S5.6.2 – TRW design description regarding FMVSS 126 requirement S5.6.2

Oversteer Correction Moment

The controller uses 2 main strategies to control the vehicle's oversteer. Each has a detection mechanism to determine if and to what extent oversteer is present. Each has a Proportional-Integral-Derivative (PID) controller that computes the necessary vehicle level torques and forces required to mitigate the oversteer. Final oversteer control is a combination and arbitration of each of the individual controllers. The oversteer correction moment is converted to wheel torque requests and consequently turned into pressure build requests at each wheel.

Detection of Oversteer from Yaw Rate

The primary input of the Oversteer controller is via Yaw Rate itself. A vehicle yaw reference is computed using sensor inputs from the vehicle and the actual vehicle's sensed yaw rate is compared to this reference. If the yaw rate from the sensor exceeds the reference or targeted yaw rate, oversteer has been detected and a controller will work to eliminating the error between the target and actual yaw rate.

The yaw rate reference is defined as the targeted yaw rate for oversteer control. It is primarily a function of driver intended yaw rate (R_Lin) and the surface limit (Ay_Over_U).

1) $$r\_lin(yawrate) = \frac{v \times \delta_H / i}{L \times \left(1 + v^2 / v_{CH}^2\right)}$$

2) $$ay\_over\_u(yawrate) = \frac{a_{Lat}}{v}$$

Where the following are directly measured from the vehicle's sensors:

v is vehicle speed calculated directly from the wheel speed sensors
δ_H is the steering angle of the hand wheel measured with the SWA sensor
a_{Lat} is the vehicle's lateral acceleration measured with an accelerometer

And the following are considered to be relatively constant throughout an ignition cycle:

v_{CH} is the vehicle's characteristic speed
i is the steering ratio between the hand wheel angle and the angle of the wheel at the road
L is the vehicle's wheel base length

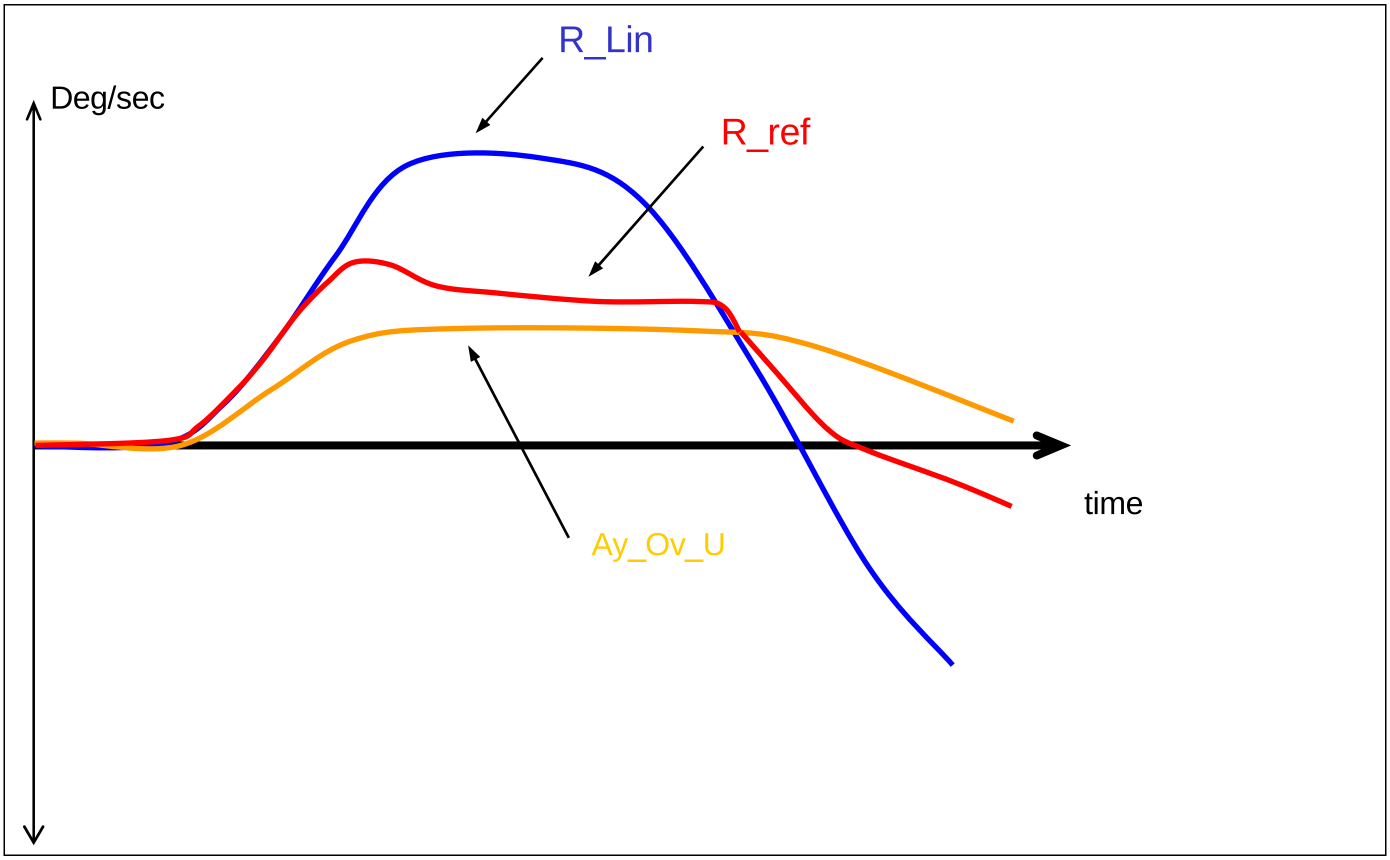


Figure 1: Example of how the Yaw Rate Reference (R_ref) is a function of R_Lin and Ay_Ov_U.

The yaw rate sensor output is then compared to the vehicle's yaw rate target to determine the extent of oversteer. If an error exists, oversteer is detected and the error is sent to a PID controller to calculate the correction moment necessary to mitigate the vehicle's oversteer.

Detection of Oversteer from Alpha (rear slip angle)

The controller estimates the vehicle's rear slip angle (alpha rear) and compares it to a threshold based on the vehicle speed and surface capability. The difference between alpha rear and the activation threshold is the oversteer error. If an error exists, oversteer is detected and the error is sent to a PID controller to calculate the correction moment necessary to mitigate the vehicle's oversteer

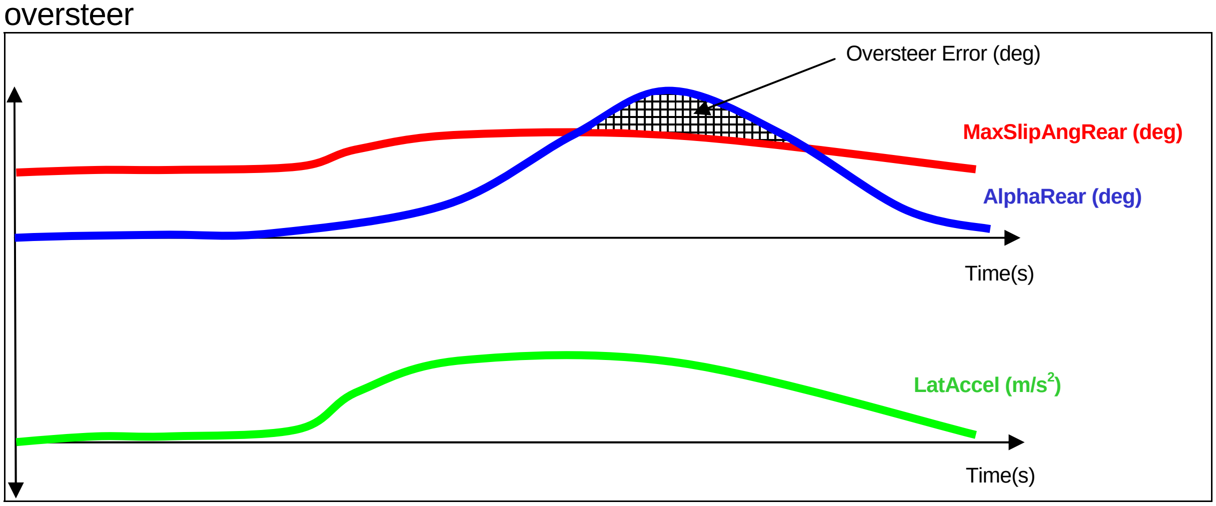
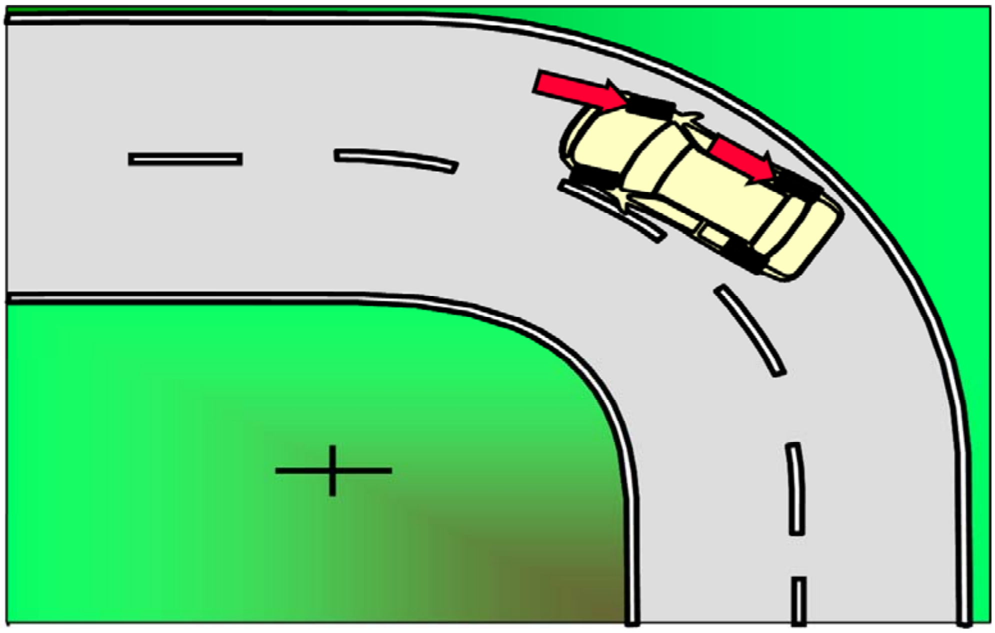


Figure 2: As AlphaRear exceeds the activation threshold (based on Lat Accel), an oversteer error is computed.

Output of the controller

The two correction moments are then compared and an arbitrator determines the optimal **Oversteer Correction Moment**. This represents the amount of torque the controller would like to place on the vehicle (about the CG) to correct the oversteer.

For differential brake intervention, the ESC System controls the outside wheels to create a yaw torque. This command can be either left or right, depending on the intent of the driver's direction. The level of pressure control is based on the Oversteer Correction Moment.



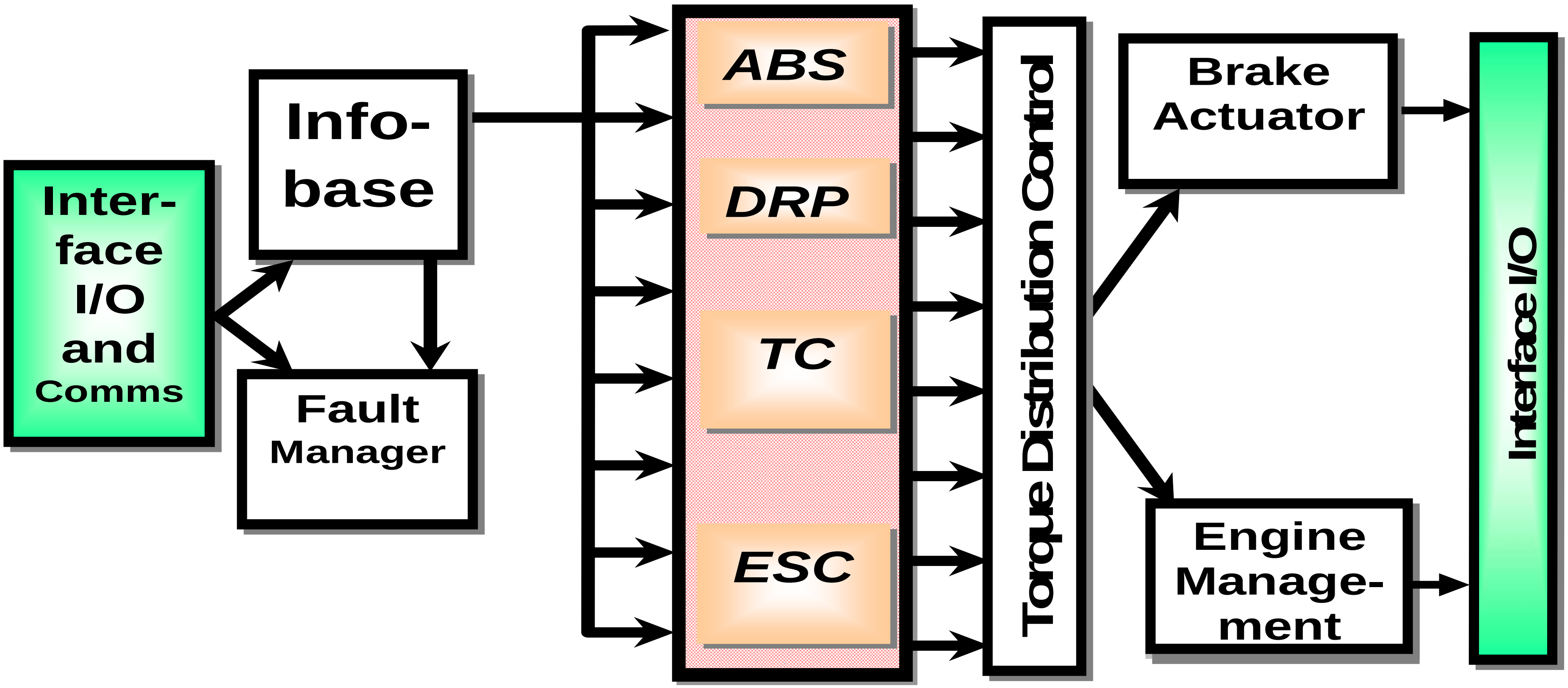
Summary of Oversteer Control

In summary, the ESC system mitigates vehicle oversteer by monitoring the following vehicle sensors:

- Wheel speeds – used to determine vehicle speed
- Yaw rate – used directly to determine vehicle yaw rate
- Steering wheel angle – used to determine steering angle at the tire and driver's intent
- Lateral acceleration – used to determine vehicle surface capability

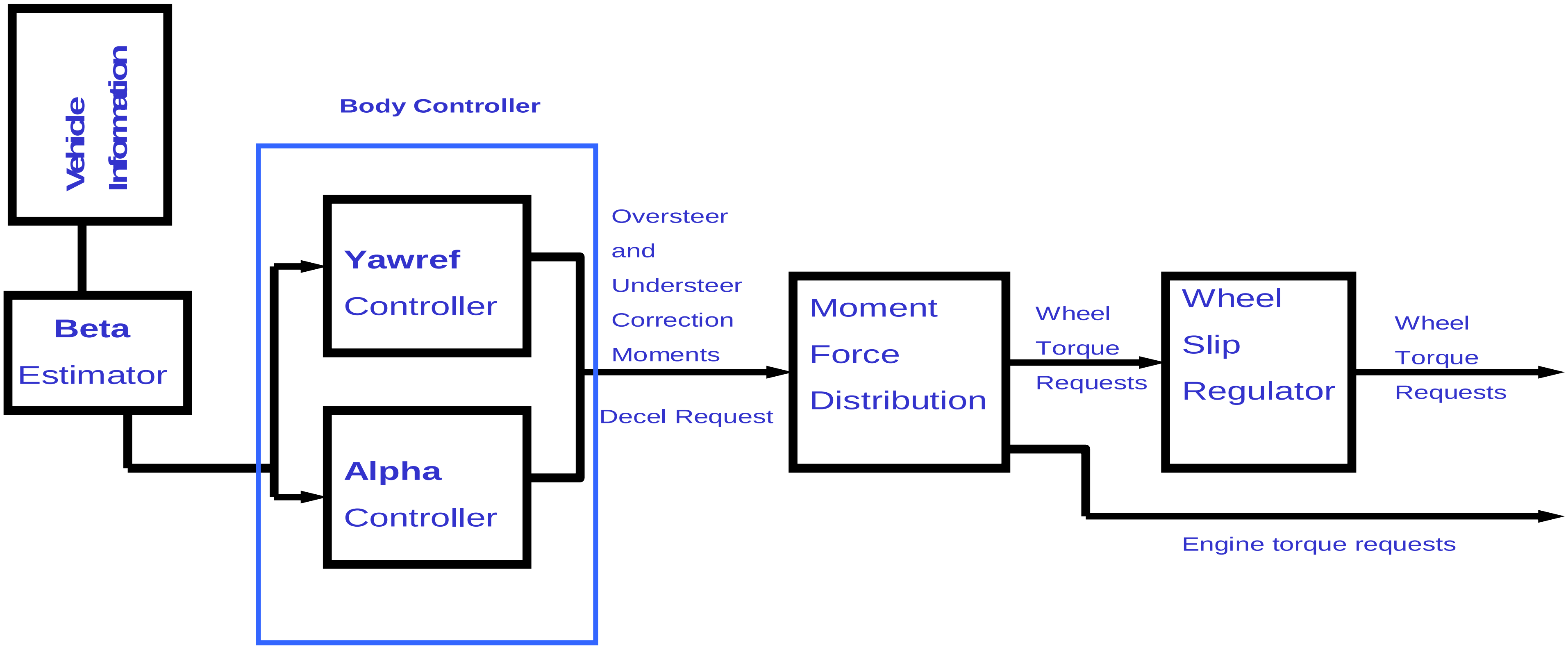
The system computes two oversteer correction moments. The primary correction comes from comparing the vehicle's yaw rate with a targeted yaw rate based on surface capability and driver's intent. The secondary correction comes from estimating the rear slip angle of the vehicle and controlling that to a defined slip error. Both moments are compared and an arbitration scheme computes the final control signals used to control the pressure of the "outside" wheels.

Capabilities within Core Architecture



S5.6.3 – TRW design description regarding FMVSS 126 requirement S5.6.3

ESC Subsystem Overview



Body Controller Outputs

Oversteer Correction Moment:

- Output of yaw reference and rear slip angle controllers

Understeer Correction Moment:

- Output of front slip angle controller

Decel Command:

- Output of front slip angle controller

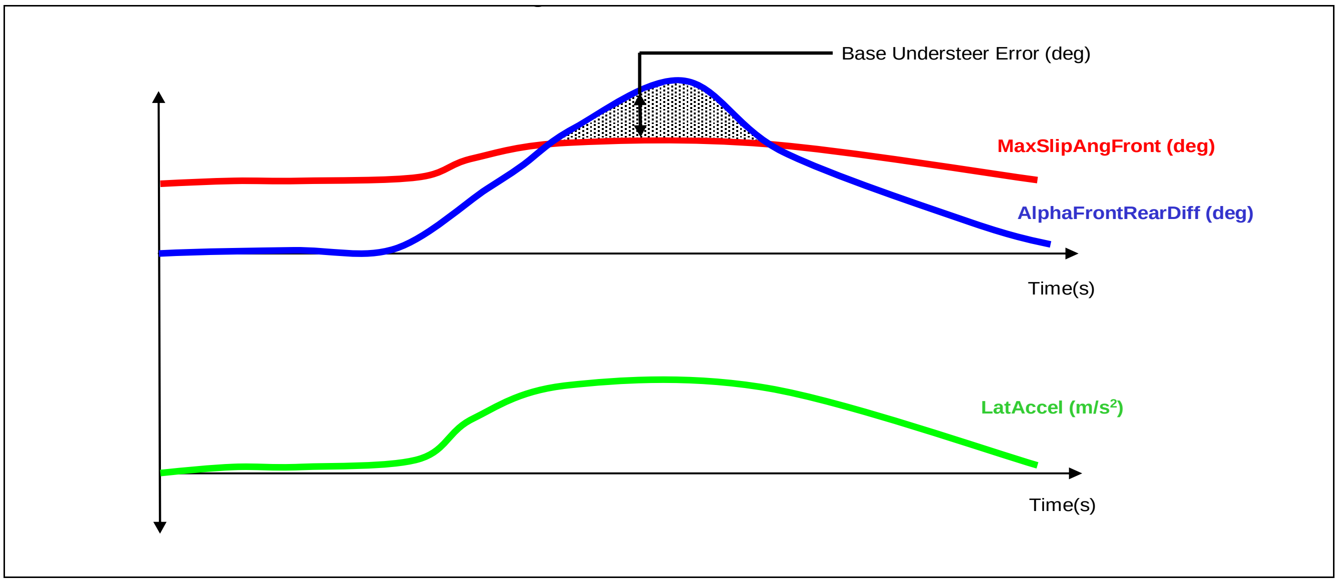
Above signals are vehicle level torque and force requests, to be actuated by whatever means (i.e. brakes or engine) inside of the Moment Force Distribution algorithm. The Moment Force Distribution algorithm will convert the vehicle level moment command request into wheel torque requests. These requests then become pressure commands at the wheel ends.

S5.6.4 – TRW design description regarding FMVSS 126 requirement S5.6.4

Understeer Control Specifics

"Front" Slip Angle Control

The controller uses a modified "Front" slip angle control scheme to mitigate vehicle understeer conditions. The ESC system actually controls "alpha front-rear difference" to a trimmable activation threshold based on surface capability and speed. A base understeer error is present if "alpha front-rear difference" exceeds activation threshold in magnitude.



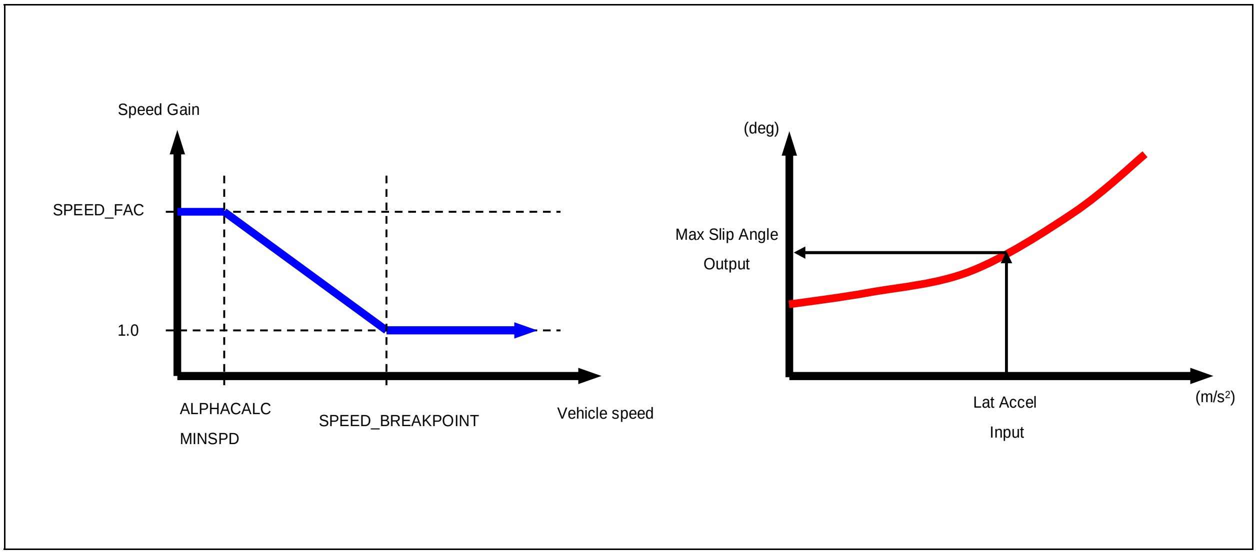
The slip angle activation threshold limits are continuously generated using parameters directly measured from the vehicle's sensor set. The base understeer error (BUE) is the dominant control parameter throughout a vehicle understeer event.

The following pages describe in detail which vehicle parameters are used to determine the BUE, which again, comes from a threshold calculation and a vehicle characteristic calculation (front/rear slip angle difference).

Activation Threshold

The activation threshold identifies when vehicle understeer is present, as well as determining the magnitude of the understeer event. In general, the following is true:

- Activation threshold maps to surface capability
    - Threshold increases as Lat Accel increases (measured quantity through Ay sensor)
    - Threshold increases as Vehicle Speed decreases (measured quantity through wheel speed sensors)



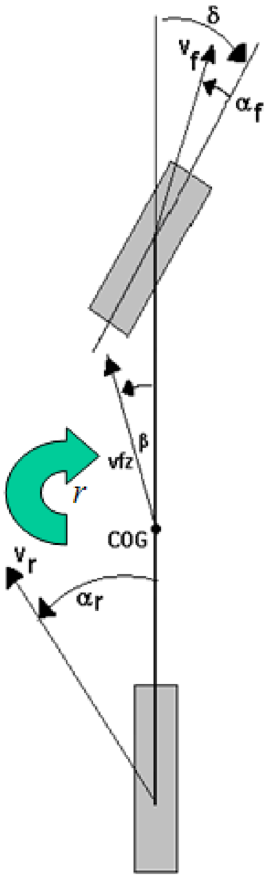
Therefore**,** the system allows for a larger front/rear slip angle difference on high mu surfaces and at lower speeds. Conversely, the threshold for activation becomes much smaller on low mu surfaces and with higher speeds. In all cases, no correction (brake or engine) will be present if a BUE does not exist (i.e. front/rear slip angle difference does not exceed the threshold).

Front/Rear Slip Angle Difference

With a threshold now established, the following derivation describes which pertinent inputs are used, how the front/rear slip angle difference is calculated, and finally how Understeer is determined.

Understeer Control Specifics

Basic definitions



Alpha Front and Alpha Rear are estimated quantities:

Eq 1) $\alpha_f = \beta - \frac{r \cdot l_f}{v_x} + \delta$ **Eq 2)** $\alpha_r = \beta + \frac{r \cdot l_r}{v_x}$

By subtracting Eq 2 from Eq 1, and simplifying the result, we obtain:

[alpha front – alpha rear]

$$\alpha_{fr\_rr\_diff} = (r_{meas} - r_{Lin})\frac{l}{v_{Fz}}$$

This equation uses measured quantities and vehicle parameters.

Understeer condition exists when:

$$(\alpha_{front} - \alpha_{rear}) > \text{Threshold}$$

The distances to the center of gravity are assumed constant and therefore do not have to be estimated throughout a drive cycle. The other parameters, yaw rate (r), vehicle speed, and steering angle are all obtained directly from sensors on the vehicle.

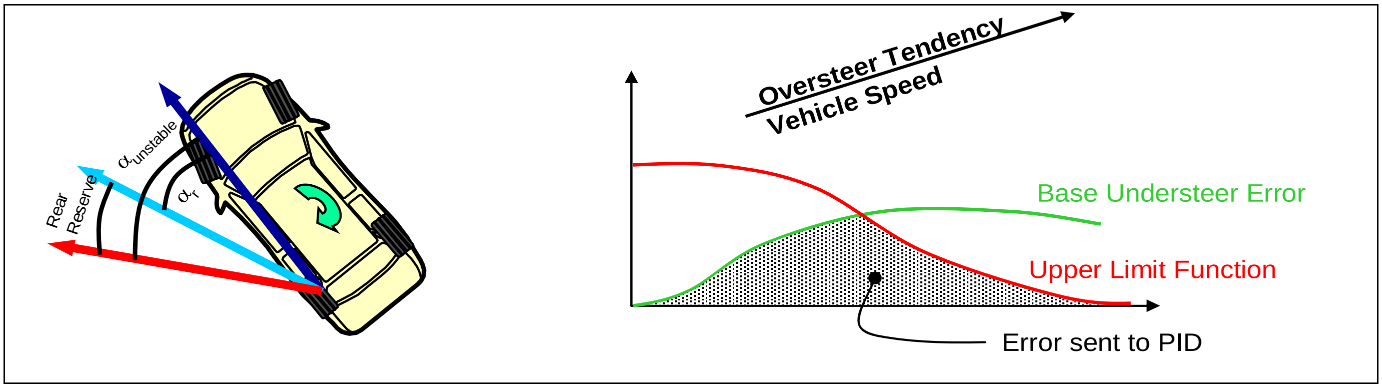
Base Understeer Error (BUE)

Based on the activation criteria, the ESC system determines how to mitigate the vehicle understeer conditions. If the front/rear slip angle difference exceeds the threshold, a BUE is computed. The system utilizes two control mechanisms to stabilize the vehicle. Both are based on the BUE. The first is using differential braking requests and second is using engine torque reduction requests.

For Differential Braking Request

- Base Understeer Error (BUE) is upper-limited by a function that:

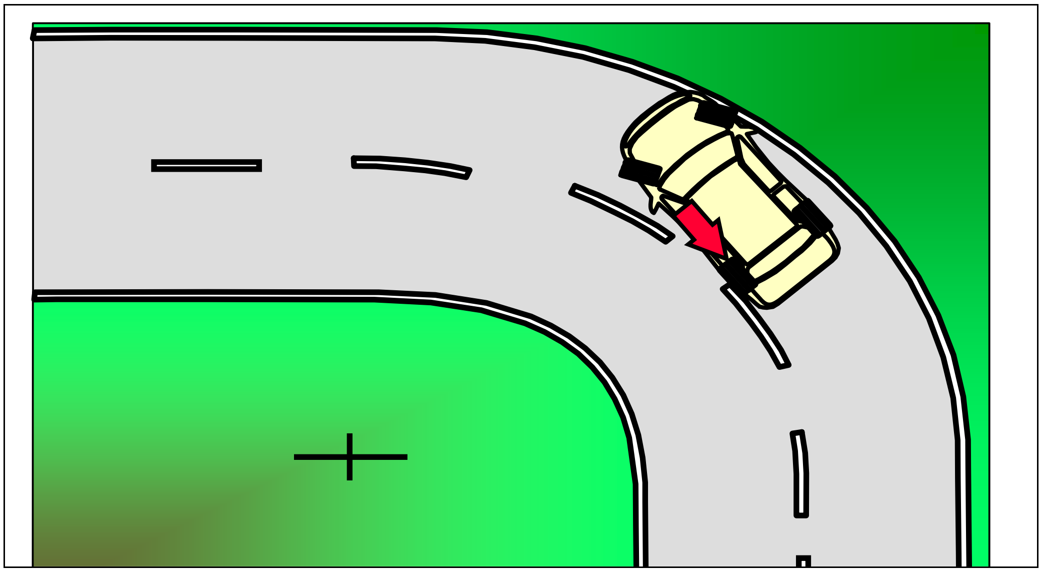
    - ➢ decreases as vehicle oversteer increases
    - ➢ decreases as vehicle speed increases
- Therefore differential braking response to understeer condition can be phased out with speed and/or “oversteer level”
- This represents a safety factor used to determine the limit on this control authority.
- BUE is input to a standard proportional-integral-derivative (PID) controller.



Active Wheels During Understeer

The output of the BUE PID controller gets converted to an **Understeer Correction Moment**. This represents the amount of torque the controller would like to place on the vehicle (about the CG) to correct the understeer.

For differential brake intervention, the ESC System controls the inside rear wheel to create a yaw torque. This command can be either left or right, depending on the intent of the driver’s direction. The level of pressure control is based on the Understeer Correction Moment.



Engine Torque Request

A drive torque signal is generated from the Decel Command which also comes from the BUE.

During system activations, a drive torque request may be issued to the powertrain that results in a decrease of available engine torque at the drive wheels. The intent is simply to decelerate the vehicle if the driver continues to desire acceleration during an oversteer event.

Summary of Understeer Control

In summary, the ESC system mitigates vehicle understeer by monitoring the following vehicle sensors:

- Wheel speeds – used to determine vehicle speed
- Yaw rate – used directly to determine vehicle yaw rate
- Steering wheel angle – used to determine steering angle at the tire
- Lateral acceleration – used to determine vehicle surface capability

The system computes a Base Understeer Error (BUE) simply by comparing two calculated variables. The BUE is the primary input in determining the amount of differential braking control and the amount of engine torque reduction requested to mitigate the vehicle from understeering.