Understanding ESP

What is ESP?

Electronic

Stability

Program

Why ESP?

Increases Driving Stability

↓

Improves Vehicle Handling

↓

Reduces Accidents

and/or

Injuries by Accidents!

What is the function of ESP?

The ESP selectively applies brake force to the vehicle wheels (individually and in combination), depending upon the requirements of the driving situation, to maintain optimal vehicle handling and safety.

What is the function of ESP?

Brake force applied by the ESP causes each braked wheel to decelerate and slip.

This changes the longitudinal and transversal forces at each wheel and influences yaw.

What is the function of ESP?

Yaw **becomes**

sideslip angle affected

and

slip angle optimized

in the desired direction.

Two conditions trigger ESP.

Understeer

Oversteer

Understeer

The vehicle pushes toward the outside of the curve.

ESP Response

The wheels facing the inner side of the curve are braked; the greatest braking force affects the rear wheels.

Understeer handling

The slip angle α of front wheel α_F is greater than the slip angle of the rear wheel α_R.
As the vehicle is driven through a curve, the front wheels lose adhesion before the rear wheels, causing the front wheels to push toward the outside of the curve.
Turning radius increases correspondingly.

Oversteer

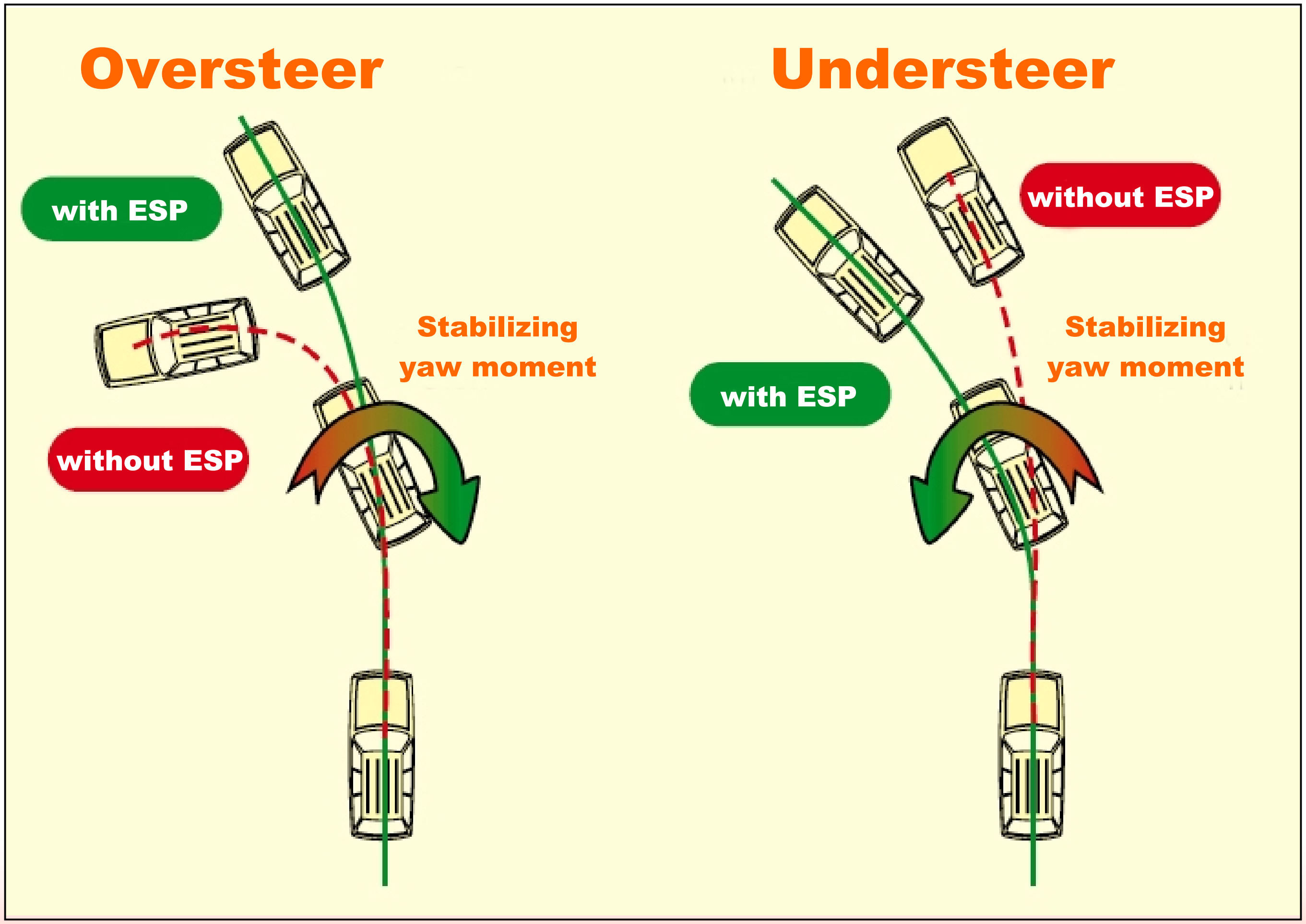
The vehicle pulls going into the curve.

ESP Response

Braking is applied to the wheels nearer the outer side of the curve. The greatest braking force is applied to the front wheels, resulting in 50% wheel slippage (50% braking force). This override produces a counter torque, which compensates the causal yaw moment.

Oversteer Handling

The slip angle α of the front wheels α_F is smaller than the slip angle of the rear wheels α_R. As the vehicle is driven through the curve, the rear wheels lose adhesion before the front wheels, causing the rear of the vehicle to slide outward. As a result, the turning radius of the vehicle is smaller than it should be as compared to the rotation applied to the steering wheel!


Oversteer
Understeer
with ESP
without ESP
Stabilizing
yaw moment
without ESP
Stabilizing
yaw moment
with ESP

What systems comprise ESP?

ESP may comprised of the following systems:

- **ABS (anti-lock brake system)**
- **ASR (anti-slip control)**
- **MSR (motor drag control)**
- **EBV (electronic brake force distributor)**

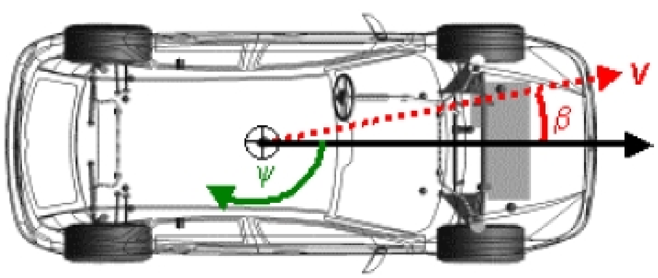
These 4 systems concentrate mainly on the longitudinal dynamics of the vehicle.
ESP integrates the yaw movement.

Oversteer, understeer, neutral steering

Oversteer	$\alpha_F < \alpha_R$
Understeer	$\alpha_F > \alpha_R$
Neutral	$\alpha_F = \alpha_R$

Objective testing methods and evaluation criteria

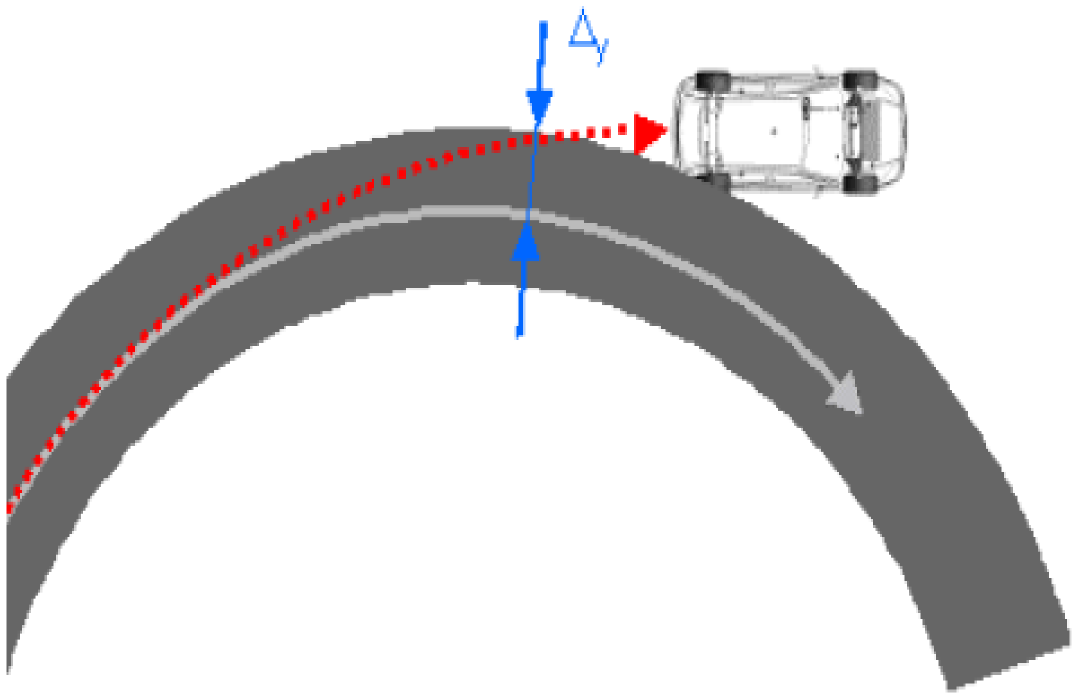
driving stability:



- yaw behavior
- sideslip angle
- slip angle
- yaw rate
- path deviation

driving direction intent: adjusted steering angle

Driving direction intent



Objective testing methods

Performance of tests that can evaluate steering and yaw behavior simultaneously.

Additional important points of the test are:

- **Reproducibility**
- **Robustness against environmental and interfering influences**
- **Relevance**

Vehicle evaluation

The following parameters are considered in vehicle evaluation:

- **Temperature**
- **Humidity**
- **Ground covering µ – jump**
- **Brand and age of the wheels**

Potential testing methods

Sine steer: **based on a *real world* double-lane change maneuver**

Pulse steer: **based on the assumption that an impulse input signal activates the vehicle via a large frequency range**

Sine steer

Increasing Sine Steer

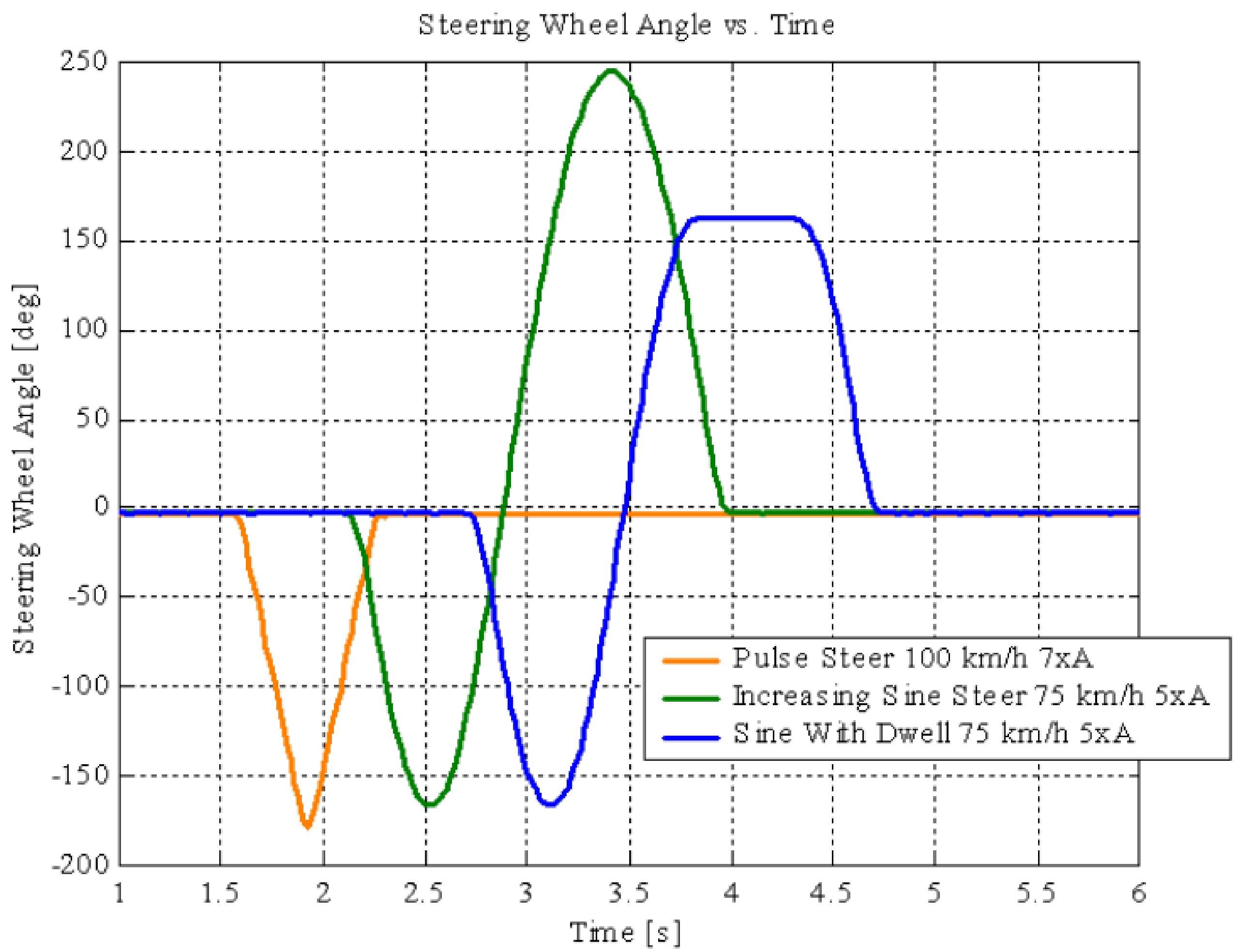
Velocity:	**75 km/h**
Duration:	**2 s**
Steering wheel angle:	**-160° ... 260°**

Sine with dwell

Velocity:	**75 km/h**
Duration:	**2.5 s**
Steering wheel angle:	**-160° ... 160°**

Pulse Steer

Velocity:	**100 km/h**
Duration:	**1 s**
Steering wheel angle:	**0° ... 170°**



Steering Wheel Angle vs. Time
Steering Wheel Angle [deg]
Time [s]
250
200
150
100
50
0
-50
-100
-150
-200
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Pulse Steer 100 km/h 7xA
Increasing Sine Steer 75 km/h 5xA
Sine With Dwell 75 km/h 5xA

Testing for ESP development

- Steady-state circular-course driving
- Braking when cornering
- Double track-changing
- Transient behavior
  - Steering angle jump
  - Sinusoidal steering angle input

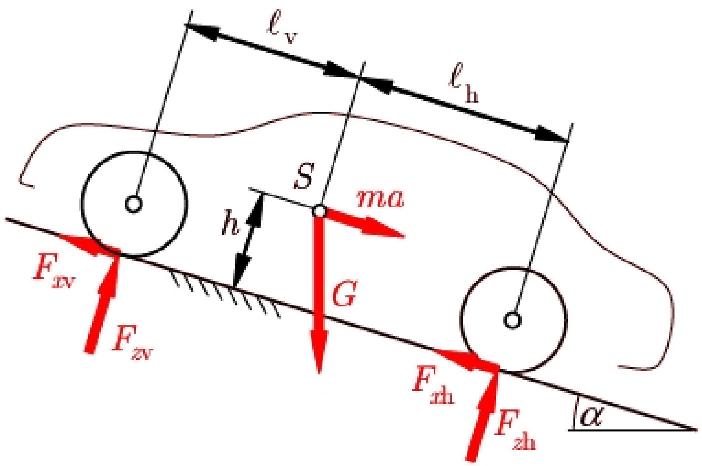
Important measured variables

- Steering angle
- Transversal acceleration
- Longitudinal acceleration/deceleration
- Yaw speed
- Sideslip angle and roll angle
- Longitudinal and transversal velocity
- Steering angle of front and rear wheels
- Slip angle of front and rear wheels

Vehicle dynamics

- Longitudinal dynamics
- Transversal dynamics
- Vertical dynamics

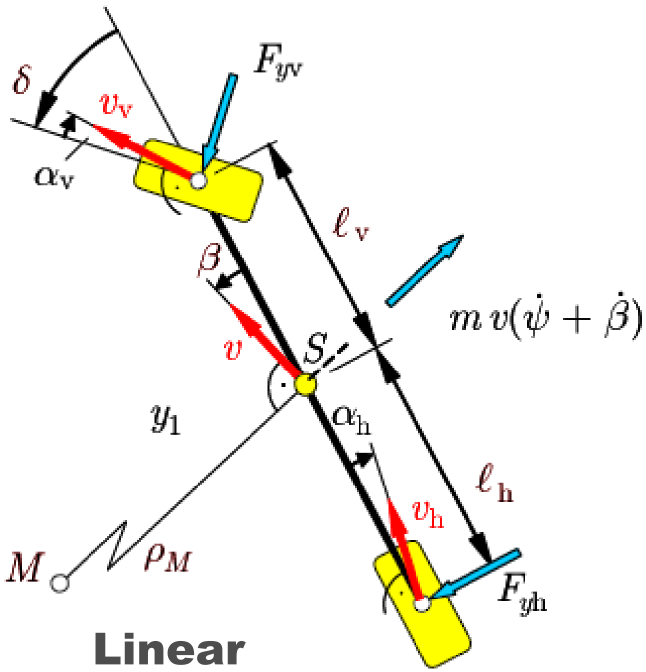
Longitudinal dynamics



Planar model of longitudinal dynamics

- **Evaluation of acceleration and braking behavior**
- **Driving resistance: wheel, air, rising, and acceleration resistance**
  (energy requirement)
- **Engine characteristics, gear balance**
  (engine supply)
- **transmission of drive and brake forces**
  (driving limits)

Transversal dynamics



Linear one-track model

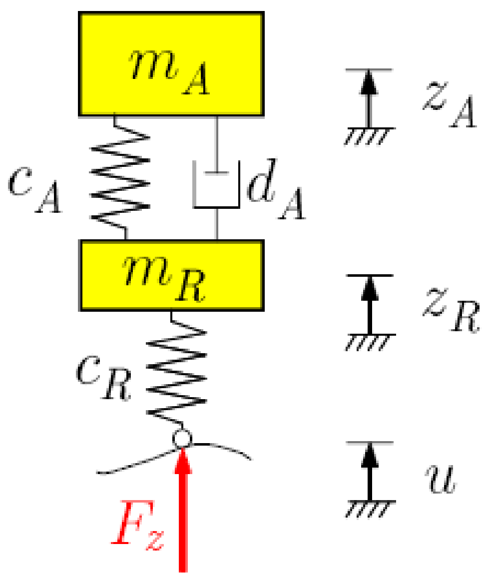
Evaluation of steering behavior
transversal acceleration $a_y < 0.4$ g

Testing maneuver
Steady-state circular-course drive:
- Self-steering behavior
- Characteristic and critical speed

Testing maneuver
Non-steady-state circular-course drive:
- transverse behavior
  steering angle → yaw angle

Parameter influences:
- wheel base l, position of center of gravity l_v
- Mass m, moment of inertia J
- Slip stiffness of the tires C_v, C_h

Vertical dynamics



Two-mass suspension model

Evaluation of vibration behavior based on two primary criteria:

1. Driving safety (wheel load)
2. Driving comfort (body acceleration)

Parameter influences:

- body mass m_A
- tire mass m_R
- body spring C_A
- tire spring C_R
- body damper d_A

What is self-steering behavior?

Self-steering is a set of vehicle steering behaviors that are of independent driver steering input!

In the case of self-steering, the driver does not steer the vehicle, the steering angle does!

Self-steering behavior is influenced by:

- Wheel load distribution
- Kinematics
- Suspension elasticity
- Wheel characteristics

How is self-steering identified?

Steady-state, circular-course test drive

Methodology:

- **Constant radius**
- **Speed is increased from slow coasting**
- **If steering angle must be changed to maintain the circular path, self-steering effects are present**

The additional angle that the wheel is turned is called slip angle.

As you recall...

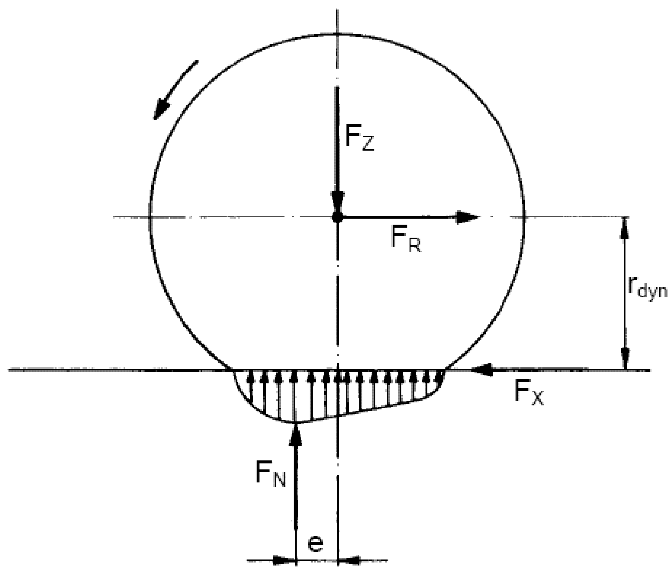
Oversteer	$\alpha_F < \alpha_R$
Understeer	$\alpha_F > \alpha_R$
Neutral	$\alpha_F = \alpha_R$

The tire

The tire is the supporting element between the road and the car body. It essentially counters the vertical force F_z (gravitational force) of the vehicle.

The elasticity of the tire generates a wheel footprint.

The tire



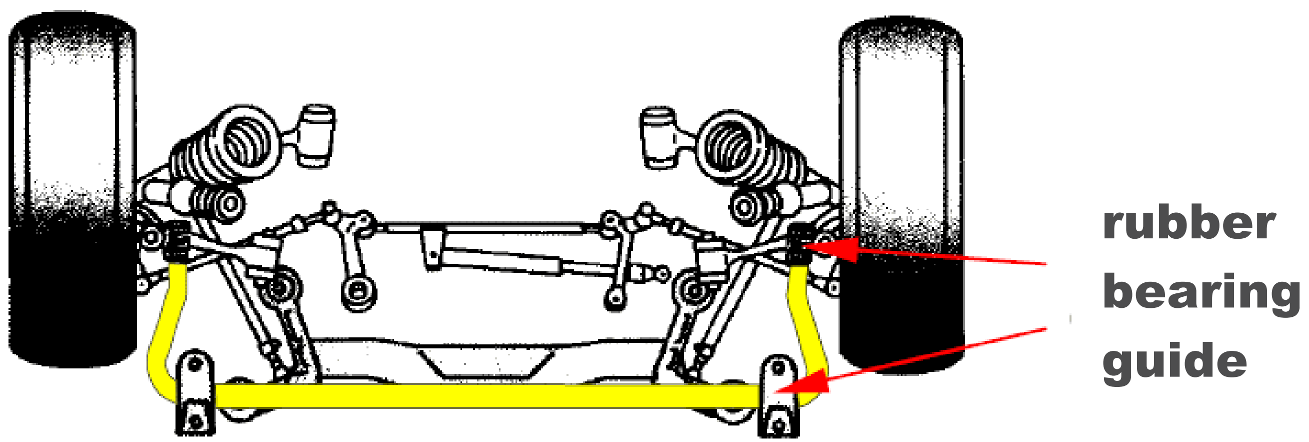
- F_R rolling resistance
- F_x reaction force
- F_Z gravitational force
- F_N normal force

The rolling resistance generates the reaction force.

Influences on roll stability

- The harder the suspension, the larger the slip angle
- A hard stabilizer at the front axle favors understeer
- A hard torsion-spring rod at the rear axle favors oversteer

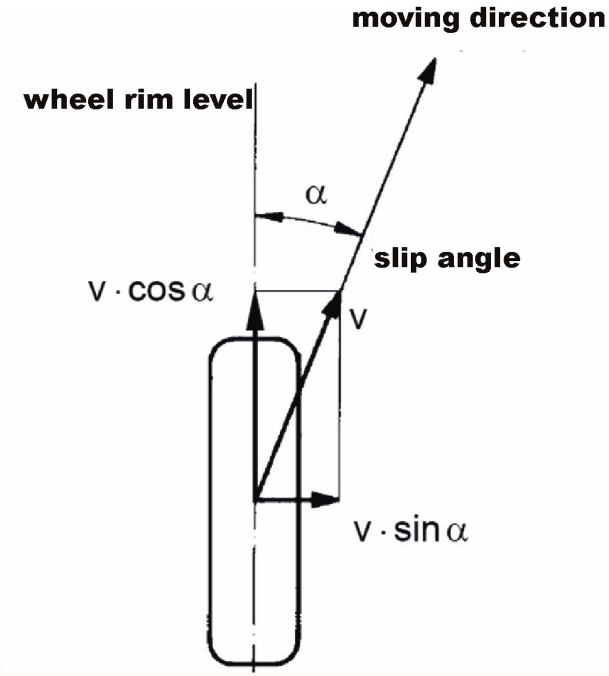
Stabilizer on front axle

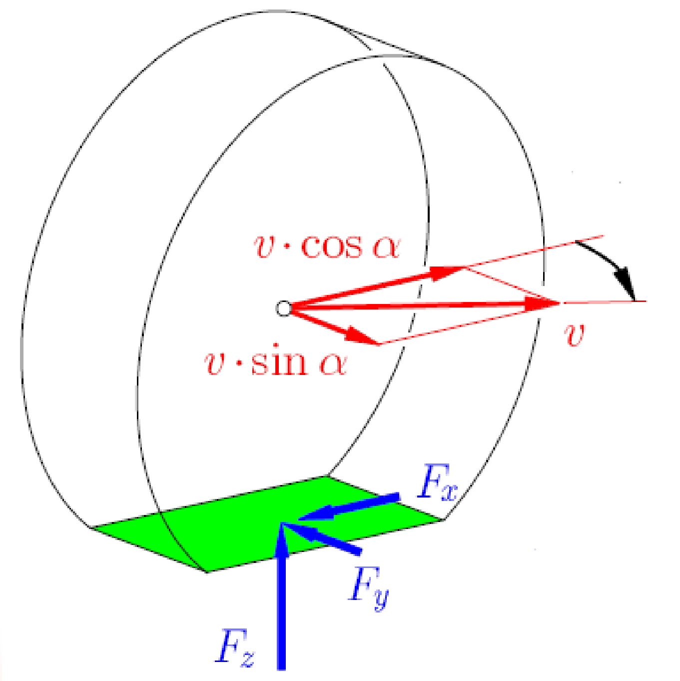


Influences on roll stability

- Driving through curves produces a transversal acceleration which results from the transversal force – cornering force F_s.
- The slip angle describes the direction difference between the wheel rim level and the moving direction of the wheel speed vector.

Slip angle


moving direction
wheel rim level
α
slip angle
v · cos α
v
v · sin α


$v \cdot \cos\alpha$
v
$v \cdot \sin\alpha$
F_x
F_y
F_z

Slip angle

Slip angle is influenced by:

- Position of the vehicle center of gravity
- Mode of drive
- Axle load distribution

Slip angle

- **Front-wheel drive: understeer**
- **Rear-wheel drive: oversteer**
- **All-wheel drive: neutral**

Evaluation

Evaluation of oversteer, understeer, and neutral steering are achieved via measurement of the following variables:

- Slip angle at all wheels
- Steering angle
- Yaw rate