Technical Product Specification

ARS513

Proposed Product Configuration for ARS513 Base

Feature	Description	Reference chapter	Quoted Configuration	Details
Hardware				
Sensor				
Mechanical	Options M-A, M-B	5.4.1	M-B	
Mounting Bracket	-	-	No	
Connector Type	Options CT-A , Sumitomo	5.4.3.2	Sumitomo	
Connector Conf.		5.4.3.3	To be agreed with customer	
Electrical	-	-		
Supply Voltage	Kl.15/30 (IGN/Ubatt), 12V/24V	5.1.1	Kl.15 12V	
MPU	RRU II (K/HB Variant)	-	RRU II K Var 4MB SDF	
Functions				
FoV	Azimuth Field of View: 45° / 50°	4.2.6	+/-50°	
OD	Object Detection Output: internal only / object list on CAN	4.1.2	object list output	
Interfaces				
CAN/CAN-FD	1x/2x CAN/CAN-FD, (non) wakeable	5.1.3.1	1x CAN-FD	
Ethernet	-	5.1.3.2	No	
Flexray	-	5.1.3.3	No	
Heating Switch	Heating for secondary surface	5.1.3.4	No	
Other I/O	LED, buzzer, etc.	-	No	
Security & Privacy	scope to be agreed with customer	4.4	Basic features	
HCC	Homologation Country Class 1-4	8.7	HCC-1 only	
Additional assumptions				
ARS511 to be used stand-alone / in fusion with camera sensor				
Only adaptation to customer's CAN matrix, no integration of customer specific algorithms or software				
Dynamic Motion Controller software module (optional) not offered				
Autosar 4.2 offered				

Table of Contents

1. Introduction

This Technical Product Specification applies to the upgraded version of the ARS510 which is ARS513 that belongs to the 5th generation of radar systems by Continental BU-ADAS.

The document describes the:

- Functional principle
- Radar specific properties
- Mechanical and electrical interfaces
- Communication interfaces
- Mounting Guidelines
- Calibration and Blockage Detection
- Environmental conditions

of the radar sensor ARS513.

1.1 Purpose

This document is the customer/quote-specific version of the Technical Product Specification (TPS) of the ARS513 radar sensor which is an extract of Continental's DOORS-based system architecture.

Until further notice this document contains preliminary design targets.

The exact performance figures and feature contents need to be agreed in the quote phase and signed within the contract.

Deviations specific to application projects have to be approved by Continental and are to be marked in project documents and specifications.

This document is valid for products based on the ARS513 generic radar sensor, which is based on Continental's Radar2018 radar sensor family.

2. References

- [1] Regulation No 131 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking Systems (AEBS) (Online, COMMISSION REGULATION (EU) No 347/2012, euroa.eu, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.214.01.0047.01.ENG)
- [2] UN/ECE status document TRANS-WP.29-343, Rev.21 (Online, unece.org, http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/updates/ECE-TRANS-WP.29-343-Rev.21.pdf)
- [3] LV 124, Electric and Electronic Components in Motor Vehicles up to 3.5 t - General Component Requirements, Test Conditions and Tests
- [4] FCC 2.1091 (b) rules for RF compliance of mobile and portable devices, https://www.gpo.gov/fdsys/pkg/CFR-2011-title47-vol1/pdf/CFR-2011-title47-vol1-part2-subpartJ-subjectgroup-id922.pdf
- [5] FCC 47 CFR 1.1310 Radiofrequency Radiation Exposure Limits https://www.gpo.gov/fdsys/granule/CFR-2010-title47-vol1/CFR-2010-title47-vol1-sec1-1310
- [6] ETSI 1999/519/EC Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields http://ec.europa.eu/health/electromagnetic_fields/docs/emf_rec519_en.pdf
- [7] BGV B11 Unfallverhütungsvorschrift Elektromagnetische Felder http://www.bgetem.de/share/wbt_emf_2015/pdf/bgv_b11_a08-2011.pdf
- [8] BroadR-Reach Phyiscal Level Specification (Online, broadcom.com, http://www.broadcom.com/products/Physical-Layer/BroadR-Reach-PHYs)

3. **Sensor Variants**

ARS513 supports a multitude of general configurations with

- different housing and variation in mechanics
  - housing variants M-A or M-B, see chapter 5.4.1
- different micro-controller versions
  - Racerunner II (K/HB variant)
- different vehicle interfaces
  - CAN-FD, HS-CAN, Ethernet, etc., see chapter 5.1.3
- different nominal operating voltages
  - nominal 12V or 24V, voltage limits see chapter 5.1.1

The mechanical variants differ in mounting of the sensor on the vehicle body or bumper. For details see section 'Housing' of chapter 'Interfaces'.

The connector configurations differ in connector shape and pin-out. For details see section 'Vehicle Connector' in chapter 'Interfaces'.

The micro-controller is selected based on the necessary computational power and further required resources.

The configuration items listed above can be selected largely independent from each other.

4. System Overview

The ARS513 is a 77 GHz radar sensor with digital beam-forming scanning antenna.

The radar system provides the following features. The exact feature content has to be defined in the quote context:

- Adaptive Cruise Control (ACC) Follow to Stop
  - ISO/FDIS 15622
  - ISO 22179
- Forward Collision Warning, Emergency Brake Assist:
  - Moving objects (0 .. 250 km/h) speed reduction 60 km/h*
  - Stationary objects (0 .. 80 km/h) speed reduction 40..50 km/h*
  - (*) these limitations apply only to radar-only architectures, i.e. without camera fusion
- Compliant with:
  - UN/ECE R131 AEBS regulation [1]
- Sensor designed for and Use Cases implemented for:
  - NHTSA Forward Collision Warning, Collision Imminent Braking
  - EuroNCAP 2018 AEB City / Inter Urban / VRU Pedestrian + Cyclist
  - [planned] EuroNCAP 2020 AEB City / Inter Urban / VRU Pedestrian + Cyclist & Junction Assist
- Auto Alignment
  - Fast auto alignment capability for end of line production testing (EoL)
  - Service alignment without special tools for service stations
  - Continuous alignment capability resp. misalignment detection during normal operation (e.g. load compensation)
- Scalable family approach with different control interface options
- Elevation measurement feature
  - Capability to distinguish over-drivable and under-drivable objects from real target objects
- Sensor fusion
  - Sensor designed (RAM, ROM, runtime) to host sensor fusion with other sensors (e.g. camera)
- Capability to host safety relevant functions
  - Automotive Safety Integrity Level (ASIL) for safety relevant functions needs to be agreed
- Outstanding interference robustness and advanced interference mitigation:
  - For general interference see section 'Interference Robustness'
  - For interference from other radar sensors see section 'Mutual Interference'

- ARS513 complies with the applicable frequency regulation standards in the following key markets:
  - European Union
  - U.S.
  - Canada
  - Russia
  - South Korea
  - Australia
  - Japan
  - China
  - Homologation in further countries is available on request.
- Compliant with UN/ECE electromagnetic compatibility regulations R 10 [2]
  - ECE R 10: E1 marking provided on customer request only
  - EN 301489 (CE sign) if sold onto the European market
  - CISPR-25 - Radio disturbance characteristics for the protection of receivers used onboard vehicles, boats, and on devices - Limits and methods of measurement
- RoHS compliant
- GADSL compliant
- The ARS513 product is fully assembled in a plastic housing and specially designed for civil automotive application. The use of encryption function is strictly controlled by the firmware made by Continental and the MCU is not removable. Therefore a classification regarding the chapters 3 and 5 of the dual use list from Europe Union and United States of America is ruled out. The final Classification Analysis of the product with the European Dual List, German Ausfuhrliste and the Commerce Control List (USA), is "not restricted" (European laws CE n° 428/2009,388/2012 and Bundesamt für Wirtschaft und Ausfuhrkontrolle) and "EAR99" (Export Administration Regulation).

4.1 Sensor Functions

4.1.1 Function Overview

Figure 1 gives an overview of the vehicle functions that can be allocated on the ARS513. These functions will be described in more detail in this chapter.

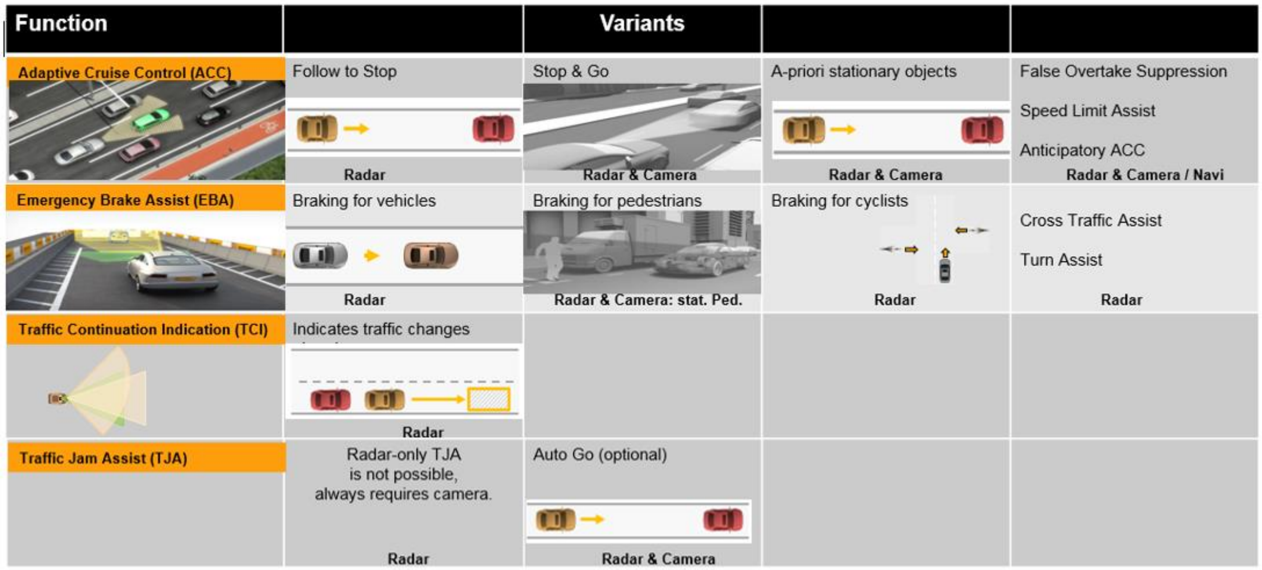


Figure 1: ARS513 Vehicle Functions

4.1.2 Object Detection (OD)

Motivation:

- OD is a generic processing step for all subsequent vehicle functions (EBA, ACC, etc.)
- OD as a 'stand-alone function' provides object list output to software modules either allocated on the radar sensor or - via some communication bus - on an external ECU. It allows the customer to define/design the functional behaviour of the vehicle functions by his own.

Description:

- OD delivers list of objects ahead
- Attributes include object dynamics, dimension, shape
- Objects are classified as pedestrians, vehicles (passenger car, truck), motorbikes or bicyclists

<u>Safety Integrity Level</u> according to ISO-26262:

- Depends on specific implementation of subsequent functions (EBA, ACC, etc.): supports functions up to ASIL B

Object Detection delivers a list of up to **40 objects** with the following data attributes:

- Object ID
- Distance (X, Y)
- Relative Velocity (X,Y)
- Width, Length, Heading
- Radar Cross Section
- Existence Probability
- Object Age (in radar cycles)
- Classification (Car, Truck, Bike, Pedestrian, etc.)
- Dynamic Property (moving, stationary, oncoming)

Further data attributes (e.g. absolute velocity, acceleration, etc.) can be agreed upon with the customer.

This list is intended as input to 3rd party software modules (e.g. customer-furnished ACC or EBA functions) which are integrated within the sensor’s software.

In order to be suitable e.g. for fusion with camera objects / camera information, the list of objects is not function specific – other than the ACC object list (see below).

The object list can also be output via the vehicle interface for use by external ECUs or sensors.

In this case the available bandwidth of the vehicle bus must be taken into account, limiting the number of objects and/or the data attributes that can be transmitted.

On a private CAN with 500 kbit/s, the sensor can typically transmit 25 objects with 16 bytes of packed data attributes each.

Faster communication buses like CAN-FD or Ethernet facilitate transmission of object lists with more objects and/or more data attributes.

4.1.3 Road Detection (RD)

Motivation:

- Road detection is important to determine whether an object is in the ego lane
- Information on number of lanes, traffic orientation and road type provide additional environmental information

Function Scope:

- Provision of an estimate of the road border (in form of a clothoid)
- Provision of the distance to the left and right border at vehicle height
- Provision of the number of lanes, traffic orientation and road type

New Features:

- Double clothoid representation of road if necessary to increase accuracy
- Independent left and right border estimation
- Additional detection of distance to road edge (grass edges, curbs)

Input via the vehicle interface:

- Stationary detections (from radar reflections) and/or stationary grid
- Vehicle dynamics information (VDY)
- Tracked objects and traces from relevant objects
- (optional) from camera: lane markings

Output via the vehicle interface:

- Road border (coupled, left and right)
- Distance to the border (to structure and to edge)
- Number of lanes, traffic orientation, road type

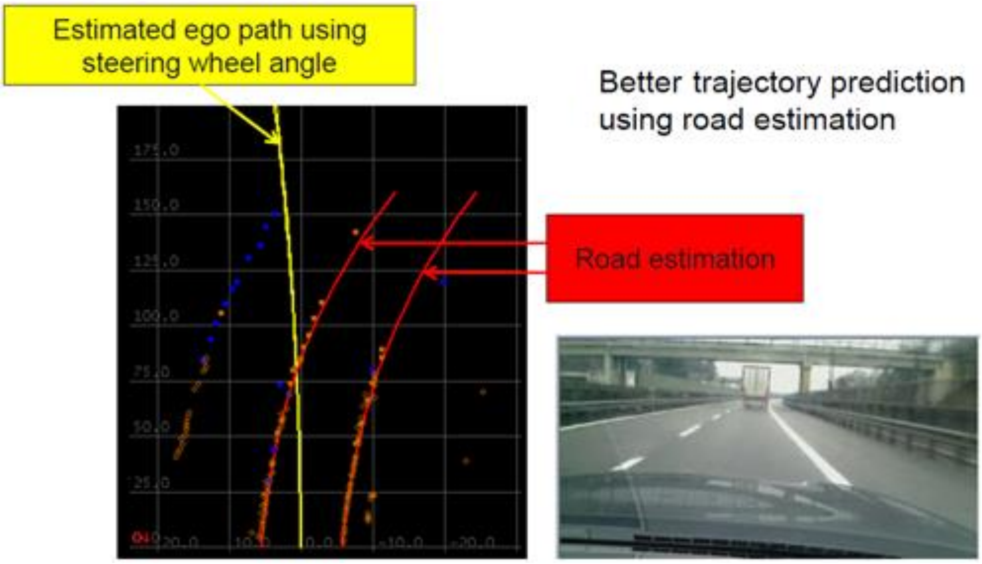


Figure 2: Road Detection

4.1.4 Radar Detection Image (RDI)

Motivation:

Continental's RDI interface is intended for architectures with a central computing ECU. In order not to lose any information for the central ECU, the radar sensor performs only raw data processing and alignment, and then - without object detection or tracking - outputs 'RDI single shots'.

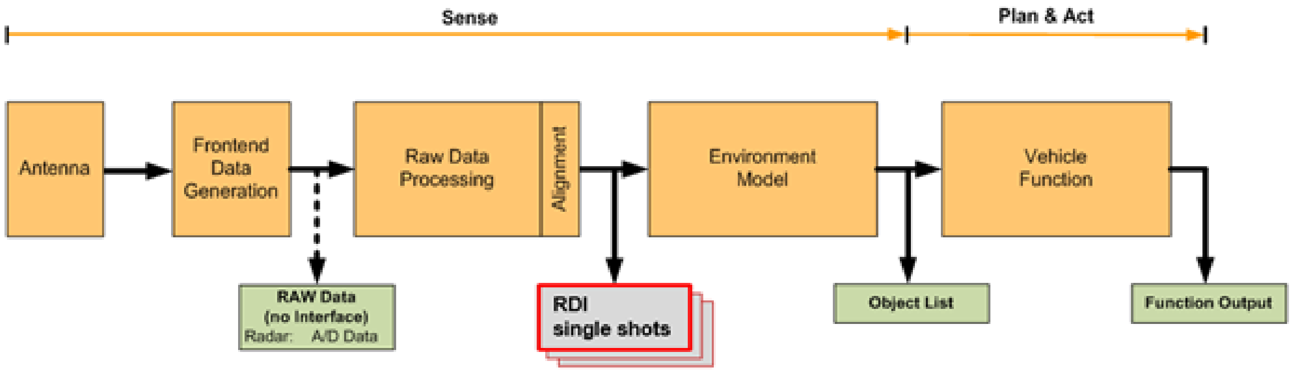


Figure 3: Radar Detection Image - Processing Chain

The RDI interface

- enables early data fusion, including 360° radar view,
- improves standardization of sensor architectures,
- has no negative impact on classic functions like ACC, EBA, etc.,
- allows flexible placement/interchange of short and long range sensors,
- can serve as input to computer vision algorithms.

Native-RDI works only with fast communication buses like Ethernet or LVDS because it typically requires 12 Mbps bandwidth.

RDI data contains 3D position (distance, azimuth, elevation), radar cross section, and Doppler speed. The RDI data is largely hardware independent (it is calibrated and aligned).

This RDI data is then fed into an environmental model (EM/CEM) running on an external ECU (e.g. ADCU or camera). RDI's 'near-raw' data still contains radar artefacts and multiple reflections. The environmental model must resolve these ambiguities or - if not possible - provide several hypotheses incl. probability weights.

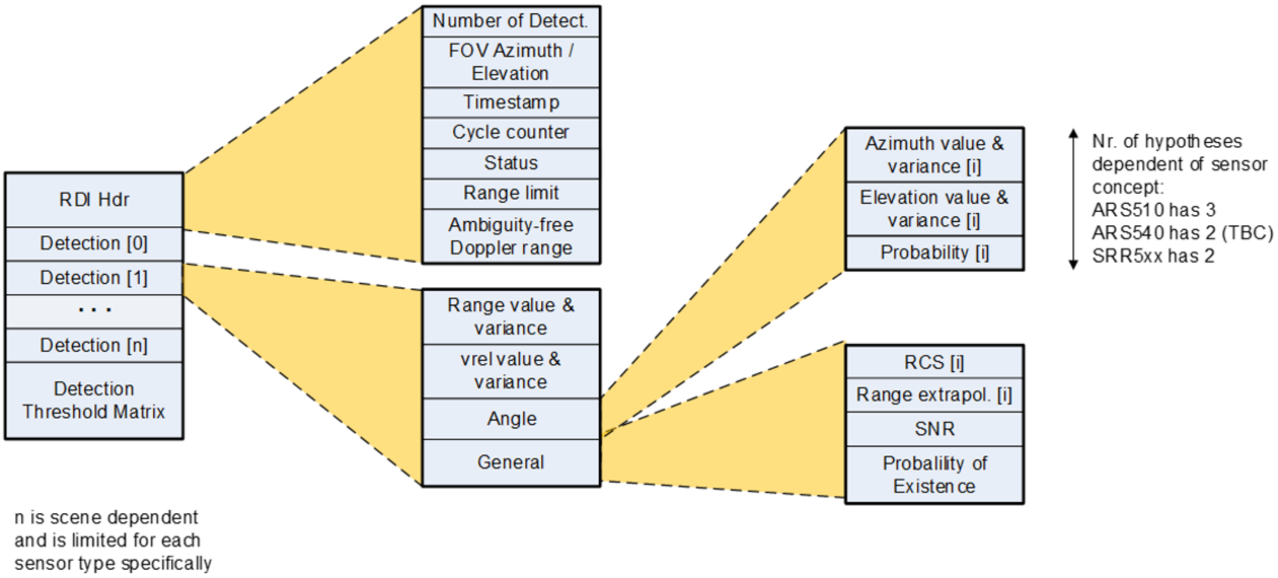


Figure 4: Radar Detection Image - Data Structure

4.2 Sensor Description

4.2.1 Radar Principle

As shown in Figure 5 the radar sensor family uses a pulse compression radar modulation scheme as basic principle for its measurements. This technique avoids the drawbacks of both the classical Pulse-Doppler and the FMCW (frequency modulated continuous wave) approach. Compared with a Pulse-Doppler principle, due to a very large duty cycle the chirped radar works with significantly higher amplitude of RF energy, resulting in a better overall SNR (signal to noise ratio).

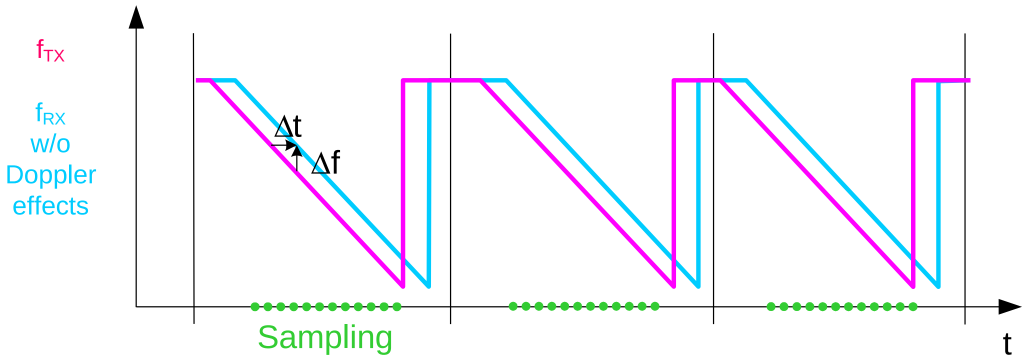


Figure 5: Radar Principle

Compared to FMCW modulation, Continental's pulse compression radar modulation makes it rather easy to separate range, velocity, and angular information in the received signals: ranges and Doppler speeds are calculated by a 2-dimensional fast Fourier transformation (2D-FFT), then the azimuth angles are determined by a subsequent third FFT.

As this procedure involves sampling out the individual chirps and processing accordingly, this radar principle is sometimes also referred to as pulse compression radar.

Another benefit of the radar principle is a software adjustable range resolution. The sensor is theoretically capable of setting its range resolution from 1 m and more up to 0.25 m (according to regulatory limits) which could be done internally based on certain traffic situation as well as parameters like vehicle speed, etc. This functionality is achieved by varying the frequency sweep of the chirps. The change can be done once for one single system cycle.

4.2.1.1 Interference Robustness

The radar principle applied and adapted by Continental has the benefit that interferences from other electromagnetic emissions will not create any ghost targets. Such interferences are converted into noise instead and will thus only affect the signal-to-noise ratio (SNR).

The sensor's algorithms check permanently if a temporary enhancement of noise is present (by comparison of short term vs. long term noise levels).

If interference is detected, the sensor's radar center frequency is switched to a new center frequency where the noise level is lower (sensor configuration dependent).

If despite a change in center frequency the noise level remains too high, customer functions (EBA, ACC) become deactivated successively, according to the noise dependent detection range calculated for a target with 10 m² RCS.

To ensure high availability, the sensor continuously monitors the noise level of all available frequency bands while functions are deactivated. Hysteresis is implemented in order to avoid toggling between activated/deactivated mode.

Additional measures are implemented besides noise level monitoring. E.g. the RX gain is decreased in case of receiver saturation.

For further details on interference robustness and mitigation see section 'Mutual Interference'.

4.2.2 Antenna Principle

Figure 6 shows the antenna principle of digital beam forming used in the radar sensor. In the example one transmitting (TX) antenna and 4 receiving (RX) antennas is used. All RX antennas receive reflections from the same target (ideally) not different in amplitude but in phase due to the slightly different distances to the target as a function of the azimuth angle αAZ.

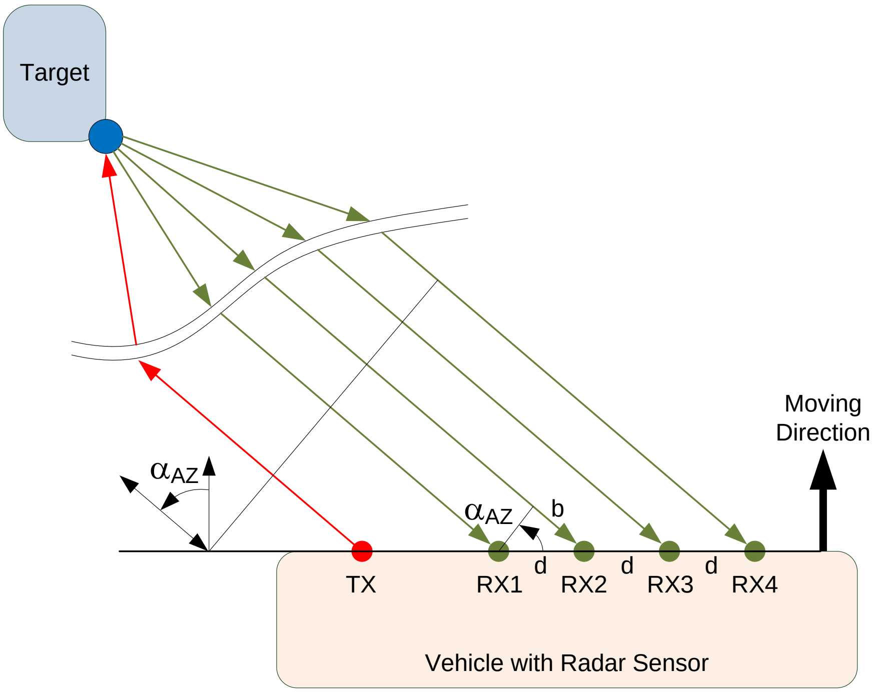


Figure 6: Antenna Principle

The relationship between phase and angle could be expressed as follows:

$$\alpha_{AZ} = \arcsin\frac{b}{d}$$

using

$$b = (\varphi_{RX1} - \varphi_{RX2}) * \frac{\lambda}{2\pi} \qquad (\varphi_{RXn} = \text{received phase of RX beam n})$$

For ARS513 the same antennas (3 TX and 4 RX) are used for a single range scan for near range and far range object detection. Selecting near range and far range scan is done via digital beam forming.

4.2.3 Mechanical Principle

As shown in one example in Figure 7, the ARS513 sensor is designed as a one-box system. Radar sensor front-end (RF-PCB) and electronic control (LF-PCB) unit share the same mechanics containing of housing and back-cover. One connector towards the vehicle electronics is provided.

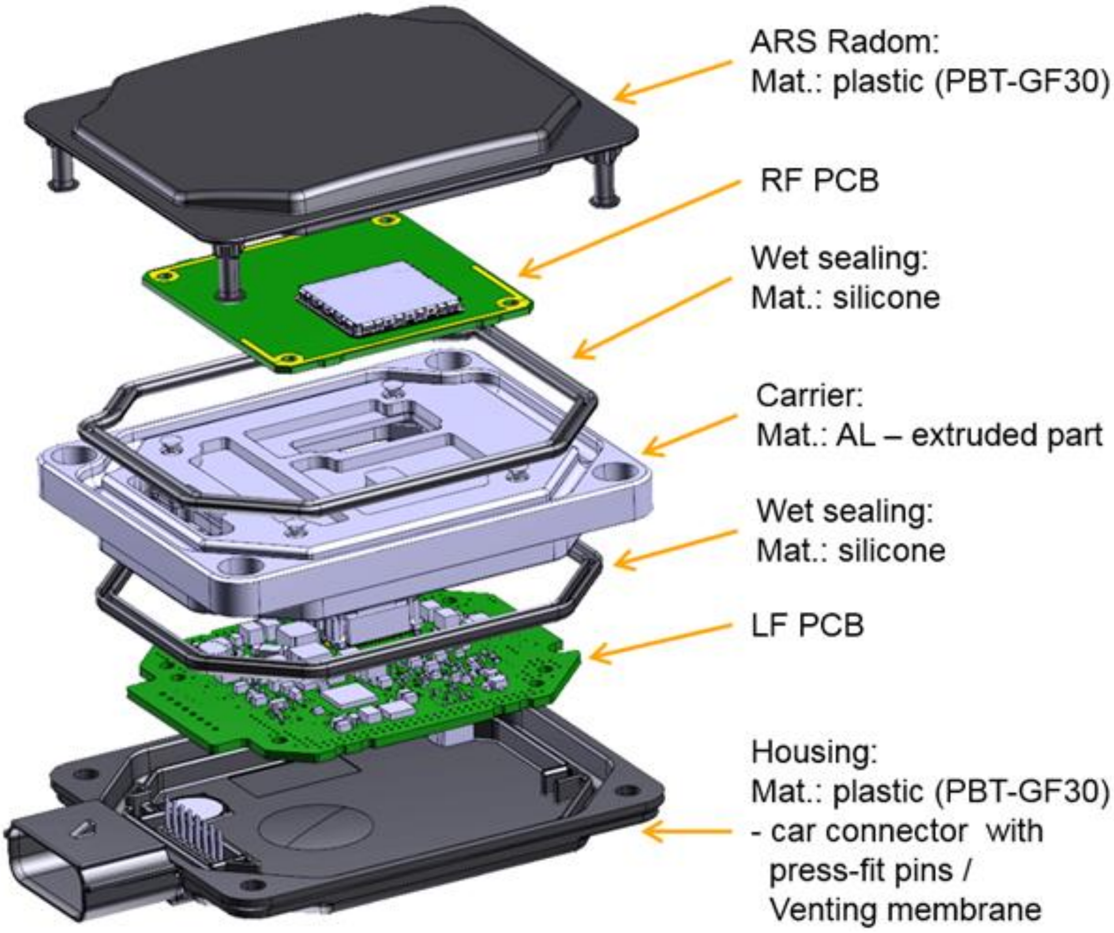


Figure 7: Generic Exploded View - Preliminary

Other than shown in this generic exploded view, the offered/quoted sensor may have different connector type/position or backplate/cover.

4.2.4 Hardware Principle

Figure 8 shows the hardware block diagram of the ARS513 including its low-frequency (LF) part and the radio frequency (RF) front-end.

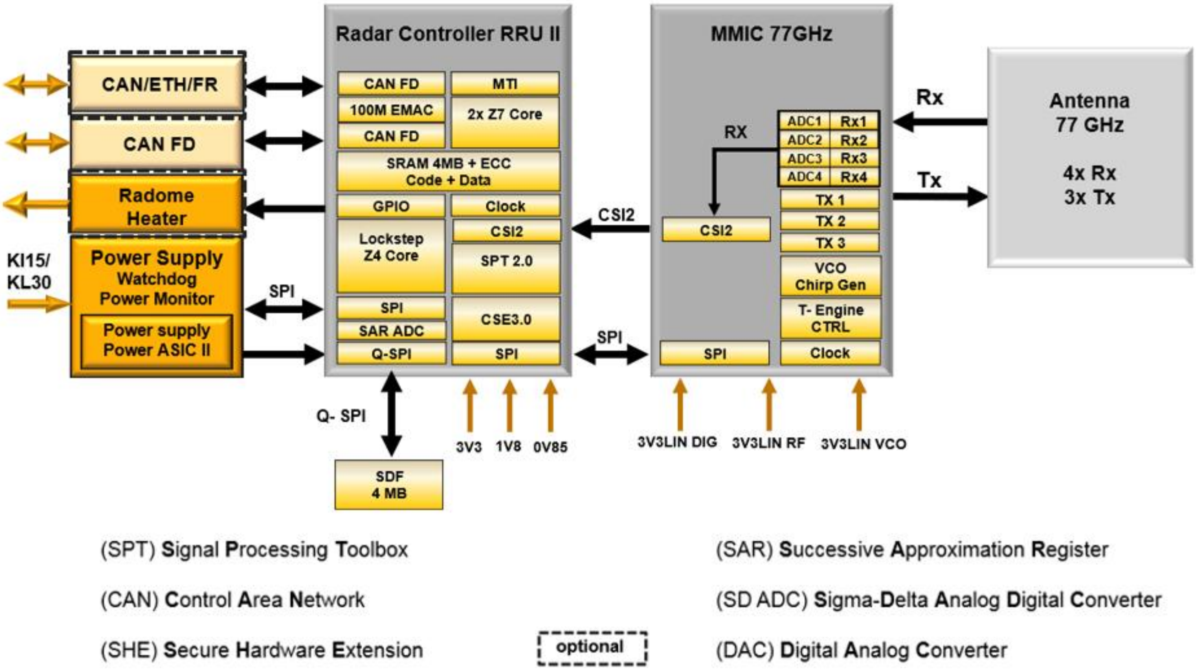


Figure 8: Hardware Block Diagram - ARS513

The main functionality of the ARS513 (Advanced Radar Sensor) is implemented by the RF chip MMIC, the Radar Controller and a specially designed power supply module.

Main Function:

- The MMIC generates a highly linear frequency sweep ramp by means of a PLL (Phased Locked Loop).
- Based on this frequency ramp, the transmit signal is created through the transmitter path of the MMIC which is being checked by internal monitoring within the MMIC for each cycle.
- The frequency ramps will be transmitted in parallel via the 3 TX antennas.
- 4 RX channels within the RX part of MMIC are responsible for down-converting and digitizing the reflected radar image.
- The digitized and down-converted signals are transmitted by a digital CSI2 interface for each channel to the Radar Controller where processing takes place in the SPT (hardware accelerated Signal Processing Toolbox).
- The processed signals are then analyzed to generate object lists and high-level functions based on customer's requests.
- Based on the processing results, control signals are provided on the vehicle interface.

The HW control unit of the Radar Controller also controls the power ASIC and the optional radome heating unit.

4.2.5 Radar Characteristics

The dynamic range of the detected radar cross section shall be at minimum between -10 dBm² to +40 dBm².

Table 1 defines the design targets for radar characteristics and detection ranges of the ARS513 sensor.

Table 1: Radar Characteristic Design Targets

		ARS513	
Distance	Range	250*m 234 m 208 m	*0° misalignment* *4° misalignment* *6° misalignment*
	Accuracy	±0.13/±0.18/±0.25m	*dependent on v_ego (**)*
	Resolution	±0.4/±0.70/±0.98m	*dependent on v_ego (**)*
Speed	Range (unambiguous)	-400 to +200 km/h	*negative value: oncoming car*
	Accuracy	±0.1 km/h	
	Resolution	0.28 km/h	
Azimuth	Range	±50°	
	Accuracy	±0.2°… ±2.25°	*±0.2° @ ±9° out of this range linear ascending up to ±2.25° @50°*
	Resolution	3,3°	*Within ±20°, linearly increases to 4.7° @50°*
	3dB beamwidth	3.1°	
Elevation	Accuracy	< 1°	
	Resolution	no resolution	
	3dB beamwidth (beamformer)	no beamforming	
	Antenna channels	3 x 4	*TX x RX*
	Sensitivity: RCS @ range	10dBsm @200m	*Just for max. misalignment of +/-3°*
	Output Power (EIRP, average)	<= 30dBm	
	Auto alignment	max. -6°… 6°	*for azimuth and elevation*
	Cycle Time	60 ms	

(*) limited by range gate length
(**) thresholds at 65/60 kph and 115/110 kph

4.2.6 Field Of View

4.2.6.1 Option 45° vs. 50°

The ARS513 is offered with two Field of View (FoV) options - either +/-45° or +/-50° in azimuth.

Both options share the same hardware and create the same HF signal (beamwidth etc.). The difference is limited to the internal radar processing software.

The **50° option** requires the OEM to provide favourable integration conditions:

The OEM should decide at project start which FoV option they prefer, as this is also relevant for the design of the radome and for the subsequent test drives.

4.2.6.2 Field of View and Detection Ranges

The Field of View (FoV) is the function relevant part of the radar cone as described in the mounting guideline section "Sensor Radar Cone".

For integration purposes one must consider an extended "Keep-out Cone" rather than the functional radar cone:

The nominal FoV is +/-50° in azimuth and +/-9° in elevation direction. Additionally, Continental recommends to add +/-6° for mounting tolerances and an additional +/-1° safety margin in azimuth.

FoV restrictions caused by installation in the vehicle must be reviewed and agreed with Continental.

Figure 9 give the detection ranges for different object classes within the +/-50° FoV of the ARS513 sensor with typical conditions.

- sensor with typical production sensitivity
- misalignment +/-3° in azimuth and elevation
- bumper attenuation 3 dB (two way)
- no strong attenuation by rain,etc.
- object detection based on 95% detection probability
- incl. 6 dB road reflection

Maximum range of 250m as depicted in the Figure 9 is dependent on the ego vehicle velocity and is valid for ego velocities above 115 kph. For ego vehicle velocities between 65 kph to 115 kph, the maximum range is reduced to 170m. For ego vehicle velocities below 65 kph, the maximum range is reduced further to 102.4m. This is done in order to achieve higher accuracy at lower velocities especially during traffic critical scenarios like in cities.

Figure 9: Detection Range for different objects (typical conditions)

Figure 10 gives the detection ranges for different object classes within the +/- 50° FoV of the ARS513 sensor at worst case conditions.

- sensor on lower production limits (worst case assumption)
- max. operating temperature (worst case assumption)
- max. misalignment +/-6° in azimuth and elevation
- bumper attenuation 3 dB (two way)
- no strong attenuation by rain,etc.
- object detection based on 95% detection probability
- incl. 6 dB road reflection

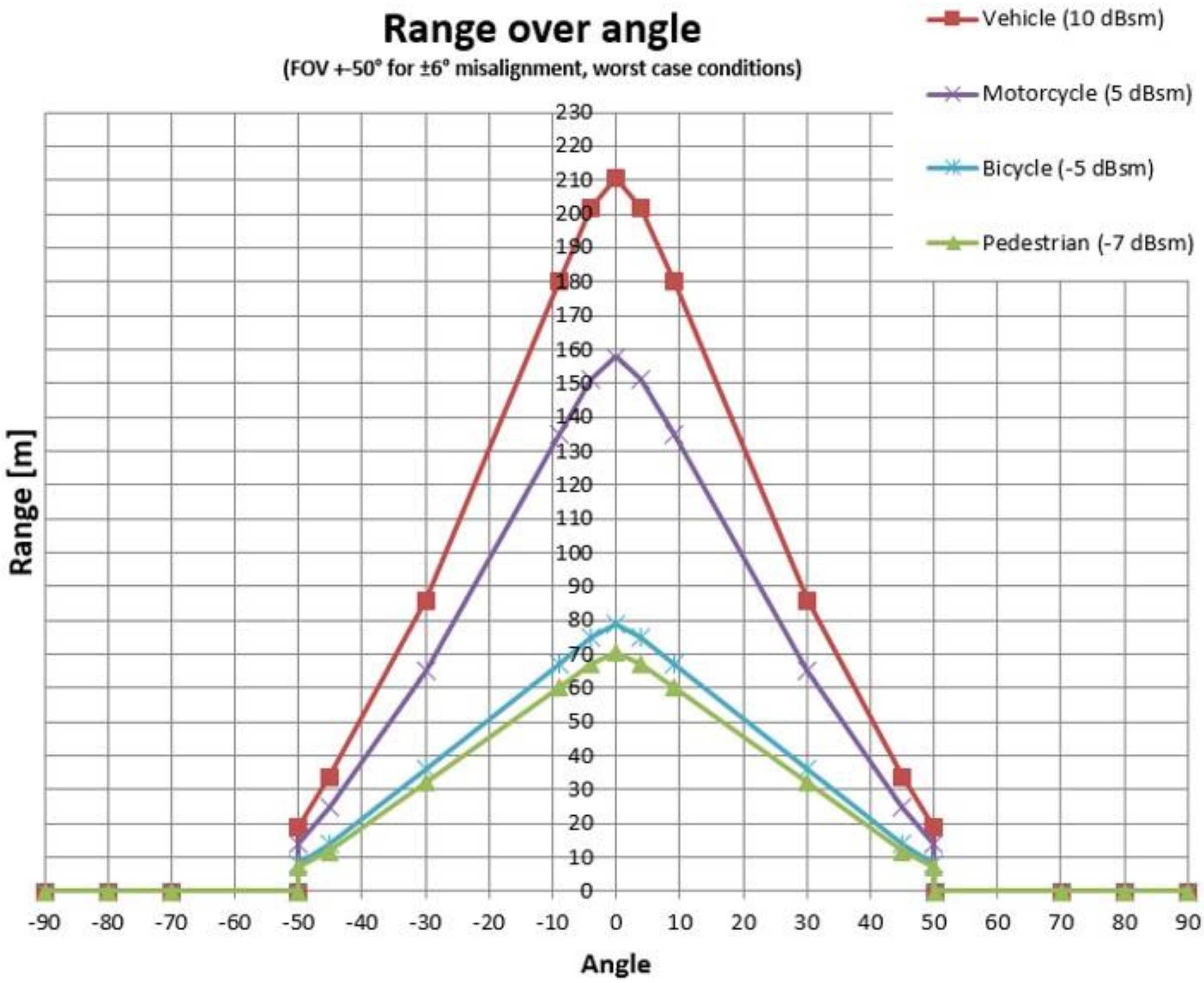


Figure 10: Detection Range for different objects (worst case conditions)

4.2.7 Radar Cone

The exact radar cones (HF cone and keep-out cone) will be provided together with the mechanic 3D data.

The matching radar cones will be provided according to the chosen field-of-view option.

If the OEM's intended installation of the sensor into the target vehicle will lead to restrictions of its field-of-view, this must be reviewed and agreed with Continental.

4.3 Functional Safety

4.3.1 Safety Goals

The ARS513 base projects have been developed on a variant-selectable Technical Safety Requirements (TSR) and Technical Safety Concept (TSC).

The safety goal realized in this sensor is to **avoid unintended braking** within the limits allowed for the specific implemented functions.

This safety goal has **maximum ASIL-B**.

The ASIL level for this safety goal depends on the application specific function implementations.

4.3.2 Safety Critical Errors

For a definition of safety critical errors refer to the sensor's technical safety concept.

This safety concept (TSC) will be mutually agreed on between the customer and Continental.

4.4 Automotive Security & Privacy

4.4.1 Basic Automotive Security & Privacy Concept

The ADAS Basic Security & Privacy Concept (BSPC) can fulfill certain countermeasures to ensure security and privacy.

As the component SPC must fit to the customer SPC on vehicle level, the description in this chapter only contains the BSPC as proposed by Continental ADAS.

The exact details including effort and cost negotiation of the SPC must be agreed between Continental ADAS and the customer.

Security & Privacy is not part of the ADAS standard quote and is treated as a change request (CR).

4.4.1.1 Security Goals

The following security goals are the base for the ADAS BSPC:

- Security Goal 1: Vehicle Interface Authenticity
  - Protection from manipulation or corruption of the communication via all connected vehicle interfaces
- Security Goal 2: Sensor Integrity
  - Protection of the sensor including its intended functionality from manipulation or corruption via the available interfaces which are accessible without removing the sensor from the vehicle
- Security Goal 3: Sensor Confidentiality
  - Protection of all secret information (e.g. keys and certificates) necessary to fulfill security goals of integrity and authenticity
- Security Goal 4: Sensor Privacy
  - Ensure authenticity, integrity, and confidentiality of privacy related information

The ADAS BSPC covers in particular:

- sensors with life cycle state „in field“ (after delivery to the OEM and during field use),
- software-based online- or OBD attacks onto the sensor.

However, the ADAS BSPC does <u>not</u> cover:

- attacks on a single hardware with specialized tools and methods right onto the sensor**,**
- manipulation during development**,**
- manipulation during “in field” return analysis and pre-production,
- attacks during those life cycle states shall not exploit attacks for “in field operation”, and

- handling of secret information for Continental and OEM production (e.g. certification, keys,...).

The final sensor security requirements including production and after sales must be agreed between Continental and the customer based on detailed security requirements derived by the customer via security analyses on vehicle level.

4.4.1.2 Basic Security Concept

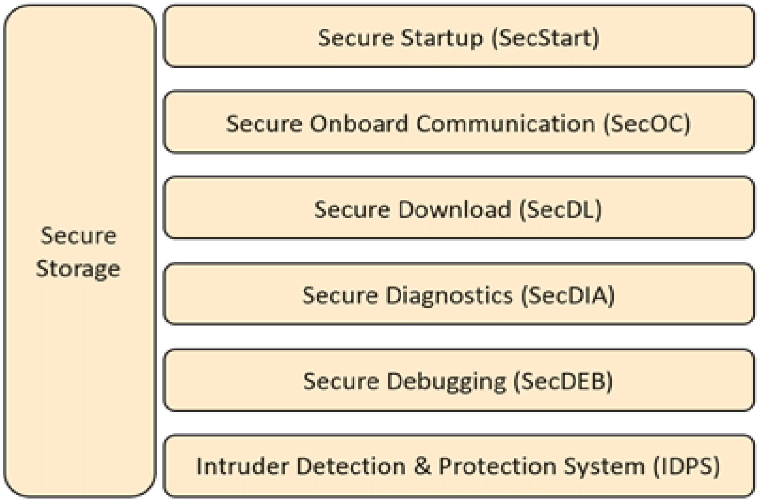


Figure 11: ARS513 Security Concept

As depicted in Figure 11 to fulfill the security goals of the ADAS BSPC the ARS513's design recommend to use following security elements:

- Secure Startup (Secure Boot) with a chain of trust
- Secure Onboard Communication
- Secure Download (Continental Bootloader + OEM Flashloader)
- Secure Diagnostic Interface (Continental + OEM)
- Secure Debugging Interface (JTAG)
- Intruder Detection and Protection System (IDPS)
- Secure Storage (Keys, etc.)

To enable these security elements the following security features could be implemented based on customer request:

- Secure Boot
- Secure Onboard Communication (AUTOSAR >=4.2)
- Cryptographic algorithms:
  - AES 128 (HW accelerator)
- Authentication algorithms:
  - CMAC using AES 128 (HW accelerator)
- Secure key handling
- True- and Pseudo Random Number Generator
- All debug interfaces (MCU) are secured on delivery (unlocking possible for field returns)

The following security features are optionally supported on request:

- Cryptographic algorithms:
  - RSA with 2048 bit (SW)
  - ECC with 256 bit (SW) - curve to be defined by customer
  - SHA-256
  - other customer specific algorithms
- Certification parser (e.g. X.509)
- Customer specific SW libraries (e.g. diagnostics)
- Event Data Logger

The elements of the ARS513 BSPC are implemented using the following HW and SW security blocks:

4.4.1.2.1 Basic Hardware Security Blocks

Figure 12 shows the basic HW security blocks available in the ARS513 sensor:

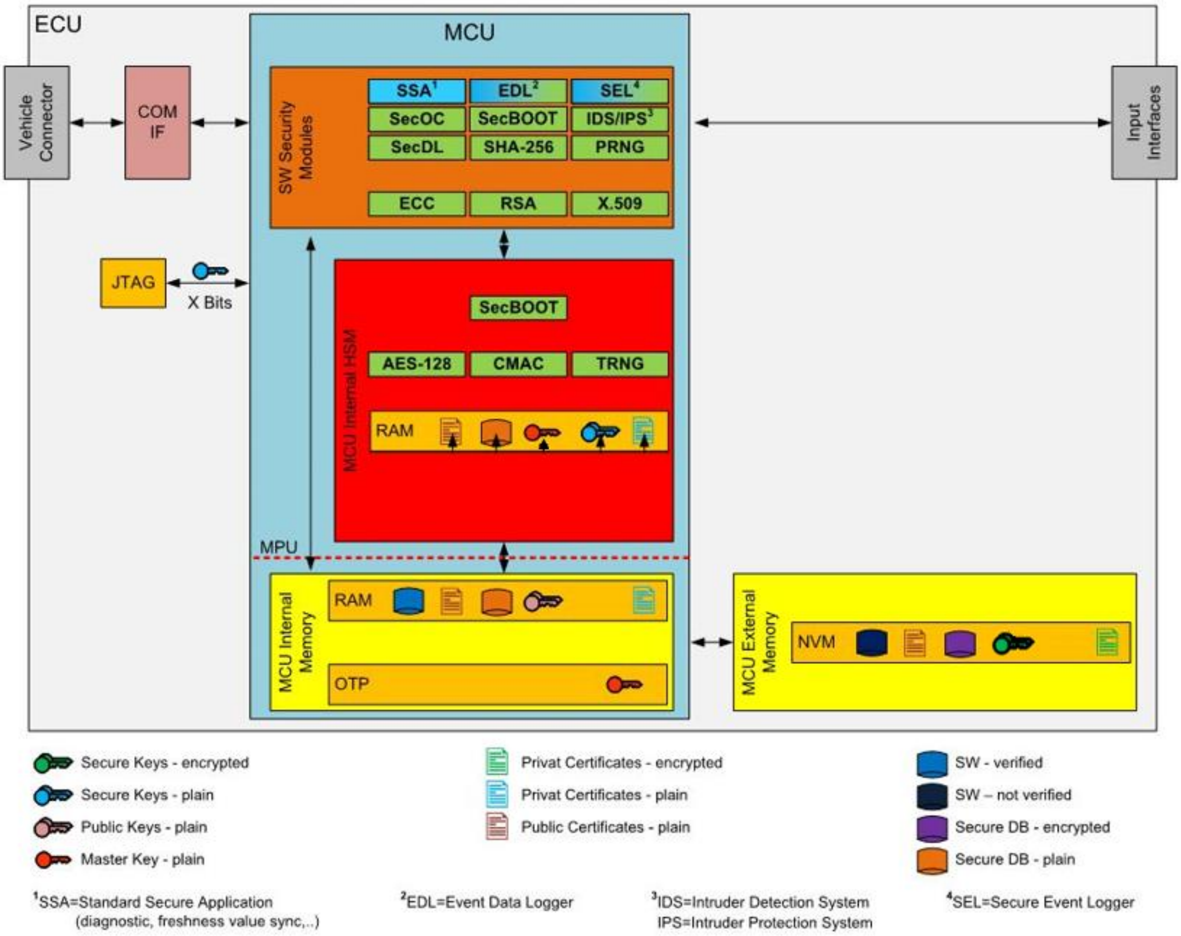


Figure 12: ARS513 Hardware Security Modules

The ARS513 basic HW security blocks include a SHE 1.1 compatible IP block and the JTAG debug interface locking/unlocking mechanism inside the main MCU.

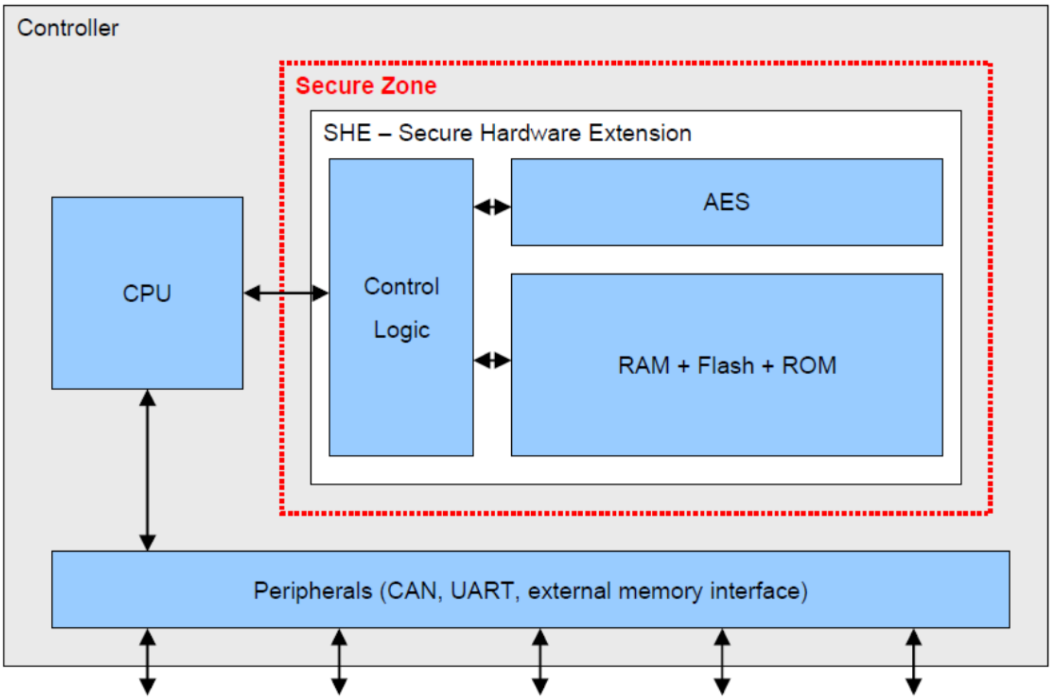


Figure 13: SHE Security Module

As indicated in Figure 13 the building block of a SHE module contains:

- Control Logic with command interface to main CPU
- HW accelerator for AES-128 (ECB and CBC mode) symmetric cryptographic algorithm
- CMAC generation and verification using the AES-128
- Secure Boot Support
- True Random Number Generator (TRNG)
- Secure Key image (encrypted Keys) in external flash memory (protected against re-play and cloning attacks) include
  - SECRET KEY
  - MASTER ECU KEY
  - BOOT MAC KEY
  - BOOT MAC
  - 50 user programmable sysmmetric AES-128 keys
  - TRNG as PRNG seed

- Small ROM (2 KB) to download the CSE firmware from system memory
- Secure RAM (32 KB) to store the CSE firmware and data (only accessible by the CSE3 itself)
- OTFAD with AES 128 (CTR) decryption.

4.4.1.2.2 Basic Software Security Blocks

Figure 14 shows the basic SW security blocks available in the ARS513 sensor.

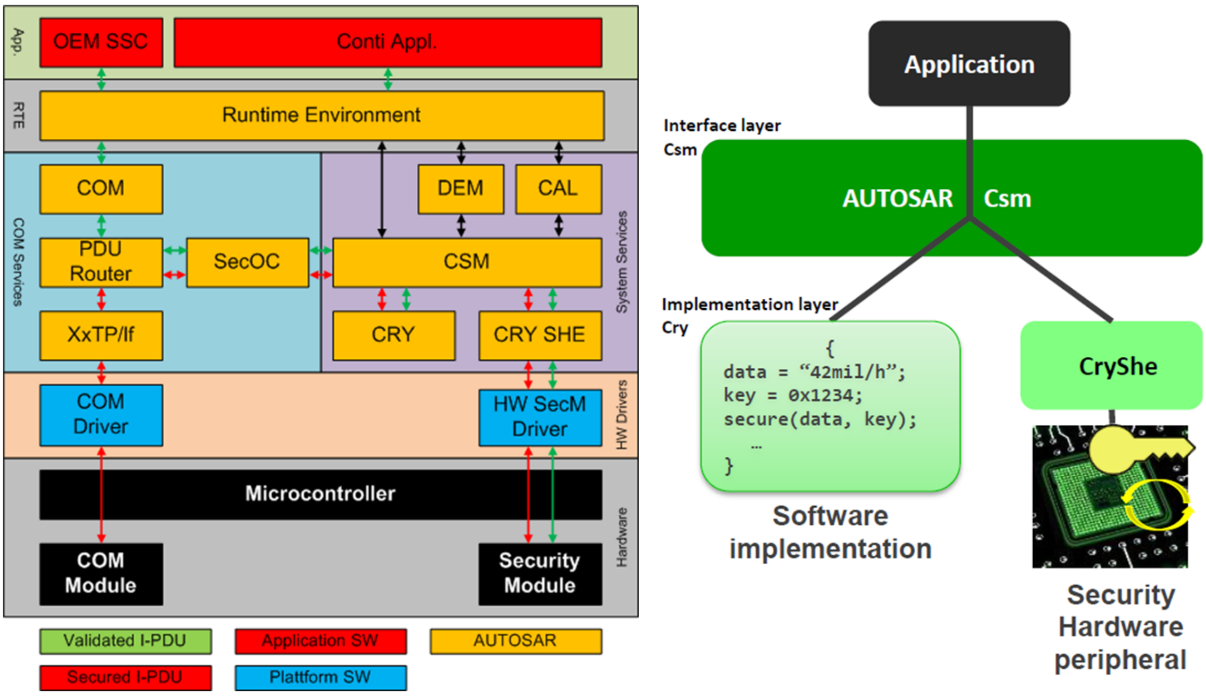


Figure 14: ARS513 Software Security Modules

The ARS513 basic SW contains the following security blocks included in the AUTOSAR (4.2 or higher) standard:

- PduR (Protocol Data Unit Router)
- SecOC (Secure Onboard Communication)
- CSM (Crypto Service Manager)
- Cry (Crypto Routine Library)
- CrySHE (Crypto Routine Library adaptation layer for the SHE module)
- Crypto Abstraction Library (CAL)

The final AUTOSAR version including security building blocks needs to be agreed between Continental and the OEM.

Additional SW security blocks not included in the AUTOSAR 4.2 standard:

- SHE module HW driver
- OEM specific SSC (Secure Software Component) for diagnostic, key management, ...
- Application SW

4.4.2 Export Controls on Cryptography

The ARS513 product fully is assembled in a plastic housing and specially designed for civil automotive applications. The use of encryption functions is strictly controlled by the firmware made by Continental and the MCU is not removable.

Therefore a classification regarding chapters 3 and 5 of the dual use list from Europe Union and United States of America is ruled out.

The final classification analysis of the product with the European Dual Use List, German Ausfuhrliste and the Commerce Control List (USA), is "not restricted" (European laws CE n° 428/2009,388/2012 and Bundesamt für Wirtschaft und Ausfuhrkontrolle) and "EAR99" (Export Administration Regulation).

4.4.3 CyberSecurity Compliance Disclaimer

CyberSecurity evidences, as required for vehicle type approval according UNECE WP.29 Regulation 155 and corresponding local regulation, are under responsibility of the CUSTOMER.

The CUSTOMER has to classified the PRODUCT as being security relevant or not being security relevant. This classification should be based on a risk assessment that takes the entire knowledge about the PRODUCT's environment/entire vehicle system into account.

In case the CUSTOMER is unsure about the risks that are specific to the PRODUCT itself and the resulting classification, CUSTOMER may request, as additional workproduct not part of standard offer, a Threat Analysis, Risk Assessment and Risk Treatment (TARA) on the level of scope of order from COMPANY. CUSTOMER will inform COMPANY as soon as possible about the classification of the PRODUCT, latest at PRODUCT concept freeze. If classification is later on still not finalized, COMPANY assumes that PRODUCT is security relevant. All consequences resulting from this assumption will be borne by CUSTOMER, in particular but without limitation regarding the time schedule, development costs and piece price of the PRODUCT. COMPANY shall have no liability related to this classification,except for damages which have been caused by COMPANY's willful intent.

If classification is being changed by the CUSTOMER and technical changes to the PRODUCT become necessary and/or the development process has to be changed, COMPANY reserves the right to submit a new offer factoring in the relevant technical and commercial aspects of the changes. All consequences resulting from those changes will be borne by CUSTOMER, in particular but without limitation regarding the time schedule, development costs and piece price of the PRODUCT. COMPANY furthermore reserves the right to retract the quotation or cancel the project should it turn out after CUSTOMER has made available the necessary information that the PRODUCT either cannot or only with unreasonable effort be developed or manufactured in a way that ensures the security and/or privacy of the PRODUCT. CUSTOMER shall be liable for all costs, expenses, losses and fees resulting from or arising in connection with these circumstances, except for damages which have been caused by COMPANY's willful intent. CUSTOMER shall indemnify, defend and hold harmless COMPANY from and against any and all third party claims related to product security and privacy.

4.4.4 CyberSecurity Maintenance Disclaimer

COMPANY regularly monitors for hardware and software related known vulnerabilities and analyses whether COMPANY developed (parts of the) product are affected. COMPANY is neither responsible nor liable for software parts that are provided by CUSTOMER or implemented on request of CUSTOMER.

In case COMPANY identifies a vulnerability on the technical solution CUSTOMER will be informed without undue delay. As a next step the target is to assess and analyze the identified vulnerability. If CUSTOMER requires a modification of the technical solution, the parties shall mutually agree on the technical and commercial condition of the required modification and a change request has to be issued by CUSTOMER.

In no case COMPANY shall be obliged to modify the technical solution or to do it at its own cost unless the vulnerability was caused by COMPANY's willful intent. Furthermore, CUSTOMER is responsible to provide the fixed supplied SW component parts, which have been previously supplied by CUSTOMER, in the version at time of delivery and, in accordance with the changed time schedule. A time plan for remediation, deployment and retesting is developed with CUSTOMER on discussion of the change request.

The beforehand described procedure about product security incident response management is valid until end of mass production phase (as defined in COMPANY quotation) of the product and covered with this quotation. COMPANY agrees to provide technical solutions necessary because of a discovered vulnerability until requirements freeze of development phase. Security maintenance and its conditions for the phase between end of mass production and end of maintenance of the product have to be defined and agreed in a specific maintenance /spare part service contract.

4.4.5 Privacy Disclaimer

CUSTOMER is fully and solely responsible to perform a comprehensive data protection impact assessment according all personal, person identifiable data (including technical data which is combinable or re-combinablewith specific persons, e.g. driver of car) within the PRODUCT, its components and with PRODUCT related goods or services for the relevant markets or countries. CUSTOMER shall provide relevant parts of such impact assessment without further request as confidential PRODUCT information at least including a detailed rating of security/privacy classification and necessary security measures of the PRODUCT.

COMPANY shall have no liability related to the handling of personally identifiable information or data incorporated into or used in conjunction with the product by CUSTOMER or its agents.

In case that any functions which collect and/or process privacy related data shall be included in the ARS513 radar sensor or collecting and/or processing of privacy relevant data provided by the product outside of the ARS513 radar sensor is considered, the installation and operation of the product may lead to the requirement of compliance with country specific legal regulations (e.g. data protection laws).

Therefore, we recommend to verify respective country specific legal regulations before installation and operation of this product with enabled collecting and/or processing of privacy related data.

4.5 Dynamic Behavior

4.5.1 Startup / Shutdown Behavior

The time from physically powering up the device until output of default data (signal not available - SNA) on the vehicle communication interface is ≤ 450 ms.

The time from physically powering up the device until all output signals are available on the vehicle communication interface is ≤ 1000 ms.

The sensor is capable of 'hot unplugging'.

A controlled shutdown shall not take longer than necessary to terminate all function, and the maximum shutdown time is less than 10 s.

Remark:

The time from powering up of the sensor until safety critical functions (e.g. EBA) are fully available, cannot be given as a fixed duration. These functions become enabled successively with improving certainty of the online alignment and the vehicle dynamics model which both depend on the movements (track, speed) and environment (static obstacles) of the starting vehicle.

4.5.2 Failure Behavior

When an error has been detected, the sensor can enter any of the following states:

- Category 3 error:
  - Fault affects function (EBA, ACC, etc.)
  - Fault detected by hardware/software, reaction performed by software
  - Reaction: Safe communication only, function degradation/disqualification
  - Diagnostic error entry in non-volatile memory
- Category 2 error:
  - Fault affects sensor infrastructure
  - Fault detected by software, reaction performed by software
  - Reaction: Safe Silence (MCU reset)
  - Diagnostic error entry in non-volatile memory
- Category 1 error:
  - Fault affects sensor infrastructure
  - Fault detected by hardware, reaction performed by hardware/software
  - Reaction: Safe Silence (MCU reset)
  - If possible: diagnostic error entry in non-volatile memory

CAT 1 & 2 faults are infrastructure-relevant, meaning the sensor can no longer be trusted to communicate reliably (e.g. RAM faults, ALU faults, etc.).

CAT 3 faults are function-relevant, meaning the sensor can still communicate its status, but the function itself (EBA, OI, etc.) is compromised (e.g. sensor front-end faults, co-processor faults, etc.).

All internally detected errors may lead to functional inhibitions and diagnostic trouble code entries (as agreed with the customer).

5. Interfaces

5.1 Electrical

5.1.1 Power Supply

The sensor supports either 12 V or 24 V nominal operating voltage. The 24 V version is implemented as a hardware population option.

Table 2 describes the Voltage supply operating modes for both the 12V and 24V variants of the radar sensor.

Table 2: Voltage Supply Operation Modes

Operation Mode	Behavior
Off	Sensor switched off
Undervoltage	- Sensor functions deactivated - Normal communication on vehicle bus - Limited fault and hardware monitoring (showing of errors) - Fault "Undervolatge" recorded
No Start/Stop cycle: Undervoltage	See above "Undervoltage"
Duriung Start/Stop cycle: normal	- Normal communication on vehicle bus - Normal hardware monitoring - Full fault monitoring
Normal	See above "Normal"
Overvoltage	- Sensor functions deactivated - Normal communication on vehicle bus - Normal hardware monitoring - Full fault monitoring (storing of fault "overvoltage")
Off/Self Protection	- No communication on vehicle bus - Internal HW overvoltage protection activated

The monitoring tolerance is ± 5% with a monitoring rate of every 10 ms.

Between 6.0V and 7.5V sensor operation can be sustained only for up to 30 seconds.

For the combined (12 V & 24 V) variant of the ARS513 sensor normal operation will be provided between 8V and 32V; the exact voltage limits for this variant are yet to be defined.

Within its hardware limits (see above), the general voltage behavior of the sensor can be programmed by software parameters; an example with hysteresis-free limits is shown in Figure 15.

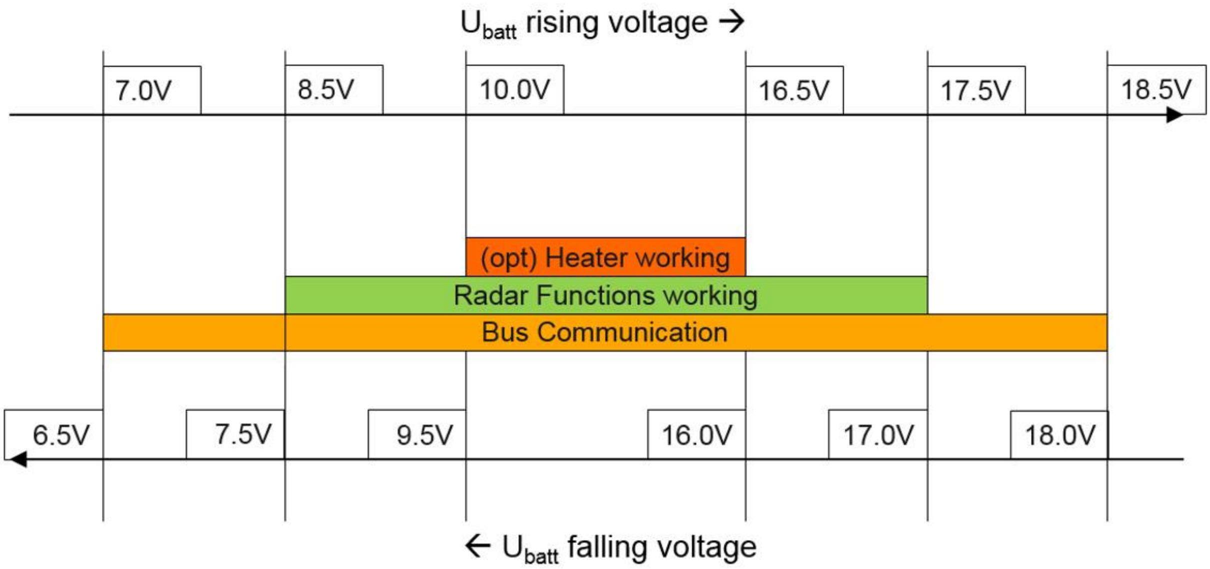


Figure 15: Software-adjustable Voltage Behavior

Table 3: Current and Power Consumption (12-24 V Variant)

Supply	Current & Power Consumption		
12 V	Current	Sleep Mode	200 µA (@12.5V Kl.30)
		Normal Operation	400 mA (typical)
		Peak Current	645 mA
	Power	Normal Operation	4.8 W (typical)
		max. Power Consumption	< 8,51 W
24 V	Current	Sleep Mode	<= 200 µA (@25.2V Kl.30)
		Normal Operation	200 mA (typical)
		Peak Current	310 mA
	Power	Normal Operation	5W (typical)
		max. Power Consumption	< 7 W
(power consumption of optional radome heater not considered here)			

5.1.2 Connecting the Sensor to the Supply System on-board

The power supply for the radar sensor is provided by vehicle UBATT via permanent battery supply (Kl. 30) or ignition (Kl. 15) and ground (Kl. 31).

The supply line has to be secured by a 10 A (TBC by Hardware) fuse.

To avoid electro-magnetic interferences through the supply lines to the control unit, the connections to UBATT and ground are to be kept as short as possible.

A longitudinal diode is used to protect the sensor from reverse-polarity.

There is a sensor variant with an internal load dump protection for customer vehicles without central load dump protection available.

The protection circuit disconnects the sensor from the battery supply voltage if the voltage level is rising above an upper hysteresis value and re-starts the sensor if the voltage level drops below the lower hysteresis value.

5.1.3 Input/Outputs

The current specification of the ARS513 sensor assumes the following combinations of communication interfaces:

- (default) 1x CAN-FD
- (optional) 1x CAN-FD with partial networking
- (optional) 2x CAN-FD
- (optional) 2x HS-CAN
- (optional) 1x Ethernet
- (optional) 1x Ethernet + 1x CAN-FD

5.1.3.1 CAN/CAN-FD Interface

The ARS513 provides a vehicle communication interface with CAN-FD with 2000 Kbit/s or CAN (500 Kbit/s) according to standard definition.

Either a host wake-up or unwakeable CAN transceiver module can be used for the sensor.

For the support of permanent battery supply (Kl.30) the CAN interface is host wake-up capable via CAN activities whereas for the support of ignition supply (Kl.15) the CAN interface is designed as not wake-up capable.

In this case, the sensor's software is configured to support the host wake-up capable CAN interface with the same CAN transceiver module.

The logical CAN interface supports the protocol as specified in ISO-11898.

5.1.3.2 Ethernet Interface (optional)

The sensor supports 100 Mbit/s Ethernet based on Broadr-Reach® physical layer specification [8].

The sensor supports Ethernet logical interface protocol based on IEEE standards 1588 v2 and 802.1AS.

5.1.3.3 Radome Heating Switch Output (optional)

The sensor provides a radome heating control to improve availability in case of freezing rain or wet snow. Usual rain and dry snow will not affect availability of the sensor. Heating power is controlled by a pulse width modulation (PWM) to compensate for driving speed, voltage level, ambient temperature, etc.

The output is a PWM modulated signal of VBATT. The heat switch and the connector pins support a maximum heater power of 35 W.

The radome heating can be powered over a separate power supply pin, decoupled from the sensor's normal power supply.

The control circuit is short-circuit-proof, protected from having incorrect polarity and protected against excessive temperatures. In case of malfunction an event is written to the error log.

The heating shall consist of a special arrangement of metallic wires. The wires in the secondary surface shall fulfill the following requirements:

- The orientation of the wires shall be perpendicular to the radar polarization; otherwise the heating acts as radar mirror and would restrict radar propagation. Since the sensor is emitting a horizontally polarized HF signal, the wires have to run vertically. If the sensor is tilted relative to the heating wires, additional losses due to polarization mismatch will occur.
- The perpendicularity of the wires shall be within 90°+/-1.5°.
- The thickness of the wires shall be smaller than 1/10 of the effective wavelength (see Figure 26) inside of the material of the secondary surface.
- The spacing of the wires shall be verified by simulation to match with the sensor.
- The spacing of the wires shall be larger than the effective wavelength (see Figure 26) inside of the material of the secondary surface.
- The attenuation caused by the heating wires shall not exceed 0.5 dB (one way) in sum not more than 3 dB.

Continental will support the customer in the design of a radome heating to ensure robust radar performance.Heating technology parameters like diameter, spacing, material, orientation etc. shall be finalized with Continental by the OEM.

Any radome heating design should be verified and released by Continental.

5.2 Data Acquisition during Development Phase

Throughout the development phase sensor data needs to be measured, recorded, replayed, simulated, and evaluated. To be able to do this, a measurement system may be applied to the sensor.

As a result of that there is a restricted area on the back of the sensor which has to be kept free to provide access to Continental's Measurement Technique Interface (MTI) via a Measurement Technique Adapter (MTA). The MTA adaptor drawings and keep-out-area are specified in the mechanical data which are handed over after project start.

The data base of recorded scenes can be re-used for evaluating new software versions (as long as no changes in RF-PCB or Raw Data Processing were implemented). Details will be discussed between Continental and the OEM during the project.

The following Figure 16 shows the rear side of the ARS513 with MTI connected.

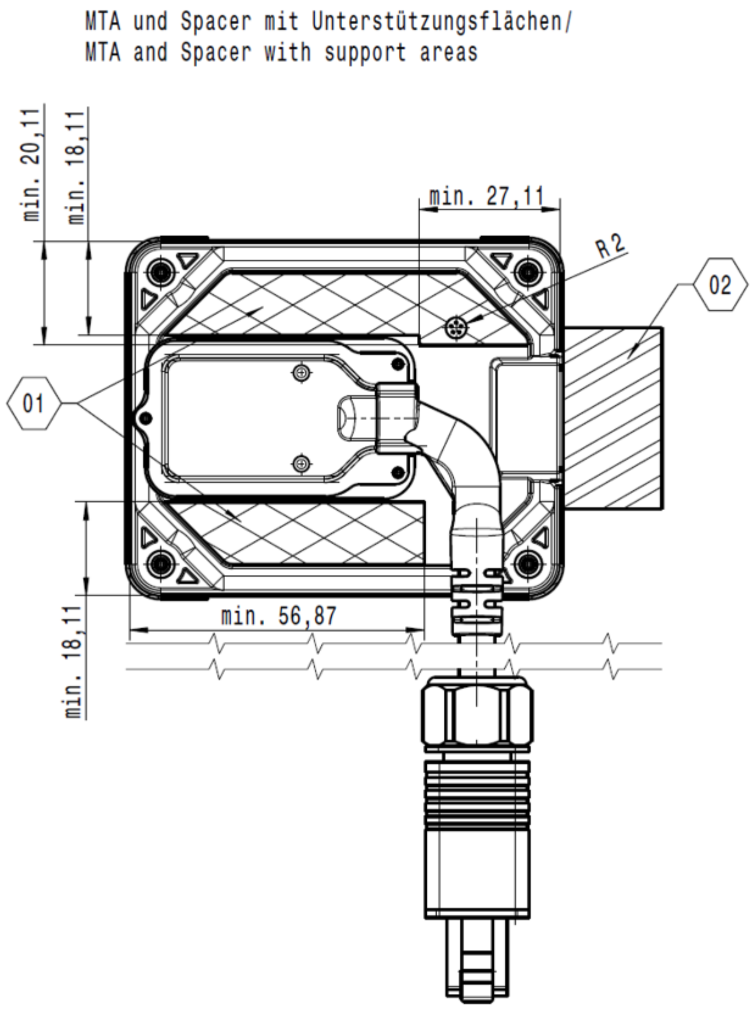


Figure 16: MTI Access Area (for Mechanics Configuration M-B)

5.3 Functional

5.3.1 Input Signals

5.3.1.1 Required Static Parameters

Following static parameters are required from the customer, as they need to be coded into the sensor.

- Wheel base
- Vehicle width
- Vehicle length
- Sensor orientation in relation to the vehicle driving direction
- Sensor longitudinal position (LongPos) in relation to the vehicle reference point
- Sensor lateral position (LatPos) in relation to the vehicle reference point
- Sensor vertical position (VerPos) in relation to the vehicle reference point

The parameters shall not vary more than +/-5 cm around the coded nominal value. In case of a larger deviation the detection of over- and under-drivable objects may be impaired.

Remark:

- The customer shall provide the tolerance window which inherits max. variation in up- and down-direction. In case of an unsymmetrical window the coded value shall be the midpoint of the window.

5.3.1.2 Required Dynamic Parameters

The following dynamic parameters are required:

- Yaw Rate
- Wheel Speed, Vehicle Speed or Wheel Circumference Velocity
- Steering Wheel Angle
- Driving direction
- Change of vehicle load capacity
- Adjustable suspension (e.g. offroad drive / onroad drive or high ego velocity)

The required signal quality depends on the expected sensor performance and needs to be reviewed and agreed between Continental and the customer. Binary message format and required precision of the dynamic input parameters will be agreed upon in separate documents.

Table 4: ARS513 Input Signals

Input Signals by Interface			
Mandatory	Dynamic Parameters	Vehicle Bus	shared
Mandatory	HMI (e.g. set ACC speed)		
Mandatory	Control Commands (e.g. start service alignment, SW updates)		
Optional	Camera Fusion (Objects + Lane + TSR)	Fusion Bus	private
Optional	Navigation System Fusion (map data + speed limits)		

5.3.2 Output Signals

Required output signals depend on expected sensor and vehicle function and need to be agreed between Continental and the customer.

Table 5: ARS513 Output Signals

Output Signals by Interface		
Object List to external ECU	Vehicle Bus	shared
EBA/ACC Brake Request		
ACC Acceleration Request		
Road Information		
Warning / HMI		
Function Degradation / Blockage Status		
Diagnostic / Error Management		
Heating of Secondary Surface (optional)	Hardwire Pin	

5.4 Mechanical

The device needs to be integrated in the front end of the vehicle.

Information to support the optimal device mounting fixture integration concept shall be shared with the customer.

For mounting location of radar sensor and secondary surface properties please refer to section 'Mounting Guidelines' of this TPS.

5.4.1 Housing

Table 6 shows the mechanic dimensions and masses.

Table 6: ARS513 - Dimension and Mass

Mechanical config		M-A	M-B	M-C
	Width	68.5 mm	68.5 mm	68.5 mm
	Length	111.0 mm (incl. mounting ears)	83.5 mm (without connector)	83.5 mm
Dimension	Height	20.0 mm	20.0 mm	20.0 mm
Mass		< 170 g	< 170 g	< 170 g

The exact dimension of the radar sensor variants could be found in the mechanical drawings which could be provided on request.

5.4.1.1 ARS513 Mechanic Configurations

Figure 17: ARS513 Mechanic Config M-A - top and bottom view

Figure 18: ARS513 Mechanic Config M-B - top view

5.4.1.1.1 Mechanic Config M-C

Figure 19: ARS513 Mechanic Config M-C - top view

5.4.2 Fixation of the ARS513 Sensor

5.4.2.1 Mechanic Configuration M-A

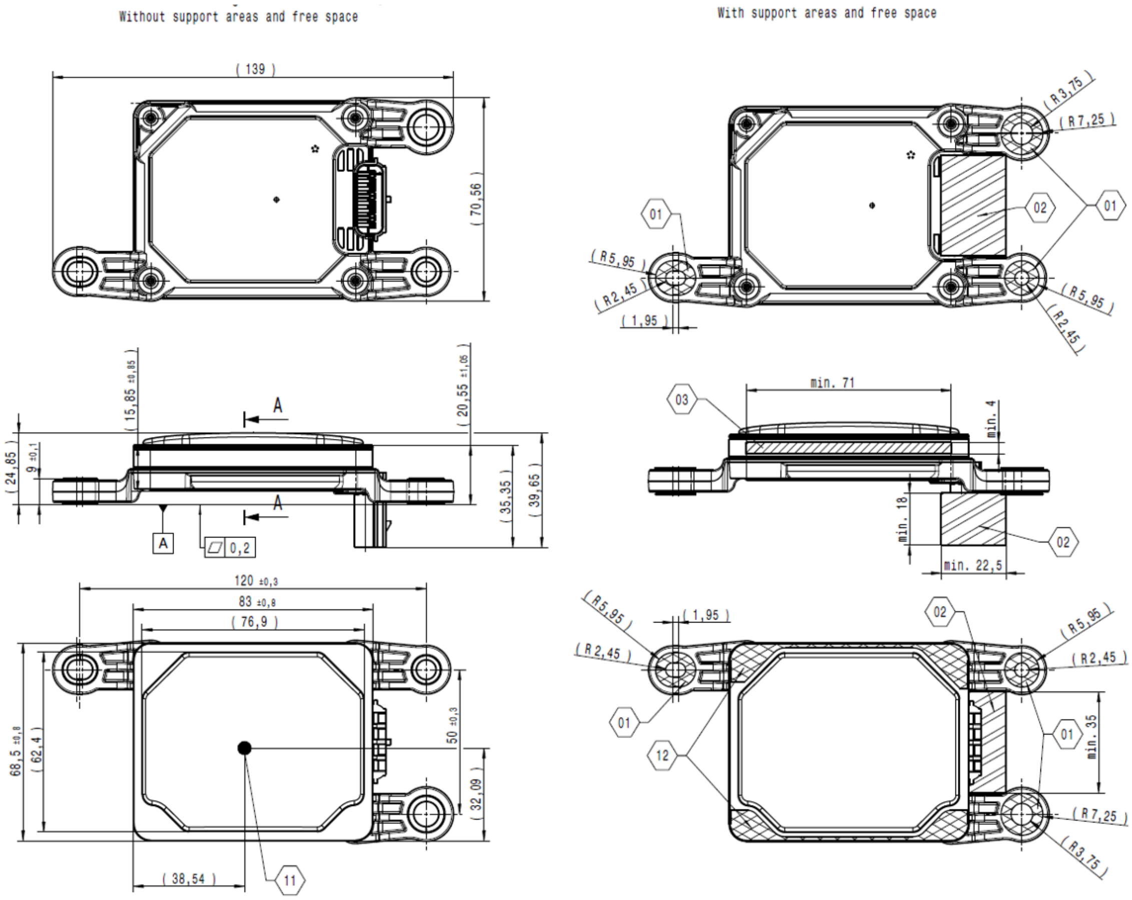


Figure 20: Mounting Dimensions M-A

5.4.2.2 Mechanic Configuration M-B

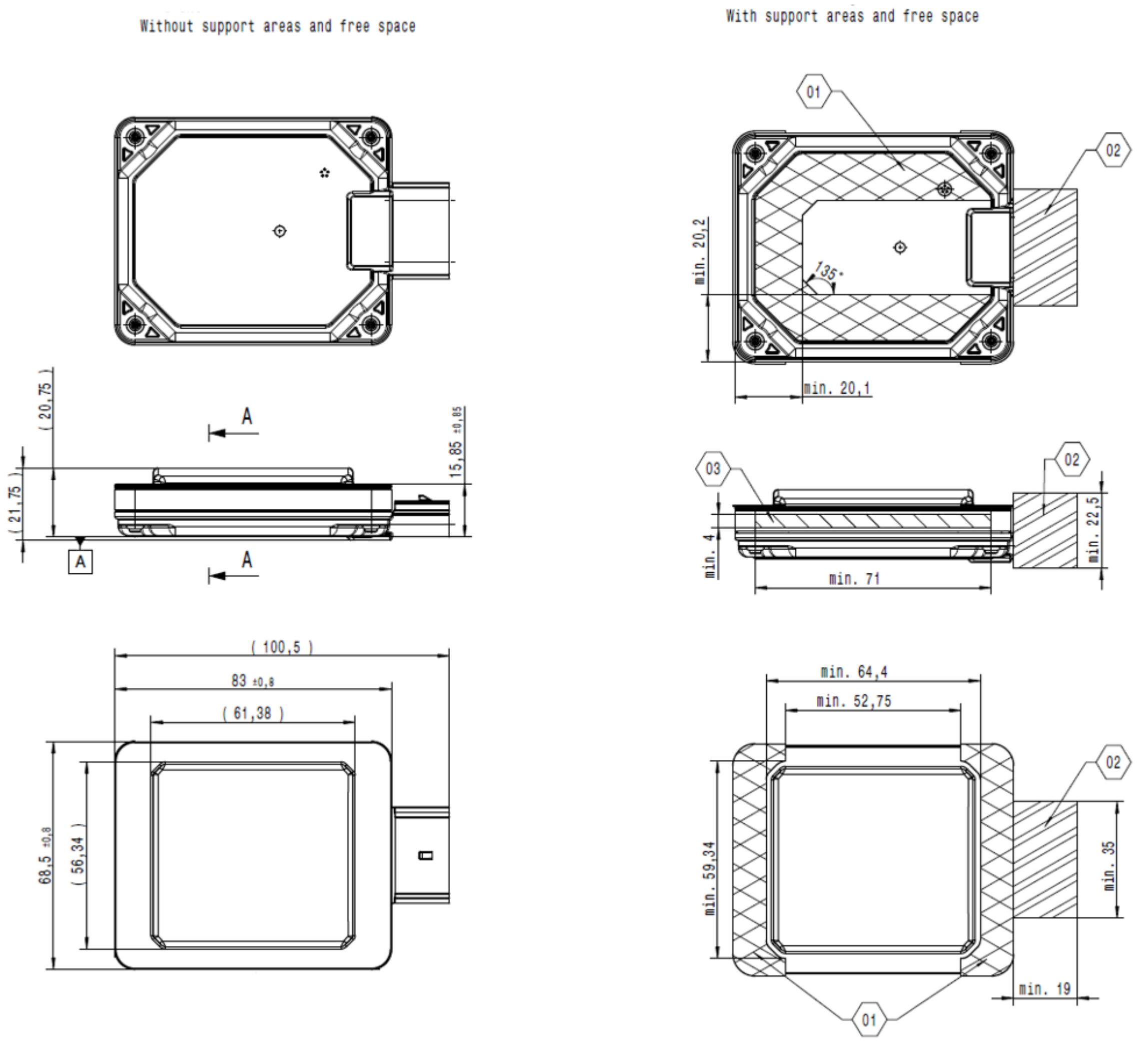


Figure 21: Mounting Dimensions M-B (preliminary)

5.4.3 Vehicle Connector

5.4.3.1 Connector Orientation

The default mounting orientation has the vehicle connector facing leftwards, from a view in driving direction. The sensor can also be mounted with the connector facing rightwards. The mounting orientation must be coded in the sensor's internal parameters.

Mounting orientation affects the position of the TX- and RX-antennas. TX- and RX-antennas have different apertures; therefore they are differently influenced by the structure of the secondary surface. To apply best performance the connector orientation shall be evaluated depending on mounting location between customer and Continental.

5.4.3.2 Vehicle Connector Type and Dimensions

Connector Type **CT-A**:

- 8 pin Molex waterproof vehicle connector
- Type: USCAR 064-S-008-I-Z02

Connector Type:

- 2*4 pin Sumitomo waterproof vehicle connector

5.4.3.3 Vehicle Connector Pin-Out

The pin assignment depends on the communication interface, optional radome heater, etc. and can be adapted according to user requirements.

5.4.4 Label

The ARS513's label consists of two parts. One label is situated on the side and is realized as data-matrix code. As shown in Figure 22, the other label is located on the front of the housing; laser marked and containing areas reserved for Continental and for the customer information.

Investigations have shown a negligible effect on radar performance.

For queries and request the serial-ID shall be stated.

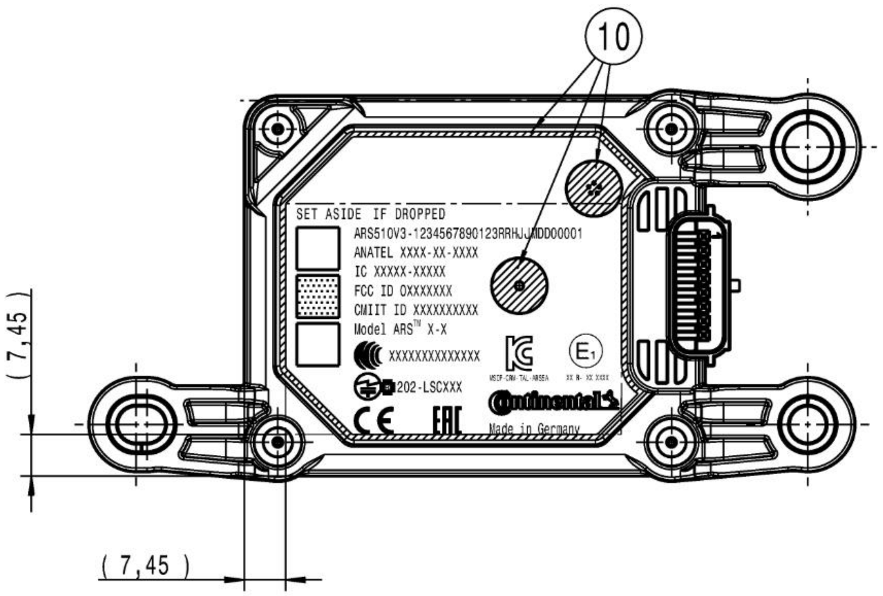


Figure 22: Label with area reserved for customer and Continental (mech. variant M-A)

5.4.5 Material

All sensor components are confirmed against GADSL (Global Automotive Declarable Substance List).

The ARS513's housing consists of following materials:

- Housing (bottom): PBT 30GF
- Carrier (center): Al alloy / pure aluminium
- Radome (top): PBT 30GF

5.5 Software

The software architecture of the sensor distinguishes between Frame-SW and Algorithm-SW feature.

The SW supports AUTOSAR Release 4.2.

Integration of 3rd party software for further function or other AUTOSAR version needs to be agreed between Continental and the customer.

5.5.1 Frame-SW

The Frame-SW can be separated in 2 main areas with following functionalities:

- Frame SW for internal functions:
  - Operating system: OS (incl. MMU/MPU)
  - Energy management
  - Hardware abstraction interface
  - Control and system services
  - Self tests
  - Radar interface
  - Algo interface
  - Thermal shut-down / voltage protection
- Frame SW for external functions:
  - Bootloader with flashing
  - Communication interface (public and private)
  - Diagnosis with error & event management (DEM's)
  - Coding and parameterization (incl. variant handling)
  - Measurement technology interface (MTI)
  - Other IOs (e.g. external Radome heating switch)
  - Configuration of Runtime Environment (RTE)

5.5.1.1 Communication Interface SW Implementation

The communication interface software handled via vehicle interconnection bus is divided in the following classes:

- Download
- Driver assistance functions
- Diagnostic functions
- Special functions (download parameters, interface measurement)

Download, diagnostic and special functions are customer specific and cannot be described in this generic product specification. Therefore only basic functions of these interfaces are described here.

The definition of the communication part of the system is expected as delivery from the customer as ARXML file

- either as ECUExtract of the system description or
- as system description containing the following configuration:

  - Message (frame trigger (cycle time)),
  - PDU groups, PDU (E2E protection),
  - Signal groups, mapping to ECU (complete with all attributes),
  - Signals (Compumethod, units, cycle time, trigger method, invalid values),
  - SW-C descriptions customer specific and composition for ADAS sensor,
  - Including the relevant links between the entities,
  - Networking and partial networking information,
  - Special BSW Rules.

Alternative formats have to be agreed.

The driver assistance specific interfaces are dependent on which functionality is integrated in the sensor. By default the following interfaces are available

- Object list with or without track assignment
- Relevant object plus neighbor objects (left, right and in front of the relevant object) if required
- FSRA acceleration interface

5.5.2 Diagnostic Interface

Following customer diagnostic protocols are supported by the sensor:

- Diagnostic over vehicle bus (CAN/CAN-FD or Ethernet)
- UDS protocol

5.5.3 Algorithmic-SW

The Algorithmic-SW can be separated in 4 main areas with following functionalities:

- Data Acquisition and Processing:
  - Radar hardware control
  - Raw signal processing
- Data Analysis and Classification:
  - Course estimation
  - Road description
  - Vehicle dynamic observer
  - Object detection and classification (including pedestrian and bicycle detection)
- High-Level Functions:
  - Adaptive cruise control
  - Emergency brake assist
  - Traffic jam assist
  - Sensor fusion
- Support and Safety Functions:

- Auto alignment
- End of line alignment
- Service alignment
- Performance degradation (Blockage)

6. Mounting Guidelines

6.1 Sensor Coordinate System

The sensor component axis or coordinate system is according to AUTOSAR and ISO-8855 standard.

Additionally the center of the sensor is defined according to the Figure 23.

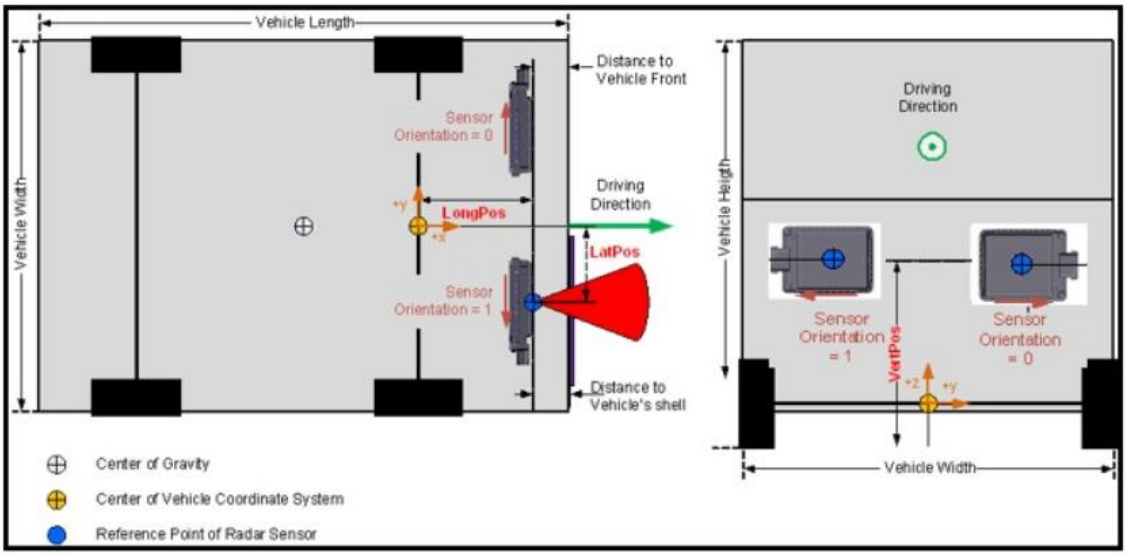


Figure 23: Sensor Coordinate System

The mounting height of the sensor shall be coded +/-5 cm around the nominal value.

6.2 Location Mounting Tolerances

The location mounting tolerances describe the admissible horizontal and vertical offset of the sensor location (reference point) compared to the vehicle axis as summarized in the mounting window given in Figure 24.

This mounting window should not be understood in a “black/white sense”, with full performance everywhere within and zero performance anywhwere outside. It rather summarizes Continental’s experience from various customer projects: Outside the given mounting window impaired sensor performance is to be expected. Any such mounting location will require substantial validation effort.

Limits of horizontal deviation based on vehicle axis (LatPos):

- Up to 600 mm out of vehicle center with nominal performance
- From 600 - 900 mm out of vehicle center: with performance limitations for full speed range ACC function

Limits of vertical deviation from road surface (VertCenter + VertPos):

- From 295 - 1000 mm above road-surface level with nominal performance

- From 1000 - 1200 mm above road-surface level with performance limitations

Notes:

- Performance limitations for full speed range ACC (FSRA) and EBA functions are expected if positioned at outer edge of specified range.
- Performance limitations for EuroNCAP Pedestrian function are expected if positioned at outer edge of specified range.
- Values are measured from the sensor centre.

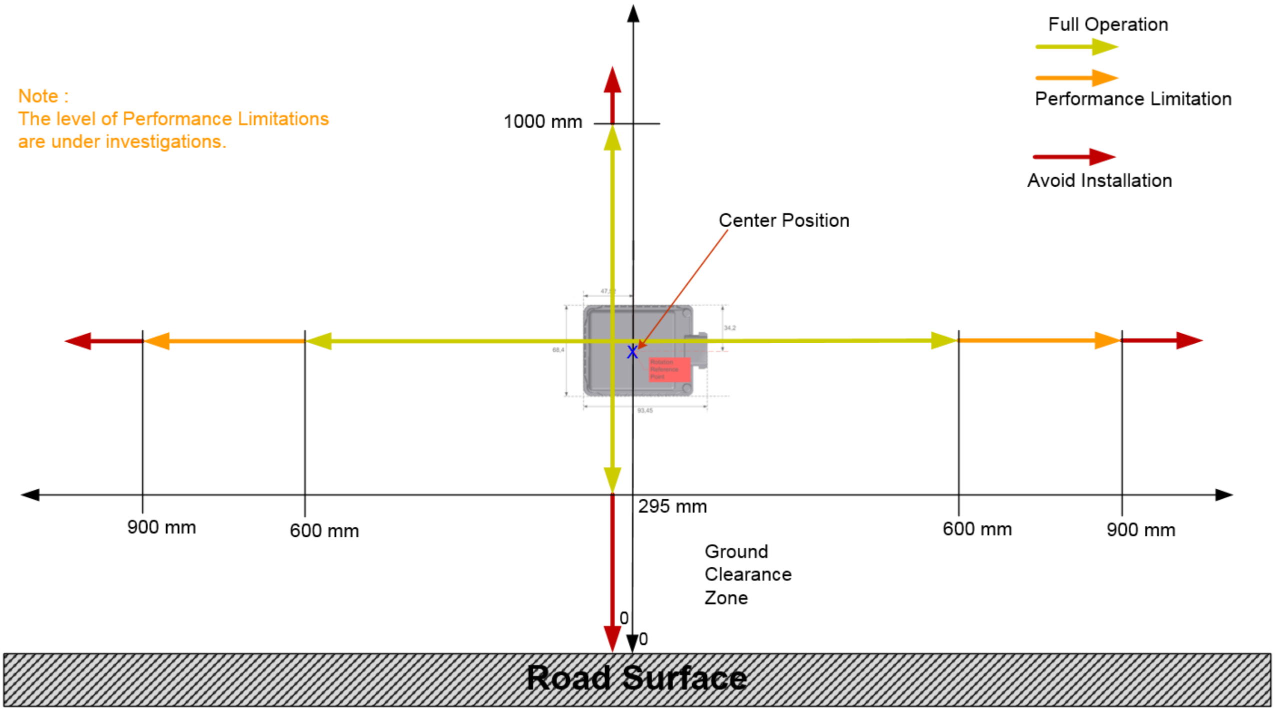


Figure 24: Mounting Location

6.3 Angular Mounting Tolerances

The maximum out of position angles to normal position (sensor-front perpendicular to road surface and perpendicular to vehicle axis) corresponds to alignment capability as given in the section "Calibration and Blockage".

The mechanical mounting tolerances include the **sum** of the following contributions:

- Drive axis-vehicle body
- Vehicle Body-Bracket
- Bracket-Sensor
- Change of loading condition (e.g. empty/full trunk)
- Wind load

The better the accuracy of drive axis-vehicle body the more mounting margin is available for the other contributions. The mounting tolerances have to be confirmed for each new vehicle platform.

The alignment feature of the sensor provides on-line calibration to compensate mounting tolerances. Misalignment consists of

- Misalignment in the factory
- Changes over lifetime
- Loading

6.4 Secondary Surface (Radome)

Between the sensor and the exterior of the car there shall be a 'secondary surface'. It protects the sensor from stone chipping and UV radiation. It also prevents direct impact of abrasive media and massive water exposure. The secondary surface may be an emblem, the bumper or a radar optimized structure.

Open mounting of the sensor (i.e. without protective secondary surface) is not supported.

The position and orientation of the sensor in relation to the secondary surface cannot generally be specified, but has to be evaluated individually.

Configuration for optimum system performance depends on:

- Thickness
- Material
- Form
- Distance
- Homogeneity
- Tilt of the secondary surface

For a given appropriate design of the secondary surface, the system can be configured in such a way, that usage is secure and unaffected even when mounting tolerances within the given limits are taken into account.

The position (distance, mounting angle) of the sensor relative to the secondary surface needs to be evaluated/validated by customer and supplier, based on measurements in the anechoic chamber at Continental and/or simulations.

6.4.1 Secondary Surface - Distance and Angle

According to the mounting position of the sensor for a specific platform, the distance between the sensor front cover and the secondary surface shall be designed large enough to avoid mechanical interferences, caused by thermal geometry changes or mechanical stress (e.g. vibrations).

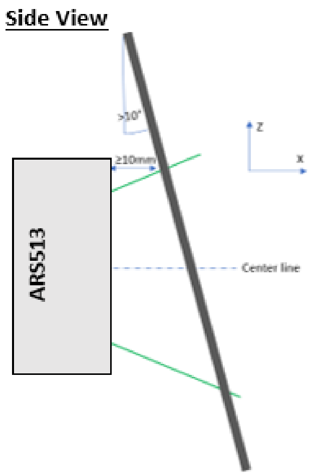


Figure 25: Distance of Secondary Surface (side view)

In addition to that, the distance to the secondary surface shall be large enough to avoid development of a constant water film or snow or mud cover. Continental recommends a minimum distance of 10 mm to the secondary surface, if the sensor is accessible by rain, snow, mud etc. indirectly. If the area between sensor and secondary surface is not accessible by rain, snow, mud, etc. the minimum distance may be reduced to 5 mm.

However, it shall also be considered, that the distance between sensor and secondary surface may have an impact on passive safety (pedestrian protection) and function availability (e.g. blockage). The impact on passive safety shall be evaluated by the customer; the impact on function availability will be evaluated by Continental.

The combination of sensor unit and mounting position shall be secured against whistling/ wheezing noise. As a proposal this should be checked in a wind tunnel by the customer.

Tilting of the secondary surface:

Relative to the sensor plane, the secondary surface may face slightly upward or downwards, but lateral angles (secondary surface facing left or right) shall be avoided.

The angle between sensor and secondary surface is therefore designated as 'tilt angle'. For the tilt angle applied to the secondary surface, the following points shall be considered:

- A too small tilt angle may introduce multipath reflection between sensor and secondary surface and might increase noise level, reduce non-ambiguous angle area and might cause ghost object issues.
- A too high tilt angle increases the effective thickness and therefore increases damping due to material losses, reduces non-ambiguous angle area and might cause ghost object issues.

- For maximum performance the tilt angle shall be 10° < x < 30°.
- This tilt angle range is valid for both sensor orientations (connector facing either right or left).
- In case the secondary surface is tilted downwards, the tilt angle shall remain within the corresponding range of -30° < x < -10°.
- If the secondary surface has optimal thickness according to Table 7, smaller tilt angles down to |x| > 10° may be accepted.
- The combination of large tilt angles and large distance to the secondary surface has to be considered with special attention.
  - Propagation paths through the engine compartment which can lead to ghost targets.
  - Multipath propagation e.g. between bracket and secondary surface resulting in higher sidelobes or inaccurate angular measurement.

6.4.2 Secondary Surface - Material Properties

Please note that material properties given by manufacturers normally refer to frequencies in the MHz-range or below. For radar frequencies (in our case 77 GHz) the dielectric constant may differ substantially from the value stated in data sheets.

Materials used as structure for the bumper/secondary surface shall have the following properties:

- Synthetic materials with low dielectric loss factors at the specific radar frequency shall be used in order to achieve low transition damping.
- Synthetic materials with low dielectric constants (ε_r) shall be used in order to obtain low surface reflection.

Possible materials for secondary surfaces are shown in Table 7.

Table 7: Dielectric Constant and optimal thickness of common bumper materials @ 77 GHz

Material	Dielectric constant ε_r @ 77 GHz	Optimum thickness [mm]	Second maximum [mm]	Third maximum [mm]
Polypropylene	2.35	1.292	2.583	3.875
Polyamide	2.75	1.194	2.388	3.582
Polycarbonate	2.80	1.183	2.366	3.550
PC-PBT (Polycarbonate-Type)	2.90	1.163	2.325	3.488
ABS (Acrylonitrile-Butadien-Styrole)	3.12	1.121	2.242	3.363
ASA (Acrylonitrile Styrene Acrylate)	3.80	1.016	2.031	3.047
PMMA (Poly Methyl Methacrylate)	3.40	1.074	2.148	3.221
SMC (Sheet Moulding Compound)	4.85	0.90	1.80	2.70

Based on experience it is important to note, that the actual properties of a certain material may also differ from supplier to supplier according to the used composition or density. Therefore, all values for the dielectric constant given in the paragraph can only be used as a guideline. Continental offers the customer to measure the dielectric constant ε_r of the intended material on a quasi-optical bench.

6.4.3 Secondary Surface - Thickness and Curvature

To achieve high permeability, the overall thickness of the secondary surface has to be carefully selected. The effective wavelength λ_{eff} in the material can be calculated on basis of the measured dielectric constant ε_r as follows:

$$\lambda_{eff} = \frac{c_0}{f}\frac{1}{\sqrt{\varepsilon_r}}$$

Figure 26: Effective Wavelength

The formula given above is only applicable for small to medium tilt angles (approx. up to 30°) of the secondary surface against the sensor front. A multiple of half of the effective wavelength within the material would be appropriate. For example, for the ABS material (ε_r = 3.12) any value of n*1.1 mm (@77 GHz, n=1,2,..) is favorable, whereby with raising thickness the attenuation is increasing.

Generally the nominal thickness of the cover material should be selected according to the minimum loss for the given tilt angle.

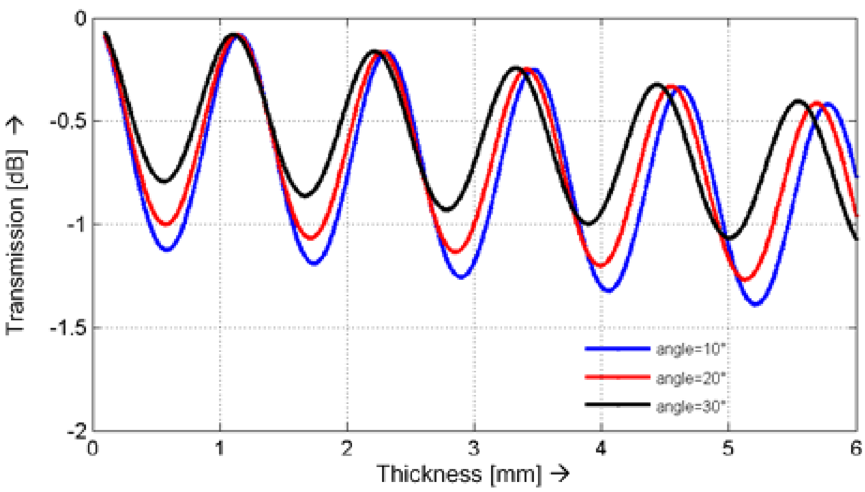


Figure 27: Attenuation in dependency of material thickness and tilt angles

To prevent distortion of the radar beams, the secondary surface shall be as planar as possible while providing constant thickness. Smaller curvature radii affect the radar beam performance and thus the function performance. The allowed curvature radius in y-direction may be calculated from Figure 28 and Figure 29.

To prevent distortions of the radar beam, the secondary surface shall not contain holes, ribbed profiles, sharp edges or abrupt thickness changes.

Exception: Grooves and ridges on the secondary surface which result in thickness variations <0.3 mm, are acceptable.

The following recommendations give a general impression of favorable boundary conditions:

- The secondary surface shall have a planar or convex shape, i.e. its sign of curvature shall not change in z-direction. (Changes of the curvature sign make the sensor/surface constellation highly sensitive to even small shifts of sensor vs. surface.)
- The minimum allowed curvature radius in z-direction corresponds to the minimum allowed curvature radius in y-direction given below.
- The curvature in y-direction of the secondary surface shall be symmetrical to the center line of the sensor.
- The maximum distance between sensor and secondary surface shall appear at the center line of the sensor.

Assuming a maximum distance of 20 mm between sensor and secondary surface (see Figure 28), the variation in distance shall be <6 mm (distance at sensor's center line versus distance at edge of radar cone).

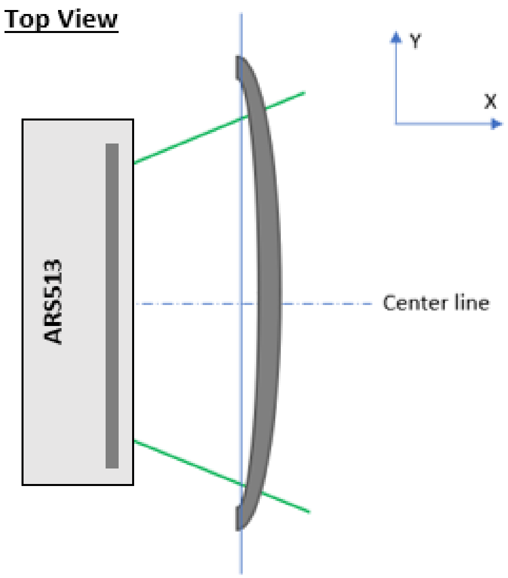


Figure 28: Curvature center position of Secondary Surface

Assuming a minimum distance of 5 mm between sensor and secondary surface (see Figure 29), the variation in distance shall be <3 mm (distance at sensor's center line versus distance at edge of radar cone).

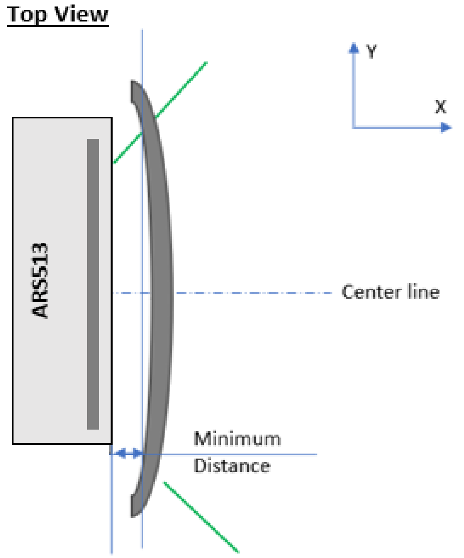


Figure 29: Distance between Sensor Surface and Secondary Surface

While single water drops on the secondary surface are not deemed critical, a closed water film could result in partial or full blockage of the sensor.

Any specific geometry of the secondary surface including the mounting structure of the radar sensor shall be provided to Continental in order to evaluate impact on functionality and performance of the sensor. In any case, radar measurements need to be performed.

6.4.4 Secondary Surface - Painting

The secondary surface can in principle be painted but a dedicated analysis and control of the different possible categories of paintings is mandatory to avoid significant performance degradation.

In general the secondary surface will carry several layers of primer, paint and varnishes. These layers in combination with the structure material will influence both surface reflection properties and the transmission damping. All kinds of metallic materials prevent respectively degrade sensor radiation and shall not be used on a secondary surface.

Elements containing metallic particles must be verified. The applicability of metallic paintings is dependent on

- The metal content (percentage) in the painting
- The size and shape of the metal particles in the painting
- Number and thicknesses of different layers of paintings and primers

The material thickness tolerance should be +/-0.1 mm. A summary of all known mechanical design guidelines for painting and structure of the secondary surface is shown in Table 8.

Table 8: Design Guidelines for Structure and Painting

Factor	GO	NO GO	Performance Degradation
Area	No interference within illuminated FoV (no clips, screws, metal parts)	Metalic parts inside the FoV	Minor interferences in the outer border of the desired area; dielectric interferences within border of FoV; interferences have to be agreed by Continental
Material	Approved material	All other materials need to be confirmed by Continental	Non approved materials have to be confirmed by Continental
Thickness	Constant thickness over whole structure as specified	Thickness deviations, which lead (in combination with material constants) to higher attenuations than specified	Minor deviations for desired thickness lead to reduced reach.
Paint/Color radome	No paint/color	Non-approved paint or varnish	If approved color is used, must specify one layer A side only and Charater Line requirements fully met.
Paint/Color bumper Function EBA	Up to 4 layers if attenuation is within spec	Violation of max. attenuation	
Holes		X	
Character Lines - Vertical	<= 0.8 mm if w/o paint	Limits to be clarified	Character lines are possible if overall thickness is constant. E.g if characterline is extruded to front, inner side of radome has to be intruded to keep thickness constant. Limit of size has to be approved.
Character Lines - Horizontal	<= 0.8 mm if w/o paint	Limits to be clarified	Characterlines are possible if overall thickness is constant. E.g if characterline is extruded to front, inner side of radome has to be intruded to keep thickness constant. Limit of size has to be approved.
Characterlines - Curvature	> 320 mm based on Continental experience from many application projects	Limits to be clarified	Limits to be clarified
Overall Surface Structure	See specification	Major deviations from specification	Minor deviations from specification
Angle between Sensor/Radome	10° < x < 30°	> 30°	< 10° the better the radome the smaller possible tilt angle
Distance	>= 10 mm (exposed environment) >= 5 mm (no snow or dirt)	too small distance or violation of radarcone	depends on radarcone and radome performance

Also dealerships, repair shops, etc. are to be instructed to adhere to these guidelines when conducting repairs or modifications of the vehicle.

6.4.5 Secondary Surface - Attenuation

The maximum attenuation of the combined secondary surface (bumper including paint) depends on required function:

To provide EBA functionality:

- One-way attenuation shall not exceed 4.0 dB
- Max. reflection coefficient shall not exceed -2.2 dB (60%)

To provide EBA functionality and ACC functionality up to 210 kph

- One-way attenuation shall not exceed 1.5 dB

6.4.6 Secondary Surface - General Recommendation

According to Continental's experience the radar sensor should be mounted behind some radar-optimized secondary surface (e.g. dedicated radar cover or OEM's logo) rather than behind the car's regular bumper because:

- Additional layers of paint or plastic foil might be put onto the bumper during repairs or aftermarket customizations
- The bumper is prone to deformations (either permanent ones due to accidents or dynamic ones due to windload)
- Radar attenuation depends significantly on the thickness of the material which might not be guaranteed by a regular bumper.

Therefore Continental advises against mounting the radar sensor behind the bumper.

6.4.7 Sample Delivery & Shipping

The customer shall provide a sufficient number of samples of secondary surfaces.

In case of sensor mounting behind the bumper, the customer shall provide samples for every bumper configuration.

The bumper shall have series characteristics including paint and varnishes. Experience shows that white and silver paint has the largest effects based on their high amount of metallic particles. In order to verify the performance of the radar sensor in the specific mounting position, suitable samples have to be provided for measurements of reflection- and transmission (damping) coefficients.

The sensor shall be protected against damages during shipping and assembly.

6.4.8 Snow deposits on the secondary surface

Snow deposits on the secondary surface may lead to additional attenuations to (parts of) the radar signal. In the worst case, these attenuations may cause partial or full blockage of the radar sensor and thus a degradation of the function performance or a complete deactivation of its functions.

In order to minimize the risk of snow deposits, the secondary surface shall be designed free of horizontal gaps or grooves.

If snow is a prevalent nuisance in the target markets, a radome heating (see above) might be considered.

6.5 Sensor Vehicle Fixation

The customer shall fulfill a set of requirements with regard to assembly and secondary surface structure properties to ensure maximum sensor performance.

The ARS513 sensor with mechanic configurations M-B and M-C support snap-fit mounting directly into a bumper. Therefore a mounting bracket which provides sufficient fixture and thermal cooling has to be provided by the customer.

Utmost care and effective measures should be taken during fixation of the clip-in version to the vehicle (chassis, bracket etc.) during series production and in repair process to ensure the sensor shall be handled only at the four corners and also during fitment the sensor shall not be rammed (forceful pressure on the central part of the sensor) in to the bracket but carefully pressed at the four corners. This is also important to save the functionality of the clips.

In the case where the sensor is dropped on the floor during production process (mishandling or uncontrollable scenarios), the OEM is responsible to discard the sensor and not use it any further. If at all the sensor is used, Continetal is not responsible for the deterioration or degradation of the performance of the sensor.

The ARS513 sensor with mechanic configurations M-A provides fixed screwing points for mounting to a metal frame.

Sensor unit fixation to the vehicle shall not create deformation of housing. The locking torque shall not exceed 7 Nm.

The sensor mounting interface elements (e.g. screws) shall be released to fulfill mechanical and electro-chemical (e.g. contact voltage) matching.

6.6 Sensor Radiation Cone

For a proper sensor performance the area in front of the sensor antenna radiation cone needs to be kept free of any materials or objects that may disturb the radar function.

The radiation cone (RF cone and keep-out cone) will be supplied to the customer by Continental. **The keep-out cone shall not be penetrated by any metallic parts of the vehicle.**

6.6.1 Radar Cone ARS513

The following Figure 30 and Figure 32 show the radiation cone in azimuth and elevation.

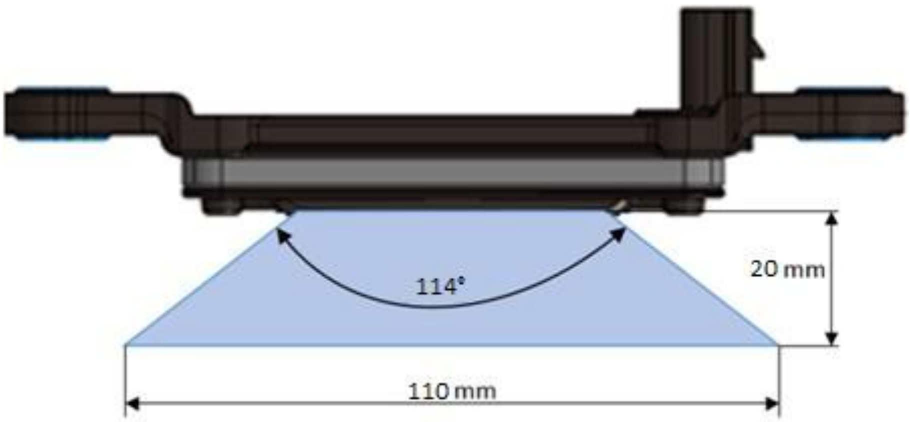


Figure 31: Radarcone ARS513- Azimuth FoV

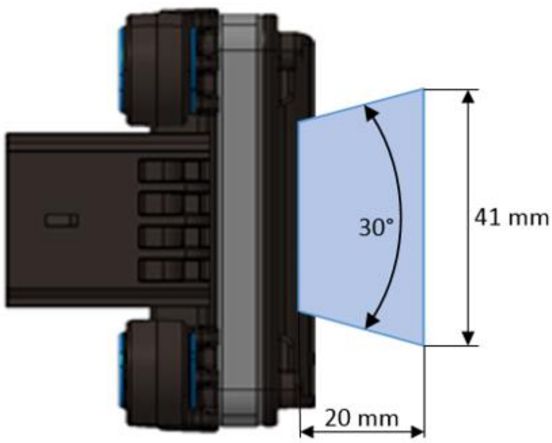


Figure 32: Radarcone ARS513 - Elevation FoV

6.6.2 Additional Requirements for the Radiation Cone

In addition, areas around the sensor radiation cone have to be taken into account according to the following Figure 33.

Figure 33: Keep-Out Zone

Legend for details of the keep-out zone:

- Red zone: "MUST" Keep Out Zone
- Yellow zone: Verification Zone (verification necessary)

Red Zone requirements:

- The OEM has to consider the mounting tolerances (position in x,y,z and yaw, pitch, roll) of the device.
- The primary radiation cone delivered by Continental does only include intrinsic tolerances.
- Extrinsic tolerances are not considered, because these are different for every vehicle platform and only known to the OEM.

Additional explanations for Yellow Zone requirements:

- Yellow Zone has to be considered due to unwanted propagations paths. Unwanted incident paths are reflections from positions aside the sensor direct into the sensor or from aside the sensor to the secondary surface and back to the sensor.
- No a-priori dimensions can be given for the yellow verification zone, because it depends strongly on the material and orientation of the components present around the sensor. The customer shall provide a CAD file with all components within 30 cm to the front and to the sides of the sensor. Nevertheless, individual measurements may be necessary.

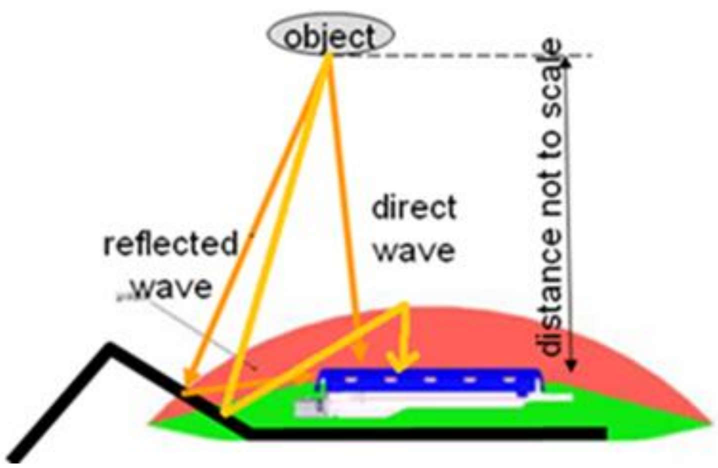


Figure 34: Influences of Chassis Reflections

The radar cone impinges the secondary surface. Due to the opening angle of the cone the area which is impinged increases with increasing distance to the radar sensor.

A minor crash of the vehicle (e.g. a parking dent) may cause a rotation of the sensor in pitch, yaw or roll. As long as the rotation angle of the sensor is less than the compensable misalignment angle in all directions, the sensor will not change to mode ‘Misalignment’. In such case, the radar cones of the sensor will rotate by the same angle as the sensor, i.e. in case of a rotation of the sensor by 6° in azimuth, all the radar cones are also rotated by 6° in azimuth.

Especially, this reserve shall be considered, if the sensor is mounted to the chassis, where a small crash (e.g. a parking dent) may cause a shift or rotation of the secondary surface while the sensor stays unchanged.

Since there is still signal power outside of the radar cones provided by Continental, we recommend another 5 mm reserve around the superposition of all radar cones, i.e. around the combination of all seven radar cones (3 Tx and 4 Rx cones).

The OEM has the responsibility to consider all other possible changes in the constellation of sensor and secondary surface that may be caused by crashes, vibrations etc. This is also valid for all situations where the secondary surface has been displaced angularly with respect to the agreed mounting position of the secondary surface (agreed between Continental and OEM) which may be caused due to minor and major crashes.

6.7 Vehicle Environment

The standard qualification of the sensor is done according to LV124 specification (see reference [3]).

Customer specific qualification needs to be agreed with Continental.

The sensor has to be installed with a maximum protection of long term water exposure to keep best performance for Radar and electrical Function. It is recommend to verify the installation into the car between the OEM and Continental.

6.7.1 Operation Temperature Range

The sensor provides full operation at an ambient operating temperature range between -40°C to +85°C.

Between +85°C and +95°C a limited operation (only bus communication, no driving functions) is provided.

The sensor provides a storage temperature range between -40°C to +105°C.

In case that the maximum internal temperature is exceeded, the sensor switches to self-protection mode.

The metal carrier between HF and LF part of the sensor is the main element for heat transfer.

- Cooling air must have sufficient access to the sensor.

For ARS513 the sensor unit environment shall perform cooling performance of 6 W during standstill and driving (@1.9 m/s air speed from the front).

Furthermore, the cooling shall not be deteriorated by radiant heat from other hot vehicle parts.

It is urgently recommended to check together with Continental whether cooling is sufficient (even under extreme conditions) for every intended mounting position.

During repainting the sensor shall be in off-state and the maximum vehicle painting temperature shall not exceed +130°C for more than 15 minutes.

In addition to that, the vehicle painting temperature shall not exceed +110°C for more than 60 minutes.

Attention: During operation in high temperature conditions the sensor can become **hot**. If the mounting position does not exclude contact of human beings, a warning sticker might be appropriate.

6.7.2 Mechanical Vibrations

The sensor is designed to withstand mechanical vibrations according to LV124 with the following profile:

Table 9: Test parameters, broadband random vibration for equipment mounted on sprung masses (vehicle body)

Excitation	Broadband random vibration	
Test duration for each dimensional axis	8 h	
Acceleration rms value	30,8 m/s²	
Vibration profile Figure 25	Frequency in Hz	Power spectral density in (m/s²)²/Hz
	5	0,884
	10	20
	55	6,5
	180	0,25
	300	0,25
	360	0,14
	1 000	0,14
	2000	0,14

The measured power spectral densities for the evaluated frequencies were linearly interpolated. This interpolation resulted in Figure 35.

The OEM shall simulate its own car-specific application vibration profile. As long as the measured power spectral densities remain below the curve in Figure 35, no degradation in the functional performance of the radar sensor is to be expected.

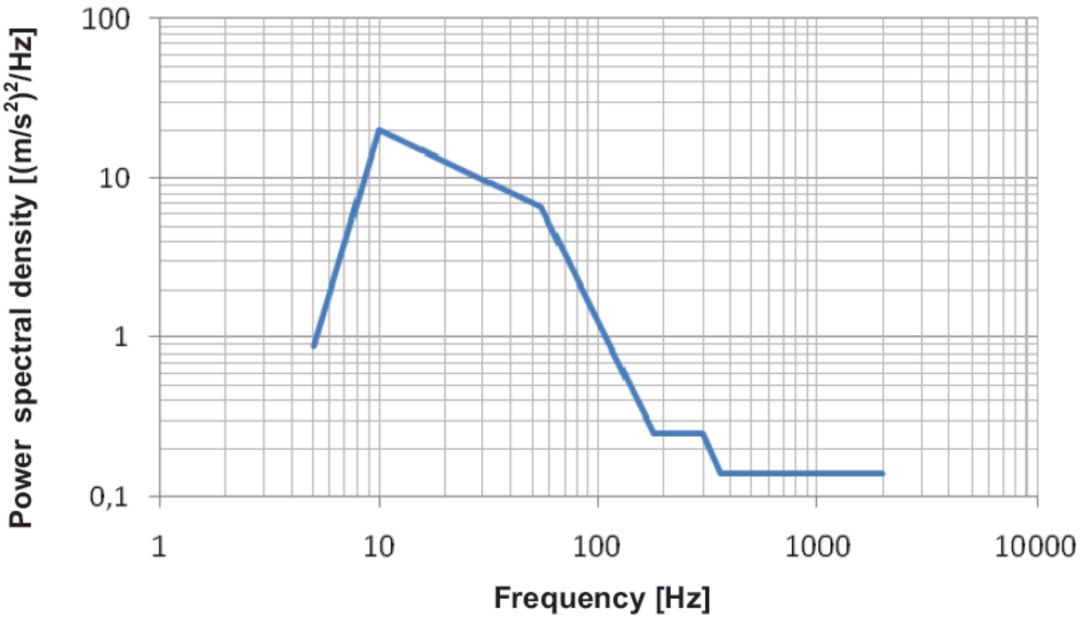


Figure 35: Vibration profile, broadband random vibration for equipment mounted on sprung masses (vehicle body)

6.7.3 Vibration Influence on Object Detection

Excessive mechanical vibrations may impair the object tracking performance.

The maximum admissible amplitudes to prevent such impairments depend on the vibration's frequency and direction. Longitudinal vibrations (in vehicle's x-direction) are more critical than lateral vibrations (in vehicle's y- or z-direction).

Shaker tests were conducted to investigate the tracking performance for both directions under various vibration frequencies and amplitudes.

Figure 36 gives maximum admissible vibration amplitudes.

Please note, that the amplitude values for lateral vibration (y/z-direction) are only lower bounds, dictated by Continental's measurement setup: even at max. shaker amplitude no impairment of tracking performance was observed.

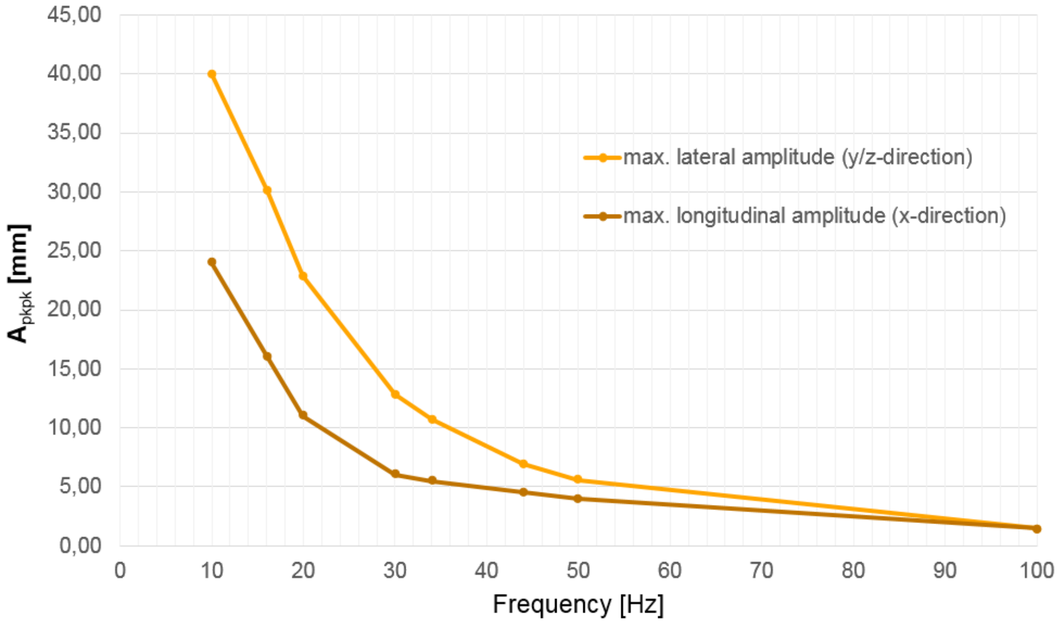


Figure 36: Maximum admissible vibration amplitudes

The longitudinal curve gives hard limits up to 50 Hz. Above 50 Hz it coincides with the lateral curve, restricted by the limitations of the measurement setup.

With increasing amplitude (at a given frequency), first the measured velocity values are affected, then the object distances. This was used to determine amplitude limits:

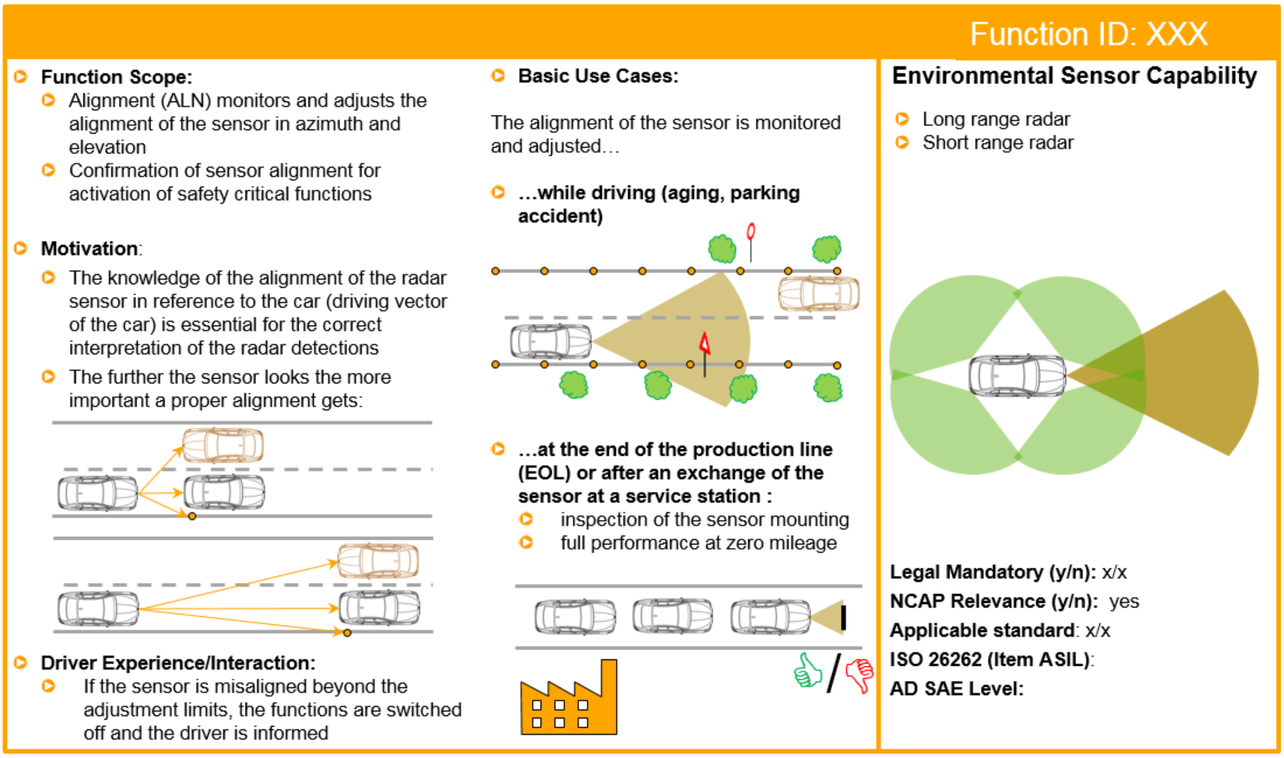
Object detection and classification, object range, and velocity measurement are within regular limits (see chapter 'Radar Characteristics') up to the stated admissible amplitudes.

No relevant differences were found between far/near scan or for measurements with/without radome.

7. Calibration and Blockage Detection

7.1 Calibration

7.1.1 Calibration Overview



7.1.2 Calibration Methods

The sensor can adjust itself both in azimuth (alpha / yaw - horizontally) and elevation (beta / pitch - vertically) directions.

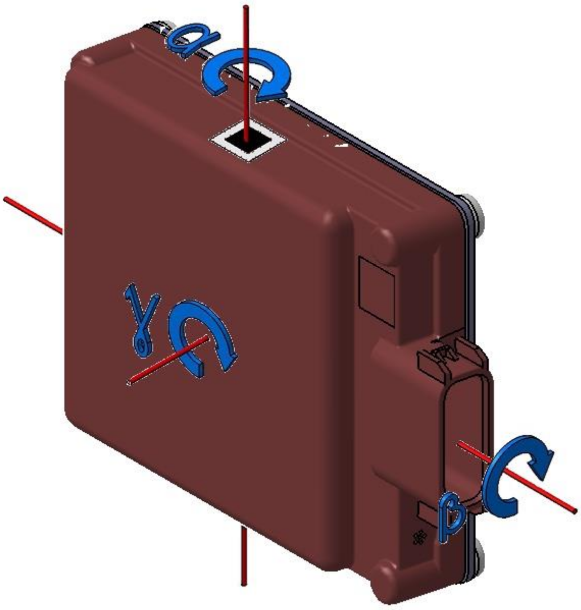


Figure 37: Naming convention for alignment angles

Misalignment includes static deviations due to sensor and mechanical fixture tolerance between sensor reference plane (as described in the drawings) and the driving direction of the vehicle and dynamic deviations caused by changes in loading and suspension.

The static misalignment should be determined by the customer via tolerance chain analysis from vehicle driving direction to sensor mounting reference plane. Temperature variations and mechanical changes over lifetime of the sensor fixture shall be taken into account.

Continental recommends to reserve +/-2° in elevation as margin for misalignment caused by loading of the car and/or adaptive suspension.

Braking may cause temporary misalignment in elevation up to +/-2° (by pitching). Due to its short duration this misalignment will not be detected by auto-alignment.

The customer shall determine the maximum misalignment via simulation or measurement.

The alignment functionality of the sensor can overall compensate the sum of dynamic and static misalignments within certain limits as stated in

Table 10.

Table 10: Total Alignment Ranges

Total Alignment Range	
Yaw - Azimuth (alpha)	±6° (for ±45° FoV) ±6° (for ±50° FoV)
Pitch - Elevation (beta)	±6°

The sensor's algorithms are robust against roll angles up to +/-5°.

Auto alignment refers to continuous monitoring of the sensor's calibration state to compensate for temperature effects, unintended mechanical impacts or mechanical misalignment at car manufacturing between the sensor component housing and the vehicle chassis.

There are several possibilities for autonomous alignment, each of these are designed for special situations:

- Online Adjustment (Misalignment Monitoring and Adjustment - MM&A)
- End of line alignment (EoL)
- Service Alignment (SA)

7.1.3 Online Adjustment

During normal operation a continuous misalignment monitoring and adjustment of the sensor calibration state will be done. This monitoring will compensate temperature effects and misalignments between the sensor component housing and the vehicle chassis due to changing of vehicle load capacity or unintended mechanical impacts. The sensor component can adjust itself in both directions azimuth (horizontally) and elevation (vertically). This method needs some minutes to achieve sufficient accuracy. Azimuth misalignment detection is based on stationary targets (no road beams are used) and the elevation misalignment detection performance depends on traffic situations (e.g. maximum accuracy with moving targets in front) while the vehicle is driving.

Safety functions (e.g. emergency braking) shall not cause intervention as long as the uncertainty about alignment state is too high. Upon detection of alignment with sufficient accuracy, the safety functions become gradually enabled. The alignment accuracy which needs to be achieved before enabling a specific safety function depends on the function itself.

The applicable safety functions and related accuracy limits for activation are defined as follows:

- EBA warnings: always enabled
- EBA brake intervention within limited longitudinal distance: The maximum distance within which objects are regarded relevant for EBA brake intervention is dynamically adjusted depending on the azimuth angle

uncertainty. This is done in a way to ensure that only objects in ego vehicle driving path will be considered, i.e. vehicles outside of predicted driving path need to be safely distinguished from vehicles in ego lane

Comfort functions (e.g. ACC) is activated after ignition start. Upon detection of misalignment which cannot be compensated, the comfort functions shall be disabled.

Misalignments within the limits will be compensated; larger ones will be notified via a vehicle bus message and stored in the error memory.

The component accuracy targets for alignment monitoring and adjustment are stated in Table 11 and Table 12.

Table 11: Alignment Monitoring KPIs (Part 1)

Description		Physical Unit	ARS513
minimal azimuth misalignment that can be adjusted within 10s	in 95% of all cases at start of an ignition cycle and at fulfilled driving conditions+ at >50kph	deg	2.4
minimal azimuth misalignment that can be adjusted within 60s		deg	1.0
minimal elevation misalignment that can be adjusted within 120s		deg	1.0
typical distance at which **azimuth** confirmed with accuracy of **1.6°** by Online Monitoring (corresponds to >35m safety function range)		m	100
typical distance at which **azimuth** confirmed with accuracy of **1.0°** by Online Monitoring (corresponds to >60m safety function range / full EBA performance)		m	250
typical distance at which **elevation** confirmed with accuracy of **3.2°** by Online Monitoring (corresponds to >35m safety function range)		m	100
typical distance at which **elevation** confirmed with accuracy of **2.0°** by Online Monitoring (corresponds to >60m safety function range / full EBA performance)		m	250

+ fulfilled driving conditions: |acceleration| < 2.5m/s²;
curve radius > 1000m ; not in disturbed environment (tunnel);
stationary radar detections within +/-9° of the field of view

Table 12: Alignment Monitoring KPIs (Part 2)

Description		Physical Unit	ARS513
maximal duration of misalignment adjustment by Online Monitoring at start of ignition cycle and fulfilled driving conditions⁺ at >50kph		min	10
maximal frequency of adjustments by Online Monitoring		1 / 1000km	2
maximal duration of Service Alignment (in terms of time at fulfilled driving conditions⁺ at >50kph)		min	10
maximal duration of EOL		sec	3
accuracy Azimuth for Online Monitoring / Service Alignment	only within mounting limits, excluding secondary surface effects	deg	0.3
accuracy Elevation for Online Monitoring / Service Alignment		deg	0.5
accuracy Azimuth for EOL (incl. 0.1deg setup accuracy for OEM, setup according spec.)		deg	0.75
accuracy Elevation for EOL (incl. 0.1deg setup accuracy for OEM, setup according spec.)		deg	1

⁺ fulfilled driving conditions: |acceleration| < 2.5m/s² ;
curve radius > 1000m; not in disturbed environment (tunnel);
stationary radar detections within +/-9° of the field of view

7.1.4 Automatic Industrial Alignment (AIA)

The AIA procedure is intended to provide the customer with an alternative to End of Line alignment (see below).

In this case the customer's production process must guarantee that all sensors are mounted within the given tolerances and thus can be adjusted; otherwise this could lead to zero-kilometer failures.

AIA provides means to adjust the alignment of the sensor in azimuth and elevation - within given limits - by driving the vehicle with yet non-aligned sensor on a short designated test track or on public roads.

AIA can be performed

- by the OEM between assembly and shipping of the car,
- by the dealership before handing over the car to the end-user,
- or even by the end-user. (This generally requires driving on public roads.)

The feature *Automatic Industrial Alignment* is similar to the Service Alignment (see below). However, in contrast to the Service Alignment there will be continuous adjustment and the device functions will gradually become available as the alignment improves (e.g. comfort functions like ACC become available once the estimated remaining misalignment drops below 0.7°).

The AIA function of the device is triggered by a customer-specific diagnostic command on the vehicle communication interface which activates the AIA mode.

The device shall be delivered to the customer with activated AIA mode.

While the device is in AIA mode all device functions (e.g. ACC, EBA) are disabled.

The device functions become gradually available as the alignment improves. Enabling of functions is defined in function specs.

The sensor's KPIs for AIA are stated in Table 11 and Table 12.

Upon reception of the diagnostic command which activates the AIA mode, the device will align itself while driving the vehicle under the conditions specified in section 'Service Alignment' below.

If any of the driving conditions is not fulfilled the device reports which condition is not met.

7.1.5 End of Line (EoL) Calibration

End of Line (EoL) alignment at the customer plant provides a fast and precise method to make ensure, that every vehicle which runs off the assembly line, has a completely aligned sensor component.

End of Line (EoL) alignment at the customer plant is recommended, but not mandatory. Vehicles could also be delivered to the end user with unaligned sensors. Then alignment will be accomplished by 'automatic industrial alignment' (AIA) (see above) during the first kilometers driven by the end user (or dealership). During AIA, all functions become enabled successively as statistical confidence in the measured azimuth and elevation angles increases.

The sensor's EoL alignment KPIs are stated in Table 11 and Table 12.

The maximum accepted misalignment angles at EoL are:

- Azimuth: +/-6° for 45° FoV option, +/-6° for 50° FoV option
- Elevation: +/-4° for both FoV options

7.1.5.1 EoL Production Line Setup

EoL alignment requires a metal plate reflector which needs to be precisely adjusted perpendicular to the vehicle driving vector. Proper alignment of the metal plate has to be ensured in both horizontal and vertical direction. Any misalignment between the vehicle driving vector and the metal plate will lead to a failure of the EoL alignment procedure (i.e. a misaligned device).

Instead of a metal plate reflector it would also be possible (but not recommended) to use a corner reflector.

The properties of an appropriate corner reflector and related placement requirements need to be agreed between the customer and Continental.

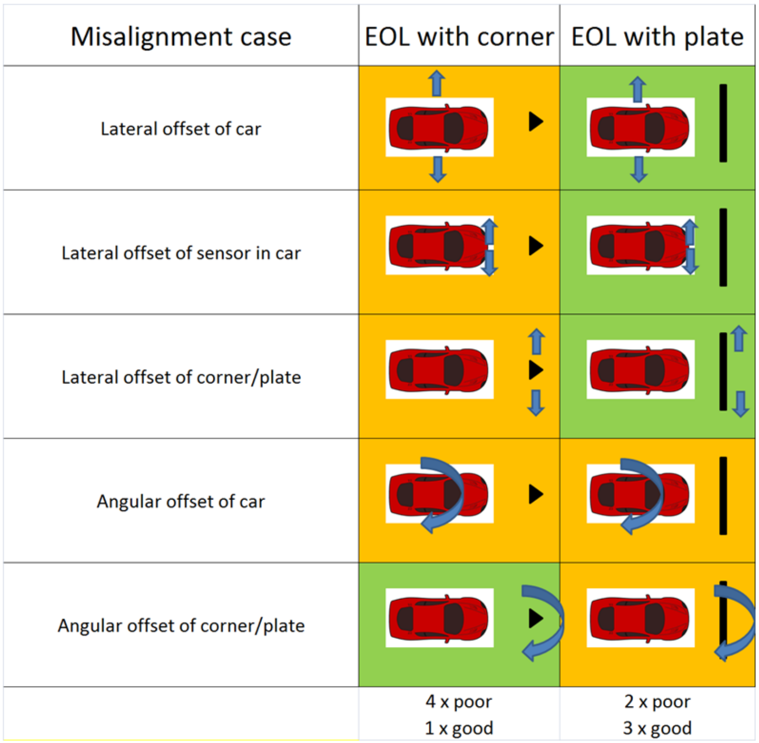


Figure 38: Advantage of plate compared to corner

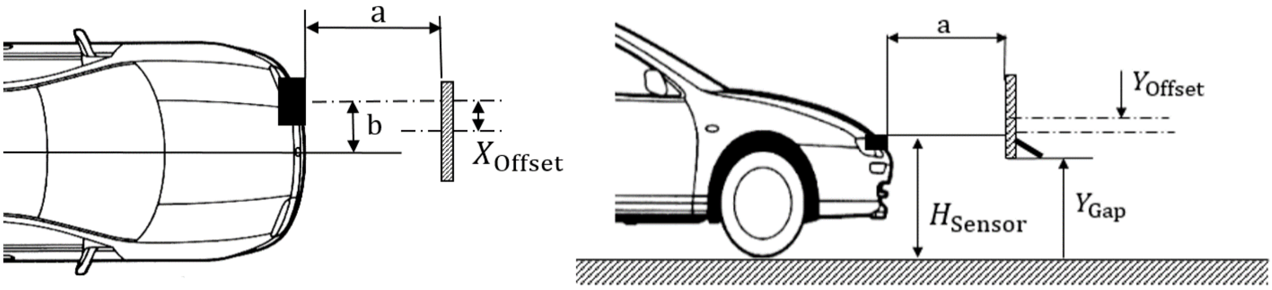


Figure 39: Setup at vehicle manufacturer's production line, top (left) and side view (right)

The distance a between sensor device and the metal plate shall be within the range 0.8 m < a < 2 m.

The tolerances in X and Y-direction have only impact on the required size of the reflector plate as calculated later.

- The EoL alignment procedure is performed in the radar frequency range 76.0 - 77.0 GHz.
- Due to the low distance *a* between sensor device and the metal plate in alignment mode, the near range artifacts are suppressed by using an increased measurement accuracy. This requires a special operation mode of the sensor with high bandwidth (but less than 1000 MHz).

All objects of any material within the area in front of the sensor device as specified by the attached diagram shall be covered with absorber material.

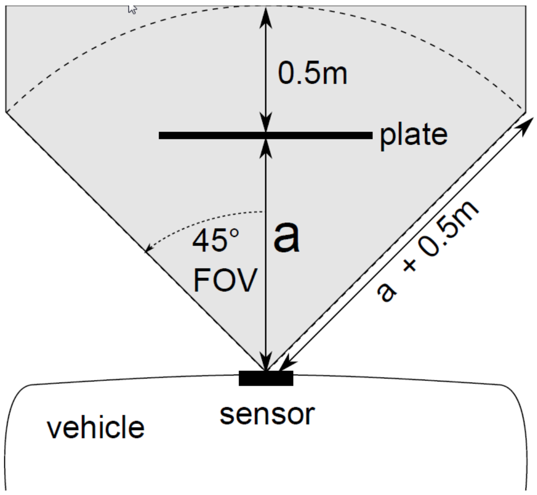


Figure 40: Keep-Out Area for EoL

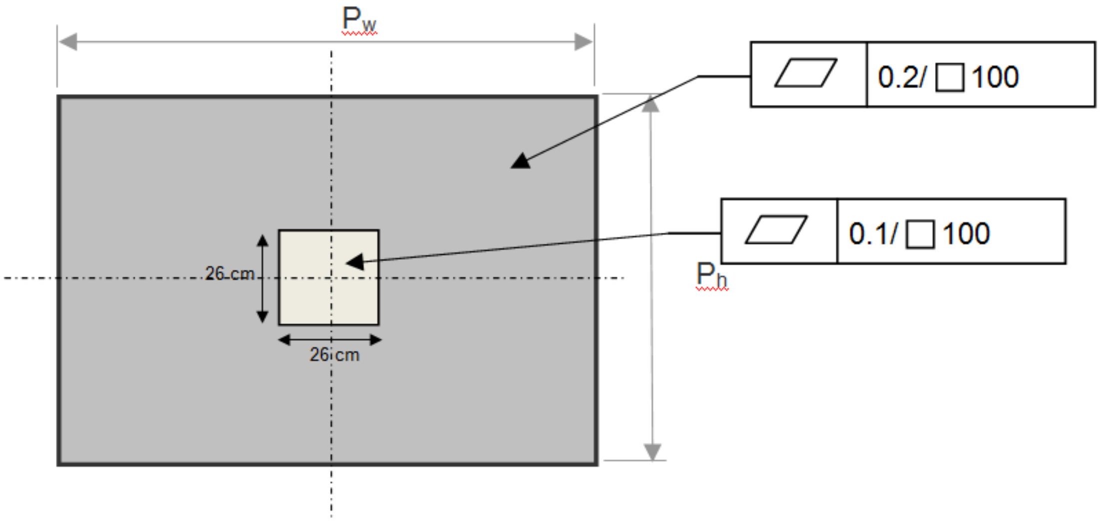


Figure 41: EoL alignment reflector plate

Requirements for the material of reflector plate:

- Aluminum
- Iron
- Steel
- Other materials like a mirror are possible, but have to be specified in more detail and have to be investigated by Continental prior to use.

Requirements for the surface finish of the plate:

- Flatness of surface shall be at least f=0.1 mm in each subarea of 80 mm x 80 mm
- Roughness RZ < 50 (is equal to <50 µm)

The reflector plate does not need to be centered and the edges of the reflector plate do not have to be in the FoV. There is no upper limit for the size of the reflector plate.

The following requirements for dimensions and placement of the reflector plate must be fulfilled:

Table 13: Dimensions and placement requirements for the EoL reflector plate

Parameter	Requirement
h_{Sensor}	0.3 … 1.2 cm
X_{offset}	Horizontal sensor mounting tolerance with respect to center of reflector plate
Y_{offset}	Vertical sensor mounting tolerance with respect to center of reflector plate
Y_{Gap}	> 3 cm (= distance between bottom edge of reflector plate and floor)
P_h	= 0.15 m + 0.2 * a + 2 * Yoffset
P_w	= 0.30 m + 0.3 * a + 2 * Xoffset

7.1.5.2 EoL Alignment Procedure

During execution of the EoL procedure the vehicle must be

- in standstill,
- unloaded,
- no driver in vehicle,
- adaptive suspension must be in default mode.

The EoL alignment function of the device is triggered by a diagnostic command EoL_ALN_START on the vehicle communication interface which activates the EoL Alignment mode. (Remark: The command is customer-specific)

Upon reception of the diagnostic command which activates the EoL alignment mode, the device aligns itself without any further external intervention within 3 seconds.

After completion of the EoL alignment procedure the device creates the internal signal EoL_ALN_STOP (Remark: exact name is customer-specific).

Triggered by the signal ALN_STATUS_REQ (Remark: exact name is customer-specific) the device outputs a message on the vehicle communication interface which reports about success or failure of the EoL Alignment procedure.

If the alignment process is aborted in case of alignment range is not sufficient, an error code (Remark: exact name is customer-specific) is stored and alignment information (sign, left/right) in service data depending on mounting orientation of the component (6o´clock/12o´clock). Additional diagnostic data is available. In this case the device shall remain in EoL alignment mode.

The device has a counter to store the number of started and the number of successfully completed EoL alignment attempts.

The values of the counters

- Number of started EoL alignments
- Number of successfully completed EoL alignments

shall be read out by special diagnostic commands and may be erased if necessary (sensor have to be unlocked) by different special diagnostic command.

In case of device replacement only coding and calibration shall be necessary for commissioning (i.e. Plug & Play).

Additional work in respect of a necessary device calibration procedure on the production line may only occur if the function test is performed within the same operation. The supplier must provide the customer with an appropriate time-efficient and cost-effective procedure for the device offered.

For EoL alignment there is no need for any mechanical adjustment of the device.

The device adjustment/calibration shall take place under the final assembly conditions, thus adapted or integrated in the vehicle system environment (e.g. under bumper, radome).

7.1.6 Service Calibration

The feature Service Alignment provides means for re-alignment of the device after vehicle repair and for first alignment after sensor replacement. In contrast to EoL alignment no special equipment is required, but as a consequence it takes some time until the re-calibration will be completed. The alignment function will be performed during a test drive while no device function will be available before completion.

In order to start Service Alignment a diagnostic command needs to be sent to the device. Then the technician has to drive the vehicle for a few minutes. After the calibration drive the sensor is either aligned or it notifies with an error message that it is not able to compensate the misalignment.

The customer has to provide the necessary HMI to create and process the vehicle bus commands which initiate and terminate the Service Alignment procedure of the sensor.

Service Alignment uses the same principle as in the auto alignment function. The service station has to switch the sensor via diagnostic command to a special operation mode. Then the technician has to drive for a few minutes with this car. Working under suitable driving and road conditions (e.g. dry and straight road) the sensor component shall provide a standard service alignment method with a rated duration of ≤15 minutes.

Under wet road and curvy worst case conditions the sensor component shall be able to perform Service Alignment within 60 minutes.

The sensor's KPIs for Service Alignment are stated in Table 11 and Table 12. After completion of this Service Alignment drive the sensor is either aligned or it notifies with an error message that it cannot compensate the misalignment.

7.1.6.1 Service Alignment Procedure

The Service Alignment function of the device is triggered by a diagnostic command on the vehicle communication interface which activates the Service Alignment mode.

While the device is in Service Alignment mode and has not yet completed the Service Alignment procedure, all device functions (e.g. ACC, EBA) are disabled.

Upon reception of the diagnostic command which activates the Service Alignment mode, the device shall align itself while driving the vehicle under the specified conditions as described below:

- Service Alignment needs to be completed after maximum 10 minutes, if the car is operated at an ego speed >30 km/h in an area of static and moving targets.
- After completion of the Service Alignment procedure a customer-specific message shall be output on the vehicle communication interface and report about success or failure.
- The Service Alignment function does not require any manual adjustment or calibration of the mounting of the device at the vehicle.
- The Service Alignment function does not require any special equipment other than means to activate the Service Alignment mode. It is only necessary to activate the Service Alignment mode and drive the vehicle on public roads.
- A functional error from which the sensor can recover in the same ignition cycle shall cause Service Alignment to be suspended, but not aborted.
- A functional error from which the sensor cannot recover in the same ignition cycle shall cause Service Alignment to be aborted.
- If the driving level is available as an input signal and if this driving level is outside the "normal driving level", Service Alignment shall be suspended.

7.1.7 Parameterization

Application specific parameterization of alignment limits (e.g. misalignment tolerances accepted at EoL) can be agreed upon between Continental and the customer.

7.2 Blockage Detection

If the sensor or secondary surface is covered by a layer which damps/distorts the radar signal, the functionality of the sensor can be degraded to an unacceptable level. Such a so-called **blockage** has to be detected.

Critical blocking elements are as listed below:

- Snow and snow slush (high attenuation due to high water content)
- Ice (has moderate attenuation, but distorts phase of waves in case of no constant layer thickness)
- Continuous water layer (not only some drops)

- Seldom special cases: aluminum foil suddenly sticking to radome, sticker glued on radome

Blockage detection can be further distinguished as follows:

- **Partial blockage**: attenuation acceptable, but quality of angular measurement degraded to an unacceptable level (e.g. high sidelobes, significant angular errors); is part or outcome of online-calibration
- **Full blockage**: large attenuation resulting in an inacceptable reduction of detection range

Since blockage detection is based on evaluation of statistics of detected objects, the device has to work without restrictions even when driving in conditions with very few radar detections like areas covered with snow, deserts, etc.

The blockage algorithm is a statistics based algorithm, therefore all changes in the environmental conditions have to be verified and confirmed by statistical evaluations. This results in a time delay between environmental changes and any system reaction.

Instant system reaction is not possible due to statistical uncertainty.

8. Environmental Conditions

8.1 Temperature Range Specification

Table 14 shows the temperature range specification for the radar sensor family.

Application projects specific deviations have to be approved by Continental and are to be marked in project documents and specifications.

Table 14: Temperature Range Specification

Temperature Ranges		
Storage	Min	-40°C
	Max	+105°C
Normal Operation	Min	-40°C
	Max	+85°C
Limited Operation (IF communication only)	Min	+85°C
	Max	+95°C

8.2 Endurance

Table 15 shows the environmental condition specification for the radar sensor family.

Table 15: Environmental Condition Specification

Environmental Condition Specification		
LV 124 Specification *(see reference [3])*	Mechanical Vibration	Profile D
	Agreed Life time (or)	10.000 h
		15 years
	Mileage	300 000 km

Table 16: Environmental temperature distribution

Temperature Distribution (operating lifetime)	
Temperature Class [°C]	Temperature Distribution
-40	6%
+23	20%
+60	65%
+80	8%
+85	1%

8.3 Electrical Conditions

The design is focused to meet standard specifications of automotive industry. Interface circuits are well known from former products. Electrical design and mechanical design will be focused to achieve high attenuation of interferences from the environment and low radiation to the environment.

E.g. the PCB is encapsulated and the connector pins are in a separate chamber built by two metallic plates. The PCB will have separate plains for ground and common voltage supplies.

8.4 Ingress Protection (IP Code)

The sensor is dust proof according to IP6Kx (ISO 20653).

The sensor is water proof according to IPx6K/7/8(1.5m, 30min)/9k.

The sensor has a venting area for pressure compensation. The customer has to integrate the sensor in such a way that this area shall not be in direct contact with pressurized water jets and effective measures shall be taken to prevent blockage of the venting membrane from dirt, mud or other liquids. Constant formation of a water film on the venting area is to be avoided as the water may get sucked inside due to pressure differences.

Also, the sensor is only watertight when the connector is plugged. In case of exposure to water when the connector is not plugged the sensor shall be discarded. And, it is recommended to perform a Water Management review of the mounting location together with Continental.

OEM directed connector / plug systems have to be released and must not have a lower IP rating than the sensor. Connector mounting direction will be according to connector specification (preferably downwards if the Sensor/Antenna design allows).

8.5 Mutual Interference

The sensor uses several internal mechanisms to suppress or at least recognize interference from other radar sources. If the received interferences are too high, the sensor detects a higher noise level which prevents the sensor to detect targets with small RCS values. If this condition is detected and at the same time there is no stable relevant object (target) the sensor stops normal operation and announces the error code “external interference”. The sensor can just communicate via vehicle bus in this mode, no object detection or other application runs on the sensor! When the interference is not detected anymore, the sensor switches back to normal operation automatically.

To avoid frequent switch off, several suppression mechanisms are implemented internally.

1. Bandwidth limitation

   The radar modulation scheme itself guarantees that any interference which has a bandwidth broader than about 1 kHz will be filtered out by the different FFT algorithm for distance and relative speed.
   - IF-Path bandwidth: 40 MHz
   - Bandwidth after 1st FFT: 150 kHz

- Bandwidth after 2nd FFT: 1 kHz

2. Over amplification control

   The sensor detects the amplitude of the IF path and can control amplification of this path to avoid over amplification and saturation. This functionality avoids ghost targets created by an amplifier which is in saturation.

3. FMCW interference suppression

   The modulation scheme “Pulse Compression” uses two FFTs to determine range and Doppler shift as two independent signals. Any signal from FMCW (“slow chirps”) radar will cause an implausible value (noise) in the second FFT.

4. Non linear filters

   Signals coming from similar radar or even from a Continental radar itself can be filtered out by non linear filter algorithm implemented in signal pre-processing chain.

   The filters work as ordered statistic or median filters based on the idea, that a signal from another sensor is much stronger than the own signal reflected by a target in same distance. A radar signal is attenuated proportional to r^2 therefore the own signal is attenuated by r^4 due to double flight time (way to target and back). The signal of another radar received on the direct way is just attenuated proportional to r^2 which generates a much bigger amplitude.

5. Pseudo noise coding

   Pseudo noise coding at different points of the micro timing of a single chirp guarantees that only the own signal reflected by targets increases over the integration time over 128 chirps for every beam. The signals from non-coherent sources will create just noise.

   The sensor's radar concept reduces the occurrences of ghost targets caused by external interferer. The sensor performance is according to industry standard with physical limitations of the radar technology, Continental is not liable for a 100% object detection performance and related claims.

8.6 Influence on Human Health

The radar sensor is compliant with international regulatory requirements (e.g. FCC and ETSI) and accordingly should not be hazardous to human health. In addition, studies by independent experts have proven that automotive radars have no negative influence on persons (e.g. 'Forschungsbericht von der Forschungsgemeinschaft Funk e.V. - Newsletter 4-00').

8.6.1 Operation of the unmounted sensor

During development or servicing it may become necessary to operate the sensor in a laboratory environment without a vehicle (bumper, body) around it. Personnel may thus get close to the sensor and be exposed to its RF emissions.

ARS radar sensors are "mobile devices" according to FCC §2.1091 (b) which proposes that generally a 20 cm distance is maintained between the "..transmitter's radiating structure and the body of the user or nearby persons..." (see reference [4]).

Given this 20 cm safety distance, the sensor's RF emissions in any direction remain within the safety limit of 1 mW/cm^2 (= 10 W/m^2) stated by

- FCC §1.1310 see reference [5],
- ETSI 1999/519/EC see reference [6], and
- BGV B11 see reference [7]

for general population / uncontrolled exposure.

8.7 Homologation Country Classes (HCC)

Frequency regulation laws differ between countries all around the world. Most common regulations are from ETSI (EU) and FCC (USA) and a lot of other countries also refer to these standards. For some countries with specific regulations different radar output power settings are required.

To ease the setting for all countries, Continental has grouped them into 4 HCCs (Homologation Country Classes) with identical RF setting (primarily output power):

- HCC-1: Rest of World (EU, US, ...)
- HCC-2: Japan
- HCC-3: - not in use -
- HCC-4: - not in use -

For all countries, any operation of a sensor without calibrated HCC set that matches the countries regulation is not permitted. Even for test drives a dedicated test license must be obtained for all countries. It is the OEMs responsibility to operate radar devices only when in compliance with the legal constraints of the respective region or country.

Any operation of a radar sensor in HCCs which are not explicitly calibrated in production will not work. If no parameter set is found for the requested HCC the sensor will switch off its functions.

Continental provides three different methods for selecting the HCC, which are described as follows. The OEM and Continental need to agree about which one of these methods shall be used for the project:

- Fixed HCC setting by Continental:
  - By default HCC selection is done in non-volatile memory ("PPAR" flashed at Conti production site).
- Fixed HCC setting by OEM:
  - As an alternative (overruling the PPAR entry) HCC selection can be saved to non-volatile memory at OEM production site or OEM service station (e.g. to “APAR”).
- HCC setting by OEM via bus signal:
  - HCC selection can be done by the vehicle via bus signal.
  - This can be done either dynamically based on the vehicle location or fixed.

For advantages and disadvantages of the mentioned methods, further documentation is available from Continental. This covers for example the questions of necessary and unnecessary performance reduction, multiple part numbers, responsibility for legal operation, effort for calibration and production yield influences.

9. Appendix

9.1 List of Figures

9.2 List of Tables

9.3 List of Abbreviations

AEBS..Advanced Emergency Braking Systems
AIA ....Automatic Initial Alignment
ASIL ....Automotive Safety Integrity Level
AUTOSAR .... AUTomotive Open System ARchitecture
BSPC..Basic Security & Privacy Concept
DEM ....Diagnosis Error Management
EoL ....End of Line
EPS ....Electric Power Steering
ETSI ....European Telecommunications Standards Institute
FCC...Federal Communications Commission
FCW..Forward Collision Warning
FFT ....Fast Fourier Transformation
FMCW ....Frequency Modulated Continuous Wave
FoV...Field of View
GADSL ....Global Automotive Declarable Substance List
HCC ....Homologation Country Class
ID..Identification Document
IO ....Input Output
LatPos ....Lateral Position
LF.. Low Frequency
LongPos...................................Longitudinal Position
MM&A ....Misalignment Monitoring and Adjustment
MTA ....Measurement Technique Adaptor
MTI...Measurement Technique Interface
OD..Object Detection
PCB...Printed Circuit Board
PWM ....Pulse Width Modulation
RCS...Radar Cross Section
RD ....Road Detection
RDI ....Radar Detection Image
RF ....Radio Frequency, Radio Frequency
ROM...Read Only Memory
RTE ....Runtime Environment
RX...Receiving Path
SA...Service Alignment
SNA ....Signal Not Available
SW..Software
TSC ....Technical Safety Concept
TSR ....Technical Safety Requirements
TTC...Time to Collision
TX...Transmitting Path

UDS .... Unified Diagnostic Services
UN/ECE .... Economic Commission for Europe of the United Nations
VerPos.................................... Vertical Position