MMÜ 753 HW 1
Deadline: 17/03/2026

THIS TAKEHOME IS MADE UP OF THREE PARTS (A, B, C)

PART A: Building the Simulation (30 pts)
Use the provided Simulink Model

For a passenger vehicle with two axles and four tires:

1. Draw the free body diagram of the vehicle body and of a single tire.
2. Derive equations of motion for vehicle longitudinal dynamics - Assume no steering at that level.
3. Rewrite the equations of motion for vehicle longitudinal, lateral, and yaw dynamics. Here you shall include front wheel steering.
4. Derive the Equation of Motion for a wheel.
5. Express the tire lateral slip angles for front and rear axle tires.
6. Write the longitudinal slip expressions for a tire during traction and braking, respectively
7. Without going into the details of suspension dynamics, derive equations for tire normal forces in terms of longitudinal and lateral accelerations of the vehicle. (Hint: Jazar)
8. Write the equations for longitudinal and lateral accelerations of the vehicle body in terms of longitudinal and lateral speeds (and their time derivatives) in the vehicle body-fixed frame.
9. Use the above questions to construct a vehicle model in Simulink. This shall involve implementing a Magic Formula tire model as well. Such a model is present in the Vehicle Dynamics Blockset. Note the tire model should be a combined slip model.

   The main inputs of the simulation should be the front tire steering input and the wheel torques. You need not model any actuator dynamics.
10. Based on the tire model in 9, calculate the cornering stiffness.
11. Based on the cornering stiffness calculated in 10, derive the matrix of the equivalent bicycle model. Show that the vehicle handling model obtained in 9 (let's call it NL model) and the bicycle model display similar responses for small values of the steering angle and for lateral accelerations less than 0.3 g.

PART B: Building and Testing ABS (40 pts)

In this part of the problem, we are going to model a braking system and some simple ABS algorithms.

12. Based on some brake pedal force input, determine the required torque inputs to be implemented for front and rear tires by applying suitable proportionality constants K_{bf} and K_{br} between pedal braking force (P) and tire torques(T_b). The torques can be written as,

$$T_{bf} = K_{bf}.P$$
$$T_{br} = K_{br}.P$$

Hints: Driver brake pedal force P<60 kg. Also, for a passenger vehicle, T_{bf}<2000Nm; T_{br}<2000Nm. T_{bf} should generally be larger than T_{br}.

13. Test your model for increasing values of *P* as shown and demonstrate that the vehicle does not lock –on dry road, mu=1- any wheel and achieves suitable deceleration when K_{bf} and K_{br} are selected correctly.

After solving 12 and 13, you should keep the values of K_{bf} and K_{br} *fixed*.

Slip Based ABS:

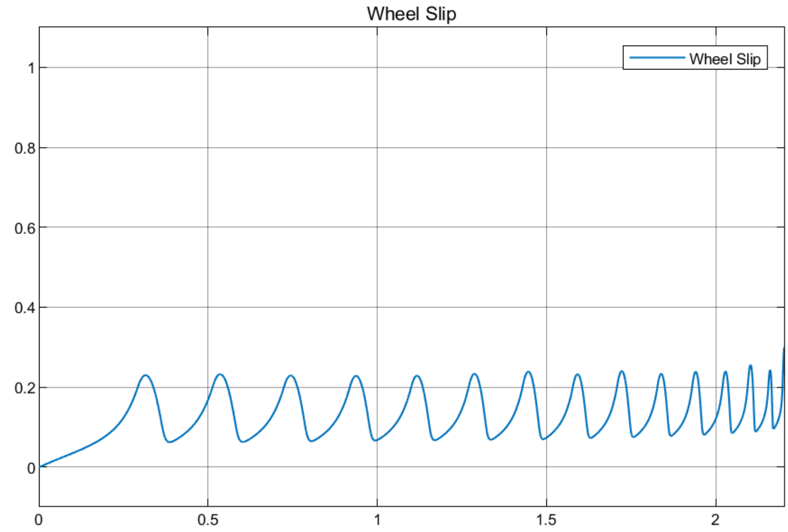
We will now discuss a very simple ABS control based on PI controller. We will assume that it is possible to calculate the longitudinal slip at each tire.

14. Explain the difficulties related to measuring longitudinal slip of a tire.

15. Draw the block diagram of a slip-based control system with reference signal λ_{ref} and measurement signal λ.

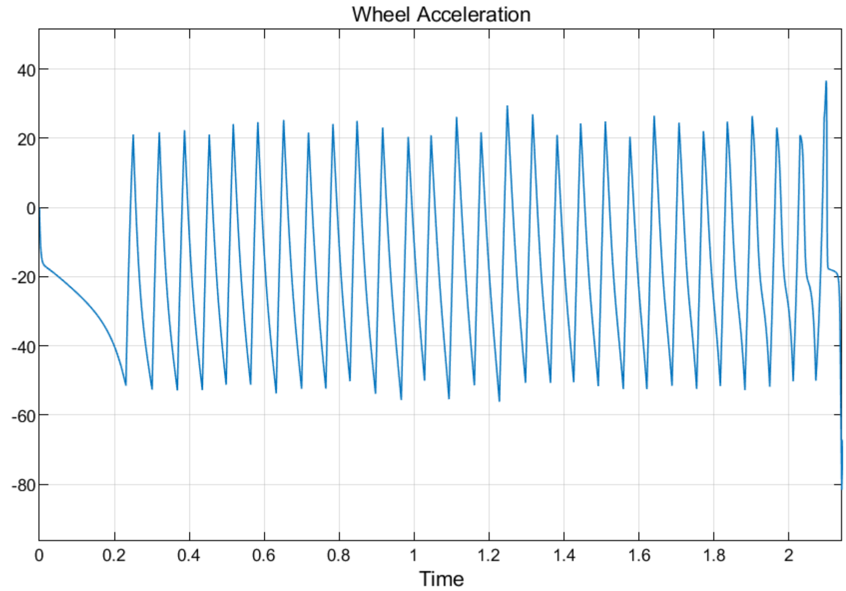
16. Implement this simple slip-based ABS controller and test on your vehicle. You may use the PID tuning option of Simulink at that level. Is it possible to obtain satisfactory reference signal tracking for any value of λ_{ref} between 0 and 1? Justify.

17. The second algorithm uses a rule-based controller instead of a PI controller; we will design a controller that applies a certain amount of torque when slip is below some lower threshold λ_1 and gradually releases brakes when slip is above an upper threshold λ_2. The diagram below shows the wheel slip for a braking simulation where the slip is controlled between an upper and lower threshold. The tunable quantities are the upper and lower slip thresholds.



Acceleration Threshold Based ABS:

18. The third algorithm must be based on wheel acceleration threshold. Similar to the slip-based algorithm, we will design a rule-based controller that releases the brakes when the wheel deceleration is below a lower acceleration threshold A_1 (usually a negative value) which predicts that wheel lock is imminent and reapplies the brakes when the wheel acceleration rises above an upper acceleration threshold A_2 (usually a positive value). The image below shows the wheel acceleration during braking with an acceleration-based ABS algorithm. The tunable parameters are the upper and lower acceleration thresholds.

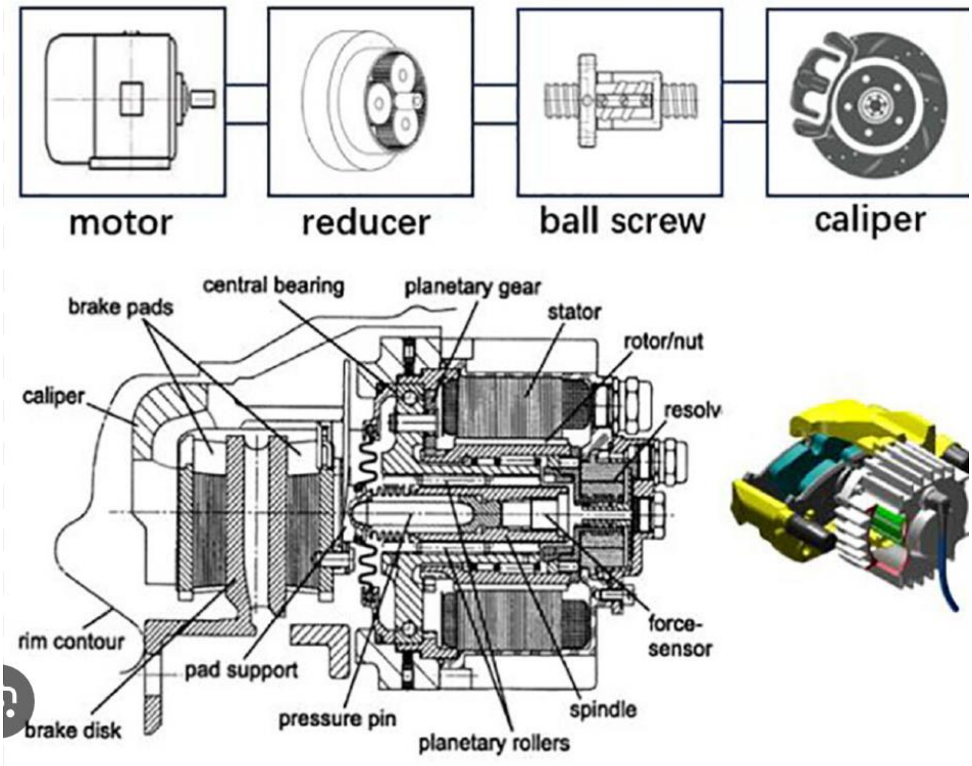


Hints: for question 17 and 18, you should implement rule based controller similar to the rule based controller explained in class and also mentioned in Peng.

Testing the algorithms

19. Test the above control algorithms for the following scenarios: a) dry road b) wet road c) jump mu d) split mu road e) checkerboard mu road f) cornering while braking

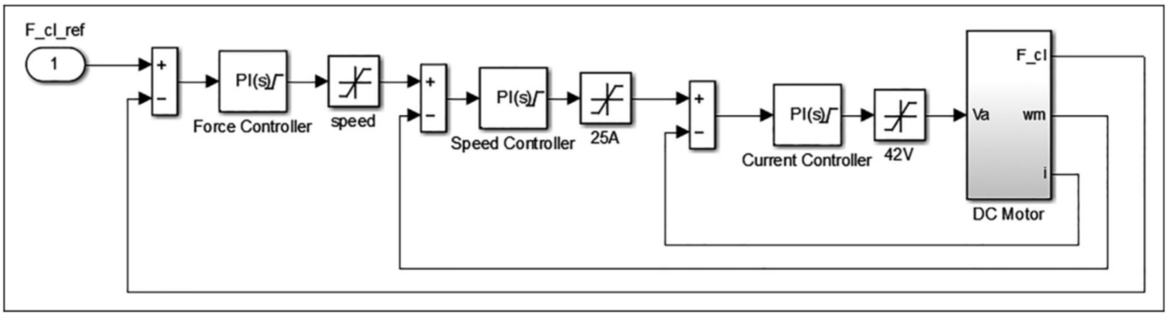
PART C: Building and Testing an EMB system for ABS (40 pts)



EMB system

Read the paper: An application of the brain limbic system–based control to the electromechanical brake system (reading the first few pages to understand the meaning of the equations is OK)

Build the EMB system below based on data given in the aforementioned paper.



Given that the reference clamping force must be produced by a separate controller (PI type) that works based on reference slip tracking, rework question 15 and 16 based on an EMB actuator.