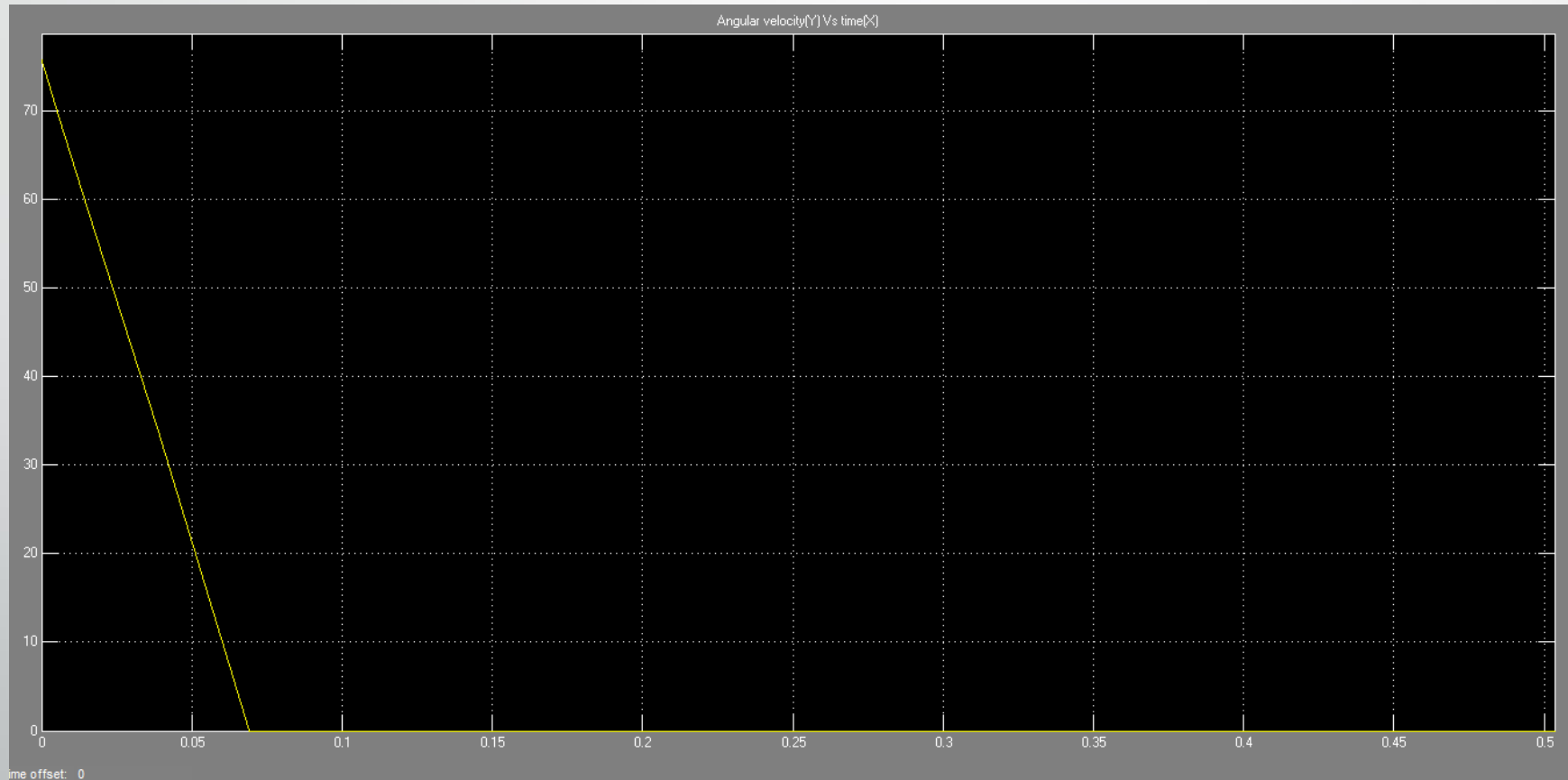
Results

- Open loop model

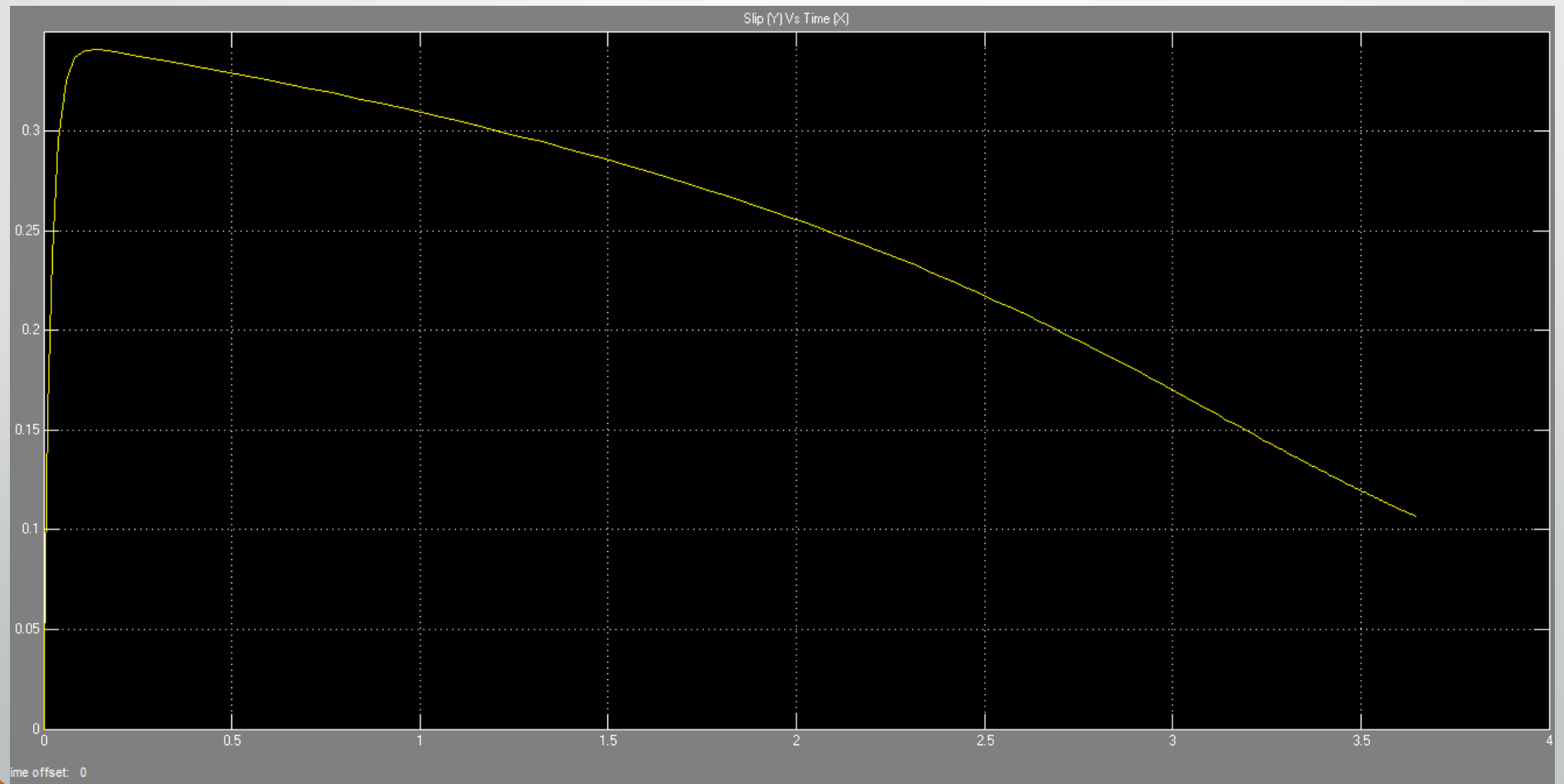- Stopping distance vs. time
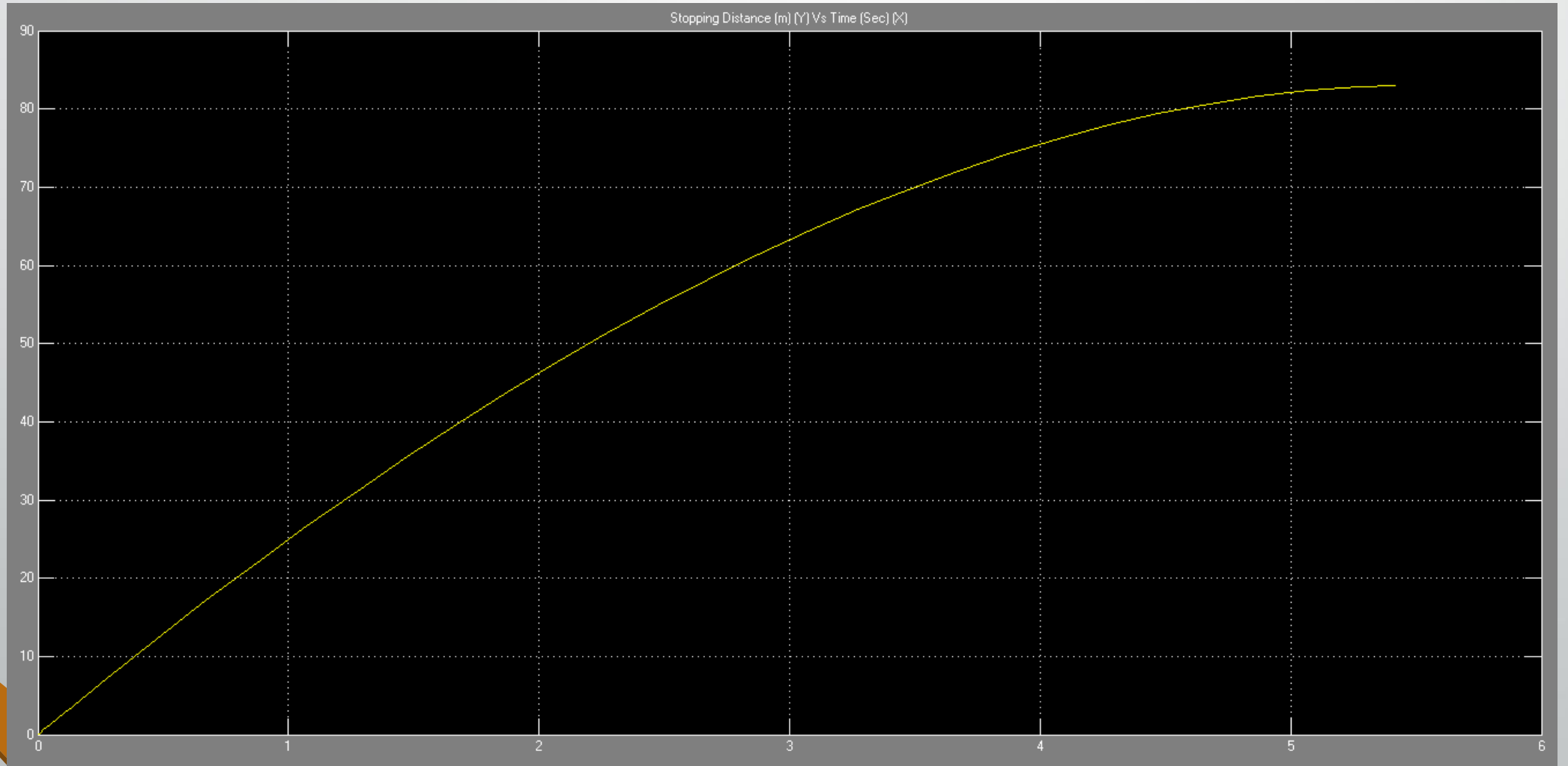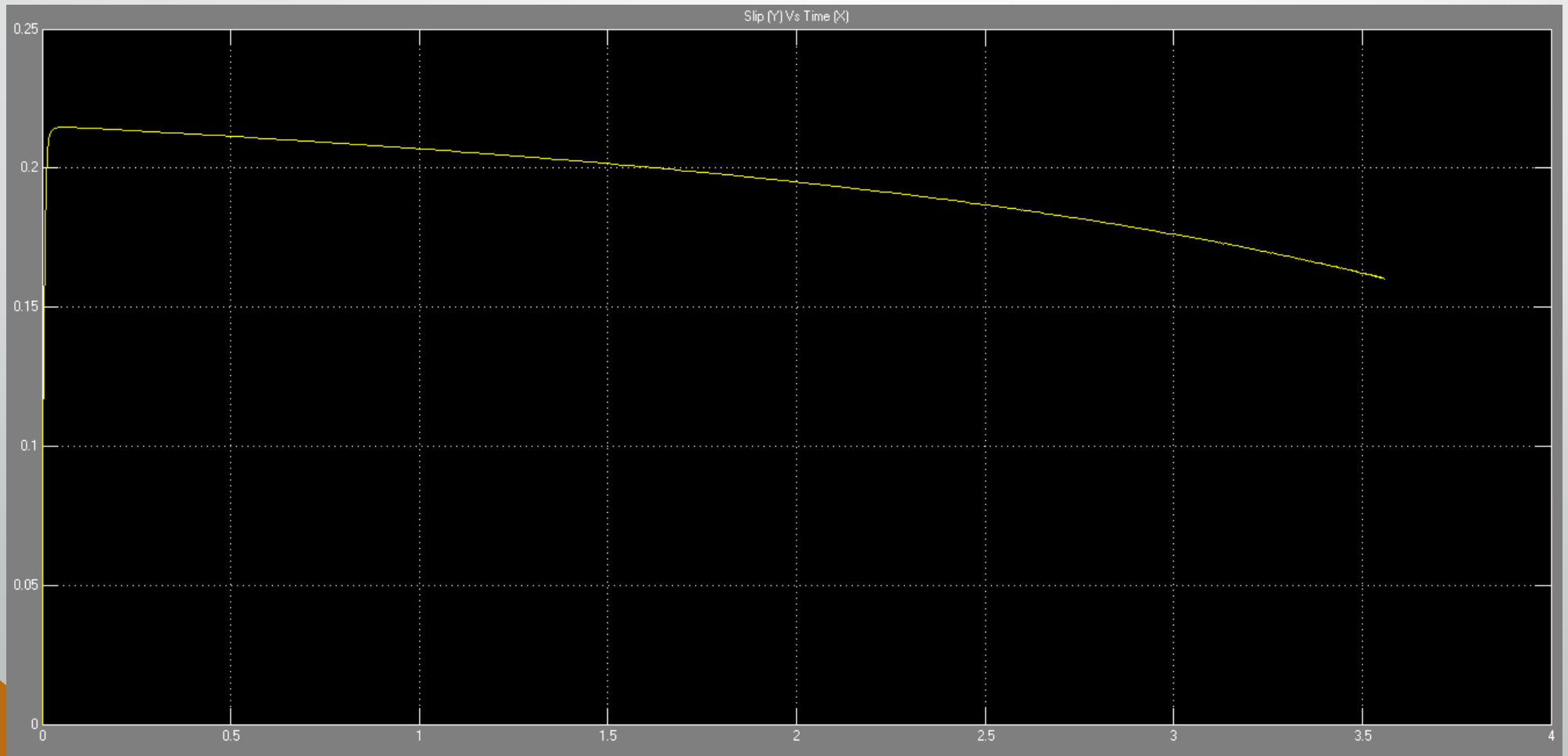
Results

- Open loop model

- Slip vs. time
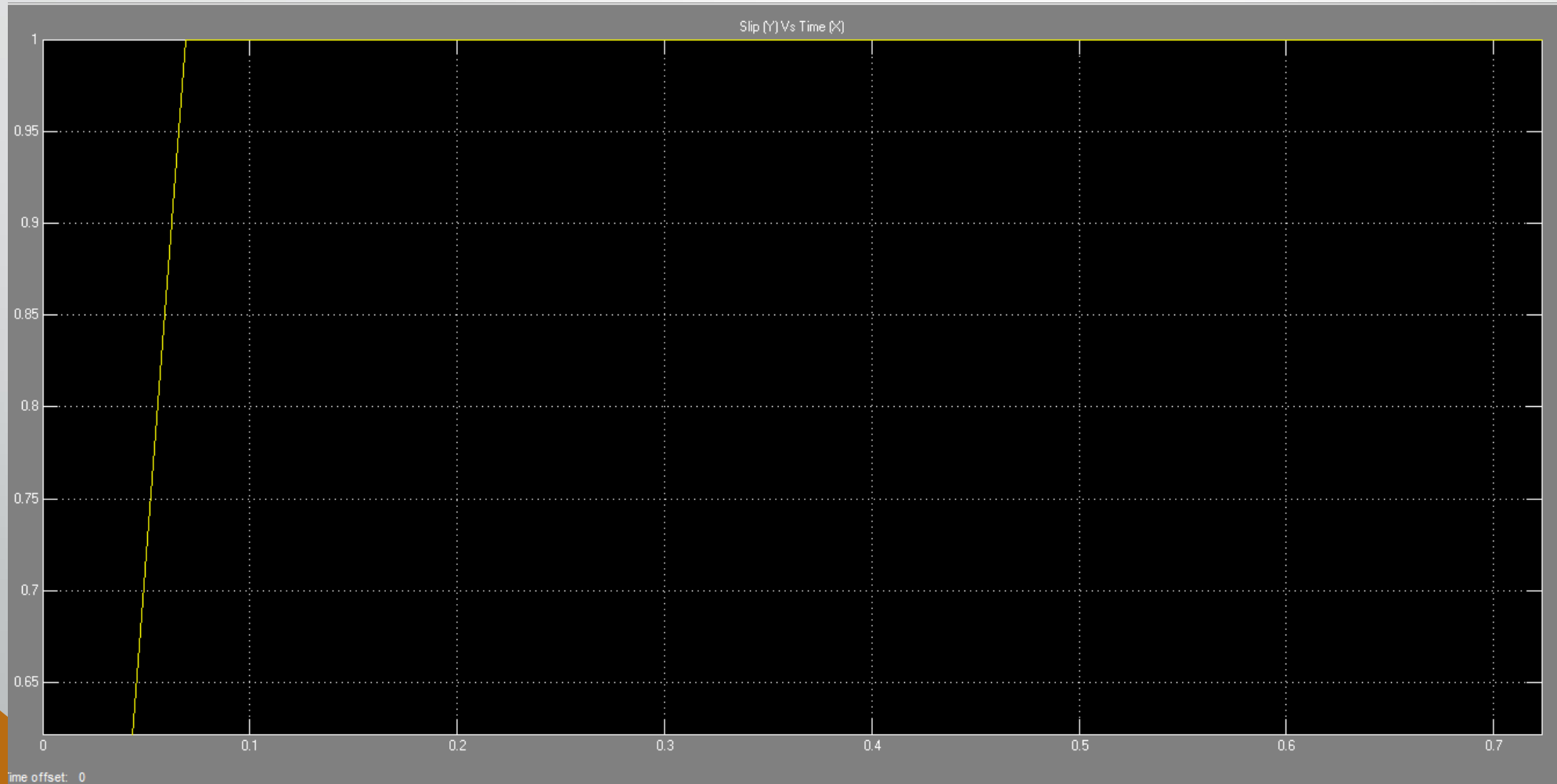
Results

- P controller

- Slip Vs. Time
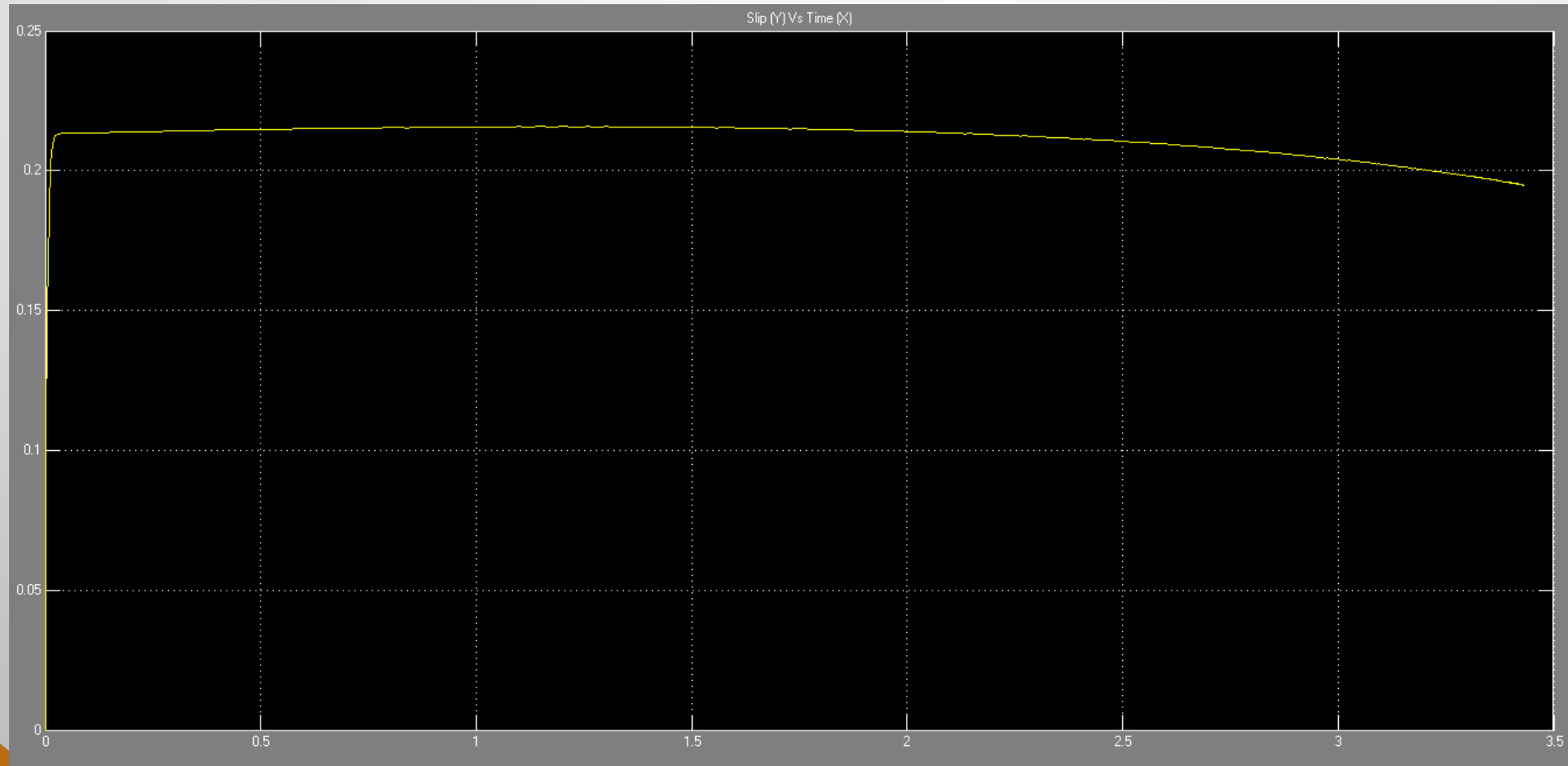
Results

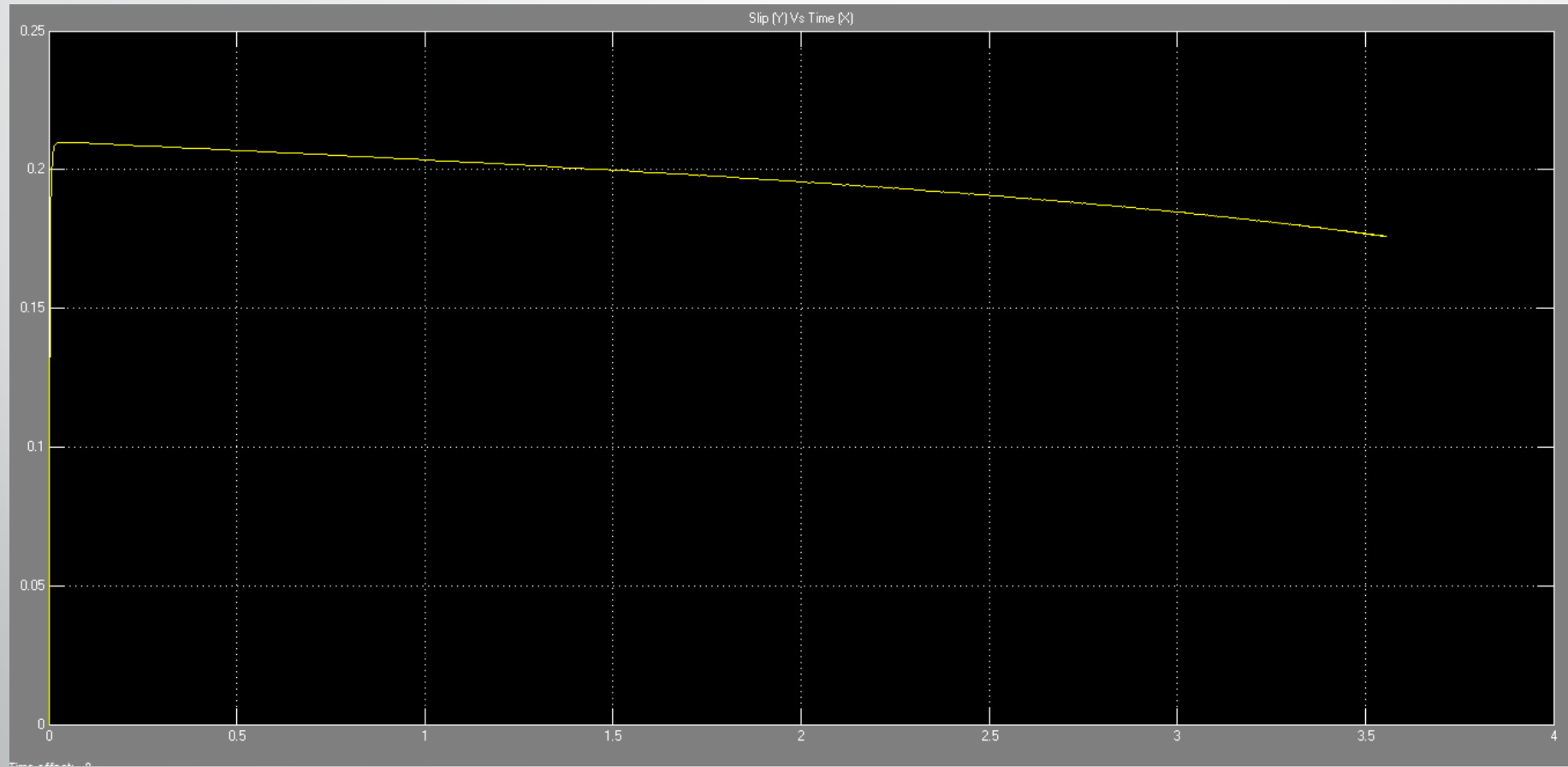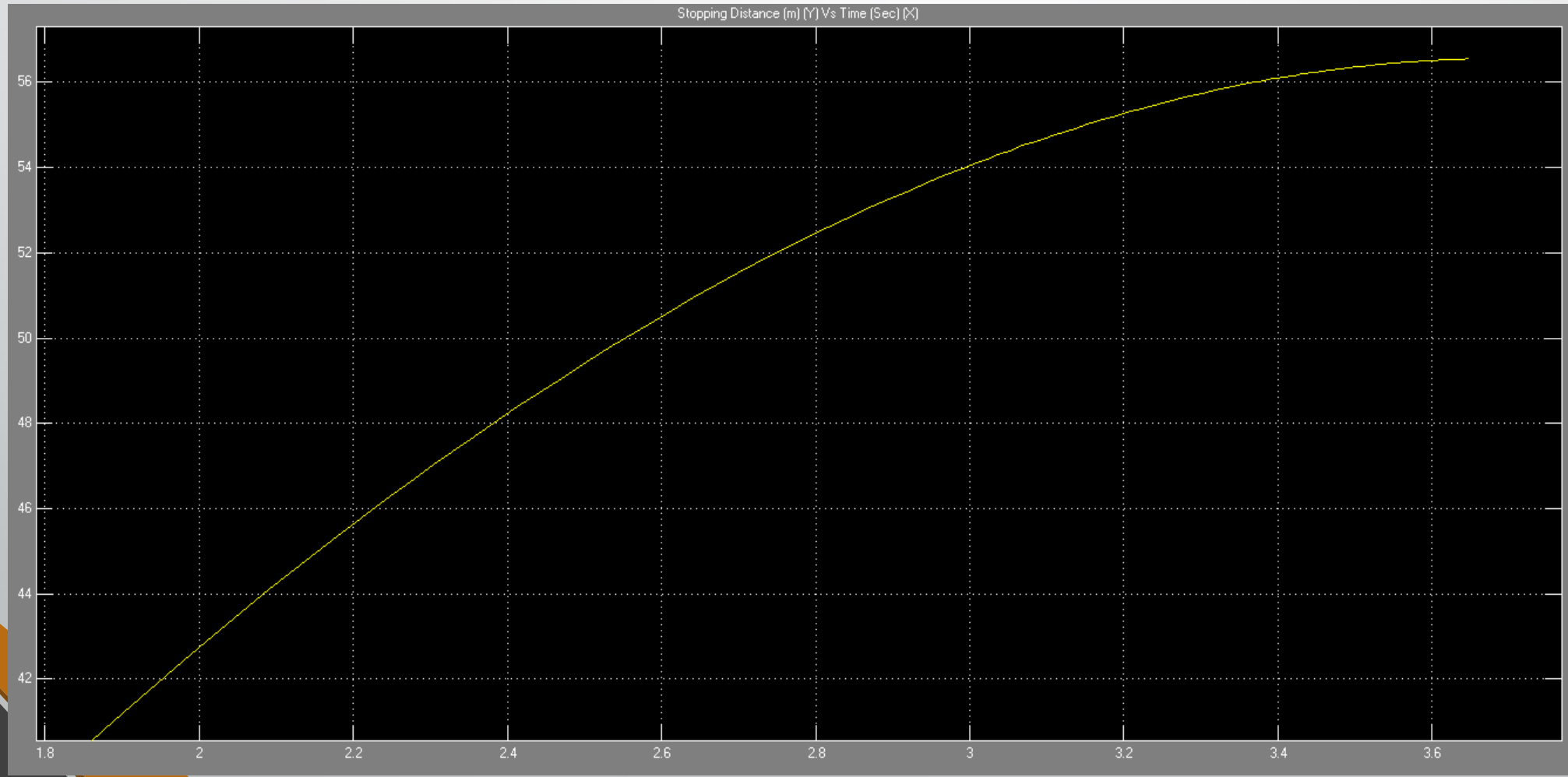- PD controller

- Slip Vs. Time

Slip (Y) Vs Time (X)

Results

- PI controller

- Slip Vs. Time

Results

- PID controller

- Slip Vs. Time

Results

- P controller

- Stopping Distance Vs. Time

Stopping Distance (m) (Y) Vs Time (Sec) (X)
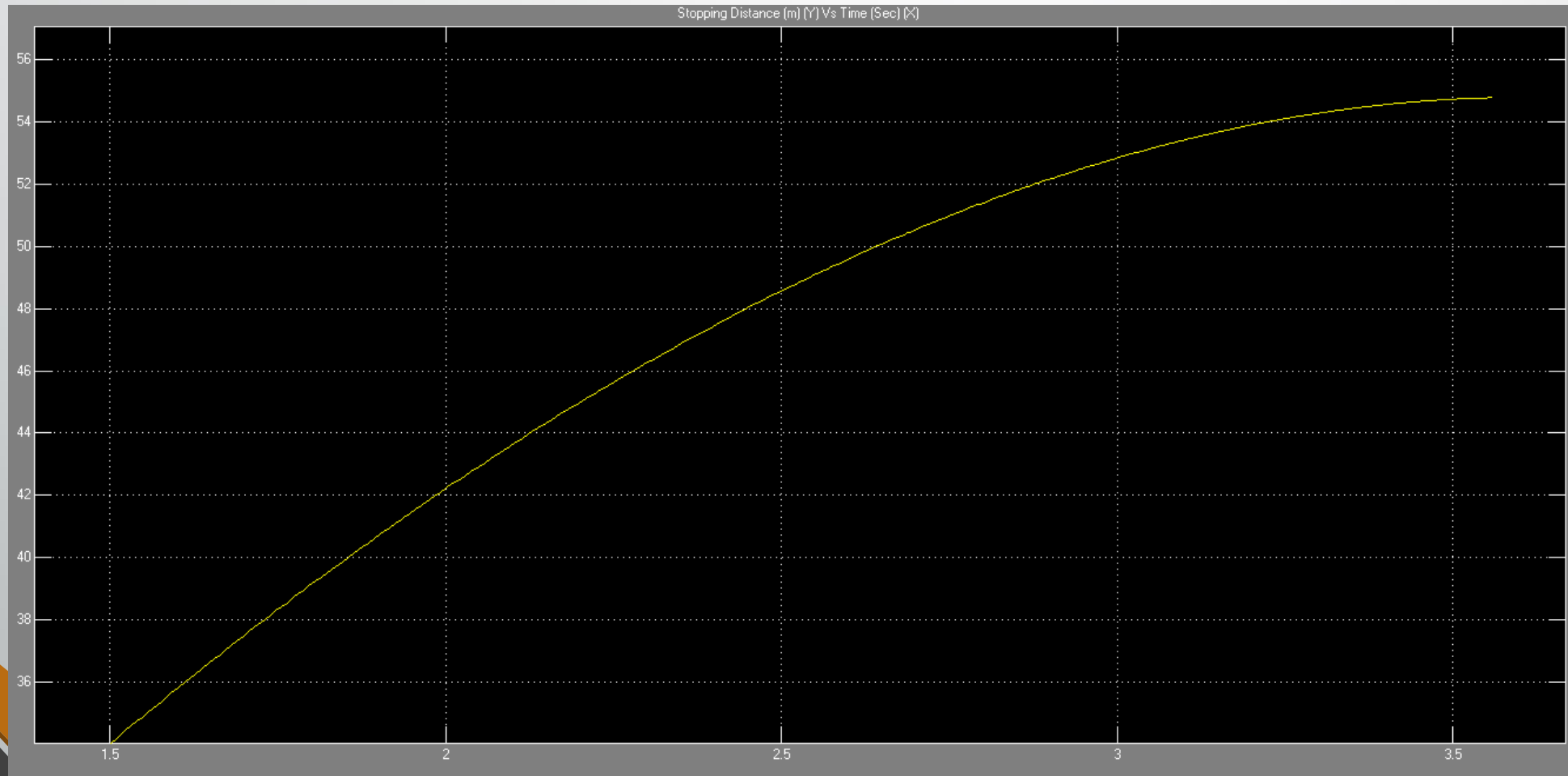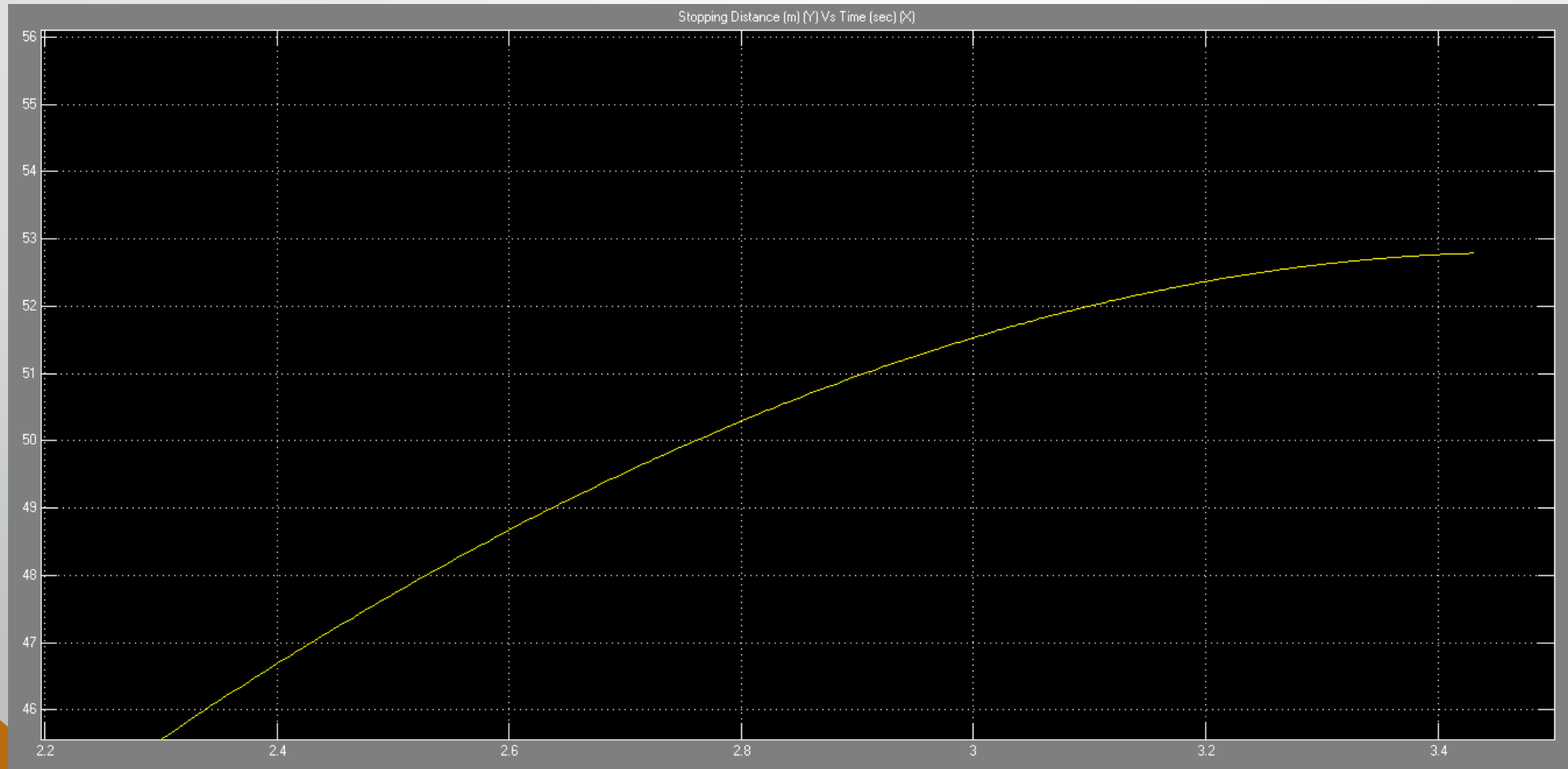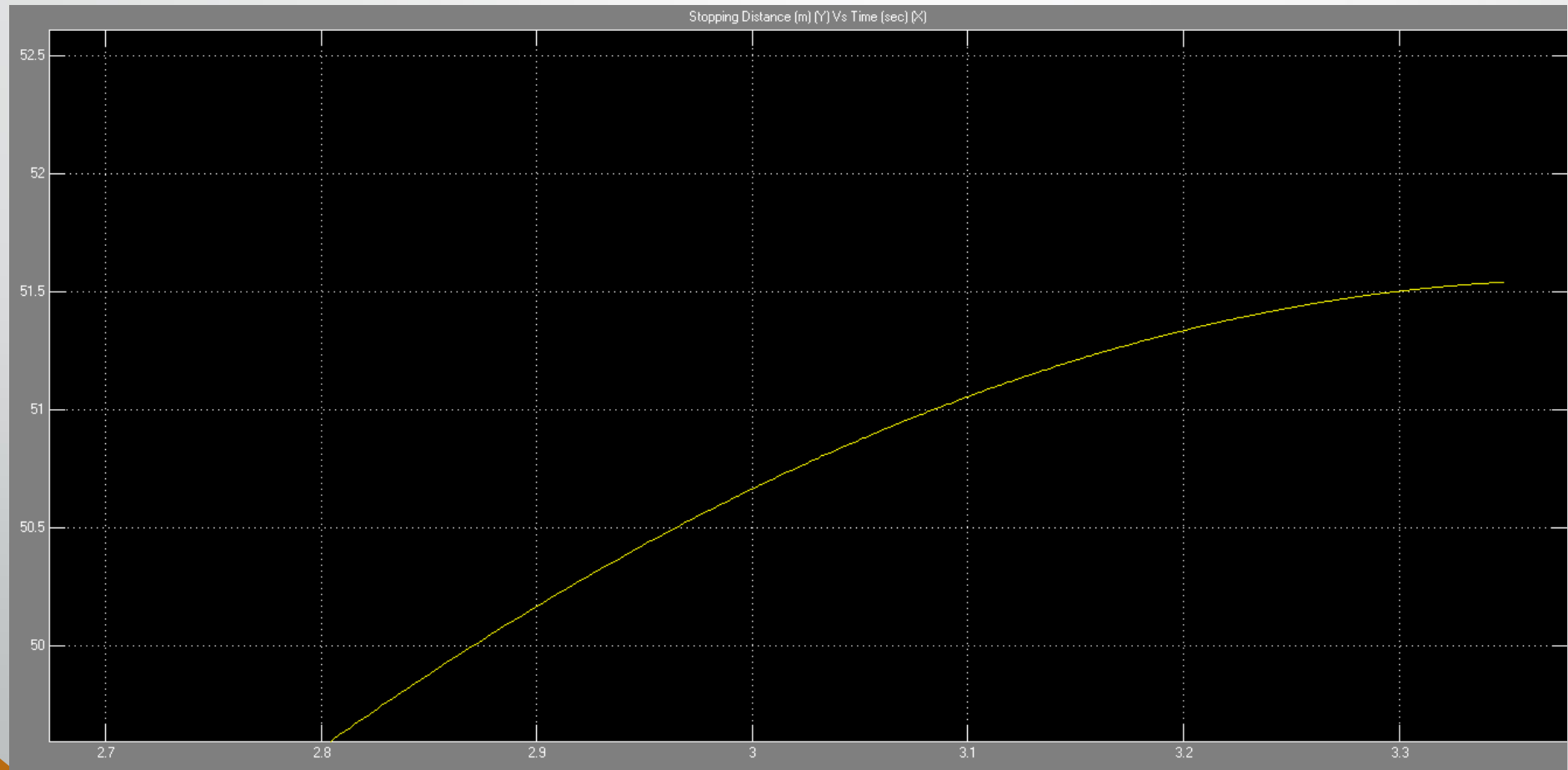
Results

- PD controller

- Stopping Distance Vs. Time

Results

- PI controller

- Stopping Distance Vs. Time

Results

- PID controller

- Stopping Distance Vs. Time

Stopping Distance (m) (Y) Vs Time (sec) (X)

Comparision

Controller	Stopping Time	Stopping Distance
Open loop	5.45	82.8
P	3.66	56.6
PD	3.56	54.7
PI	3.45	52.7
PID	3.35	51.5

Discussion

- It is obvious that ABS improves the braking performance

- The stopping distance after using ABS system has considerably reduced.

- The error in slip and desired slip is used to manipulate brake pressure in brake cylinder.

- Only a linear model was considered and does not include actual road conditions.

- The system here is modelled only for straight line braking.

- In case of cornering, the side slip ratio would be controlled so that wheels don't lock and thus ensuring steerability.

Future work

- Nonlinear control
- Animation in MATLAB

References

- A. B. Sharkawy,'Genetic fuzzy self-tuning PID controllers for antilock braking systems'; Engineering Applications of Artificial Intelligence, vol. 23, pp. 1041–1052, 2010

- Thesis by Parth Bharat Bhivathe, 'Modelling and development of Anti Lock Braking system'; National Institute of Technology Raurkela

- Jeonghoon Song, Woo Seong Che, 'Comparison between braking and steering yaw moment controllers considering ABS control aspects'; Elsevier, Mechatronics 19 (2009) 1126–1133

- Simulink help

- Matworks

- Thank You