Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP)

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ABSTRACT

In spite of improvements in passive safety and efforts to alter driver behavior, the absolute number of highway fatalities in 2002 increased to the highest level since 1990 in the US.

ESP is an active safety technology that assists the driver to keep the vehicle on the intended path and thereby helps to prevent accidents. ESP is especially effective in keeping the vehicle on the road and mitigating rollover accidents which account for over 1/3 of all fatalities in single vehicle accidents.

In 1995 Bosch was the first supplier to introduce electronic stability control (ESC) for the Mercedes-Benz S-Class sedan. Since then, Bosch has produced more than 10 million systems worldwide which are marketed as ESP - Electronic Stability Program.

In this report Bosch will present ESP contributions to active safety and the required adaptations to support four wheel driven vehicles and to mitigate rollover situations.

INTRODUCTION

Worldwide traffic is increasing with more and more vehicles on the road. Considering the different regions of the world, the development of the mobility shows a clear correlation to the gross domestic product (Fig. 1). With further economical growth, we will see more increase in mobility and in traffic density throughout the world. This will require additional efforts to furthermore enhance the road safety.

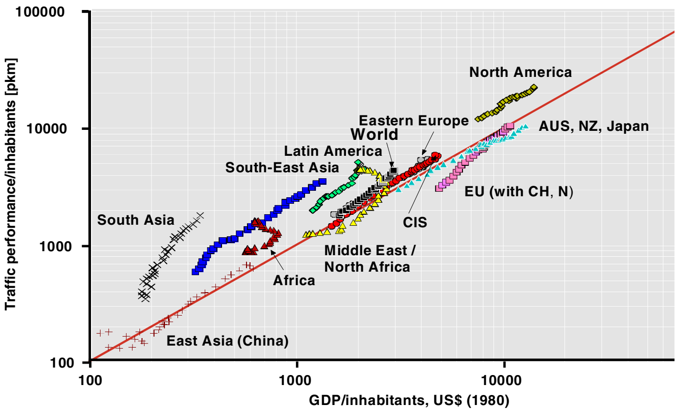
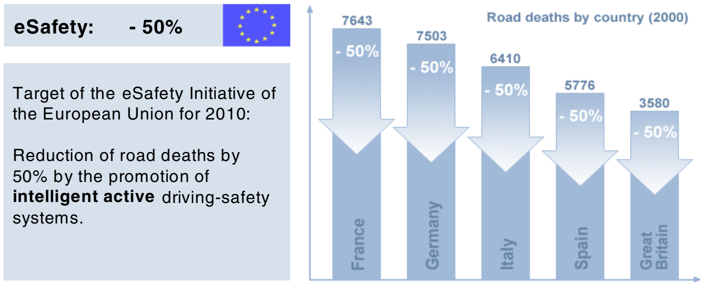


Fig. 1: Development of mobility depending on Gross Domestic Product (GDP) [1]

The statistics for the European Union demonstrate alarming results. They show a total of 1.3 million accidents for the year 2000 with 1.7 million injured persons and more than 40.000 fatalities. The target of the eSafety Initiative of the European Union for 2010 is set to reduce road deaths by 50%, e.g. by the promotion of intelligent active driving safety systems (Fig. 2).



Target of the eSafety Initiative of the European Union for 2010:

Reduction of road deaths by 50% by the promotion of **intelligent active** driving-safety systems.

Traffic safety situation European Union (status year 2000):
1 300 000 accidents, 40 000 deaths, 1 700 000 injured

Fig. 2: European eSafety initiative

Japan has set a similar target and also NA is actively pursuing advances in road safety.

MAIN SECTION

The progress of crash energy absorbing car body design and the standard fitting of airbags significantly improved the passive safety especially combined with the use of seat belts. But many of the serious accidents happen through loss of control in critical driving situations. When the vehicle goes into a skid, a side accident is the frequent result. With a reduced protection zone for the occupants compared to front crashes, these accidents show an amplified severity.

Especially with vehicles of an elevated center of gravity like sport utility vehicles (SUV) and light trucks (LT) the loss of control with subsequent skidding may even lead to a rollover. Most of the rollovers are caused either by tripping at an obstacle or in the soil. The severity of rollover accidents is extremely high. Accounting for only 2% of the total crashes, they contributed in 2002 with 10.656 fatalities to one third of all occupant fatalities (Fig. 3) in the US.

US Accident fatality statistics			
Total Accidents		**Fatalities**	
Involved Vehicles:		Occupant Fatalities:	
10.6 Mio		32.335	
Point of Impact		**Severity (by fatalities)**	
Frontal crash:	46 %	Frontal crash:	39 %
Side crash:	29 %	Side crash:	23 %
Rollover:	2 %	Rollover:	33 %

Fig. 3: North America accident fatality statistics

A study performed by the University of Iowa at the National Advanced Driving Simulator showed a strong impact of ESP on vehicle stability [2]. The primary question was "Does the presence of an ESP system aid the driver in maintaining control of the vehicle in critical situations?". Based on all analyses completed there was a 24.5 percentage point reduction between situations in which the drivers lost control with the system present and situations without ESP. This constitutes an 88% reduction in loss of control. Looking at the data from an improvement standpoint, 34% more drivers retained control with ESP than without. Based on the study results it was concluded that there is significant and meaningful safety benefit associated with driving a vehicle equipped with an ESP system.

Supporting conclusions are drawn by VW [1]. Based on their accidentology, ESP is considered to avoid 80% of the accidents caused by skidding. VW concludes that the safety benefit of ESP is even greater than that of the Airbag. According to VW a 100% installation rate would result in Germany in a 20% reduction of road fatalities and this even with an ESP installation rate of already 53% in 2003.

Based on the analysis of traffic accidents statistics, Toyota [3] estimated that the accident rate of vehicles with ESP for more severe accidents is approximately reduced by 50% for single car accidents and reduced by 40% for head-on collisions with other automobiles. The casualty rate of vehicles with ESP showed approximately a 35% reduction for both types of accidents.

The results of the studies show a consistent picture of the ESP with remarkable safety benefits. Further potential is available especially with functional extensions for SUV and light trucks concerning rollover mitigation and four wheel drive adaptations.

However it is important to say that ESP cannot prevent all accidents or adjust for all driver errors. Essential for a safe road traffic are still appropriate driving practices, common sense and a good traffic judgement.

STABILIZING CONCEPT

In critical driving situations most drivers are overburdened with the stabilizing task. According to Foerster [4] the average driver can neither judge the friction coefficient of the road nor the grip reserves of the tires. The drivers are typically startled by the altered vehicle behavior in in-stable driving situations; as a result, a well-considered and thought-out reaction of the driver can not be expected. For that reason the ESP has to be designed to stabilize the vehicle even in situations with panic reactions and driving failures like exaggerated steering.

The reason why stabilizing a vehicle in critical situations is so challenging can be shown by considering the physical effects. Steering of a vehicle yields in a yaw moment which results in a directional change. The effect of a given steering angle depends on the actual side slip angle [5, 6]. Only slight alterations of the yaw moment are possible at large side slip angles even for extensive steering interventions which can be seen in Fig. 4.

The characteristic side slip angles, where the steerability of the vehicle is vanishing, are dependent on the road friction coefficient. On dry asphalt it is around ±12° as shown in Fig. 4, whereas on polished ice it is in the range of ±2°. The driver experiences in all day traffic situations side slip angle values of typically not more than ±2°.

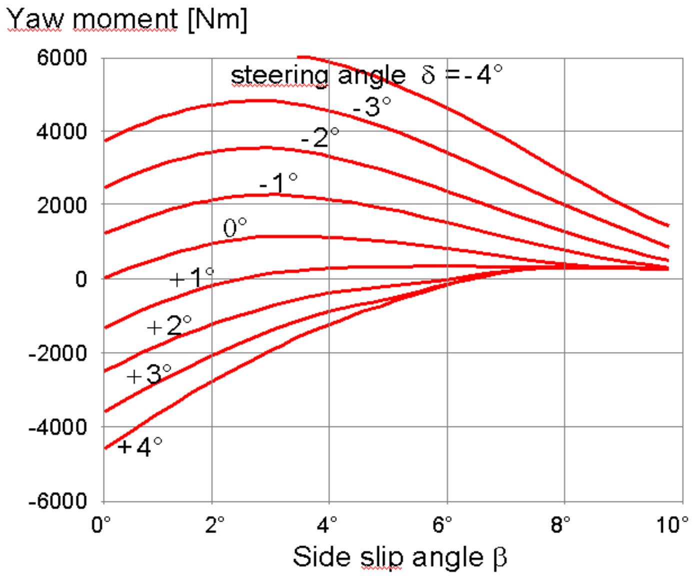


Fig. 4: Influence of side slip angle on yaw moment for different steering angles at high tire-road friction [5, 6].

So one of the main tasks of ESP is the limitation of side slip angle dependent on the actual friction coefficient.

Even in the range of characteristic side slip angles, where the effectiveness of steering is rather limited, ESP can exercise remarkable yaw moments by brake interventions. The tire characteristic determines the longitudinal slip value $_0$ where the maximum brake force is generated. The slip value $_0$ is typically in the range of 10%. Considering the left front wheel during right hand cornering (Fig. 5, wheel 1), the resulting wheel force in free rolling condition F_R(=0) is in lateral direction. By adjusting the tire slip to Λ_0, the maximum brake force F_B($_0$) is applied and by this means the lateral force is reduced to F_S($_0$). The resulting force vector F_R($_0$) is turned relative to the tire thereby modifying the yaw moment, the longitudinal and the lateral forces.

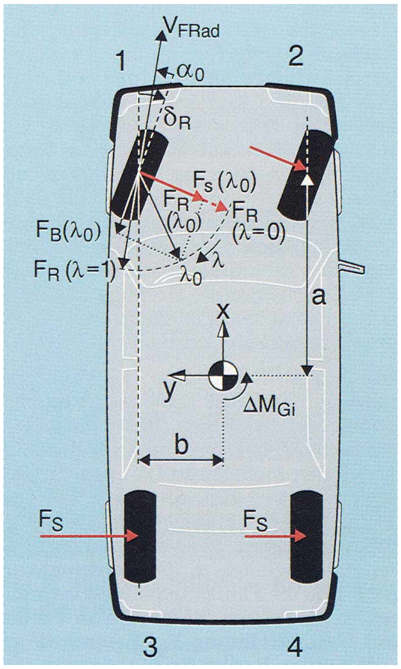


Fig. 5: Turning of resulting wheel force by tire slip control.

The required yaw moment can be applied by controlling the longitudinal tire slip and in that way employing it as a vehicle dynamics control variable. This approach is utilized with anti-lock and traction slip control, yaw rate control with restricted side slip angle and with a limitation of lateral acceleration for rollover mitigation functionality.

During the last few years the segment of four wheel driven vehicles got more and more popular. The main focus of attention is the range of SUV and LT vehicles that are suitable for use on public roads but also have qualities under off-road conditions. Part of the off-road capacities are due to the elevated center of gravity which augments the susceptibility to rollover. This makes SUV and LT the preferred target for ESP applications.

Special adaptations of the ESP system and the control concept are required for the cooperation with a four wheel drive (4WD) power train.

ADAPTATIONS TO FOUR WHEEL DRIVE

Several center coupling concepts are used in the various types of four wheel driven vehicles. Most of them can be combined with an ESP system.

The major element of a four wheel driven (4WD) vehicle is the center coupling. The objective is to distribute drive torque to the front and rear axle and at the same time to permit different axle velocities that occur as soon as the vehicle drives around a bend (Fig. 6).

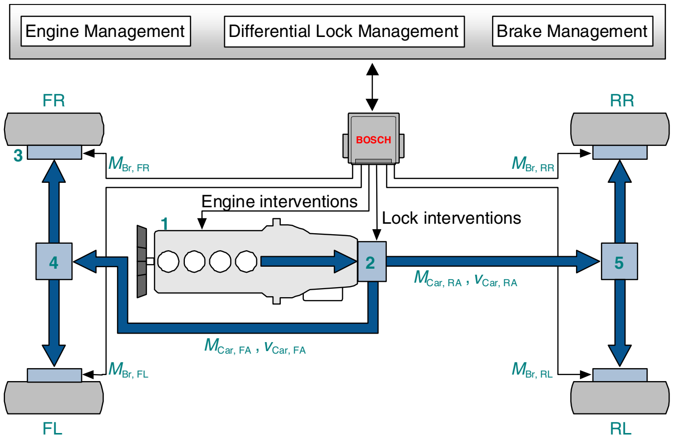


Fig. 6: Control concept for four wheel drive trains with engine (1), center coupling (2), brake (3), differential front/rear axle (4/5).

The classic solution for a 4WD drive train is the open center differential. Its disadvantage is - analogous to a transversal axle differential - the drive torque limitation of an axle if the other one shows increased slip. In the worst case a 4WD car with an open center differential does not move if only one wheel is spinning.

With an ESP system available, this drive train concept can be supported by the brake interventions of the traction slip control without the necessity to install additional longitudinal and transversal lock devices (Fig. 7). The longitudinal differential lock controller in the ESP restrains the difference speed between both axles through a symmetric brake intervention on both wheels of one axle. The transversal differential lock controls the difference speed on one axle through wheel individual brake interventions.

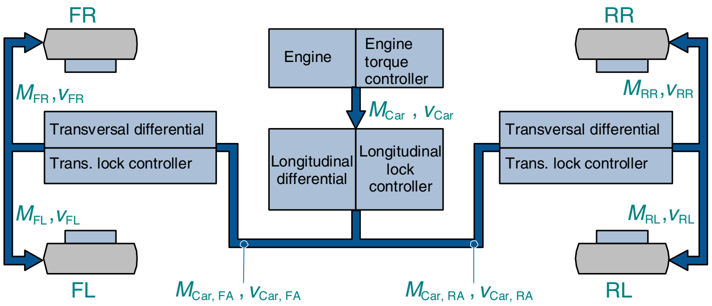


Fig. 7: Four wheel drive with longitudinal and transversal brake lock

Another class of differential locks or center couplings are self-locking devices, where the locking degree depends on torque or rotation speed differences between the two driven axles. Examples are Torsen - for Torque-sensing - or viscous coupling. If their locking potential is exceeded, the above described longitudinal differential lock via brake intervention will support and secure the lock functionality.

A 100% mechanical differential lock is useful for heavy off-road applications, as it prevents any axle speed differences. Since ESP relies on a wheel individual slip control, a cooperation with a mechanically locked center differential is not feasible unless the lock is opened either manually or electronically. Even anti-lock control (ABS) is deactivated or distinctively reduced.

Apart from the mentioned devices that have a system inherent locking effect, there are center couplings that can be fully influenced by an external controller – so called Center Coupling Control (CCC). In this case an electric or hydraulic actuator operates a clutch, providing adjustable locking torque. In combination with vehicle dynamics signals, as vehicle speed and wheel speeds, yaw rate, lateral acceleration and engine torque, the locking torque can be adjusted to tune to the desired vehicle dynamics behavior suitable for the specific driving conditions (Fig. 8).

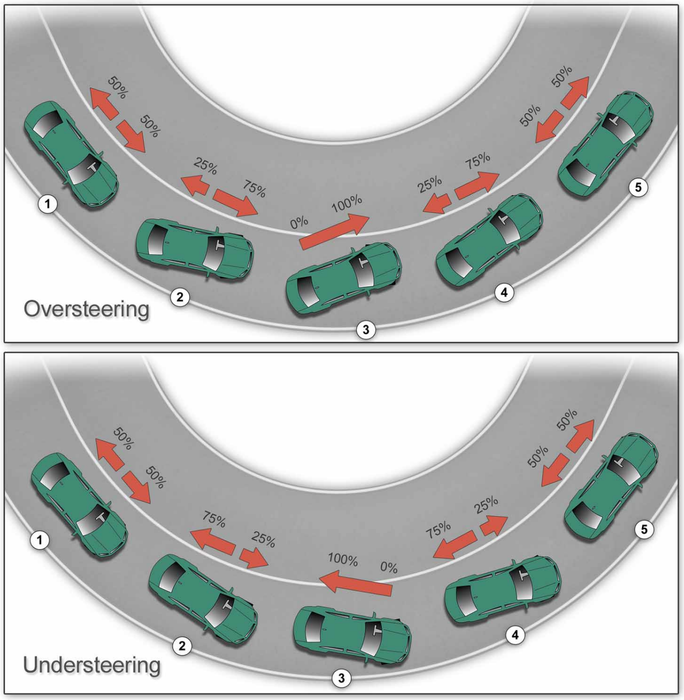


Fig. 8: Influence of drive torque distribution on vehicle dynamics behavior like over-steering and under-steering. Shown is the maximum possible flexibility of drive torque distribution; actual flexibility depends on drive train configuration.

Even in critical driving situations the variable drive torque distribution can positively influence the road behavior of the vehicle. By shifting drive torque to the rear axle, the under-steering behavior of a vehicle can be reduced; by shifting drive torque to the front axle, the over-steering behavior can be trimmed down (Fig. 8). Overall a more responsive vehicle handling can be achieved.

The ESP is well suited to extend the brake and engine torque interventions with a center coupling torque interface to optimize the dynamic behavior of the vehicle. One example is shown in Fig. 9. The ESP detects an understeering situation and requests a reduction of the coupling torque transferred to the front axle. Beside this drive torque transfer an additional ESP brake intervention on the curve inner rear wheel supports in case of strong understeering to achieve the desired vehicle yaw rate.

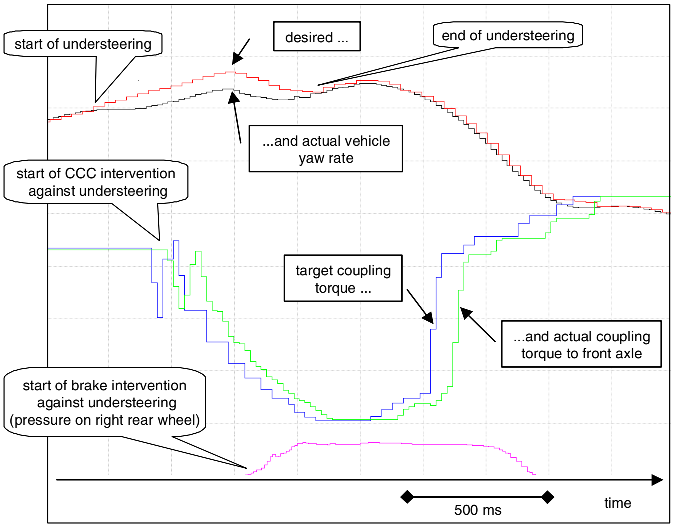


Fig. 9: Understeering intervention with a shift of drive torque followed by a supporting brake intervention. Sporty SUV vehicle with 4WD, center coupling control and ESP8.

For vehicle dynamics and traction optimization a controllable, well defined opening and closing of the coupling is necessary.

On the other hand, during a wheel individual brake intervention, a fully or partially locked center coupling would result in an unintended torque transfer. Therefore a fast opening must also be demanded during stabilizing brake interventions and an active ABS function. In some instances, it may also be necessary during partial braking to allow the "Electronic Brake Distribution" function to prevent the over-braking of the rear axle. This requires the clutch to be opened in less than 100ms.

Additional adaptations support off-road functionality. The off-road features of the ESP controller improve robustness and maintain superior traction under off-road conditions.

These features are:

Adaptation of start of control thresholds for vehicle dynamics under off-road conditions; increased yaw rate target allowed.
Self tuning of traction target slip dependent on the road surface and terrain.
Lessening of engine torque reductions to maintain traction even under difficult drive conditions.
Adaptive pre-control for the brake torque controller.
Enhanced vehicle speed estimation under off-road conditions even without use of longitudinal acceleration sensor.
Robustness measurements for the ABS controller with increased target slip under off-road conditions.

The off-road situation can be detected automatically by a special function of the ESP. Based on wheel speed sensor signals, the off-road detection function analyses wheel excitations and looks for specific oscillations in the wheel circumference speed. Alternatively the driver may select the off-road adaptations via a switch setting, the activation of a countershaft gearbox or the vertical adjustment of a level control system.

In powerful ESP systems for 4WD vehicles, even different performance settings can be selected by the driver. This can be as simple as disabling the engine torque reduction triggered by the ESP to allow for full driver control of the propulsion. Other possibilities are terrain specific adaptations to surfaces like ice, snow, grass, sand, mud or bedrock.

Some drive train concepts allow a flexible configuration by switching from rear wheel drive or front wheel drive to 4WD. Even 4WD with locked center differential is possible. With a cooperating ESP system, the stabilizing and traction control functionality can be automatically adjusted to the selected drive train concept.

In cooperation with four wheel drive train concepts, ESP delivers the expected safety benefits and excellent off-road functionality. Since most of the respective vehicles are characterized by an elevated center of gravity, road safety can be further improved by implementing rollover mitigation functionality.

ROLLOVER MITIGATION

The complex events of automobile crashes involve three main contributing factors and their interactions [7]:

the driver,
the driving environment like weather, road condition, time of day,
and the vehicle.

In the US, about 10% of all road accidents are non-collision crashes, but approximately 90% of such single-vehicle crashes account for fatalities [8]. The SUV and LT with their elevated center of gravity (CoG) show an amplified rollover propensity. This is reflected in their increased rollover rates. Due to the ever increasing popularity of these vehicles, the percentage of fatal rollover crashes escalated significantly within the last decade.

A vehicle rollover occurs when the lateral forces create a large enough moment around the longitudinal roll axis of the vehicle for a sufficient length of time.

Critical lateral forces can be generated under a variety of conditions. The vast majority of rollover crashes take place after a driver lost control over the vehicle. By skidding off the road, the vehicle may get in lateral contact with a mechanical obstacle like a curb, a pot hole or a plowed furrow which yields a sudden large roll moment. This results in a so called tripped rollover in contrast to an un-tripped or friction rollover. The latter takes place on roads during severe steering maneuvers solely as a result of the lateral cornering forces.

Although the ratio of un-tripped to tripped rollovers is small, the un-tripped rollovers account for the most severe crashes.

Accident analysis has shown that the ratio of the track width T and the height of the center of gravity h_{CoG} gives a first indication for the rollover propensity of vehicles.

$$SSF = \frac{T}{2 \cdot h_{CoG}} \qquad \text{Static Stability Factor}$$

The SSF is an important parameter affecting vehicle rollover risk and is both relevant for tripped as well as un-tripped rollover. The track width is a fixed parameter while the center of gravity height varies with subject to different load conditions. Through a one rigid body model - which means no distinction between the mass of the chassis and the sprung mass of the vehicle body – the SSF relates geometrical vehicle data to the level of lateral acceleration that will result in a rollover.

A one rigid body model cannot predict time dependent details of an on-road rollover critical situation. For transient maneuvers involving high lateral accelerations, many vehicle design parameters have an effect on the vehicle handling behavior like e.g. front to rear roll couple distribution, roll axis location, tire behavior, suspension characteristics and roll resonant frequency. These handling characteristics significantly influence the ability of the driver to maintain control in an emergency situation.

To assess a vehicle's handling performance with reference to rollover, the SSF is complemented by metrics derived from dynamic testing which can be partially influenced by electronic stability control. In the US, beginning with the rollover ratings for model year 2004, the National Highway Traffic Safety Administration (NHTSA) will combine the SSF measurement of the vehicle with the dynamic performance in the so-called fishhook or road edge recovery maneuver [8].

To improve the relationship between the real world rollover risk and the SSF-based rollover prediction, the NHTSA defined a new indicator called Rollrate.

$$Rollrate_{SSF} = \frac{1}{1 + e^{(c_1 + c_2 * \ln(SSF - 0.90))}}$$

The parameters c_1=2.7546 and c_2=1.1814 are derived from a detailed analysis of U.S. crash data using a logistic regression model.

Based on the result of the dynamic test, the static Rollrate value is either increased or decreased. In case of a positive test result, the Rollrate is evaluated with the parameters c_1=2.8891 and c_2=1.1686 based on crash data analysis; for a failed test, the parameters are c_1=2.6968 and c_2=1.1686.

Therefore, the dynamic Rollrate replaces the static SSF to get the star rating for a single vehicle according to the following table (Fig. 10).

Star	New criterion:		Previous:
	Rollrate	in terms of SSF:	SSF
*****	<= 0.1	>= 1.4532	> 1.45
****	in [0.1; 0.2]	in [1.1764; 1.4531]	in [1.25; 1.44]
***	in [0.2; 0.3]	in [1.0743; 1.1763]	in [1.13; 1.24]
**	in [0.3; 0.4]	in [1.0194; 1.0742]	in [1.04; 1.12]
*	> 0.4	<= 1.0193	< 1.03

Fig. 10: NHTSA star rating in case of a positive dynamic test compared with the previously static SSF rating only. Table derived from [8].

If the Fishhook test is passed successfully due to a highly effective vehicle stabilizing system, the corresponding Rollrate may result in a better NHTSA star rating compared with the static evaluation only and more, the rollover risk for the vehicle is essentially reduced.

The load condition influence on the rollover propensity is shown in figure 11 in a simplified manner for different types of cars and loading conditions. The static stability factor for typical passenger cars is far above the lateral acceleration which can be transferred by the maximum tire grip. This is the reason why passenger cars are usually not subject to un-tripped rollovers even in extreme loading conditions. If the adhesion limit between the tires and the road surface is reached before the lateral acceleration gets rollover critical, the vehicle starts to skid over the front wheels.

The situation is different especially for light commercial vehicles, where elevated loading may play a major role.

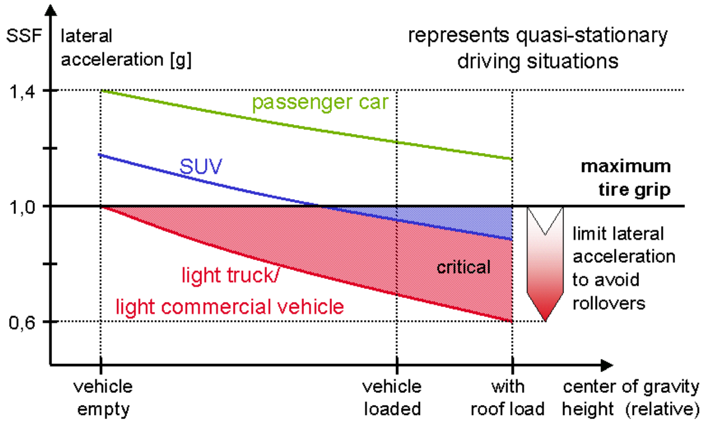


Fig. 11: Typical critical lateral accelerations for rollover dependent on loading conditions reflecting different types of vehicles

At the physical limit the tire behavior is extremely nonlinear and the linearized tire-wheel-brake system is even unstable. As a result, the vehicle may suddenly spin and the driver is caught by surprise.

Changing the direction of the resultant tire forces of individual wheels by specific wheel slip demands applies a stabilizing yaw moment (see Fig. 5) . Besides standard ESP, active steering can be used as well to increase the vehicle's tracking stability [9]. Both concepts mentioned as well as

Active Roll Control [10] or Electronic Damper Control [11] can in general help to avoid critical situations and as a result indirectly help to reduce the rollover risk.

Besides the classification according to the rollover reason, rollover scenarios can be divided into highly dynamic maneuvers, e.g. obstacle avoidance, or quasi stationary maneuvers like circular driving with steadily increasing steering wheel angle. The latter can arise while driving on a highway exit with excess speed.

The Bosch Rollover Mitigation Functions (RMF) are based on the standard ESP sensor set and provide a scalable structure concerning the determination of rollover critical situations and brake/engine control (Fig. 12). Other solutions additionally use a roll rate sensor [12].

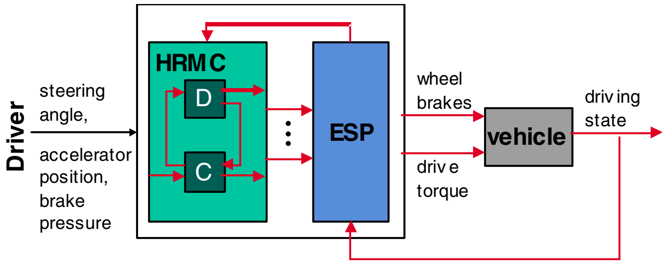


Fig. 12: Structure of the entire vehicle stabilizing system with the basic Electronic Stability Program ESP and the Hybrid Rollover Mitigation Controller(HRMC) with discrete (D) and continuous (C) dynamics parts.

Considering well-known obstacle avoidance maneuvers or severe steering maneuvers like the NHTSA "Fishhook", a classification can be made in

first turn maneuvers (e.g. J-turn, decreasing radius turn, first steering input of single or double lane change, or NHTSA Fishhook),
second turn maneuvers (constant radius turn with additional steering input, second steering input of a single or double lane change, or NHTSA Fishhook), and
further turn maneuvers (third or further steering input of a double lane change or slalom).

Each turn or even a subset of the corresponding time interval is characterized by a set of typical driver's inputs as well as a typical vehicle response. Consequently, each dynamic steering maneuver can be divided into several time slots which follow each other in a specific manner. To get an appropriate stabilization, the controller must provide suitable intervention strategy and strength for each of the described phases.

This is why for the detection of severe steering maneuvers and a suitable anti-rollover control, a hybrid dynamical system is used (Fig. 12). The input, output and state of such a system is composed of a discrete and a continuous part; the discrete dynamics **D** and the continuous dynamics **C** are connected by adequate interfaces (for details on hybrid dynamical systems, e.g. see [13]).

The discrete states represent the different defined phases within highly-dynamical steering maneuvers: one possible set of discrete states comprises

an *Initial* state taken if no roll-stabilizing intervention is necessary
a *Pre-fill* state to apply the brake pads to the brake discs thereby reducing the pressure build up time,
a *Hold* state for *first turn maneuvers* with a high lateral acceleration,
a *Steer-back* state with special pre-fill measures for steering back in highly dynamical maneuvers, and
a *Counter-fly* state for the second steady steering interval in multi-directional maneuvers.

Transitions between the discrete states are essentially influenced by the driver's input and the vehicle reaction. Continuous states vary over time dependent on the discrete state. They are influenced by continuous inputs like the steering wheel angle, the lateral acceleration, the yaw rate, the longitudinal velocity, the body slip angle, and other reference variables essential for the rollover prediction. Ackermann and Odenthal propose a rollover coefficient based on the tire vertical loads [9] which are usually not available in a standard ESP systems with the required accuracy. The Bosch approach uses only existing sensor signals and estimated values to predict the vehicle's rollover propensity. For example, based on the well-known single-track model, an early lead for a subsequent high lateral acceleration is given by

$$c_{pre} = \dot{\psi} \cdot v_x - a_y \approx -\dot{\beta} \cdot v_x$$

$\dot{\psi}$: yaw rate
v_x : longitudinal velocity
a_y : lateral acceleration
$\dot{\beta}$: change in body slip angle

With a rapid change of the body slip angle weighted with v_x, the lateral acceleration will heavily increase short after.

The Hybrid Rollover Mitigation Controller outputs derived from its states are e.g. the brake torque and brake slip values for the appropriate wheels. The general control strategy is a fast active brake pressure increase at the curve outside wheels especially at the front axle initiated by suitable brake slip and brake torque target values. This reduces the lateral forces as well as the longitudinal speed of the vehicle and results in an increased curve radius. Subsequently the track can be regained due to the reduced speed. In these special situations the brake intervention is usually combined with a cut back on engine torque.

In general, the hydraulic braking system must provide a fast pressure increase over a wide temperature range. For that, the brake caliper size, the brake tube dimensions, and the characteristics of the utilized brake fluid are very important.

As an example, a NHTSA Fishhook maneuver with a sporty SUV model is taken to illustrate the rollover mitigation by a hybrid controller (Fig. 13). The steering input is depicted in terms of steering wheel angle whereas the vehicle reaction is expressed in terms of lateral acceleration and yaw rate. The stepped variable at the top of the chart indicates the discrete states of the hybrid controller. The curves at the bottom show the target brake torque values for the left and right wheel. During severe steering back a brake torque pre-control at the curve inside wheel (right wheel) is used to apply the brake pads to the brake discs to reduce pressure build up time (see Fig. 13, dotted lines).

Such a hybrid controller can easily be extended beyond the previously mentioned discrete states to cover other driving situations like e.g. slalom driving.

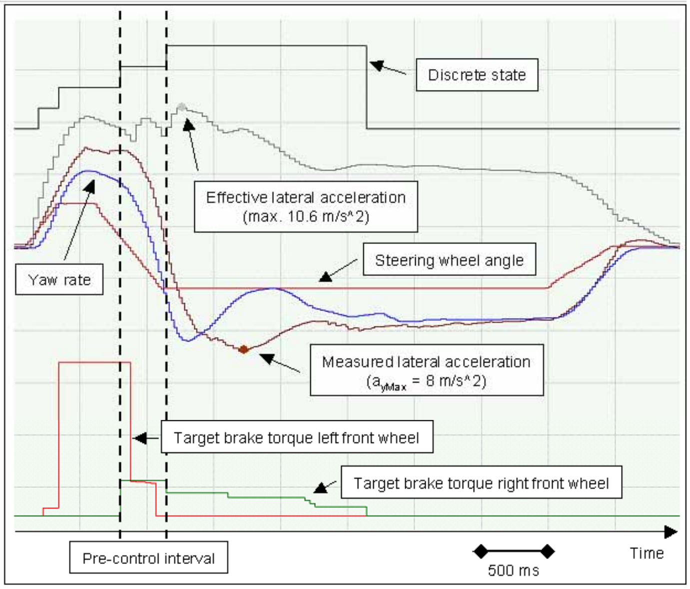


Figure 13: Example of a severe steering maneuver: NHTSA Fishhook with a sporty SUV model with ESP 8; entrance velocity vF=72 km/h.

Since the major parameter to recognize rollover-critical driving situations is the measured lateral acceleration a_y relative to the center of gravity. This value plays an important role in the execution and release of roll-stabilizing interventions and in the determination of the suitable strength. However, only the measured lateral acceleration is not sufficient to clearly detect rollover-critical situations in due time and to prevent incorrect interventions at high lateral accelerations in otherwise uncritical driving situations. Beside the lateral acceleration a_y, a lead in the form of the lateral acceleration gradient, the steering angle velocity and the steering angle itself are used to calculate a so-called effective lateral acceleration. In the Fishhook example above, the effective lateral acceleration is plotted indicating the rollover propensity during this severe steering maneuver.

If the fixed release threshold dependent on the beforehand mentioned effective lateral acceleration is used to execute roll-stabilizing interventions, an improved behavior can be realized for the empty as well as fully laden vehicle with a minimized comfort impairment due to early braking interventions. For vehicles with a high variance of the center of gravity height, an adaptive rollover mitigation strategy is designed. It uses the vehicle's mass and the estimated CoG position to adjust the threshold for brake interventions. This ensures timely interventions with the correct intensity and minimized comfort impairment.

CONCLUSION

The results of several independent studies show a consistent picture of the ESP with remarkable safety benefits and proof the positive impact. Further potential is available with functional extensions especially for SUV and light trucks concerning rollover mitigation and 4WD adaptations. The ESP with Rollover Mitigation functions helps the driver to stay on the road and to avoid tripping obstacles by a specific yaw control. It also supports the driver with an optimized lateral acceleration control to manage rollover critical on-road situations. In cooperation with four wheel drive train concepts, ESP delivers at the same time the expected safety benefits and excellent off-road and handling functionality.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

ESC: Electronic Stability Control
ESP: Electronic Stability Program
SUV: Sport Utility Vehicle
LT: Light Truck
4WD: Four Wheel Drive
ABS: Anti-Lock Control
CCC: Center Coupling Control
CoG: Center of Gravity
SSF: Static Stability Factor
NHTSA: National Highway Traffic Safety Administration
RMF: Rollover Mitigation Function
HRMC: Hybrid Rollover Mitigation Controller