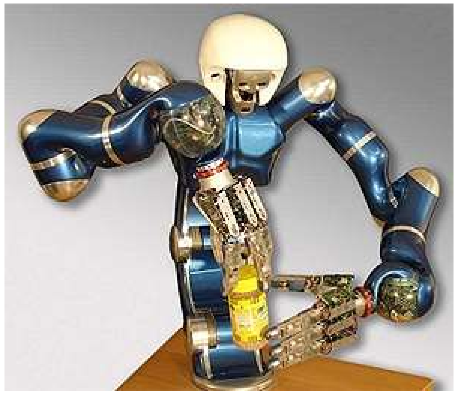
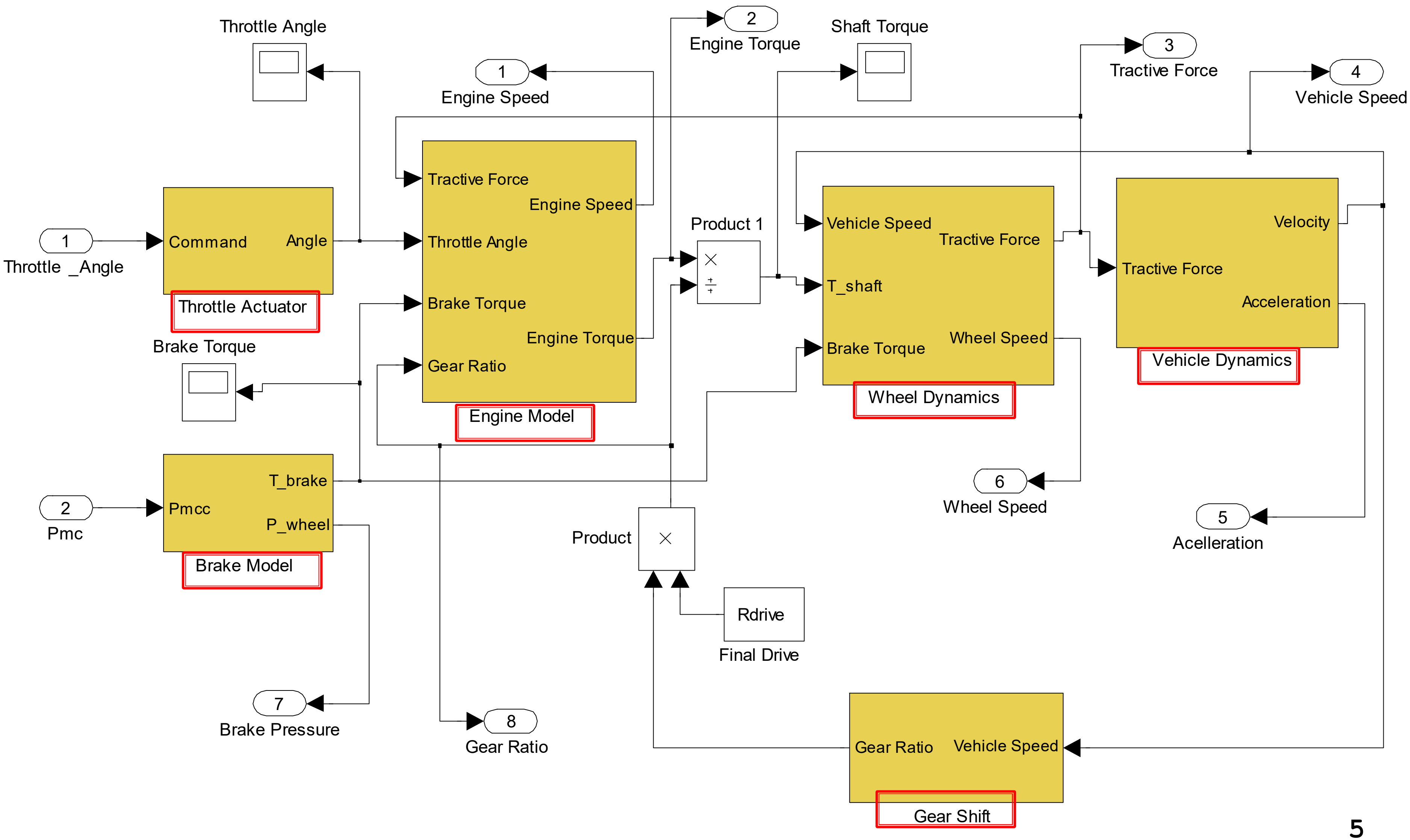
Control System Design for Automated Driving

Lecture 05



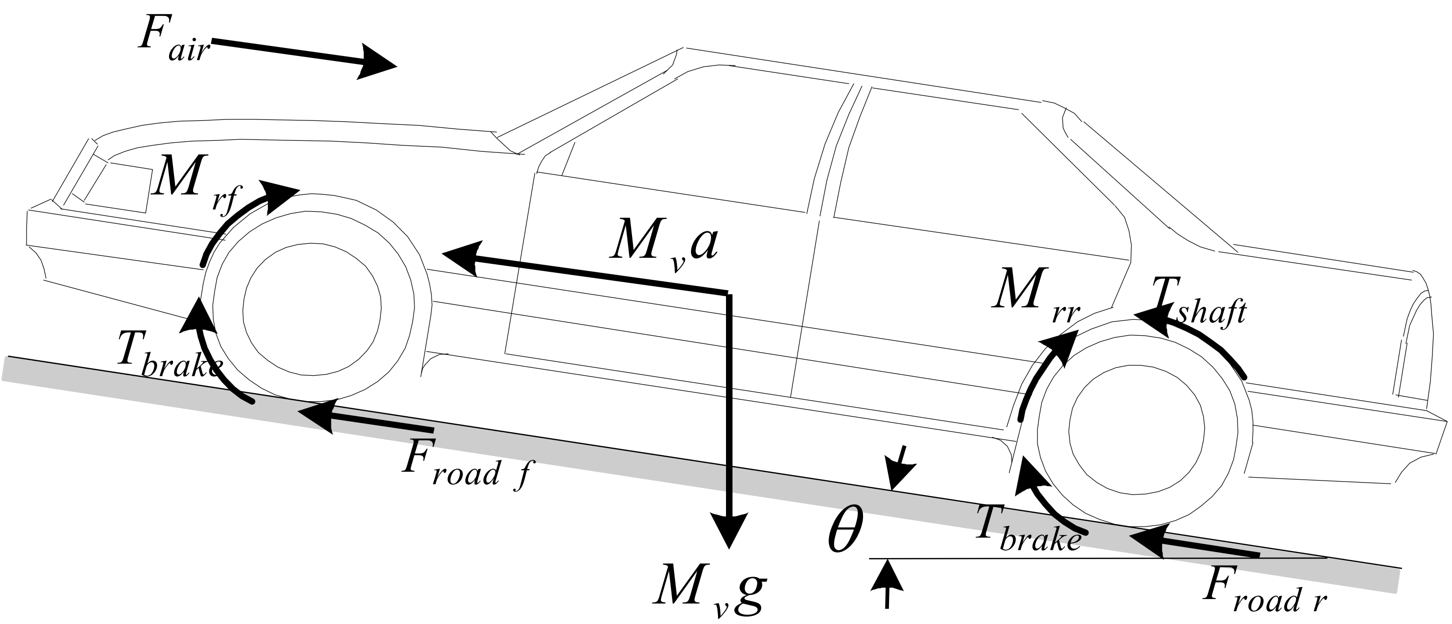
Simulink Model of Vehicle Longitudinal Dynamics

Simulink Model of Vehicle Longitudinal Dynamics



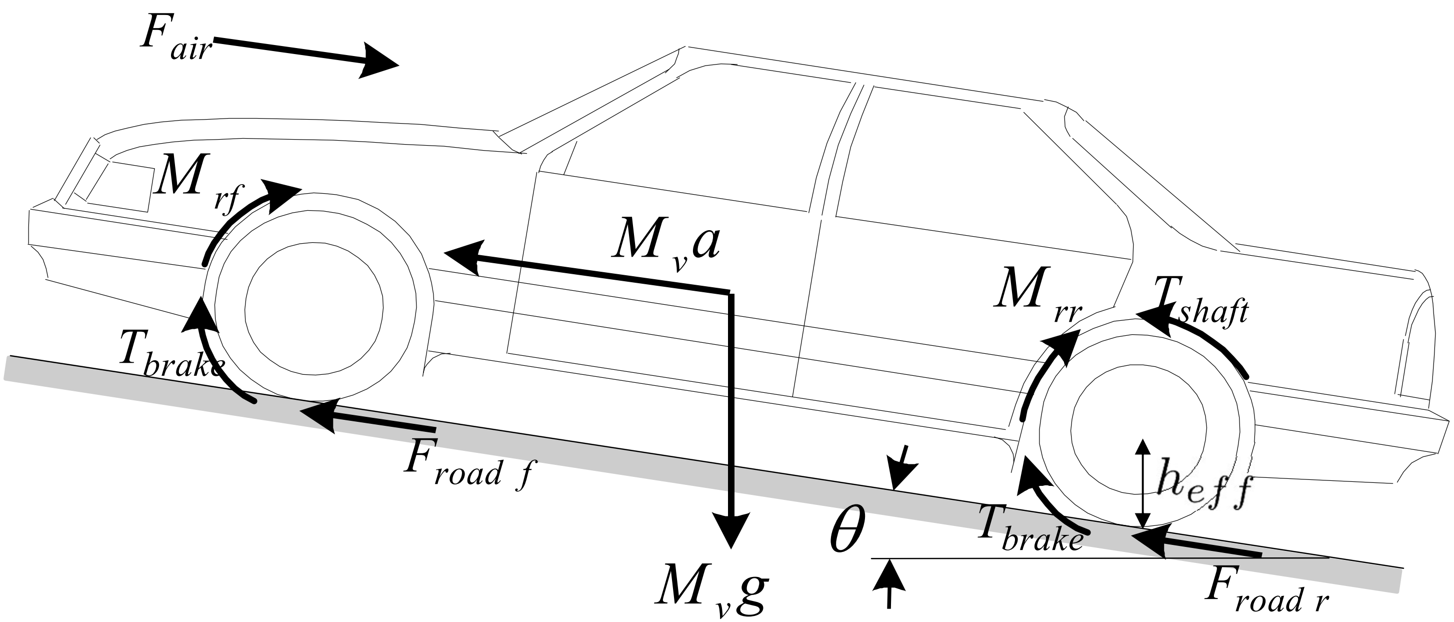
Longitudinal Vehicle & Wheel Dynamics

- Aerodynamic Drag $F_{air} = \frac{\rho}{2} C_d A_f v^2$
- Rolling Resistance F_{roll} = constant
- Road Traction Force F_{road} from Tire Model
- Brake Torque T_{brake} from Brake Model
- Shaft Torque T_{shaft} from Engine & Transmission Model



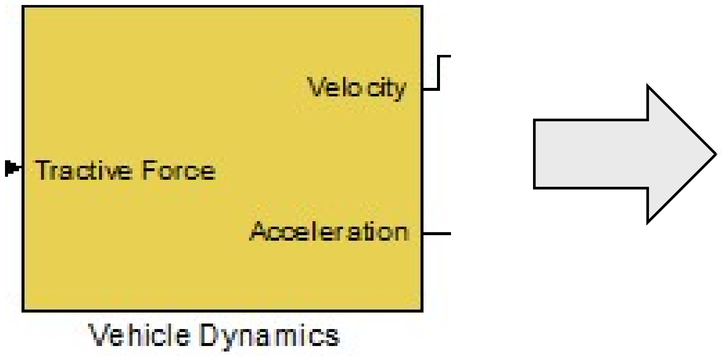
Longitudinal Vehicle & Wheel Dynamics

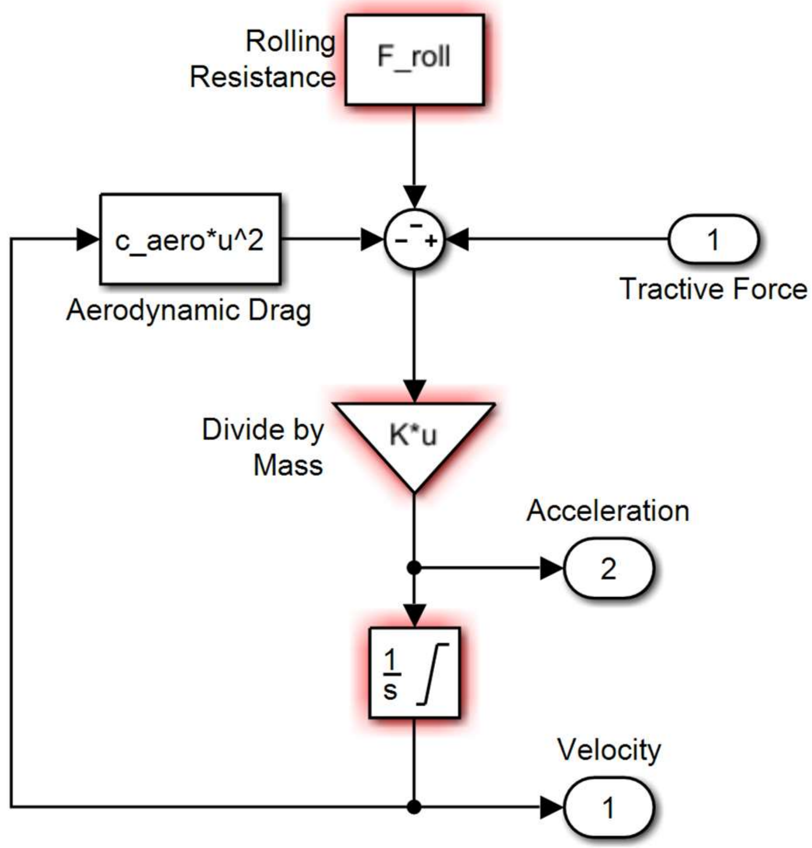
- Nonlinear Longitudinal Vehicle Dynamics
  - Vehicle Dynamics $M\dot{v} = F_{road} - F_{roll} - F_{air} - Mg\sin\theta$
  - Wheel Dynamics $J_\omega\dot{\omega} = T_{shaft} - T_{brake} - h_{eff}F_{road}$



Longitudinal Vehicle Dynamics

- Simulink Model of $M\dot{v} = F_{road} - F_{roll} - F_{air} - Mg\sin\theta$ (with $\theta = 0$)



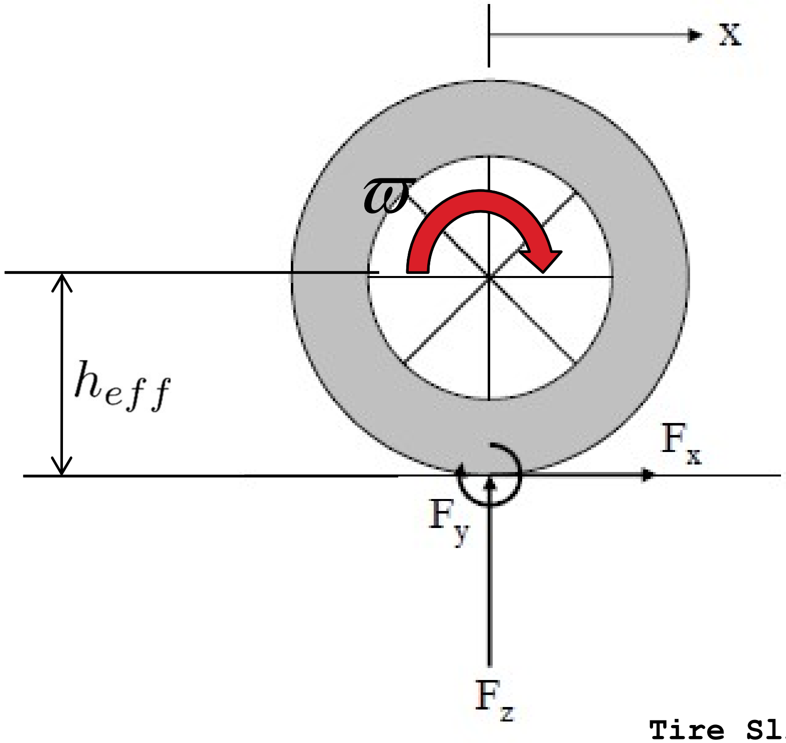


Tire Model

- Tire Road Force F_{road} is usually modeled by empirical relationship between slip and force.

- Definition of Longitudinal Tire Slip ratio

$$s = \frac{h_{eff}\omega - v}{\max(h_{eff}\omega, v)}$$



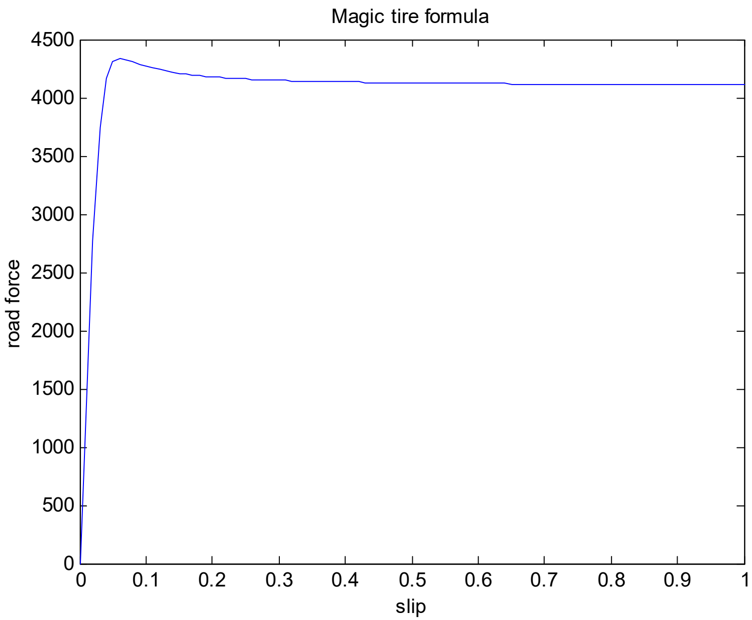
Tire Slip 관련 영상
https://www.youtube.com/watch?v=tsnYqCRWTbE

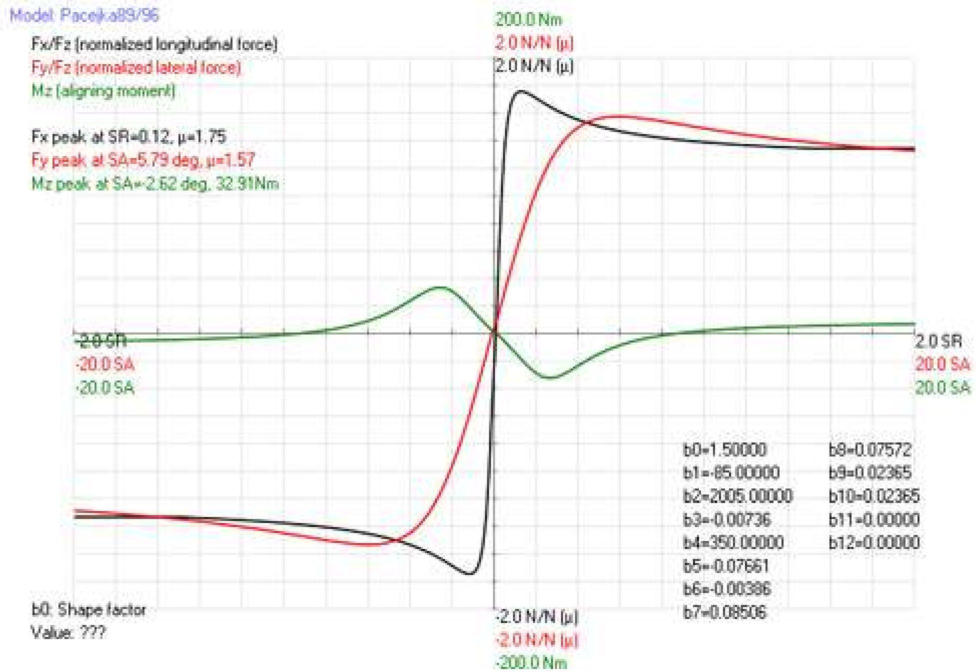
Tire Model

- Bakker-Pacejka 'Magic Tire Formula'

$$F_{road} = D\sin\left[C\arctan\left\{B(s+S_h)-E\left(B(s+S_h)-\arctan\left(B(s+S_h)\right)\right)\right\}\right]$$

  - S_h : bias in the slip curve caused by change in effective tire radii, camber angle and etc.



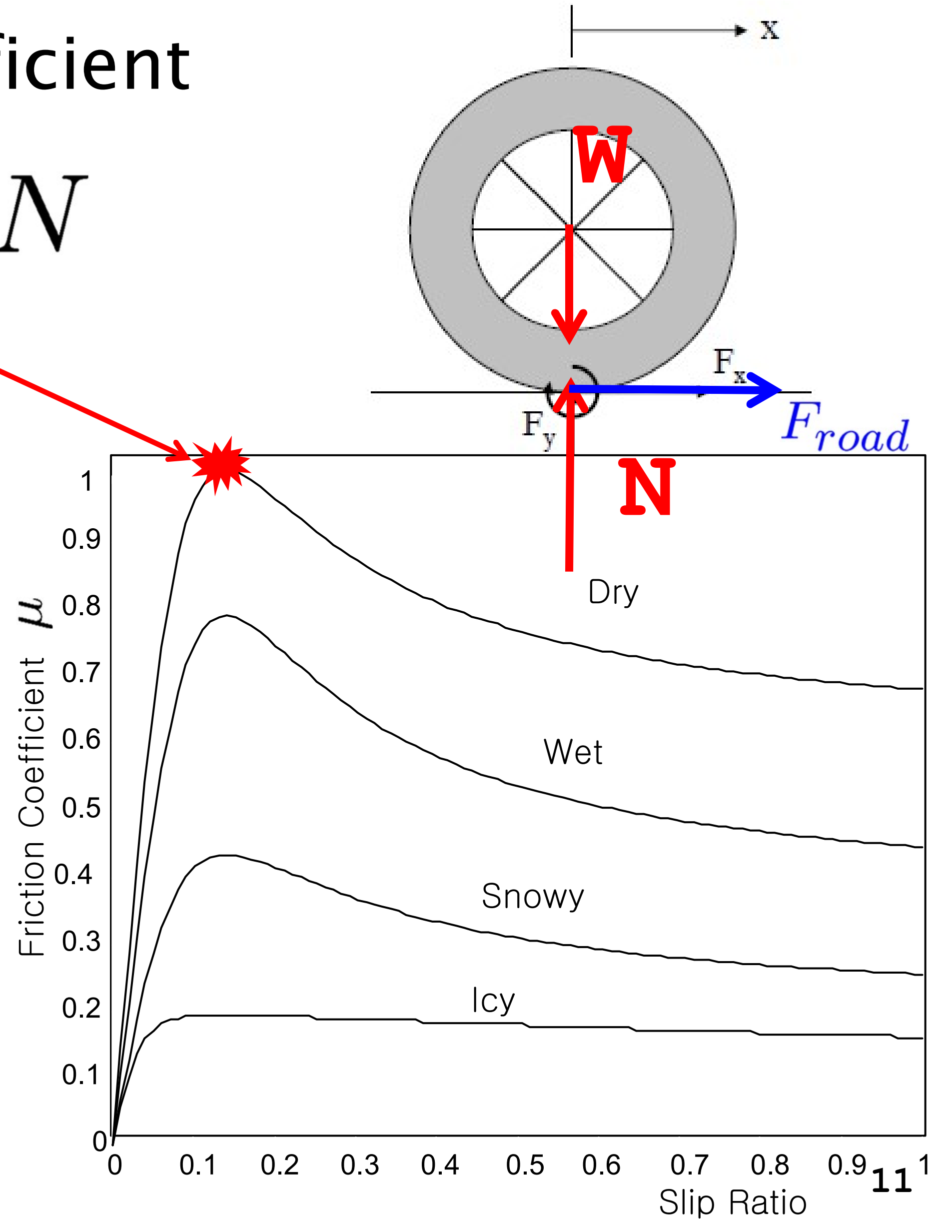


Road Force & μ_{MAX}

- Maximum Friction Coefficient

$$F_{road} \leq \boxed{\mu\mathrm{max}} N$$

  - Road Condition
  - Tire Type
  - Tread Pattern
  - Tread Depth
  - Velocity

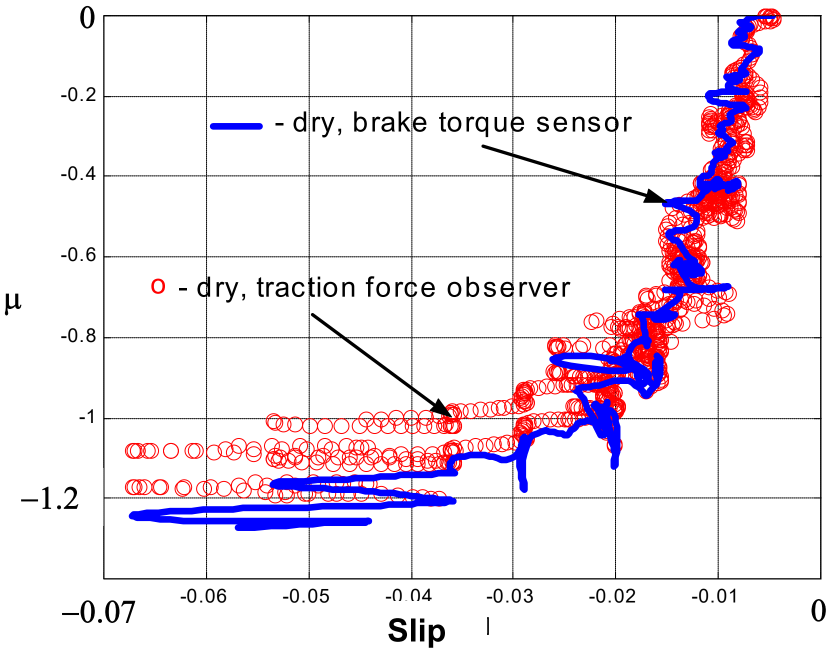


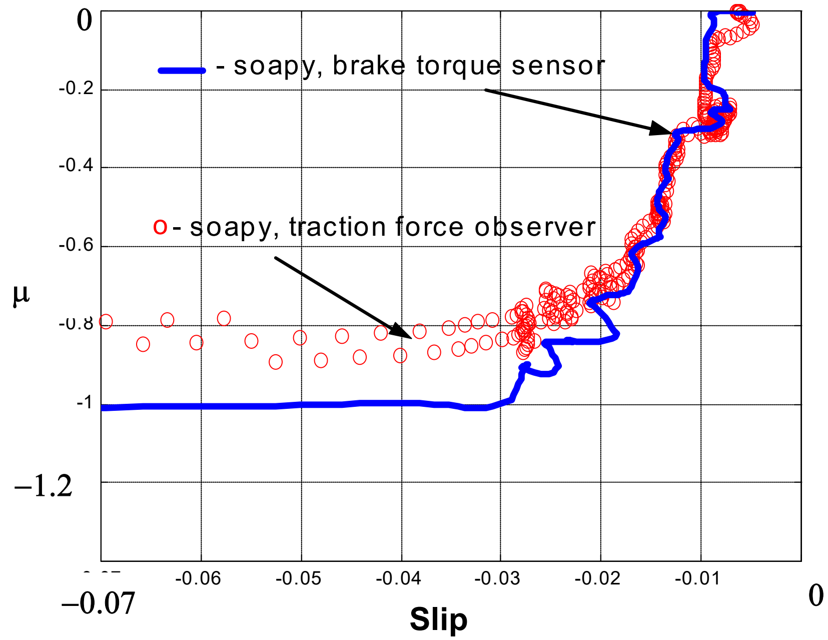
- Fiction Coefficient Definition

  as Normalized Force

$$\Rightarrow \quad \mu = F_{road}/N$$

Experimental slip curves



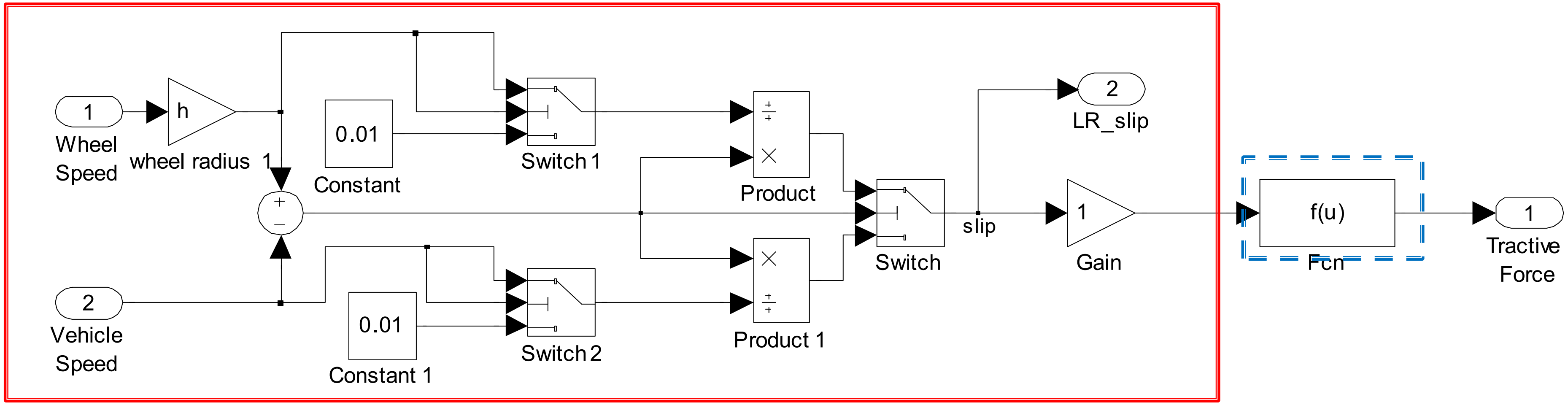


Tire Model

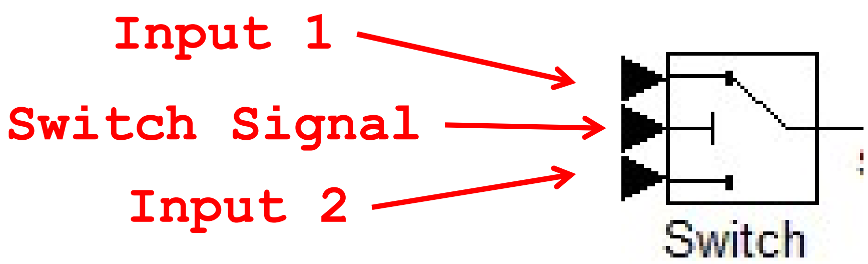
- Simulink Model of Tire
  - Constant block is used to avoid the case of "divide by zero".

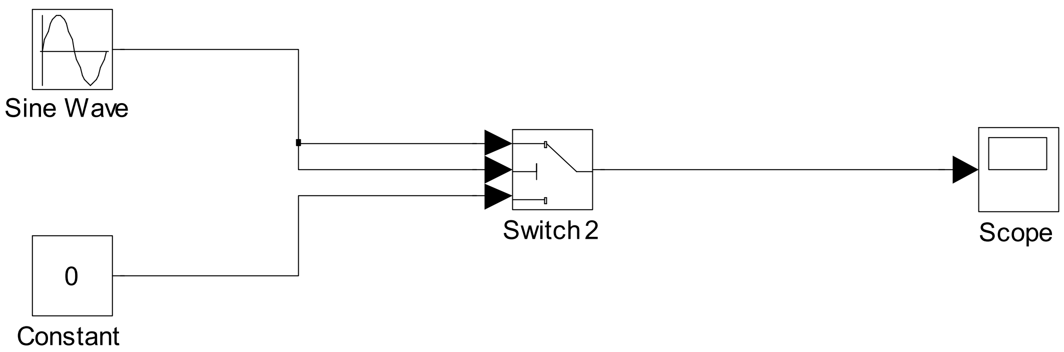
$$\boxed{s = \frac{h_{eff}\omega - v}{\max(h_{eff}\omega, v)}}$$

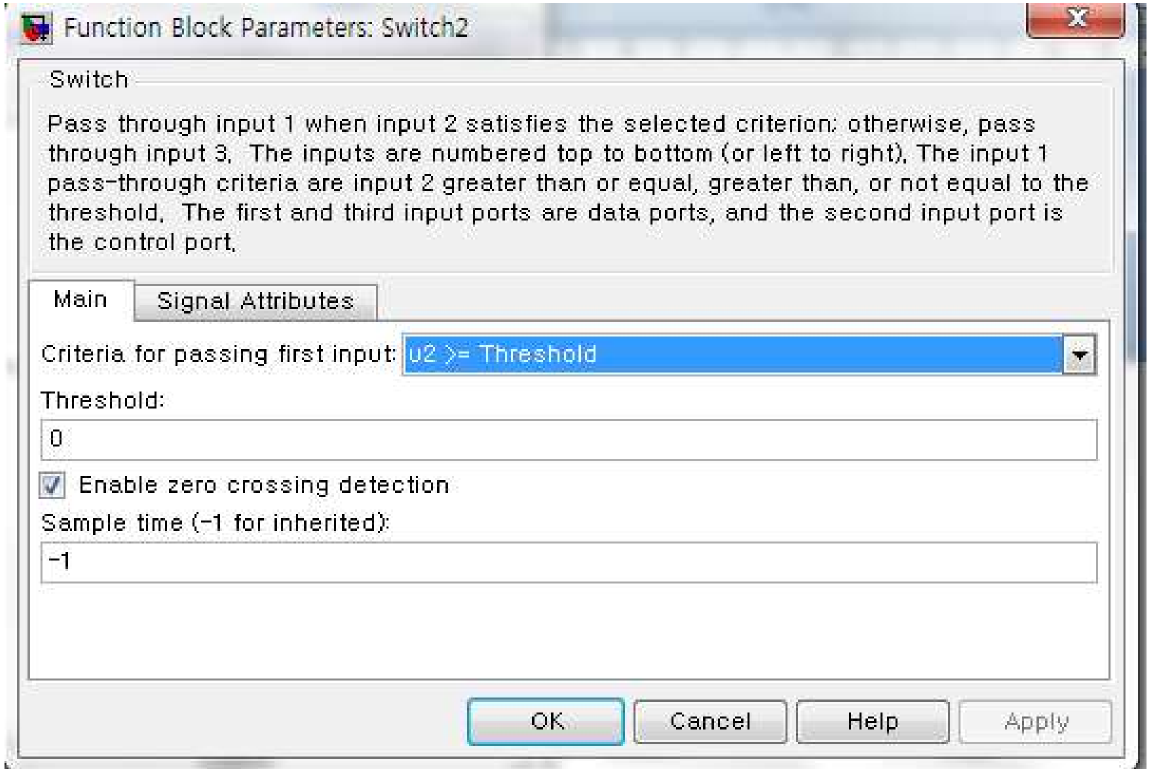
$$F_{road} = D\sin\left[C\arctan\left\{B\left(s+S_h\right) - E\left(B\left(s+S_h\right) - \arctan\left(B\left(s+S_h\right)\right)\right)\right\}\right]$$

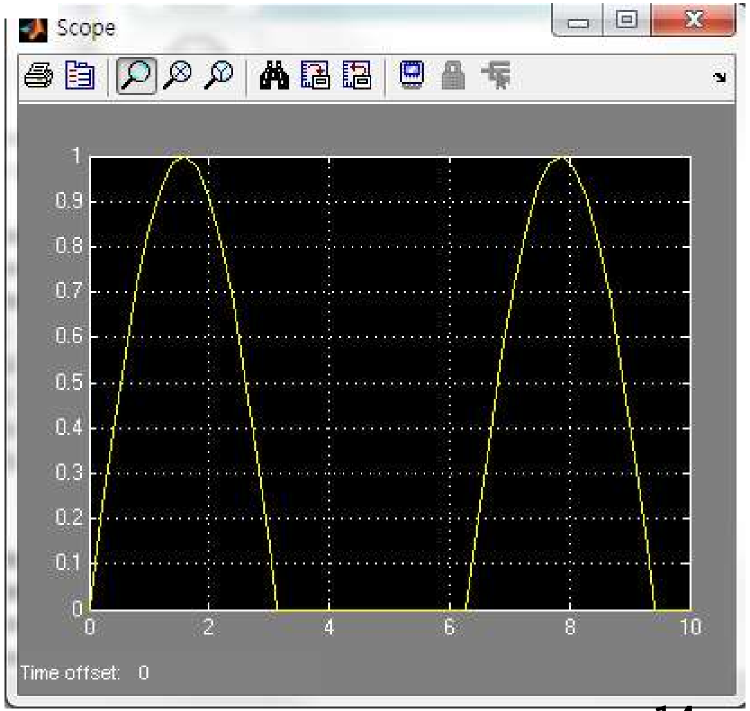


Tire Model


Input 1
Switch Signal
Input 2
Switch


Sine Wave
Switch2
Scope
0
Constant

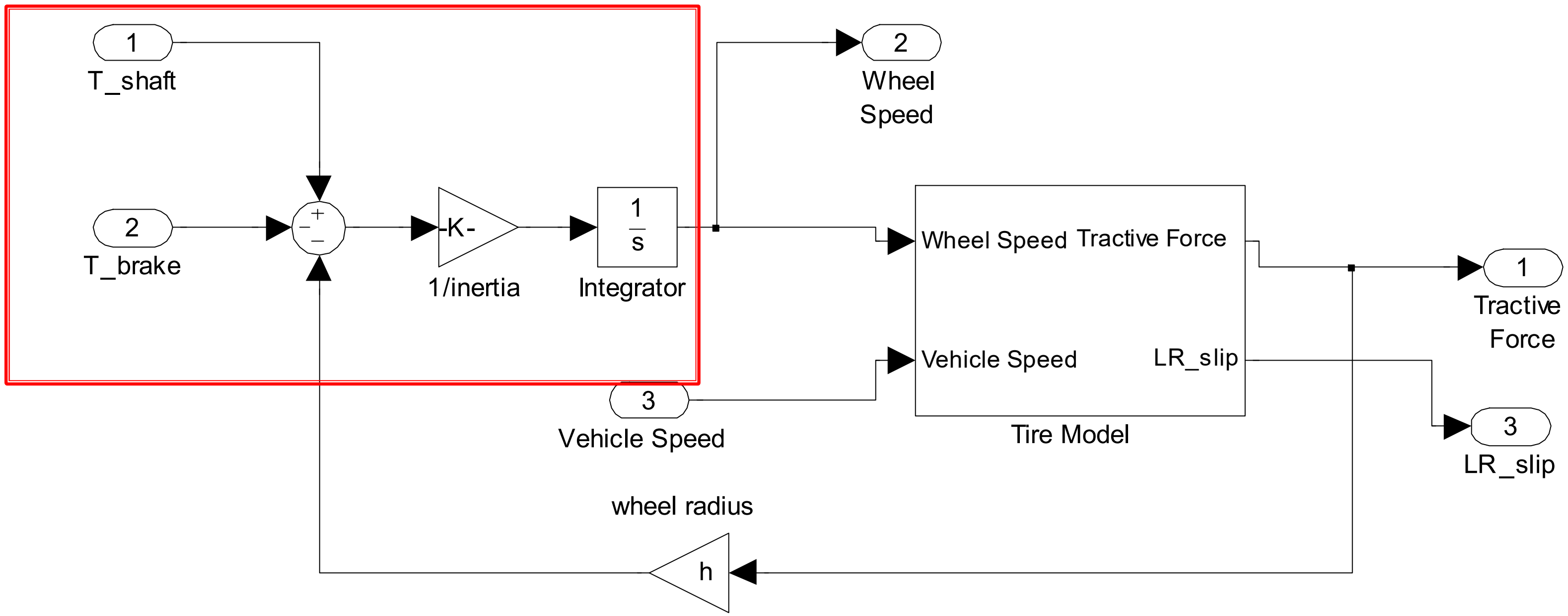

Function Block Parameters: Switch2
Switch
Pass through input 1 when input 2 satisfies the selected criterion; otherwise, pass through input 3. The inputs are numbered top to bottom (or left to right). The input 1 pass-through criteria are input 2 greater than or equal, greater than, or not equal to the threshold. The first and third input ports are data ports, and the second input port is the control port.
Main
Signal Attributes
Criteria for passing first input: u2 >= Threshold
Threshold:
0
Enable zero crossing detection
Sample time (-1 for inherited):
-1
OK
Cancel
Help
Apply


Scope
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Time offset: 0

Wheel Dynamics

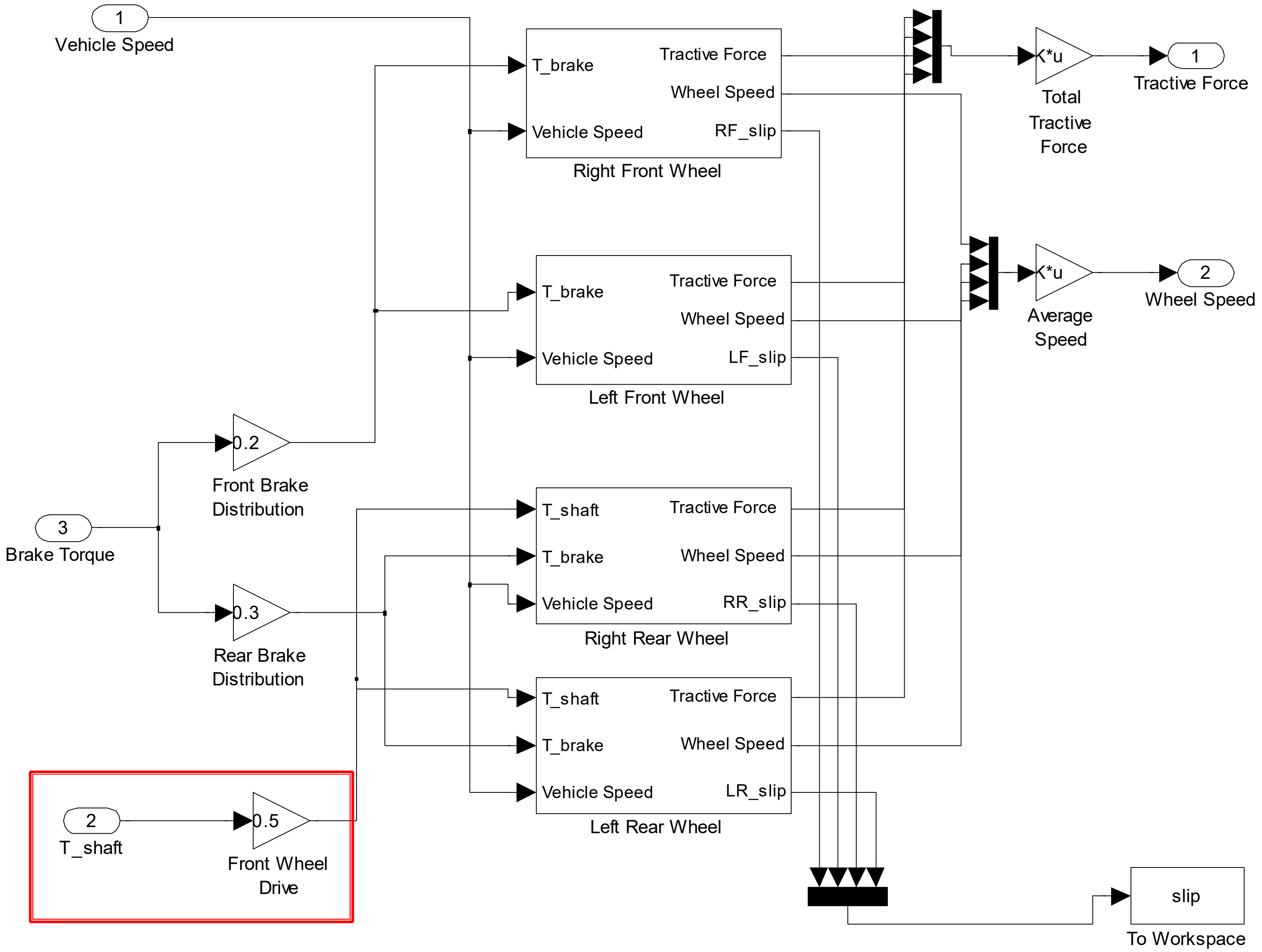
- Wheel Dynamics

$$\boxed{J_\omega \dot{\omega} = T_{shaft} - T_{brake} - h_{eff} F_{road}}$$



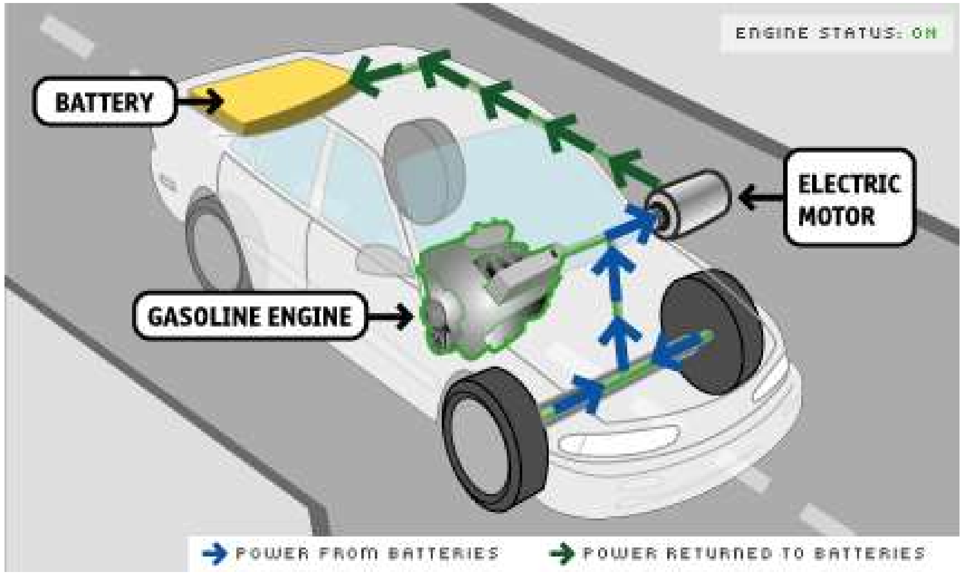
Wheel Dynamics

- Front Wheel Drive Model



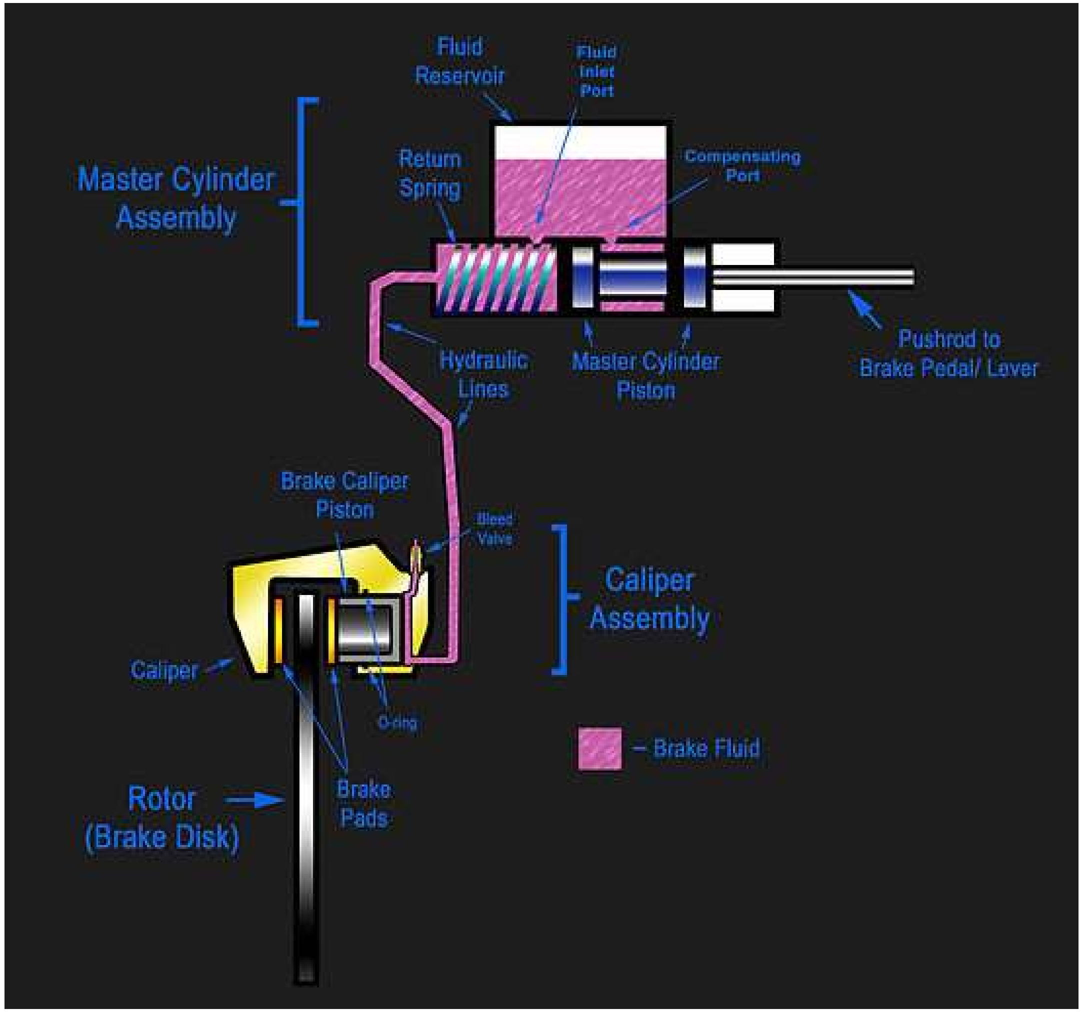
브레이크 제어

- 브레이크
  - 마찰을 이용하여 차량의 운동에너지를 열에너지로 변환시켜 감속
  - 최근 Hybrid Electric Vehicle(HEV) 는 회생제동시스템을 이용하여 운동에너지를 전기에너지로 변환시켜 버려지는 에너지를 재사용하여 연비 향상



Brake Model

- Hydraulic Disc Brake

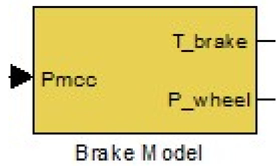


- 브레이크 제동력 전달
  - 브레이크 페달
    → Push rod
    → 마스터실린더
    → 브레이크 오일
    → 브레이크 피스톤
    → 브레이크 패드
    → 브레이크 디스크

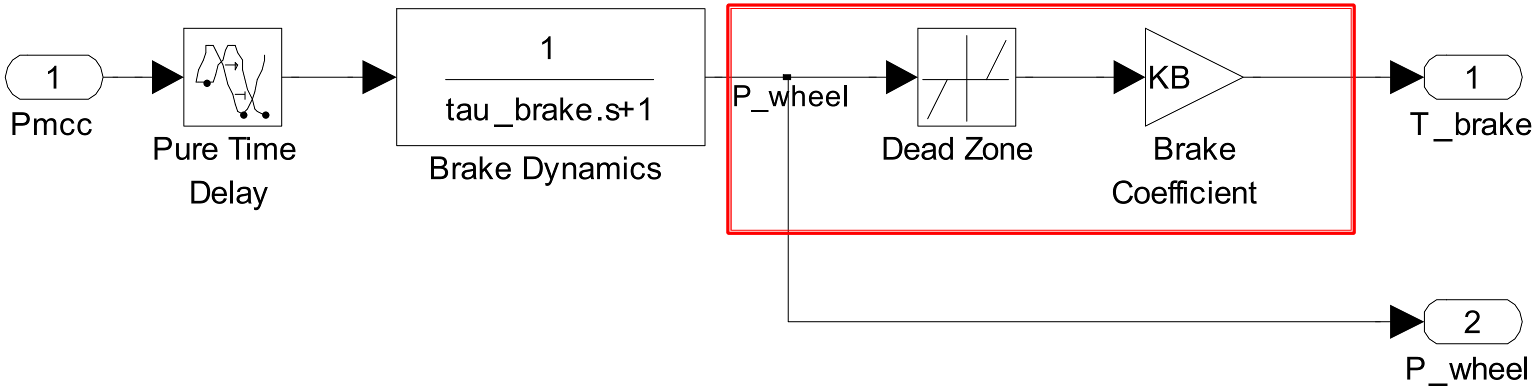
Brake Model

- Hydraulic Master Cylinder Pressure Model
- Constant Weight Distribution Assumption
- Simple Proportional Model

$$T_b = \begin{cases} K_b(P_w - P_{po}), & P_w \geq P_{po} \\ 0, & \text{otherwise} \end{cases}$$

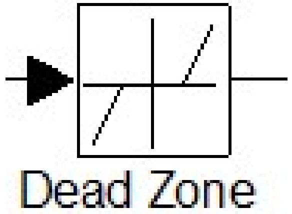


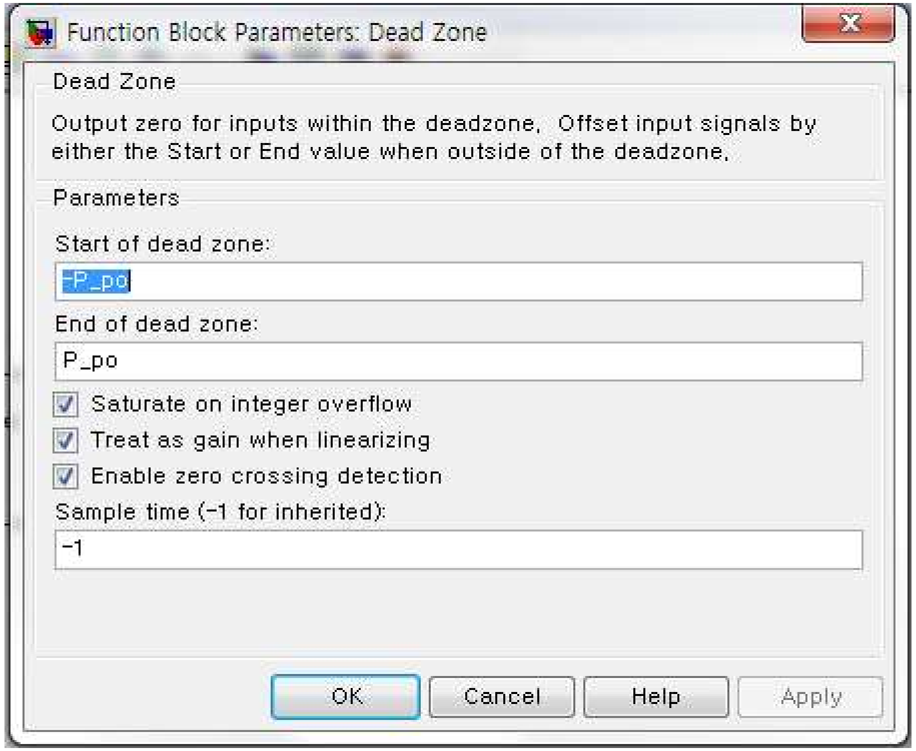
- K_b Brake Coefficient
- P_{po} Pushout Pressure
- P_{mc} Master Cylinder Pressure
- P_w Wheel Pressure

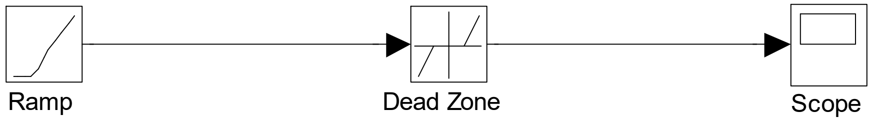


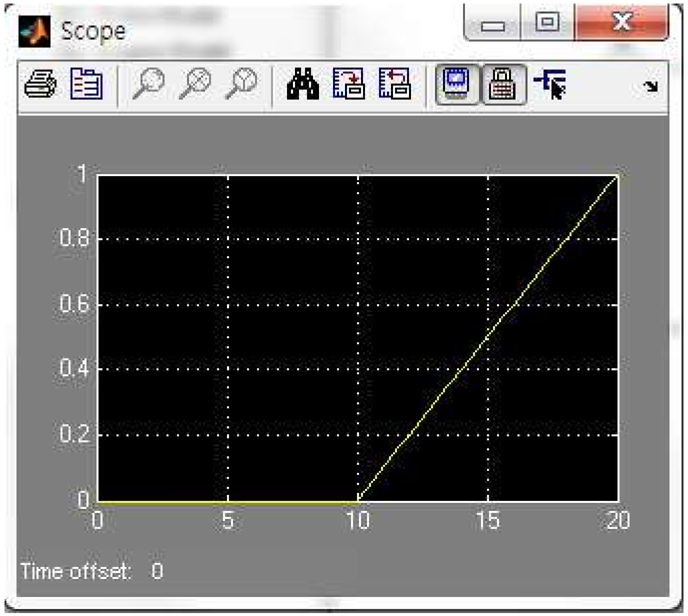
Brake Model

- Dead Zone
  - Typical Nonlinear Dynamics
  - Zero the output before the input value is below a certain thresholds



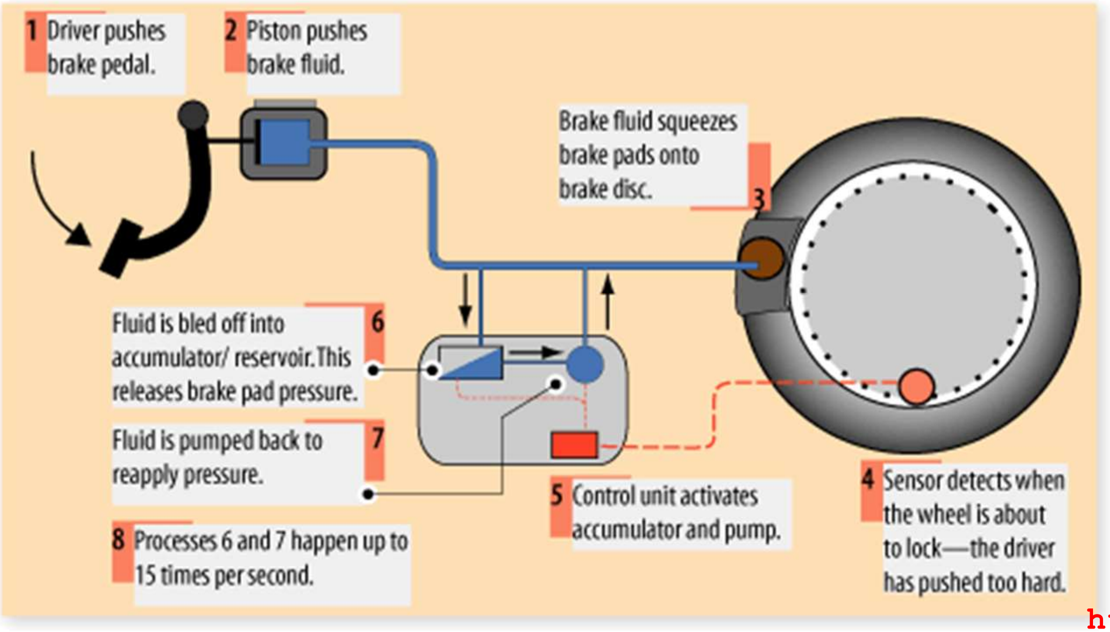


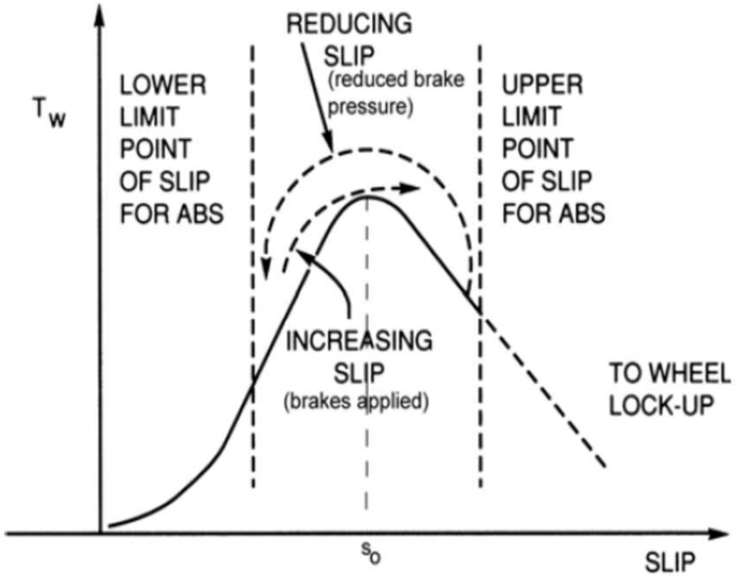




전자식 브레이크 제어

- Anti-lock Brake System (ABS)
  - 브레이크에 과도한 힘이 작용하여 브레이크 패드가 디스크를 꽉 물어 타이어가 잠기는 현상을 방지
  - 타이어가 잠기면 자동차는 조향성을 잃고 마찰력이 감소하는 것을 방지





https://www.youtube.com/watch?v=Zg6zufVDqU

전자식 브레이크 제어

- Electronic Stability Control
  - 브레이크를 통해 횡방향 미끄러짐을 최소화할 수 있도록 제어
  - Understeer, Oversteer를 최소화하기 위하여 좌우 브레이크를 다르게 적용