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Road vehicles - Adaptive Cruise Control Systems - Performance requirements and test procedures

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Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

This Draft International Standard was prepared by Technical Committee ISO/TC204 Transportation Information & Control Systems / Working Group 14 - Vehicle/Roadway Warning & Control Systems.

Annexes A and B are provided as normative annexes.

Introduction

"The main system function of Adaptive Cruise Control is to control vehicle speed adaptively to a forward vehicle by using information about: (1) ranging to forward vehicles, (2) the motion of the subject (ACC equipped) vehicle and (3) driver commands. (see figure 1 – Functional ACC elements) Based upon the information acquired, the controller (identified as "ACC control strategy" in Figure 1) sends commands to actuators for carrying out its longitudinal control strategy and it also sends status information to the driver."

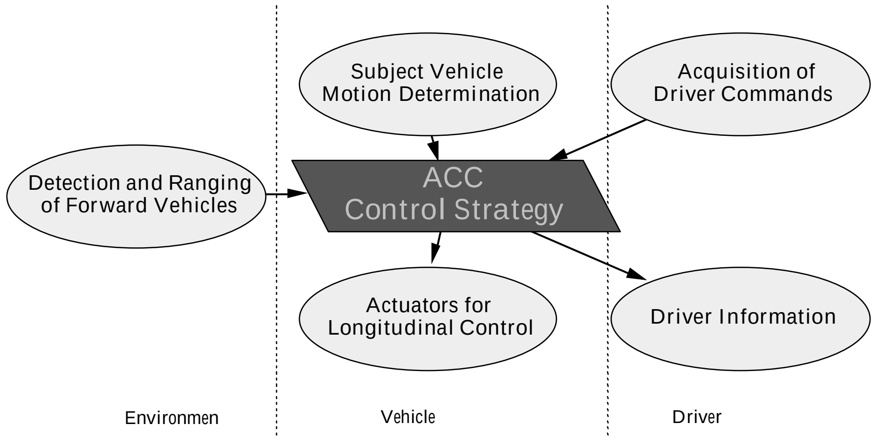


Figure 1 — Functional ACC elements

The goal of ACC is a partial automation of the longitudinal vehicle control and the reduction of the workload of the driver with the aim to support and relieve the driver in a convenient manner.

The ACC standard may be used as a system level standard by other standards, which extend the ACC to a more detailed standard e.g. for specific sensor concepts or higher level of functionality. So, issues like specific requirements for the sensor function and performance or communication links for co-operative solutions will not be considered here.

Road vehicles - Adaptive Cruise Control Systems - Performance requirements and test procedures

1 Scope

This International Standard contains the basic control strategy, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for Adaptive Cruise Control (ACC) systems. Adaptive cruise control is fundamentally intended to provide longitudinal control of equipped vehicles while travelling on highways under free-flowing traffic conditions. ACC may be augmented with other capabilities, such as forward obstacle warning.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For updated references, the latest editing of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 825-1 :1993 - *Safety of laser products; part 1; equipment classification, requirements and user’s guide* (includes update of 1994)

ISO 6161:1981 - Personal eye protectors - *Filters and eye protectors against laser radiation*

ISO 2575 - Road vehicles – *Symbols for controls indicators and telltales*

ECE – Regulation No. 13-H *Uniform Provisions concerning the approval of passenger cars with regard to braking*

3 Terms and definitions[1] [2]

For the purpose of this International Standard, the following definitions apply.

3.1
active brake control
A function, which causes application of the brake(s), not applied by the driver, in this case controlled by the ACC system.

3.2
Adaptive Cruise Control
An enhancement to conventional cruise control systems (see Conventional Cruise Control) which allows the subject vehicle to follow a forward vehicle at an appropriate distance by controlling the engine and/or power train and potentially the brake.

[1] Telltales (on board symbols) for ACC, ACC malfunctions will be adopted in ISO2575.

[2] Definition in compliance with Glossary of ISO/TC204/WG14

3.3
brake
Brake means the part in which the forces opposing the movement of the vehicle develop. It may be a friction brake (when the forces are generated by friction between two parts of the vehicle moving relatively to one another); an electrical brake (when the forces are generated by electro-magnetic action between two parts of the vehicle moving relatively but not in contact with one another); a fluid brake (when the forces are generated by the action of a fluid situated between two parts of the vehicle moving relatively to one another); or an engine brake (when the forces are derived from an artificial increase in the braking action, transmitted to the wheels, of the engine).

NOTE 1 Definition according to ECE-R 13-H.

NOTE 2 For purposes of this ACC standard transmission control devices are not considered as brakes.

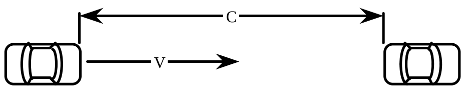
3.4
clearance
Distance from the forward vehicle's trailing surface to the subject vehicle's leading surface.

3.5
conventional cruise control
System capable of controlling the speed of a vehicle as set by the driver.

3.6
forward vehicle
Vehicle in front of and moving in the same direction and travelling on the same roadway as the subject vehicle.

3.7
free-flowing traffic
Smooth flowing and heavy traffic excluding stop & go and emergency braking situations.

3.8
time gap τ
Time interval for travelling a distance which is the clearance 'c' between consecutive vehicles. Time gap is related to vehicle speed 'v' and clearance c by: $\tau = c/v$.



3.9
set speed
The desired travel speed, set by either the driver or by some control system that is external to the ACC system. The set speed is the maximum desired speed of the vehicle while under ACC control.

3.10
steady state
The condition whereby the value of the described parameter does not change with respect to time, distance, etc. A circle can be described as a curve with a steady state radius. Similarly, a vehicle travelling at constant speed can be described as travelling at steady state speed.

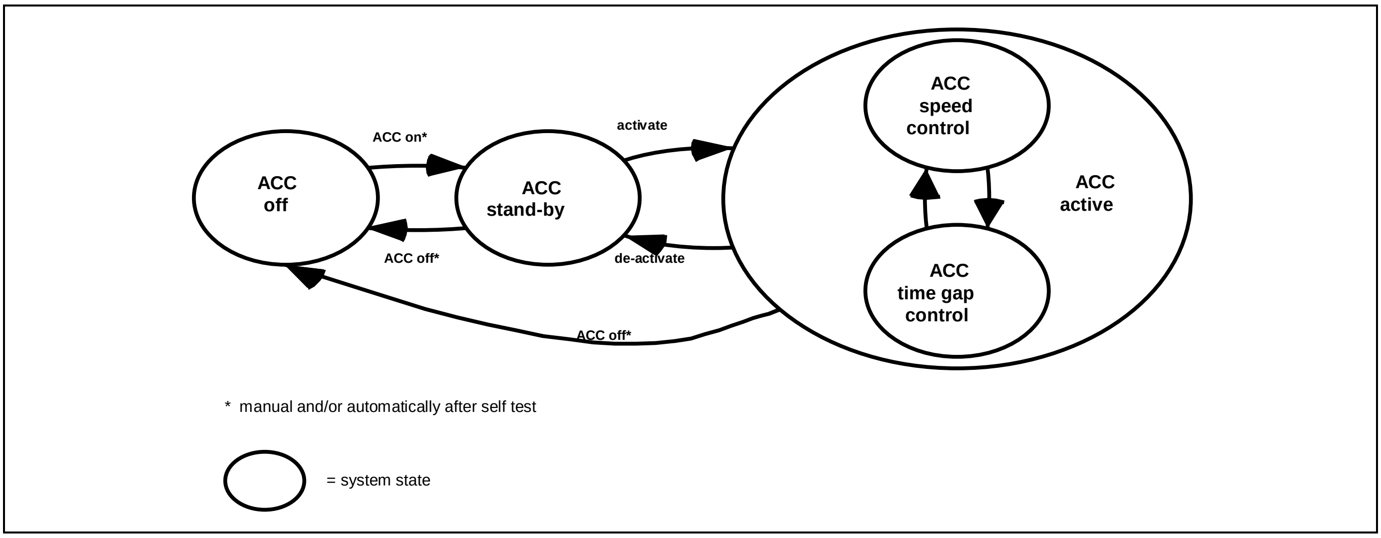
3.11
subject vehicle
The vehicle equipped with the ACC system in question and related to the topic of discussion.

3.12
system states
For this standard three system states will be distinguished (ref. Figure 2 – ACC states and transitions)

3.12.1
ACC off state
Direct access for activation of 'ACC active state' is disabled.

3.12.2
ACC stand-by state
No longitudinal control by ACC system. System is ready for activation by the driver.

3.12.3
ACC active state
The state in which the system controls speed and/or time gap.



NOTE – * Manual transition describes a switch to enable/disable ACC function. Automatic switch off can be forced by failure reaction.

Figure 2 — ACC states and transitions

4 Symbols and units

A	utilised area, general for area
A_t	Illuminated surface
$a_{lateral\_max}$	Maximum allowed lateral acceleration in curves
a_{min}	Minimum allowed longitudinal acceleration = Maximum allowed longitudinal deceleration
a_{max}	Maximum allowed longitudinal acceleration
a_{test}	Maximum allowed acceleration during curve test
$a_{vehicle\_max}$	Maximum possible deceleration capability during manual driving
CTT	Coefficient for Test Target for infrared reflectors
c	clearance, inter vehicle distance
d	distance, between object and sensor, general for distance
d_0	distance, below which there is no need for detection of a target vehicle
d_1	distance, below which no distance measurement or determination of relative speed is required
d_2	distance for measurement purpose
d_A	distance between source and projected plane A
d_{max}	maximum detection range on straight roads
d_{max_curve}	maximum detection range on curves
E_t	intensity of irradiation, out of transmitter
FOV	Field of View
HDA	Horizontal detection area
I_0	radiated intensity
I_{ref}	radiated intensity in a given direction
L	length of a side of a radar test reflector
R	circle radius, curve radius
RCS	RADAR Cross Section
R_{circle}	actual radius of curve
R_{min}	minimum curve radius
$T_{brake\ max}$	minimum time to achieve maximum deceleration
t_0	time, start test
t_1	time, start manoeuvre
t_2	time, end manoeuvre
t_3	time, end test
v	the true subject vehicle speed over ground
v_{circle}	maximum speed on a curve for a given lateral acceleration $a_{lateral\_max}$
v_{circle_start}	vehicle speed as it enters a curve of radius R
v_{low}	minimum speed at which automatic acceleration is allowed
v_{set}	vehicle set speed
v_{set_max}	maximum selectable set speed
v_{set_min}	minimum selectable set speed
$v_{vehicle\_end}$	vehicle speed at the end of a test
$v_{vehicle\_max}$	maximum vehicle speed
$v_{vehicle\_start}$	vehicle speed at the start of a test
y_{max}	width of FOV measured from the centre line at d_{max_curve}
α	half angle of field of view
λ	wavelength of radar wave
τ	Gap, time gap between vehicles
$\tau_{max}(v)$	maximum possible steady-state time gap at a given speed v
τ_{max}	maximum selectable time gap
$\tau_{min}(v)$	minimum steady-state time gap at speed v
τ_{min}	minimum selectable time gap
Φ	radiated power
Ω	solid angle
Ω_0	solid angle (of the source)
Ω_1	illuminated solid angle

5 Classification

5.1 Type of ACC systems

Different configurations of actuators for longitudinal control result in very different system behaviour. Therefore four types of ACC systems are addressed in this standard:

Table 1 — Classification of ACC system types

Type	Manual Clutch Operation Required	Active Brake Control
1a	yes	no
1b	no	no
2a	yes	yes
2b	no	yes

The deceleration capability of the ACC system shall be clearly stated in the vehicle owners manual.

In case of active brake intervention in vehicles with a clutch pedal (Type 2a) the driver shall be informed clearly and early about a potential conflict between brake and engine idle control, if the clutch cannot be disengaged automatically. A practicable and unambiguous handing-over procedure shall be provided for the driver. (see 6.3.1 – Operation elements and system reactions)

5.2 Classification of curve capabilities

This standard permits ACC systems of different curve capabilities as specified in Table 2 – ACC performance classifications.

Table 2 — ACC performance classifications

Dimensions in metres

Performance Class	Curve radius capability
I	not specified
II	>= 500
III	>= 250
IV	>= 125

6 Requirements

6.1 Basic control strategy

ACC systems shall as a minimum, provide the following control strategy and state transitions. The following constitutes the fundamental behaviour of ACC systems.

- When the ACC is active, the vehicle speed shall be controlled automatically either to maintain a time gap to a forward vehicle, or to maintain the set speed, whichever speed is lower. The change between these two control modes is made automatically by the ACC system.
- The steady-state time gap may be either self adjusting by the system or adjustable by the driver. (refer to 6.3.1 – Operation elements and system reactions)
- The transition from „ACC-stand-by“ to „ACC-active“ shall be inhibited if the subject vehicle's speed is below a minimum operational speed, v_{low}. Additionally, if the vehicle's speed drops below v_{low} while the system is in the „ACC-active“ state, automatic acceleration shall be inhibited. Optionally, the ACC system may drop from „ACC-active“ to „ACC-stand-by“. (refer to 6.3.2 – Display elements and 6.4 – Operational limits)
- If there are more than one forward vehicle the one to be followed shall be selected automatically. (refer to 6.2.5.2 – Target discrimination)

6.2 Functionality

6.2.1 Control modes

The transition between the control modes (time gap controlled or speed controlled) shall be made automatically.

6.2.2 Clearance capabilities

τ_{min} shall be the minimum selectable time gap for following control mode under steady-state conditions for all speeds v. $\tau_{min}(v)$ shall be greater than or equal to τ_{min} = 1,0 s.

At least one time gap (τ) in the range of 1,5 s to 2,2 s shall be provided.

6.2.3 Speed of subject vehicle

The ACC system shall be able to determine the speed of the subject vehicle.

6.2.4 Stationary targets

ACC systems may ignore stationary targets. The driver shall be informed about this at least in the owners manual.

6.2.5 Following capability

Under steady-state conditions, ACC systems shall comply with the minimum time gap limit as defined in 6.2.2 – Clearance capabilities.

During transient conditions the time gap may temporarily fall below the limit. If such a situation occurs, the system shall adjust the time gap to attain the limit within an appropriate time.

The ACC shall have detection range, target discrimination and curve capabilities as specified below.

6.2.5.1 Detection range on straight roads (performance class I + II + III + IV)

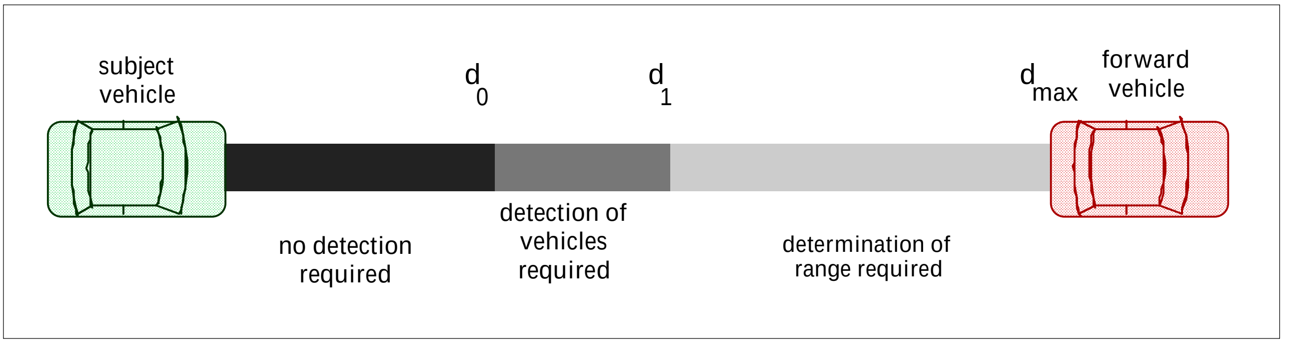


Figure 3 — Zones of detection

If a forward vehicle is present within the distance range d_1 to d_{max}, the ACC system shall measure the range between the forward and subject vehicles.

$$d_{max}\ [m] = \tau_{max}(v_{set\_max})\ [s] \times v_{set\_max}\ [m/s] \tag{1}$$

If a forward vehicle is present within the distance range d_0 to d_1, the ACC system shall detect the presence of the vehicle but is not required to measure the range to the vehicle nor the relative speed between the forward and subject vehicles. If a forward vehicle is detected within this range, the system shall increase the clearance and/or inhibit automatic acceleration.

$$d_1\ [m] = \tau_{min}(v_{low})\ [s] \times v_{low}\ [m/s] \tag{2}$$

If a forward vehicle is present within the distance of d_0, the ACC system is not required to detect the presence of the vehicle.

$$d_0\ [m] = MAX(2\ [m], (0{,}25\ [s] \times v_{low}\ [m/s])) \tag{3}$$

6.2.5.2 Target discrimination

If there are more than one forward vehicle on straight roads and for performance class II + III + IV also in steady state curves, the forward vehicle in the subject vehicle's lane shall be selected for ACC control in typical ACC situations as represented by the test scenario. (see 7.4 Target discrimination test)

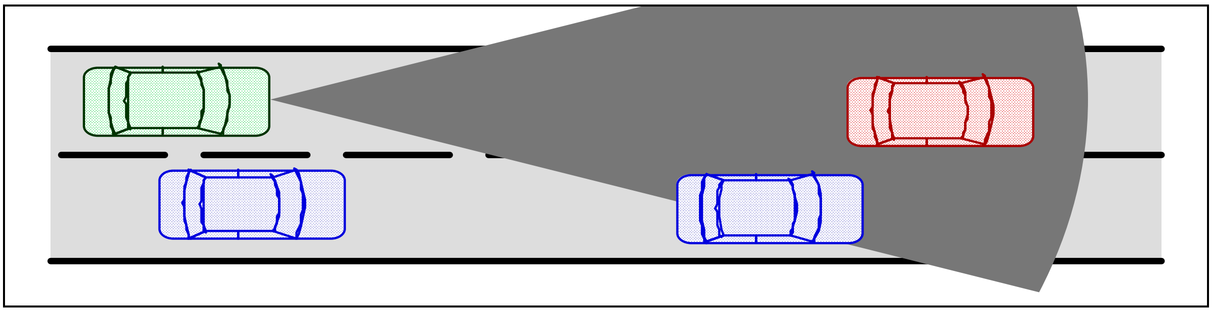


Figure 4 — Target discrimination

6.2.5.3 Curve capability (perfomance class II + III + IV :)

The ACC system shall enable steady state vehicle following with a time gap of $\tau_{max}(v_{circle})$, on straight roads (class I + II + III + IV) and curves with a radius down to $R_{min,II}$ = 500 m (class II + III + IV) and $R_{min,III}$ = 250 m (class III + IV) and $R_{min,IV}$ = 125 m (class IV). Therefore the system shall be capable to follow a forward vehicle with the steady state time gap $\tau_{max}(v_{circle})$, if the forward vehicle cruises on a constant curve radius R_{min} with a constant speed v_{circle}.

$$v_{circle}[m/s] = \sqrt{a_{lateral\_max}[m/s^2] \times R_{min}[m]} \tag{4}$$

where

$\tau_{max}(v)$ is the maximum possible steady state time gap while driving with a speed v.

$a_{lateral\_max}$ is the design lateral acceleration for curves on highways.

The values to use are

$a_{lateral\_max,II}$ = 2,0 m/s² and

$a_{lateral\_max,III}$ = 2,3 m/s² and

$a_{lateral\_max,IV}$ = 2,3 m/s². (see Annex A.1)

6.3 Basic driver interface and intervention capabilities

The system shall provide the following controls and intervention capabilities:

6.3.1 Operation elements and system reactions

- ACC systems shall provide a means for the driver to select a desired set speed.

- Braking by the driver shall deactivate ACC function at least if the driver initiated brake force demand is higher than the ACC initiated brake force. (leading to ACC standby state; ref. Figure 2 – ACC states and transitions) The ACC-system shall not lead to a significant transient reduction of braking response to the driver's braking input (refer to ECE-R 13-H). There shall not be a significant reduction of braking response to the driver's intervention on the brake pedal even when the ACC-system has been braking automatically.

- Type 1a and 2a ACC systems shall either temporarily suspend operation but remain in the ACC-active state or transition to ACC-stand-by if the driver depresses the clutch pedal. For type 2a systems, the Automatic brake manoeuvre can be continued during the use of the clutch pedal. After the system releases the brakes, the system may either resume ACC control or transition to ACC-stand-by in response to the driver depressing the clutch.

- The larger of the power demands from either the driver or the ACC system will be used to drive the engine power actuator (e.g. throttle actuator). This always gives the driver authority to override the ACC system engine power control.
  If the power demand of the driver is greater than that of the ACC system automatic braking shall be disengaged with an immediate brake force release. A driver intervention on the accelerator pedal shall not lead to a significant delay of response to driver’s input.

- Automatic brake activation (ACC type 2 only) shall not lead to locked wheels for periods longer than anti lock devices (ABS) would allow. This need not require an anti lock device (ABS) system.

- Automatic power control by ACC shall not lead to excessive positive wheel slip for periods longer than traction control would allow. This need not require a traction control system.

- ACC systems may automatically adjust the time gap without action by the driver in order to respond to the driving environment (i.e. poor weather). However, the adjusted time gap shall not be less than the minimum time gap selected by the driver.

- If the system allows the driver to select a desired time gap, the selection method shall conform to either one of the following:
  1) If the system retains the last selected time gap after it is switched to ACC OFF, as shown in Figure 2, the time gap shall be clearly presented to the driver at least upon system activation.

  2) If the system does not retain the last selected time gap after it is switched to ACC OFF, as shown in Figure 2, the time gap shall be set to a predefined default value of 1,5 s or greater.

- If there is a conventional cruise control function in addition to ACC there shall be no automatic switching between the ACC and conventional cruise control.

6.3.2 Display elements

- A minimum feed back information for the driver contains activation state (ACC system is active or not active) and the set speed. This can be done by a combined output, e.g. displaying of set speed information only when ACC is active.

- If the ACC system shuts down or is not available due to a failure, the driver shall be informed. If a symbol is used to notify the driver, a standard symbol shall be employed. (see Annex B)

- If the vehicle is equipped with both ACC and conventional cruise control systems, the driver should be made aware of which system is operating.

- A "Vehicle-detected" signal, with the meaning that the ACC system has detected a forward vehicle which will be used for the adaptation of the control, is recommended, but is not mandatory.

6.3.3 Symbols

The graphical symbols shown in Annex B shall be used.

6.4 Operational limits

Automatic positive acceleration of ACC requires a vehicle speed v_{low} of at least 5 m/s.[3]

There shall not be a sudden brake force release in the case of an automatic deactivation of the ACC system below v_{low}.

The minimum set speed shall be v_{set_min} >= 7 m/s and $v_{set\_min} >= v_{low}$.

Automatic mean fully developed deceleration of ACC systems shall not exceed 3,0 m/s^2. (average over 2 s)

The mean rate of automatic deceleration shall not exceed 2,5 m/s^3. (average over 1 s)

Automatic acceleration of ACC systems shall not exceed 2,0 m/s^2 (a_{max} <= 2,0 m/s^2).

6.5 Activation of brake lights (ACC Type 2 only)

If automatic service braking is applied, the brake light shall be illuminated. When the ACC system applies other deceleration devices the system may illuminate the brake lights. The brake lights shall be illuminated within 100 ms after ACC system initiated the service brake. To prevent irritating brake light flickering, the brake light may remain on for a reasonable time after the ACC initiated braking has ended.

6.6 Failure reactions

- Table 3 and Table 4 show the required reactions to failures depending on which subsystem fails.

- The failures described in Table 3 and Table 4 shall result in immediate notification to the driver (except in the case of a gearbox failure with Type 2 systems). The notification shall remain active until the system is switched off.

- The reactivation of the ACC system shall be prohibited until a successful self test, initiated by either ignition off/on or ACC-off/on, is accomplished.

[3] This guarantees a significant differentiation to stop & go. The lowest existing Conventional Cruise Control system limit = 5 m/s.

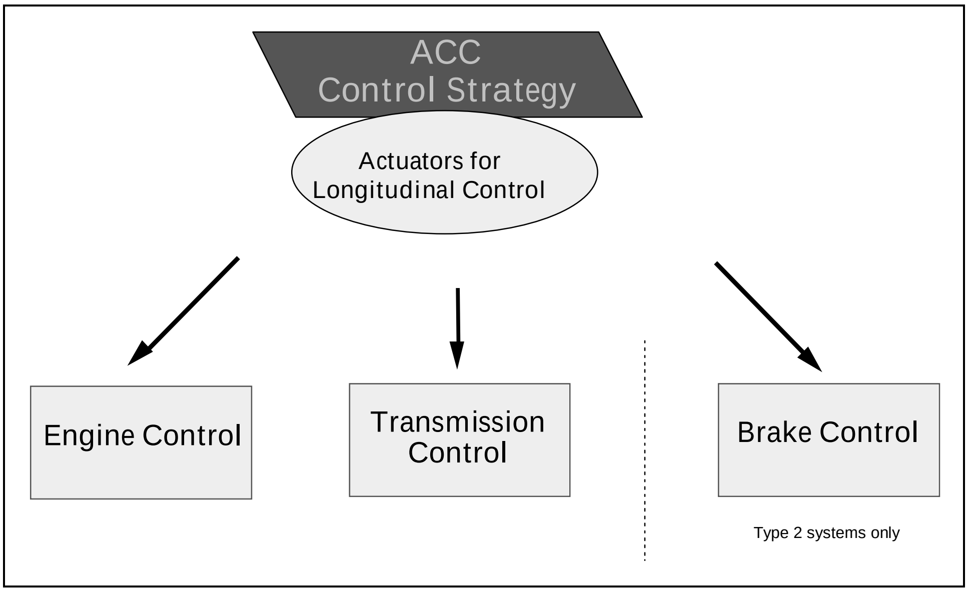


Figure 5 — Actuators for longitudinal control

Table 3 – Failure reactions for ACC type 1

Failure in subsystem:		Failure occurs whilst ACC is operating in: Deceleration control mode	Engine control mode
1	Engine	ACC engine control mode shall be relinquished.	ACC engine control mode shall be relinquished.
2	Gearbox	ACC control mode shall be relinquished.	ACC engine control mode shall be relinquished.
3	Sensor	Shall maintain same strategy as the time before fault at least as long as $v > v_{low}$. The system shall be switched off immediately after driver intervention by brake or accelerator pedal or ACC off switch.	ACC engine control mode shall be relinquished.
4	ACC controller	ACC control mode shall be relinquished.	ACC control mode shall be relinquished.

Table 4 – Failure reactions for ACC type 2

Failure in subsystem:		Failure occurs whilst ACC is operating in: Brake control mode	Engine control mode
1	Engine	Should maintain braking as required at least for the actual / current braking manoeuvre.	ACC engine control mode shall be relinquished.
2	Brake system[4]	ACC control mode shall be relinquished.	ACC engine control mode shall be relinquished.
3	Sensor	Should initiate a controller strategy starting with the last valid braking command. The system shall be switched off immediately after driver intervention by brake or accelerator pedal or ACC off switch.	ACC engine control mode shall be relinquished.
4	ACC controller	ACC control mode shall be relinquished.	ACC control mode shall be relinquished.

[4] If a malfunction within the gear controller occurs, the brake will be able to handle the deceleration function.

7 Performance evaluation test methods

7.1 Environmental conditions

a) Test location shall be on a flat, dry asphalt or concrete surface.

b) Temperature range shall be 20 °C +/-20 °C.

c) Horizontal visibility range shall be greater than 1 km.

7.2 Test target specification

7.2.1 Infrared LIDAR :

The infrared test target is defined by a infrared coefficient for test target (CTT) and the cross section of the test target.

The minimum cross section for test targets A and B is 20 cm^2.

Test target A: Test target A is a diffuse reflector with a CTT = 2,0 $m^2/sr \pm 10$ %. (refer to Annex A)

Test target B: Test target B is a diffuse reflector with a CTT = 1,0 $m^2/sr \pm 10$ %.

7.2.2 Millimetre wave RADAR :

The radar test target is defined by a Radar Cross Section (RCS).

For the frequency range between 50 and 95 GHz:

Test target A: The RCS for test target A shall be 10 m^2.

Test target B: The RCS for test target B shall be 3 m^2.

For significant different frequency ranges, the RCS shall be determined and defined. (refer to Annex A)

7.3 Detection range test

(refer to 6.2.5.1 – Detection range on straight roads (performance class I + II + III + IV))

Test procedure for d_0, d_1, d_2 and d_{max}.

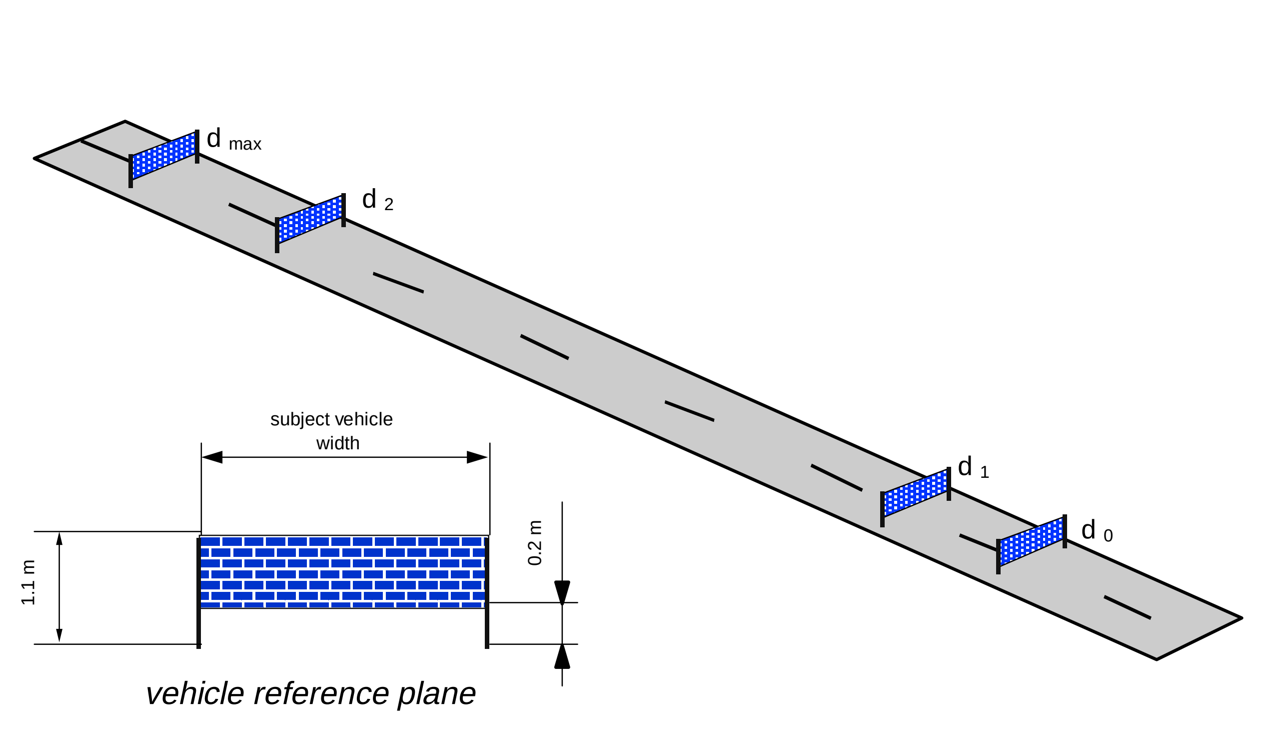


Figure 6 – Longitudinal detection zone

The vehicle reference plane corresponds to a rectangle in the format of 0,9 m by subject vehicle-width beginning at a height of 0,2 m. The detection area considers different places within the vehicle front-end plane. It is also restricted by the minimum height of passenger cars. During testing the defined reflector shall be detected at least at one lateral position within the vehicle reference plane at the position d_{max}. (Refer Figure 6 – Longitudinal detection zone)

- For the position d_{max}, the test target A shall be used.
- For the position d_0, d_1 and d_2, the test target B shall be used.
- The d_2 point refers to a fixed measurement point at 75 m in front of the vehicle.
- Range testing should be done dynamically. As an option, static testing may be permissible.

The test shall be repeated 20 times at the same distance. The maximum detection time should not exceed 3 s after presentation of the target. The system has to detect the test target at least 18 times. (90%)

7.4 Target discrimination test

(refer to 6.2.5.2 – Target discrimination)

7.4.1 Initial conditions

Two forward vehicles of the same model are travelling along side each other at a speed of $v_{vehicle\_start}$. The spacing between the longitudinal centrelines of the forward vehicles is 3,5 m +/- 0,25 m. The width of the forward vehicles shall be between 1,4 and 2,0 m.
The subject vehicle is cruising behind one of the forward vehicles in steady state time gap control mode. The forward vehicle that the subject vehicle follows is designated the target vehicle. The time gap = $\tau_{max}(v_{vehicle\_start})$ and

the set speed > $v_{vehicle\_end}$. The lateral displacement of the longitudinal centreline of the subject vehicle relative to the longitudinal centreline of the target vehicle shall be less than 0,5 m.

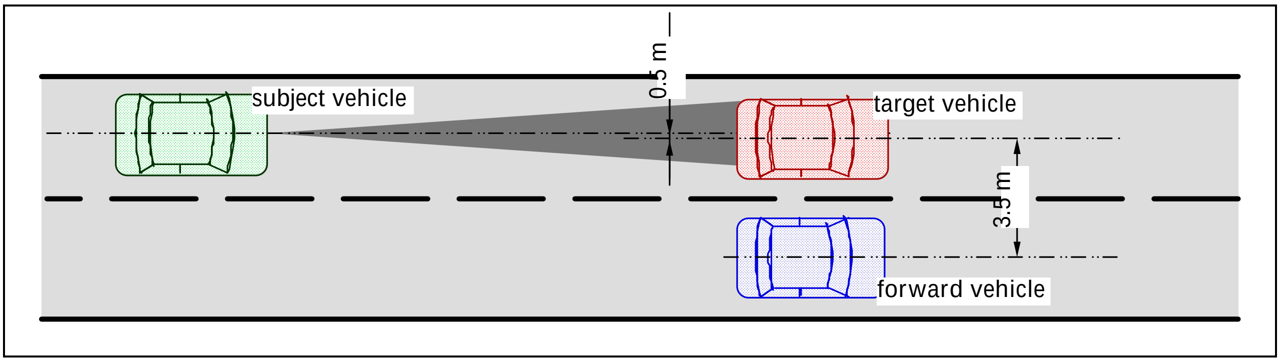


Figure 7 – Discrimination test - start conditions

7.4.2 Test procedure

The target vehicle accelerates to $v_{vehicle\_end}$. The test is successfully fulfilled if the subject vehicle passes the forward vehicle in the adjacent lane while under ACC control.

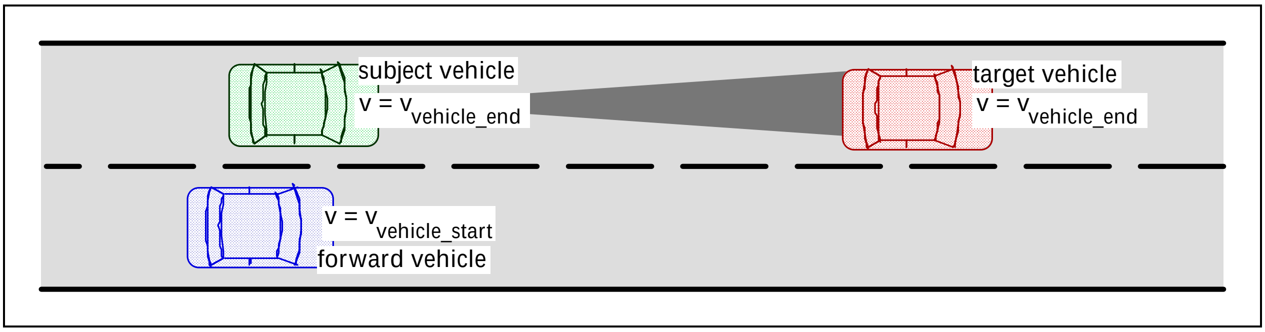


Figure 8 – Discrimination test - end conditions

$v_{vehicle\_end}$ = 27 m/s (~100 km/h).

Note - If the vehicle is not capable of this speed, $v_{vehicle\_end}$ = 22 m/s (~80 km/h) shall be used.

$v_{vehicle\_start} = v_{vehicle\_end}$ - 3 m/s.

7.5 Curve capability test

(refer to 6.2.5.3 – Curve capability (performance class II + III + IV:))

This test should take into consideration the road geometry prediction in combination with the field of view of the ACC system's sensor.
Different methods of road geometry prediction and headway sensing result in the need for a driving scenario.

7.5.1 Test field (class II, III + IV):

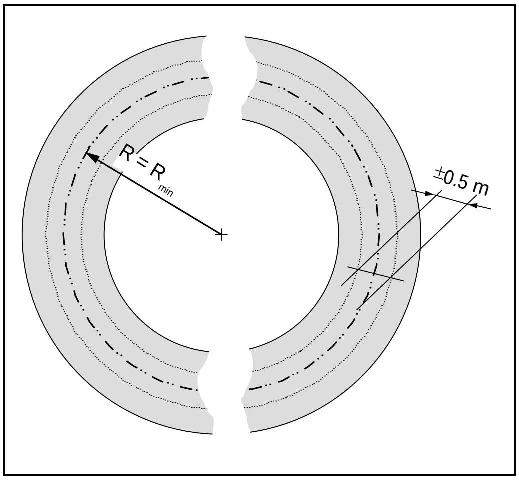


Figure 9 – Outline test track

The test track shall consist of either circular track of constant radius or a sufficiently long segment of curve of constant radius. The radius should be within 80 to 100% of R_{min}. The direction of travel on the track shall be both clockwise and counter clockwise. There is no restriction concerning lane markings, guard rails, etc.

Note: For class II systems the tests shall be done for R_{minII} = 500 m.

For class III systems the tests shall be done for R_{minIII} = 250 m. For class IV systems the tests shall be done for R_{minIV} = 125 m.

7.5.2 Curve Capability Target vehicle

The target vehicle shall be equipped with the test target A as defined in section 7.2 – Test target specification. The test target shall be placed on the rear end of the vehicle. The remaining exposed vehicle surface shall be concealed in such a way that the rear surface, with the test target removed, represents an RCS of no greater than 2 m^2 or a reflectivity of no greater than 20 % of the test target.

7.5.3 Driving scenario:

The subject vehicle follows the target vehicle along the same path (+/- 0,5 m lateral separation as measured from the centrelines of both vehicles) in time gap control mode. The two cars shall conform to the test start conditions as defined in Figure 7 – Discrimination test – start conditions (subject and target vehicle only) prior to the start of the test. Details of the test are shown in Table 5 – Test Conditions for the Curve Capability Test and in Figure 10 – Example of Test Track Layout.

The speed of the target vehicle at the start of the test is given by
$v_{circle\_start} = \min((a_{lateral\_max} \times R)^{1/2}, v_{vehicle\_max})$ +/- 1m/s (5)

where $a_{lateral\_max}$ depends on the curve radius (see A.1 – Horizontal detection area for curve performance class II)

$$v_{circle\_start} = \min\left((a_{lateral\_max} \times R)^{1/2}, v_{vehicle\_max}\right) \pm 1 \text{ m/s} \tag{6}$$

where $a_{lateral\_max}$ depends on the curve radius (see Annex A):

$a_{lateral\_max}$ = 2,0 m/s^2 for R = R_{minII} = 500 m ;

$a_{lateral\_max}$ = 2,3 m/s^2 for R = R_{minIII} = 250 m ;

$a_{lateral\_max}$ = 2,3 m/s^2 for R = R_{minIV} = 125 m.

At the proper time, the target vehicle decelerates and the reaction of the subject vehicle is observed. The subject vehicle shall start to decelerate due to the decreasing distance to the target vehicle before the time gap falls below 2/3 τ_{max}.

The subject vehicle shall start to decelerate due to the decreasing distance to the target vehicle before the time gap falls below 2/3 τ_{max}.

Table 5 - Test Conditions for the Curve Capability Test

	Test Preliminary	**Test Start Conditions**	**1st Test Manoeuvre**	**2nd Test Manoeuvre**
Target vehicle				
- speed	V_{circle_start} = constant		decrease velocity by 3,5 ± 0,5 m / s	v_{circle} = constant = v_{circle_start} - 3,5 m / s ± 1 m / s
- time	min. 10 s	x	2 s	
- radius	>= R as defined in 7.5.1; may vary	R = constant (see 7.5.1)		
Subject vehicle				
- speed	as controlled by ACC			
- acceleration	<= 0,5 m / s²		Deceleration to be observed	
- radius	>= R as defined in 7.5.1; may vary	R = constant (see 7.5.1)		
- time gap to target vehicle	τ_{max} (v_{circle_start}) ± 25%		as controlled by ACC; shall be observed	

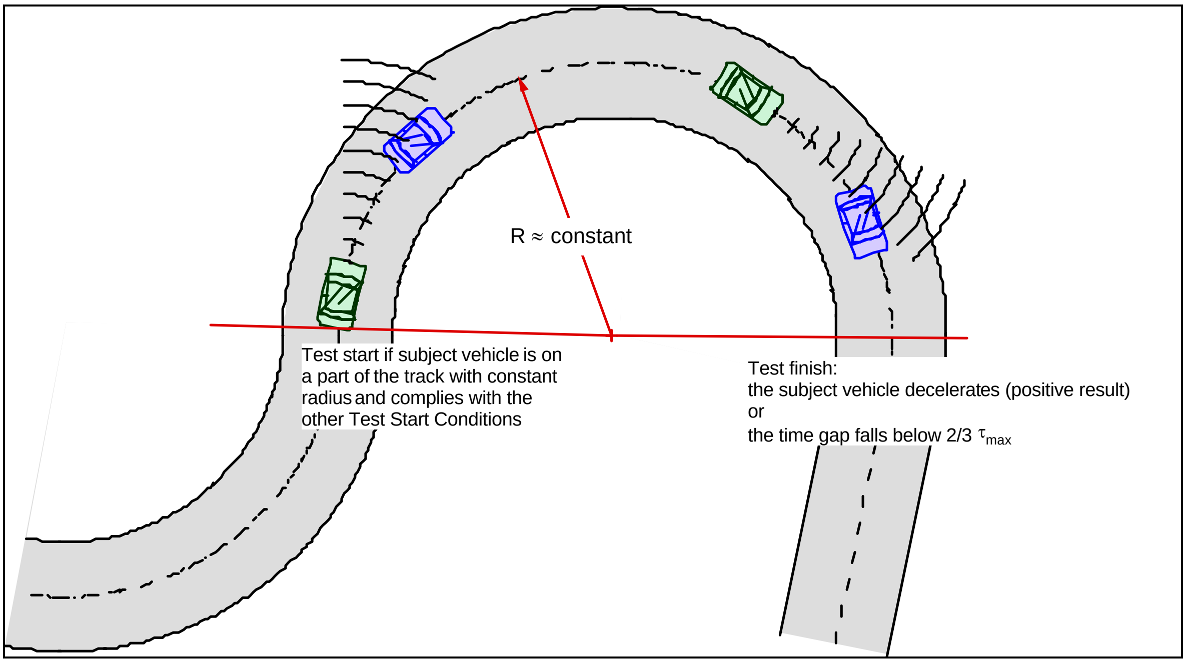


Figure 10 – Example of Test Track Layout

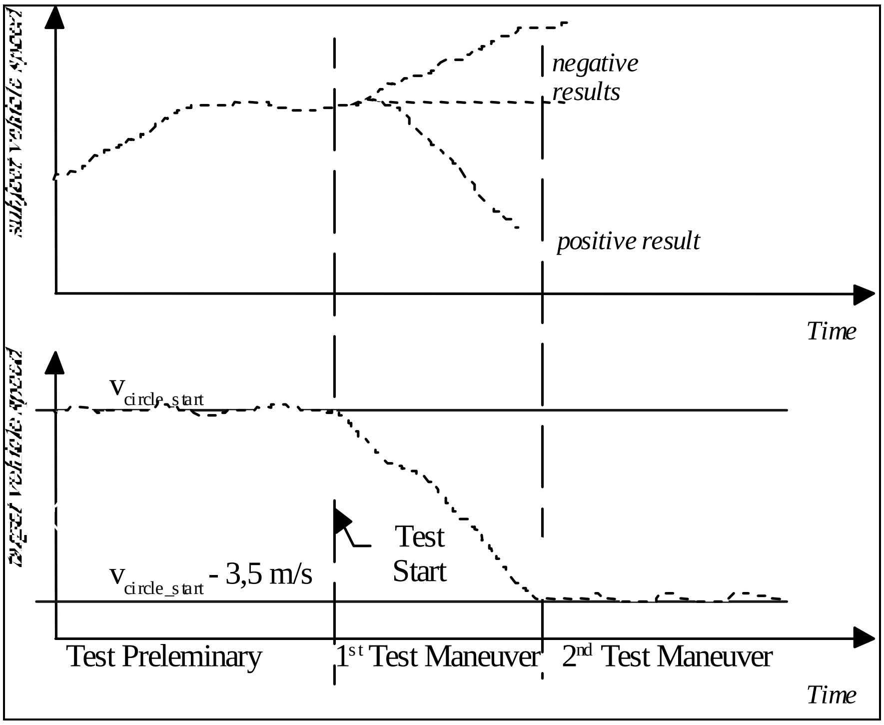


Figure 11- Timing of Curve Capability Test

Annex A
(normative)

Technical Information

A.1 Horizontal detection area for curve performance classes II, III, and IV

As a minimum requirement the detection and ranging shall cover at least the closest forward vehicle on the assumed trajectory on straight roads and in the constant radius part of curves. The required length of the considered trajectory depends on the vehicle speed, which itself is limited by maximum speed and lateral acceleration constraints.

Based on the above concept a horizontal detection area (HDA) can be derived as a guide for an appropriate sensor design.

The definition of the HDA is based on the following assumptions and definitions:

1. The driving trajectory of the subject vehicle and forward vehicle(s) is a circle with the radius R.[5]

1. Radius R is greater than or equal to R_{min}.

2. For simplicity the width of subject vehicle and forward vehicle(s) are neglected[6]. The subject vehicle speed v is less than or equal to v_{set_max}.

3. The absolute value of lateral acceleration at the maximum speed in curves v_{circle} does not exceed $a_{lateral\_max}$.

4. Within curves a preview range for detection and measurement shall be higher than $\tau_{max}(v_{circle})$ x v.

5. The preview range is limited by the maximum detection range value d_{max}, defined in section 6.2.6.1.

Consequences:

With the limits (2, 5 and 6) an envelope of the required HDA can be calculated. The geometry is defined by three parameters only:

[5] A straight road is a “circle” with radius infinity (or curvature = 0)

[6] The fact that the standard vehicles have a real width with distributed reflectors compensates for the fact that the vehicles do not drive exactly in the middle of the lane.

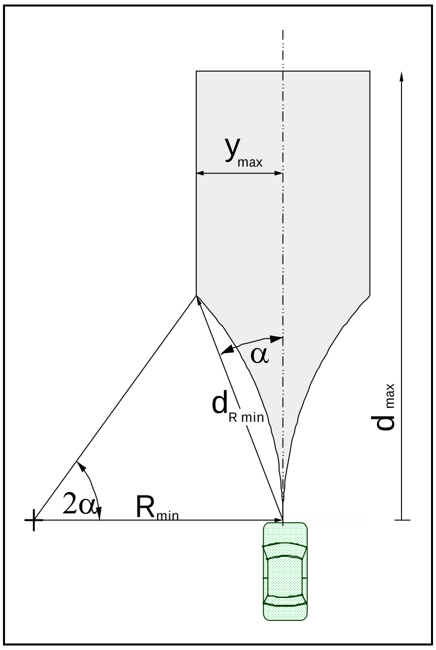


Figure A.1 – Horizontal detection area

1. $d_{\max}$
2. $y_{\max} = \frac{\tau_{\max}(v_{circle})^2}{2} \text{ x } a_{lateral\_\max}$
3. $\mathrm{d}_{\mathrm{Rmin}} = \tau_{\max}(v_{circle}) \text{ x } \sqrt{a_{lateral\_\max} \text{ x } R_{\min}}$

The detection in this HDA envelope is sufficient, but not necessary. The minimum requirement shall detect a forward vehicle on the trajectory that the subject vehicle is following.

Exceptions at small distances see section Following Capabilities.

Table A.6 - HDA formulas

Basic Formulas

$$d_R = 2 \text{ x } \sin(\alpha) \text{ x } R \Leftrightarrow \alpha = \arcsin\left(\frac{d_R}{2R}\right)$$

$$y_{\max} = d_R \text{ x} \sin(\alpha) \Leftrightarrow R = \frac{d_R^{\,2}}{2y_{\max}}$$

Limitation of speed in curves to a maximum lateral acceleration

$$v_{circle} = \sqrt{a_{lateral\_\max} \text{ x } R}$$

Constant preview time $[\tau_{\max}(v_{circle})]$ leads to v_{circle} - proportional d_R

$$\tau_{\max}(v_{circle}) := \frac{d_R}{v_{circle}} \Rightarrow d_R = \tau_{\max}(v_{circle}) \text{ x } \sqrt{a_{lateral\_\max} \text{ x } R}$$

$$\Leftrightarrow \tau_{\max}(v_{circle}) = \frac{2 \text{ x } \sin(\alpha) \text{ x } R}{\sqrt{a_{lateral\_\max} * R}} = 2 \text{ x } \sin(\alpha)\sqrt{\frac{R}{a_{lateral\_\max}}}$$

$$\Leftrightarrow \alpha = \arcsin\left(\frac{\tau_{\max}(v_{circle}) \text{ x } v_{circle\ \max}}{2R}\right) = \arcsin\left(\frac{\tau_{\max}(v_{circle})}{2} \text{ x } \sqrt{\frac{a_{lateral\ \max}}{R}}\right)$$

$$\Leftrightarrow y_{\max} = d_R \text{ x } \frac{\tau_{\max}(v_{circle})}{2} \text{ x } \sqrt{\frac{a_{lateral\_\max}}{R}} = \frac{\tau_{\max}(v_{circle})^2}{2} \text{ x } a_{lateral\_\max}$$

Calculation Example:

Design –Parameters:			***Required for Class II systems***			***Results: minimum requirements***		
$\tau_{max}(v_{set\_max})$	=	2 s	$a_{lateral\_max}$	=	2 m/s^2	d_0	=	2,5 m
v_{set_max} (162 km/h)	=	45 m/s	R_{min}	=	500 m	d_1	=	16 m
						d_{max}	>	90 m
v_{low}	=	10 m/s				v_{circle}	=	31,67 m/s
$\tau_{min}(v_{low})$	=	1,6 s				y_{max}	=	4 m
						d_{Rmin}	=	63 m
						α	=	+/-3,7 °

Design –Parameters:			***Required for Class IV systems***			***Results: minimum requirements***		
$\tau_{max}(v_{set\_max})$	=	2 s	$a_{lateral\_max}$	=	2,3 m/s^2	d_0	=	2 m
v_{set_max} (180 km/h)	=	50 m/s	R_{min}	=	125 m	d_1	=	7 m
						d_{max}	>	100 m
v_{low}	=	5 m/s				v_{circle}	=	16,94 m/s
$\tau_{min}(v_{low})$	=	1,0 s				y_{max}	=	4,6 m
						d_{Rmin}	=	31,6 m
						α	=	+/-7,8 °

A.2 LIDAR - coefficient of test target

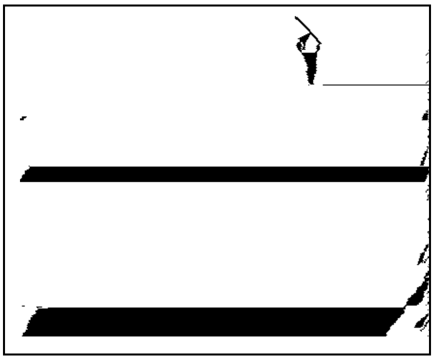


Figure A.2 - Solid angle

Solid angle [Ω]

The solid angle [Ω] is the ratio of the irradiated portion of the surface of light to the square of the radius of the sphere.

$$\Omega = \frac{A}{{d_A}^2} \text{ x } \Omega_0$$

Ω = solid angle, unit steradians [sr]

A = utilised area

d_A= distance between source and projected area A

Ω_0 = solid angle of the source [1sr]

Radiated Intensity [I]

The radiated intensity [I] is given by the radiated power [Φ] out of a radiation source, inside an area [Ω].

$$I_{ref} = \frac{d\Phi_{ref}}{d\Omega_1}$$

where

I_{ref} = radiated intensity in a given direction, out of the reflector, measured in front of the receiver surface. [W/sr];

Φ_{ref} = radiated power [W] ;

Ω_1 = illuminated solid angle [sr].

Intensity of irradiation [E]

Intensity of irradiation is the ratio of the incident radiated power to the area of illuminated surface. E is the density by surface of the illumination.

$$E_t = \frac{d\Phi_t}{dA_t} \left[W/_{m^2} \right]$$

Coefficient for Test Target [CTT]

The test target is defined by a coefficient of a reflector, which represents the reflectivity of a dirty car without any retro-reflector.

$$CTT = \frac{I_{ref}}{E_t}$$

where

I_{ref} = radiated intensity in a given direction, out of the reflector, measured in front of the receiver surface. [W/sr]

E_t = intensity of irradiation, out of the transmitter $\left[\frac{W}{m^2}\right]$

CTT = Coefficient for Test Target $\left[\frac{m^2}{sr}\right]$

The reflector with the defined CTT shall have a weighting of the reflection ≥ 8 x 10^{-3} sr.

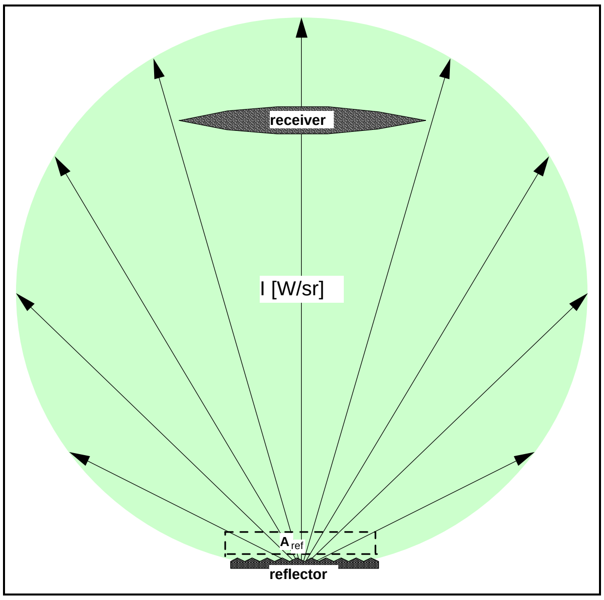


Figure A.3 – Receiver scenario

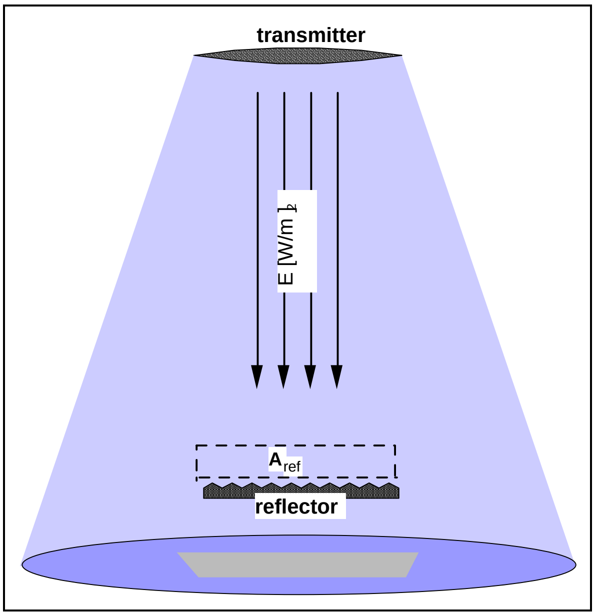


Figure A.4 – Transmitter scenario

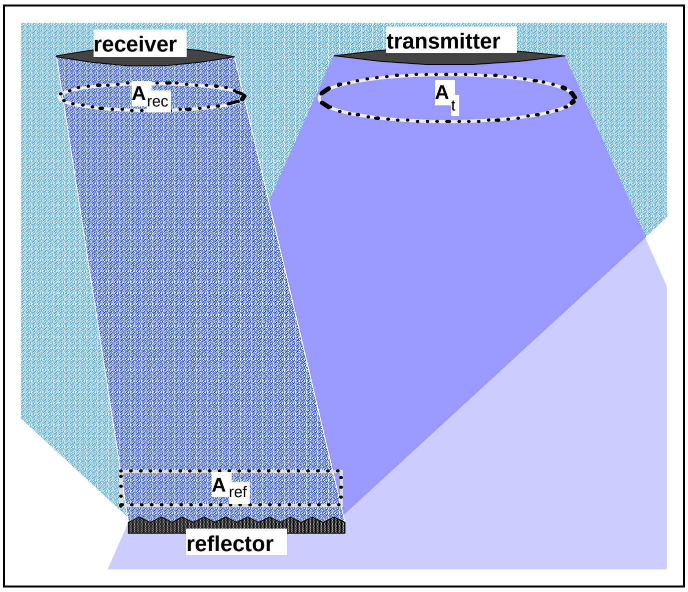


Figure A.5 Reflector scenario

The CTT Coefficient for Test Target only describes the quality of a reflector (damping). For the test procedure it is sufficient to have a corner reflector (reduction of the surface to 'a point'). But it is also possible to have a larger surface of reflection, if the whole reflectivity of the reflector surface does not exceed the mentioned value.

Reflector Size:

The size of the reflector shall be defined. Experience shows, a lambert-reflector with a size of approximately 1,7 m^2 is the best, in case of vehicle representation, solution. A different method could be a 'triple' reflector with the size of approximately 20 cm^2.

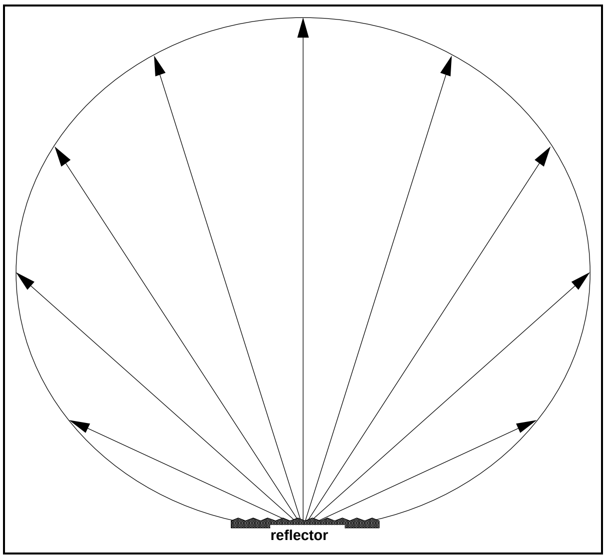


Figure A.6 - Lambert reflector

The lambert - reflects the whole energy inside a sphere area.

$$\Phi_{\oplus} = \pi \text{ x } I_0 \text{ x } \Omega_0$$

where

$\Phi_{\oplus}$ is the radiated power [W] ;

I_0 is the radiated intensity[W/sr] ;

Ω_0 is the solid angle [sr].

A size of 1,7 m^2 represents the cross-section of a small vehicle.

A.3 Definition of the RCS of a corner cube type test target

The Test Target is defined by a RADAR Cross Section (RCS).

- RCS = 10 ±3 m^2. For today known frequencies (60, 77, 90 GHz), 10 m^2 represents at least 95 % of all vehicles driving on motorways. For significant different frequency ranges, investigations shall be done.

- Aspect of test target should be as shown in figure A.7.

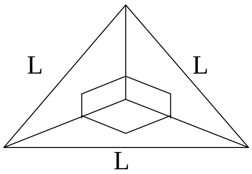
Standard test target	General formula for calculating RCS
Corner Cube reflector 	$RCS = (4 \text{ x } \pi \text{ x } L^4) / (3 \text{ x } \lambda^2)$ λ = wavelength L= length of each side

Figure A.7 - RADAR test target

A.4 Following capability

Regarding d_0, the 0,25 second value is based more on experience than on technical data. For values less than 0,25 seconds, the assumption is that the driver will intervene immediately so there is no need to avoid acceleration of ACC (for a scenario of cut-in at low speed). If the time gap is in the order of 0,5 second or more, then there is no guarantee that the driver will intervene. So the system shall be able to detect and avoid acceleration.

Annex B
(normative)

Symbols

Standard symbols regarding ACC functions as specified in ISO 2575

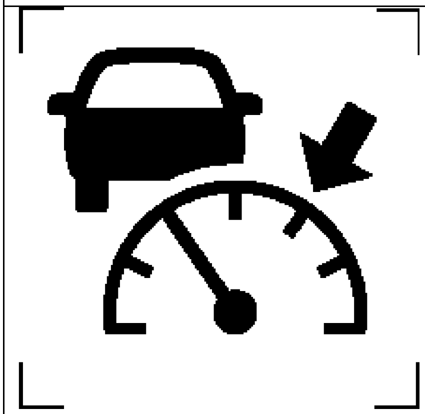
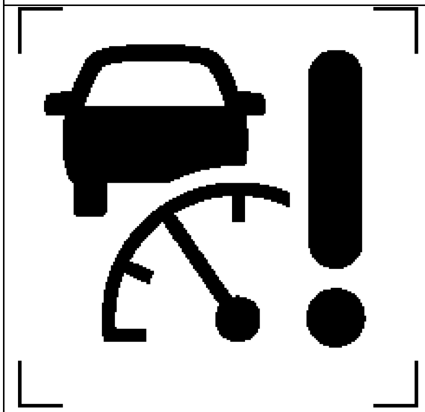
Symbol	Description	ISO/IEC registration No.
	ACC	ISO 7000-
	ACC malfunction	ISO 7000-

Figure B.1 – ACC Symbols

The figures shown here in Annex B are the most recent depictions of the ACC symbols. Upon the completion of the ISO/TC22/SC13/WG5 standardisation of these symbols, they shall be used with ACC systems to conform to this standard.

Bibliography

The values for $a_{lateral,max}$ are adopted to the driver behaviour in curves (95%-drivers), refer to Figure Bib.1 – Lateral acceleration of the average driver below.

Literature sources:

A Policy on Geometric Design of Highways and Streets : 1994

American Association of State Highway and Transportation Officials , ISBN 1-56051-068-4

Richtlinien für die Anlage von Straßen - RAS - Teil: Linienführung (RAS-L)

Forschungsgesellschaft für Straßen und Verkehrswesen - Arbeitsgruppe Strassenentwurf

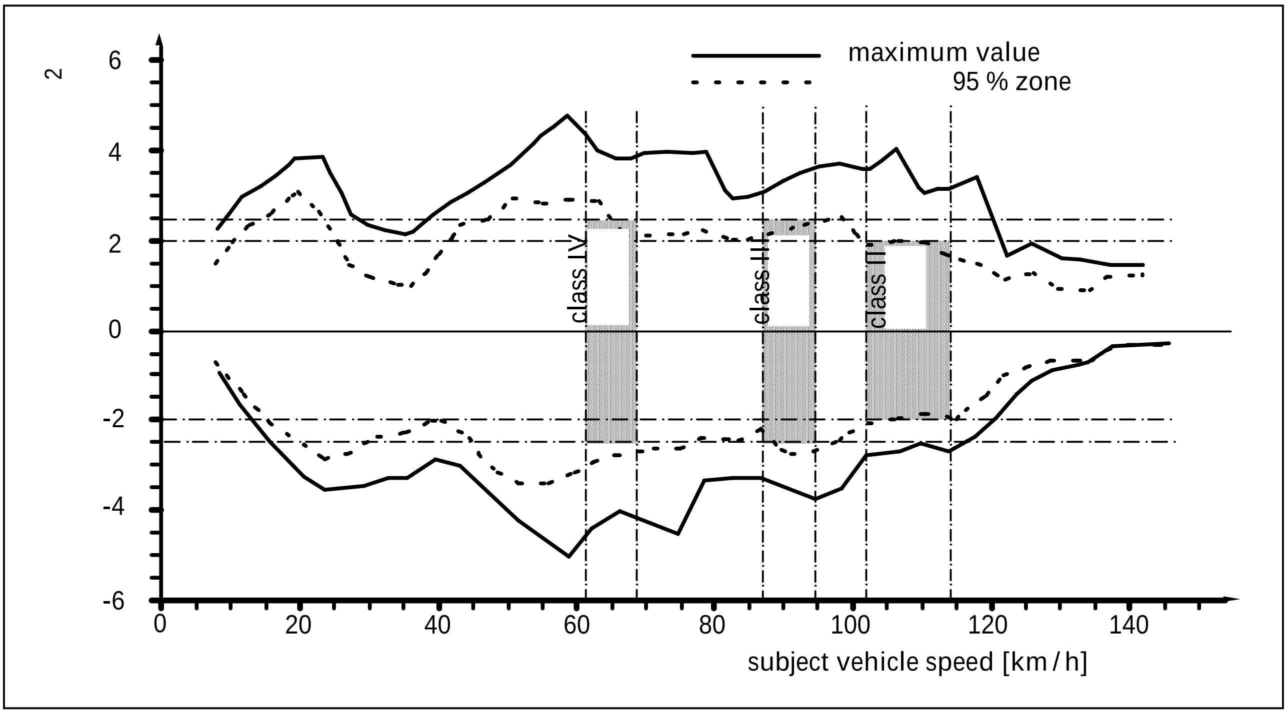


Figure Bib.1 – Lateral acceleration of the average driver

Source:

“Vermeiden querdynamisch kritischer Fahrzustände durch Fahrzustansüberwachung”

“Avoidance of critical driving states in case of lateral acceleration by using driving state supervision” VDI Bericht 91/1991

Prof. Dr.-Ing. M. Mitschke, Dr.-Ing. H. Wallentowitz, Dr.-Ing. E. Schwartz