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System Reference document (SRdoc);
Transmission characteristics;
Technical characteristics for radiodetermination equipment
for ground based vehicular applications
within the frequency range 77 GHz to 81 GHz

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

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Introduction

The present document includes necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

Driver assistance functions based on automotive radar sensors are available in vehicles since about 20 years. During this time, the frequency ranges for the operation of the automotive radar sensors changed. In 2004, it was decided to move the band of operation for high resolution automotive radar sensors from the range 21,65 GHz - 26,65 GHz (24 GHz UWB band) to the range 77 GHz - 81 GHz (79 GHz band) as the new frequency band. The decision was taken, in order to avoid compatibility issues with the radio astronomy service as the primary user in this band.

When describing the automotive radar system for the compatibility studies in the 79 GHz band in 2004, it was assumed that the automotive radar sensors operating in this band would use the same technology as the high resolution sensors in the 24 GHz UWB band that were available at that time. Therefore these parameters were used in the compatibility studies for 79 GHz band in the process of developing the European regulation for automotive radars.

The regulation for the 79 GHz band is untouched since then.

Within the last 15 years, RF technology and signal processing evolved, that allows to develop 79 GHz automotive radar sensors that provide more functions and better RF performance than it was foreseen in 2004.

Within the last 5 years the demand for radar based driver assistance functions increased significantly and the number of radar equipped vehicles is increasing.

The performance of radar based driver assistance functions evolved over the last years. Radar based functions will also be a key technology for highly automated or autonomous driving vehicles.

In the light of these developments, this document proposes to revise the current European Regulation for 79 GHz automotive radars in order to enable use of 79 GHz automotive radar for the described current and future usages.

1 Scope

The present document describes radio determination equipment for ground based vehicular applications within the 79 GHz band which may require a change of the present frequency designation/utilization within the EU/CEPT.

The present document provides information on the existing and intended applications, the technical parameters, the relation to the existing spectrum regulation (ECC/DEC(04)03 [i.10] and 2004/545/EC [i.11]).

The present document includes in particular:

- Market information.
- Technical information including expected sharing and compatibility issues.
- Regulatory issues.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ERC Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)".

[i.2] Commission Implementing Decision (EU) 2017/1483 of 8 August 2017 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2006/804/EC.

[i.3] ERC Report 003 (February 1991): "Harmonisation of frequency bands to be designated for road transport information systems", Lisbon.

[i.4] ERC/DEC(92)02: "ERC Decision of 22 October 1992 on the frequency bands to be designated for the coordinated introduction of Road Transport Telematic Systems".

NOTE: This document is withdrawn.

[i.5] ECC/DEC/(02)01: "ECC Decision of 15 March 2002 on the frequency bands to be designated for the co-ordinated introduction of Road Transport and Traffic Telematic Systems".

NOTE: This document is withdrawn.

[i.6] ETSI TR 101 982 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio equipment to be used in the 24 GHz band; System Reference Document for automotive collision warning Short Range Radar".

[i.7] ECC Report 23: "Compatibility of automotive collision warning Short Range Radar operating at 24 GHz with FS, EESS and Radio Astronomy, Cavtat, May 2003".

[i.8] ETSI TR 102 263 (V1.1.2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Radio equipment to be used in the 77 GHz to 81 GHz band; System Reference Document for automotive collision warning Short Range Radar".

[i.9] ECC Report 56 (October 2004): "Compatibility of automotive collision warning short range radar operating at 79 GHz with radio communication services", Stockholm.

[i.10] ECC/DEC(04)03: "The frequency band 77-81 GHz to be designated for the use of Automotive Short Range Radars".

NOTE: Approved 19 March 2004, Corrected 6 March 2015.

[i.11] Commission Decision 2004/545/EC of 8 July 2004 on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community.

[i.12] ECC/DEC(04)10: "ECC Decision of 12 November 2004 amended 01 June 2012 on the frequency bands to be designated for the temporary introduction of Automotive Short Range Radars (SRR)".

[i.13] Commission Implementing Decision (EU) 2017/2077 of 10 November 2017 amending Decision 2005/50/EC on the harmonisation of the 24 GHz range radio spectrum band for the time-limited use by automotive short-range radar equipment in the Community.

[i.14] ETSI TR 102 664 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Short range radar to be used in the 24 GHz to 27,5 GHz band; System Reference document".

[i.15] ECC Report 158 (January 2011): "The impact of 26 GHz SRR applications using ultra-wideband (UWB) technology on radio services", Cardiff.

[i.16] ETSI EN 301 091-1 (V2.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 1: Ground based vehicular radar".

[i.17] ETSI EN 302 264 (V2.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.18] H. Meinel: "Automotive Radar - History", state-of-the-art and future trends, EuRAD 2012.

[i.19] Texas Instruments: AWR1243: "76-to-81 GHz High Performance Automotive MMIC".

NOTE: Available at http://www.ti.com/product/AWR1243.

[i.20] F. Pfeiffer: "Analyse und Optimierung von Radomen für automobile Radarsensoren", PhD thesis 2009 (in German).

NOTE: Available at https://mediatum.ub.tum.de/doc/814771/814771.pdf.

[i.21] ITU Radio Regulations, edition of 2016.

[i.22] Recommendation ITU-R M.2057-1 (01/2018): "Systems characteristics of automotive radars operating in the frequency band 76 - 81 GHz for intelligent transport systems applications".

[i.23] European Commission 2018/0145[COD]: "Proposal for a Regulation of the European Parliament and of the Council on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018/… and repealing Regulations (EC) No 78/2009, (EC) No 79/2009 and (EC) no 661/2009", (Text with EEA relevance) {SEC(2018)270 final} - {SWD(2018) 190 final} - {SWD(2018)191 final}.

[i.24] European Commission: "Benefit and Feasibility of a Range of New Technologies and Unregulated Measures in the fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users (March 2015)".

[i.25] Department Of Transportation, National Highway Traffic Safety Administration, [Docket No. NHTSA-2015-0119]: "New Car Assessment Program (NCAP)".

[i.26] Report ITU-R M.2322-0 (11/2014): "Systems characteristics and compatibility of automotive radars operating in the frequency band 77.5 - 78 GHz for sharing studies".

[i.27] DAT Group: "DAT Report 2016".

NOTE: Available at https://www.dat.de/fileadmin/media/download/DAT-Report/DAT-Report-2016.pdf.

[i.28] "Automotive Radar Market - Expected to Reach $12.1 Billion by 2025".

NOTE: Available at https://www.prnewswire.com/news-releases/automotive-radar-market---expected-to-reach-121-billion-by-2025-300575733.html.

[i.29] MOSARIM documents: Project description: "ICT for Safety and Energy Efficiency in Mobility".

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[i.30] NTHSA: "Radar congestion study".

NOTE: Available at https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13790_radarstudy_092518_v2b-tag.pdf.

[i.31] SAE J3016™: "Automated driving levels", January 2019.

NOTE: Available at https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic.

[i.32] National Radio Astronomy Observatory Report: "Measurements of Automotive Radar Emissions received by a Radio Astronomy Observatory" Kitt Peak Measurements.

NOTE: Available at https://library.nrao.edu/public/memos/edtn/EDTN_219.pdf.

[i.33] IEEE paper: "Reduced Interference of 79GHz UWB Automotive Radars to Radio Astronomy Stations by Signal Integration Effects".

NOTE: Available at https://ieeexplore.ieee.org/document/6101015.
https://www.researchgate.net/publication/254010829_Reduced_interference_of_79GHz_UWB_automotive_radars_to_radio_astronomy_stations_by_signal_integration_effects.

[i.34] IMIKO public funded project website (German only).

NOTE: Available at https://www.elektronikforschung.de/projekte/imiko-radar.

[i.35] Cedric Malaquin: "The Automotive Radar Market", Workshop WW-02, EuRAD 2018.

[i.36] ISO 22178:2009: "Intelligent transport systems -- Low speed following (LSF) systems -- Performance requirements and test procedures".

[i.37] ISO 22839:2013: "Intelligent transport systems -- Forward vehicle collision mitigation systems -- Operation, performance, and verification requirements".

[i.38] ISO 16787:2017: "Intelligent transport systems -- Assisted parking system (APS) -- Performance requirements and test procedures".

[i.39] ISO 19237:2017: "Intelligent transport systems -- Pedestrian detection and collision mitigation systems (PDCMS) -- Performance requirements and test procedures".

[i.40] ISO/AWI23374: "Intelligent transport systems -- Automotive valet parking systems (AVPS) -- System framework, communication interface, and vehicle operation".

[i.41] ISO/DIS 21202: "Intelligent transport systems -- Partially Automated Lane Change Systems (PALS) -- Functional/operational requirements and test procedures".

[i.42] UNECE: "Proposal for Technical requirements for an automated lane keeping system".

NOTE: Available at https://wiki.unece.org/download/attachments/80380916/ACSF-22-03%20%28Chair%29%20Base%20document_for_low_speed_ALKS.pdf?api=v2.

[i.43] UNECE: "Automatic lane change following a request by the driver".

NOTE: Available at https://wiki.unece.org/download/attachments/50856793/ACSF-15-16-Rev.1%20-%20%28Secretary%29%20-%20Preliminary%20consolidated%20document%20after%2015th%20meeting%20with%20proposals%20for%20amendments%20incl.%20ESF.docx?api=v2.

[i.44] ETSI EN 305 550 (V1.2.1) (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 40 GHz to 246 GHz frequency range".

[i.45] ETSI EN 302 372 (V2.1.1): "Short Range Devices (SRD); Tank Level Probing Radar (TLPR) equipment operating in the frequency ranges 4,5 GHz to 7 GHz, 8,5 GHz to 10,6 GHz, 24,05 GHz to 27 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.46] ETSI EN 302 729 (V2.1.1): "Short Range Devices (SRD); Level Probing Radar (LPR) equipment operating in the frequency ranges 6 GHz to 8,5 GHz, 24,05 GHz to 26,5 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.47] ETSI EN 301 783 (V2.1.1): "Commercially available amateur radio equipment; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.48] ETSI EN 303 360 (V1.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Obstacle Detection Radars for Use on Manned Rotorcraft".

[i.49] ETSI EN 301 091-2 (V2.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 2: Fixed infrastructure radar equipment".

[i.50] ETSI EN 301 091-3 (V1.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 3: Railway/Road Crossings obstacle detection system applications".

[i.51] ETSI EN 302 217 (V3.1.1) (all parts): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas".

[i.52] Automotive Radar Market by Range (Long Range, Medium & Short Range), by Vehicle Type (Passenger Car, Commercial Vehicle), by Application (Adaptive Cruise Control, Autonomous Emergency Braking, Blind Spot Detection, Forward Collision Warning System, Intelligent Park Assist), by Geography (U.S., Mexico, Canada, U.K., Germany, France, Italy, China, India, Japan) - Global Market Size, Share, Development, Growth, and Demand Forecast, 2016-2023.

NOTE: Available at https://www.psmarketresearch.com/market-analysis/automotive-radar-market.

[i.53] Grand View Research: "Automotive Radar Market".

NOTE: Available at https://www.grandviewresearch.com/press-release/global-automotive-radar-market.

[i.54] "Global Automotive Radar Market is to Obtain a Market Valuation of Around US$ 4.9 bn Due to Increased Interest for Various Advanced Features".

NOTE: Available at https://www.transparencymarketresearch.com/pressrelease/automotive-radar-market.htm.

[i.55] JRC Scientific and Policy Reports: "Cross Section Measurements of Pedestrian Dummies and Humans in the 24/77 GHz Frequency Bands" Joaquim Fortuny-Guasch, Jean-Marc Chareau", 2013.

[i.56] ISO 15622:2018: "Intelligent transport systems -- Adaptive cruise control systems -- Performance requirements and test procedures".

[i.57] ERC Report 25: "The European Table of Frequency Allocations and Applications in the Frequency Range 8.3 kHz to 3000 GHz", March 2019.

[i.58] ETSI TR 102 704 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Radar sensors for non-automotive; ground based vehicular applications in the 76 GHz to 77 GHz frequency range".

[i.59] Euro NCAP Roadmap 2025.

NOTE: Available at https://cdn.euroncap.com/media/30700/euroncap-roadmap-2025-v4.pdf.

[i.60] ECC Decision (18)06: "Harmonized technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz", approved July 2018.

[i.61] Report ITU-R RA.2457-0 (06/2019): "Coexistence between the radio astronomy service and radiolocation service applications in the frequency band 76-81 GHz".

[i.62] NHTSA Announces Coming Upgrades to New Car Assessment Program.

NOTE: Available at https://www.nhtsa.gov/press-releases/ncap-upgrades-coming.

[i.63] Recommendation ITU-R RA.769-2: "Protection criteria used for radio astronomical measurements".

[i.64] Final Acts World Radiocommunication Conference Geneva 2015. Resolution 759 (WRC-15) Technical studies on the coexistence of the radiolocation service and the amateur, amateur-satellite and radio astronomy services in the frequency band 76-81 GHz.

[i.65] ERTRAC automated driving roadmap.

NOTE: Available at https://connectedautomateddriving.eu/wp-content/uploads/2017/07/2017-05-29_ERTRAC-Roadmap.pdf.

[i.66] Victoria Police Institute: "Autonmous Vehicle Implementation Predictions".

NOTE: Available at https://www.vtpi.org/avip.pdf.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

Duty Cycle (DC): product of the pulse repetition frequency (PRF) and the pulse duration t_{pulse}

equivalent isotropically radiated power (e.i.r.p.): product of "power fed into the antenna" and "antenna gain"

NOTE: The e.i.r.p is used for both peak and average power.

Frequency Modulated Continuous Wave (FMCW): based on a periodically linear frequency sweep of the transmit signal

NOTE 1: For distance measurement sensors often a sawtooth or a triangular modulation scheme is used.

NOTE 2: By mixing the current transmit signal with the reflected signal the round trip time of the individual echoes and thus the distance of the different targets can be determined.

NOTE 3: Although the instantaneous bandwidth of a FMCW Radar is close to zero the recorded power versus time variation results in a wideband spectrum which is clearly not pulsed.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

ε_r	Dielectric constant
X_e	Dielectric susceptibility: ε_r -1

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACC	Automatic Cruise Control
ADAS	Advanced Driver Assistance System
AEB	Automatic Emergency Braking
AI	Artifical Intelligence
APA	Automated Parking Assist
APS	Assisted Parking System
ARIB	Association of Radio Industries and Businesses (Japan)
AVPS	Automotive Valet Parking System
BMBF	German Ministry of Education and Research
BSD	Blind Spot Detection
BW	Band Width
CAGR	Cumultative Annual Growth Rate
CE	Comission Européenne
CEPT	European Conference of Post and Telecommunications administrations
CMOS	Complementary Metal Oxide Semiconductor
DAT	Deutsche Automobil Treunhand (German Automobile Trust)
DOT	Department Of Transportation (US)
ECA	European Common Allocations table
ECC	Electronic Communications Committee
EIRP	Equivalent Isotropic Radiated Power
ERC	European Radiocommunication Committee
EU	European Union
Euro NCAP	European New Car Assessment Program
FCC	Federal Communications Comission (US)
FCM	Front Crash Mitigation
FCW	Forward Collision Warning
FM	Frequency Modulation
FMCW	Frequency Modulated Continuous Wave
FP	Framework Programmes for research and technological development of European Union
HAD	Highly Automated Driving
HZAP	Home Zone Automated Parking
IDA	Infocomm Development Authority of Singapore
IMDA	Infocomm Media Development Authority (Singapore)
IMIKO	German research project: Interferenzminimierung durch Kooperation bei Radarsensoren für autonome Elektrofahrzeuge (funded by German Ministry of Education and Research)
ISM	Industrial Science and Medical (frequency band)
ISO	International Organization for Standardization
ITU-R	International Telecommunication Union - Radio Sector
LDW	Lane Departure Warning
LED	Light Emitting Diode
Lidar	Light detection and ranging
LKA	Lane Keeping Assistant
LKS	Lane Keeping-assist System
LPR	Level Probing Radar
LRR	Long Range Radar
LSF	Low speed following system

MRR	Mid Range Radar
NCAP	New Car Assessment Programme
NHTSA	National Highway Transportation Safety Administration (USA)
NTHSA	National Highway Traffic Safety Administration (US)
OBW	Occupied BandWidth
OFDM	Orthogonal Frequency Division Modulation
PALS	Partially Automated Lane Change Systems
PDCMS	Pedestrian Detection and Collision Mitigation System
PSD	Power Spectral Density
RAS	Radio Astronomy Service
RCS	Radar Cross Section
RES	Resolution (ITU-R)
RR	ITU-R Radio Regulations
RRA	National Radio Research Agency (South Korea)
RX	Receiver
SAE	Society of Automotive Engineers
SRD	Short Range Device
SRR	Short Range Radar
SRS	Space Research Service
SVS	Surround View System
TG	Task Group (ETSI)
TLPR	Tank Level Probing Radar
TX	Transmitter
UNECE	United Nations Economic Commission for Europe
UPA	Ultrasonic Park Assistant
US NCAP	US New Car Assessment Program
US	United States
USRR	Ultra Short Range Radar
UWB	Ultra-Wide Band technology
VCO	Voltage Controlled Oscillator
VRU	Vulnerable Road User
VRU-AEB	Vulnerable Road User - Automatic Emergency Braking (pedestrians & bicyclists)
WRC	World Radio Communications Conference

4 Comments on the System Reference Document

4.1 From ETSI members: Great Circle Design and Navtech Radar

The present document discusses only vehicular applications, which is in line with its title and scope.
There are, however, many other possible applications for radiodetermination at these frequencies.

The relevant WRC-15 decision (footnote 5.559B) [i.21] states:

The use of the frequency band 77.5-78 GHz by the radiolocation service shall be limited to short-range radar for ground-based applications, including automotive radars. The technical characteristics of these radars are provided in the most recent version of Recommendation ITU-R M.2057. The provisions of No. 4.10 do not apply (WRC-15).

It is the clear intention of ITU that the use should be all ground-based applications and not exclusively automotive or vehicular radar. CEPT is requested to bear this in mind and to revise the designation to "ground-based radiodetermination applications", not just for 77,5 GHz - 78 GHz but for the whole band 76 GHz - 81 GHz.

Secondly, the present document requests a change in status for vehicular radar and the removal in the relevant ECC and EC Decisions of references to: *must operate on a non-interference and non-protected basis.*

This is the point of view of some ETSI members:

"We note that the most likely source of interference to a vehicle radar is another vehicle radar. Therefore, such a change of status cannot and should not be considered until there is a credible solution to the question of vehicle radar to vehicle radar interference".

5 Presentation of system and technology

5.1 Background on current technology

Radar sensors for supporting the driver of a vehicle have been under development by companies in Europe, the United States and Asia for several decades [i.18]. Early prototypes were operated in various frequency ranges such as 10 GHz, 16 GHz, 24 GHz, 35 GHz, 50 GHz or 94 GHz.

Then, in 1996, the first series production busses and trucks were equipped in the United States with front and side looking collision warning radars, operating at approximately 10 GHz and 24 GHz.

A few years later, the first series production cars were equipped with:

- front looking radars for adaptive cruise control, operating in the band 76 GHz - 77 GHz;
- rear corner radars for parking support and blind spot detection, operating in the 24 GHz ultra-wideband range;
- rear corner radars for blind spot detection and lane change assistance, operating in the 24 GHz narrow band range.

Since then, advances in RF circuit integration, advances in microcontroller performance and advances in software algorithms helped to further improve the sensor performance, to add additional assistance functions and to reduce the sensor price so that today millions of 24 GHz (narrow band) and 76 GHz - 77 GHz radar sensors per year are installed in new vehicles, ranging from small city cars up to luxury cars, thus supporting more and more drivers in safer driving.

It should be noted, that following the current regulation for automotive radars in the 24 GHz UWB band will be phased out in Europe by 2020 [i.12]. Since in the meanwhile this band became one of the 5G pioneer bands [i.60], it is expected that all other administrations that implement of IMT-2020, will also phase out the regulation for 24 GHz UWB automotive radars in the near future.

Table 1: Overview of radar sensors and use cases in current vehicles

Frequency range	Mounting position in vehicle	Classification	Non-exhaustive list of typical Use-cases
24,05 GHz - 24,25 GHz	Front	MRR	Distance warning
	Rear corners	MRR	Blind-spot detection, lane change assistance, rear cross traffic alert, precrash rear, exit assistance
24,25 GHz - 26,65 GHz (UWB) is Phased out in Europe by 2022 [i.12] 5G pioneer band in Europe [i.60]	Front	SRR	Stop-and-go
	Rear corners	SRR	Blind-spot detection, lane change assistance, rear cross traffic alert, precrash rear, exit assistance
76 GHz - 77 GHz	Front	LRR	Adaptive cruise control
	Front corners	MRR	Front cross traffic alert
	Rear corners	MRR	Blind-spot detection, lane change assistance, rear cross traffic alert, precrash rear, exit assistance
77 GHz - 81 GHz	Not specified	Not specified	Up to now (09/2019), 2 automotive radar sensors received equipment type approval in the US, use case for both is parking support. No information available yet from other parts of the world

Remarks:

- The regulation for 24 GHz UWB radar sensors are time limited to 2022 [i.12]. The functions that are currently provided by 24 GHz UWB radar sensors are envisaged to be implemented in 79 GHz sensors.
- The regulation of 24 GHz narrow band and 76 GHz radar sensors are not time limited and will see continued use in the future.
- The fast development which took place over time lead to some inconsistency in naming and the usage of terms with regards to automotive radar categories: In some documents all automotive radars are called "Short Range Radars (SRR)" because the maximum measurement range of up to approximately 250 m is short compared to several kilometres for other radars used for example by airplanes or ships.
- This document and other documents dealing specifically with automotive radars use the terms to describe certain categories based on the function and application of the auto radar sensor. Typically 4 categories of automotive radar sensors are described. The exact value for the measurement range of a category is not consistent and depends on each document. It should be noted that to ensure stable function in the given measurement range of a sensor, the RF-coverage range of the device should be larger.
- Typical values for the 4 categories are "Ultra Short Range Radar (USRR)" with a maximum measurement range up to 15 m, "Short Range Radar (SRR)" only for devices with a maximum measurement range of up to approximately 50 m, while devices with up to 150 m are called "Mid-Range Radar (MRR)" and devices up to 250 m or more are called "Long Range Radar (LRR)".

In parallel, over time ISO worked on standardization of assistance functions (see Table 2). Certain functions defined by ISO can only be supported or provided by radar technology.

Table 2: Examples of ISO standards for current driver assistance systems

ISO standards	Summary of Content
ISO 22178:2009 [i.36]	The ISO standard covers functions and test method of a low speed following system, to control vehicle speed adaptively to a forward vehicle by using information like ranging and motion.
ISO 22839:2013 [i.37]	The ISO standard covers functions and test method regarding Forward Vehicle Collision Mitigation Systems, to be able to reduce the severity of forward vehicle collisions that cannot be avoided, including the likelihood of forward collision with forward vehicles might be reduced.
ISO 16787:2017 [i.38]	The ISO standard for Assisted Parking System (APS) addresses light-duty vehicles with such APS. The document establishes minimum functionality requirements regarding detection of suitable parking spaces, calculation of trajectories and lateral control of the vehicle. Also, Information regarding relevant obstacles in the driving path can also be included in the functionality.
ISO 19237:2017 [i.39]	The ISO standard describes requirements and test methods regarding Pedestrian Detection and Collision Mitigation Systems (PDCMS) to reduce the severity of pedestrian collisions that cannot be avoided. Target is to reduce the likelihood of fatality. Parameters like range and motion of pedestrian and/or subject vehicle is defined to derived commands and warnings for the driver.

In parallel, over time the radio regulation for automotive radars has been developed in Europe Starting with 24 GHz narrowband (see [i.1] and [i.2], which has been available for a long time as a ISM band, followed by 76 GHz - 77 GHz between 1991 and 2002 (see [i.3], [i.4] and [i.5]), 24 GHz Ultra-wideband between 2002 and 2011 (see [i.6], [i.7], [i.12], [i.13], [i.14] and [i.15]) and finally 79 GHz ultra-wideband in 2004 (see [i.8], [i.9], [i.10] and [i.11]).

It should be noted that some of the above referenced documents have been withdrawn in the meantime and they are listed here to provide a full picture of the development over the years.

5.2 Description of future technology

Development roadmaps and regulatory requirements foresee further price/performance improvements of a single sensor allowing also new use cases and thus further improvement of road traffic safety (see Figure 1 and Annex A).

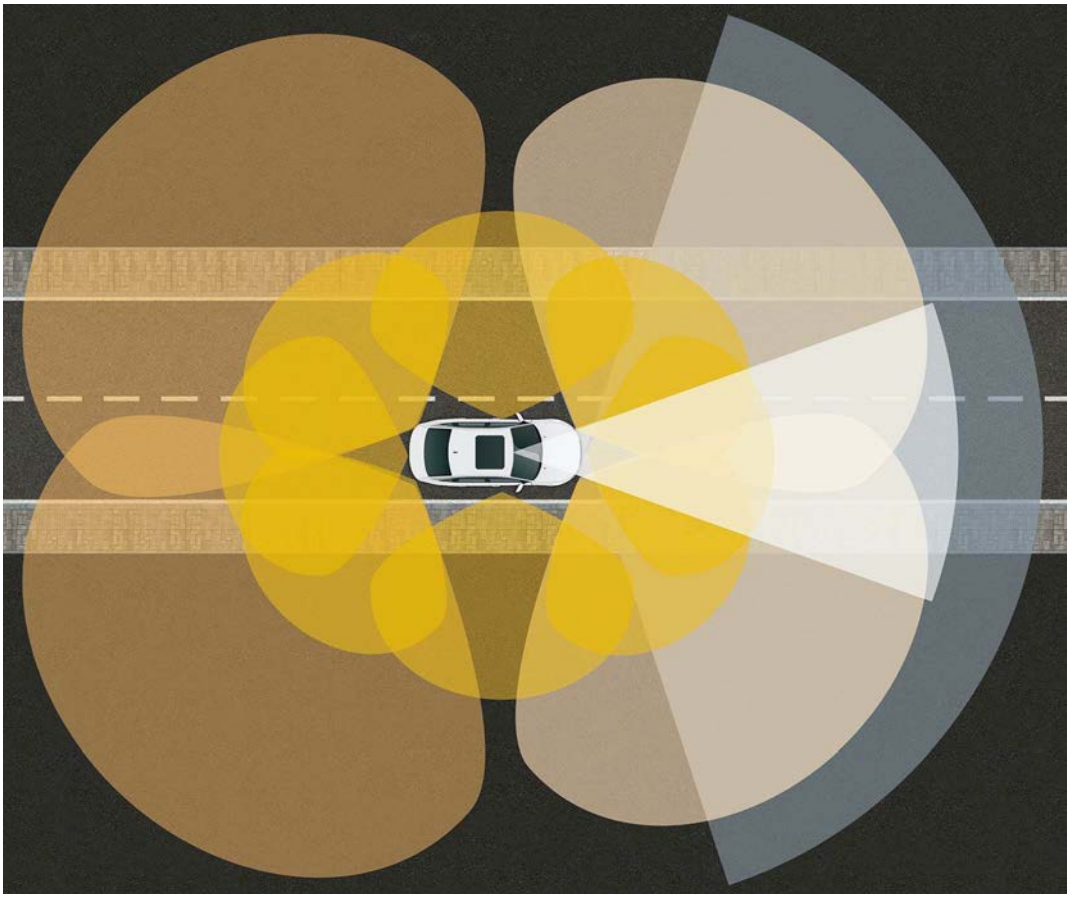


Figure 1: Example for the coverage range of radar sensors at one vehicle to achieve 360 degrees coverage (source: HELLA)

In part the growth is motivated by governments setting mandatory requirements for car manufacturers to include features like AEB (Automatic Emergency Breaking, Pedestrian Detection (VRU-AEB), or product rating agencies like Euro NCAP assigning higher ratings if safety functions are available as optional or standard equipment (see [i.23], [i.24] and [i.25]).

The European Commission has issued a proposal [i.23] for the mandatory inclusion of multiple ADAS technologies In [i.24] it is stated "The current proposal addresses the main problem of persistent high number of road accidents that in turn leads to a high number of fatalities and severe injuries and provides measures to increase safety at vehicle level so as to either avoid and lower the number of accidents or lower the severity of un-avoided accidents to limit the number of fatalities and severe injuries".

Figure 2: European Commission views on the need for regulatory action [i.24]

The European Commission [i.24] is proposing that within 3 years all ***new*** models introduced on the market **should have 11 advanced safety features**, such as:

- Advanced emergency braking.
- Alcohol interlock installation facilitation (cars, vans, trucks and buses).
- Drowsiness and attention detection (cars, vans, trucks and buses).
- Distraction recognition/prevention (cars, vans, trucks and buses).
- Event (accident) data recorder (cars and vans).
- Emergency stop signal (cars, vans, trucks and buses).
- Intelligent speed assistance (cars, vans, trucks and buses).
- Lane keeping assist (cars and vans).
- Reversing camera or detection system (cars, vans, trucks and buses).

Further measures are proposed to be added a few years later.

Different countries and regions have already implemented safety functions, new evolved functions are planned. The regional NCAP organizations (e.g. Euro NCAP, US NCAP, etc.) have already developed their road maps for implementing new functions for the next period ([i.59] and [i.62]).

Through fusion of several vehicular perception sensors (e.g. camera, lidar and radar) a sensing performance is on the horizon, powerful enough for automated driving. By additionally using communication between vehicles or infrastructure the data set used by a car to decide on its next actions can be further improved.

The Society of Automotive Engineers (SAE) has defined five levels of automomous driving. The relevant SAE standard SAE J3016™ that defines the levels of automated driving can be found in [i.31].

In Germany, currently series production cars up to level 2 are allowed to be used on the roads. First series production cars are available carrying all technology to in principle also support level 3. Some manufacturers and groups of manufacturers are developing highly and fully automated vehicles (levels 4 and 5). End of 2018, the first robotic taxi service was started by Waymo™ in Phoenix (Arizona).

Highly automated autonomous driving level 4 and fully automated cars of level 5 are expected to provide new forms and modes of transportation, changing the way mobility is provided.

UNECE and ISO are already working on respective regulations and standards (see examples in Table 3).

Table 3: Examples of regulations and standards under development for more automated driving

ISO/AWI23374: Intelligent transport systems -- Automotive valet parking systems (AVPS) -- System framework, communication interface, and vehicle operation [i.40]
ISO/DIS 21202: Intelligent transport systems -- Partially Automated Lane Change Systems (PALS) -- Functional/operational requirements and test procedures [i.41]
UNECE Proposal for Technical Requirements for an Automated Lane Keeping System [i.42]
UNECE Automatic lane change following a request by the driver, Informal Working Group on Automatically Commanded Steering Functions [i.43]

6 Market information

German DAT report [i.27] shows for 2015 that 11 % of German drivers buying a new car chose an ACC radar system (meaning a radar sensor at the vehicle front) and 9 % chose a lane-change-assist radar system (meaning two radar sensors at the vehicle back).

Because of the drivers described in clause 5, the number of vehicles with radar sensors and the number of radar sensors per vehicle will increase see Tables 4 and 5.

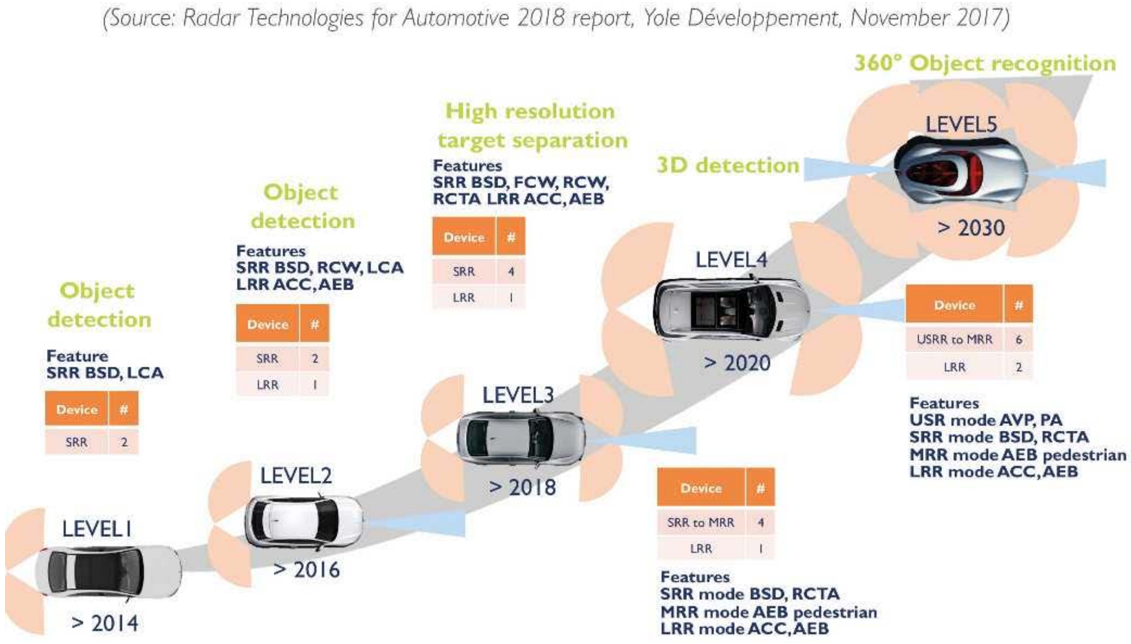


Figure 3: Required number of automotive radar sensors per vehicle and realized functions for implementing the different SAE levels of autonomous driving [i.35]

Several sources provide estimates about timeframe and volume for the implementation of the SAE automated driving levels. In [i.65] clause 3 development paths for the implementation of automotive driving functions are provided. The analysis provided in [i.65] dates from 2017. Developments and technology was evolving since then. In [i.66] exhibit 26 provides a more upto date projection for autonomous vehicle sales, fleet and travel. It is to be noted that the percentage of level 5 systems will have a moderate increase in the mid future.

The increase in the percentage of the higher automated driving levels, leads to an increase in demand for automotive radar sensors. Automotive radar is a key sensor technology for automated driving functions.

This also means an increase in the total radar sensor value with a growing portion to 79 GHz radars (see Table 4).

Table 4: Forecast of radar module sale in Million US$ [i.35]

Year	Module value approximately in Million US$
2016	2 000
2017	3 000
2018	4 500
2019	5 500
2020	6 000
2021	7 000
2022	7 500

According to company "Prescient & Strategic Intelligence", the global automotive radar market had a size of approximately 3 billion US$ in 2017 "and is expected to witness a Cumulative Annual Growth Rate (CAGR) of 21 %" [i.52].

According to company "Research and Markets", the global automotive radar market will reach a volume of approximately 12 billion US$ is 2025 [i.28].

The same result is also obtained by company "Grand View Research" [i.53].

More cautious are the estimations of company "Transparency Market Research" who give a value of around 4,9 billion US$ in 2026 [i.54].

7 Technical information

7.1 Detailed technical description

7.1.1 Required Tx bandwidth and Tx power for sensor use categories

The provided estimations of the required bandwidth and transmit power in Table 5 are for a single radar sensor for current and future use cases.

The future requirements for radar based functions will increase, because more automated driving means less driver attention meaning new or higher sensor requirements with respect to detection range (give vehicle enough time to compute a vehicle reaction) and resolution of objects (now also debris on the road has to be detected and reacted on). Therefore, the values given in the Table 5 illustrate how based on the new proposal regarding increase in power spectral density limits the performance of the sensor function based on category level will increase.

Results calculated based on the current regulation and the proposed regulation are listed and can be compared.

Table 5: Resulting Detection performance increase comparing current regulation to the target regulation for a single radar sensor

Radar use cases	Example applications	Typical Modulation bandwidth	Current Power spectral density and mean e.i.r.p	Requested Power spectral density and Mean e.i.r.p.	Typical detection range based on current regulation	Typical detection range based on requested regulation
Ultra-short range	Parking support	3 GHz	**-16 dBm/MHz** **19 dBm**	**No change** See note 4	Slim parking pole at **1 m** possible	Future: additionally detect smaller obstacles on the road surface
Short range	Blind spot detection	800 MHz	**-9 dBm/MHz** **20 dBm** See note 1	**-3 dBm/MHz** **26 dBm**	Small Child at **14 m** Pedestrian at **17 m** Bicycle at **22 m** See note 3	Small Child at **20 m** Pedestrian at **23 m** Bicycle at **31 m**
Mid-range	Lane change assist	450 MHz	**-9 dBm/MHz** **16 dBm** See note 1	**10 dBm/MHz** **35 dBm**	Small Child at **15 m** Pedestrian at **18 m** Bicycle at **23 m** Motor cycle at **31 m** Car at **56 m** See note 3	Small Child at **44 m** Pedestrian at **58 m** Bicycle at **69 m** Motor cycle at **94 m** Car at **166 m**
Long range	Adaptive cruise control	250 MHz	**-9 dBm/MHz** **13 dBm** See note 1	**20 dBm/MHz** **40 dBm** See note 2	Motor cycle at **35 m** Car at **62 m** See note 3	Motor cycle at **166 m** Car at **296 m**

NOTE 1: Current regulation limit considering bumper loss requirement.
NOTE 2: The calculated value is 43dB m for 250 MHz, but limited to 40 dBm based on regulation proposal.
EXAMPLE: Relationship between power spectral density PSD (dBm/MHz), bandwidth BW [MHz] and EIRP [dBm] is calculated by EIRP = PSD + 10 × log (BW).
NOTE 3: Radar sensors following the current regulation cannot meet todays and future requirements regarding detection range for the given objects. Example: UNECE requests that in an automated lane changing system a motorcycle should be detected in a minimum distance of 55 m, for the automated lane keeping system a motorcycle should be detected in a minimum distance of 46 m. For Turn assist functions a minimum detection distance for bicycles is 30 m.
NOTE 4: No change in the limit is required; so the current -3 dBm/MHz limit is maintained.

Summary: A significant increase in performance can be seen based on the given used cases, when comparing current to the proposed regulation. This will significantly increase the detection range for vulnerable road users, like children, pedestrians, bicycle (including ebike) riders and motor cycle drivers.

This also shows the current regulation is only providing limited number of used cases considering the large 4 GHz spectrum provided. The current regulation limits the used cases to parking and a blind spot detection with limited function. The change in regulation will therefore exploding the full spectrum capacity and use the spectrum efficiently, allowing the use of the spectrum for different and various applications regarding the related frequency band. Therefore, higher Power spectral density is required in 79 GHz band.

7.1.2 mm-wave technology

Integrated mm-wave technology has evolved since the making available of the band in Europe in 2004.

Because of progress in semiconductor technology, active components evolved from discrete RF transistors and diodes over GaAs-based oscillator, amplifier and mixer MMICs over SiGe-based transceiver MMICs to CMOS-based radar system chips (RSCs). Today several semiconductor manufacturers, offer highly integrated RSCs covering the frequency ranges 76 GHz - 77 GHz and 77 GHz - 81 GHz with very similar fundamental RF properties, for example [i.19]:

Typical key parameters meters of such chipsets are:

- Transmitter output power typical 12 dBm (76 GHz - 81 GHz).
- Receiver noise figure typical 15 dB (76 GHz - 77 GHz), typical 16 dB (77 GHz - 81 GHz).

Because of progress in simulation tools and materials, antennas evolved in bandwidth and general performance.

It is concluded that with the evolved available technology, the proposed bandwidth and power levels as given in Table 6 are achievable.

7.1.3 Interference Mitigation techniques

With an increasing number of radar sensors on the roads, the avoidance of interference becomes more and more challenging. During the last years, Mutual interference between automotive radars was described in various publications.

Analysing and developing counter measures against mutual interference has become an important topic over the years. Resulting from this consideration, the automotive industry set up MOSARIM (MOre Safety for All by Radar Interference Mitigation). MOSARIM was set up as a public funded project under the EU FP 7 framework this project went 3 years from 2010-2012 with participation of OEMs, automotive radar sensor manufactures, universities and research institutes. The project proposed countermeasures and mitigation techniques in 6 different domains. The full details for the measures in each domain can be found in the MOSARIM reports [i.29].

Example approaches to handling interference are:

- Adapting the timing of a sensor (limited by period after which the car needs an update from the sensor on the environmental situation, typically 40 ms - 100 ms).
- Adapting the frequency range used by a sensor (limited by frequency regulation).
- Repairing disturbed receive signals in processing after digitization.
- Random timing.
- Coded signals.

Due to progress in CMOS technology and the resulting increased computational power of the microcontrollers used inside radar sensors, and progress of RF circuit technology (see clause 7.1.2), some of the proposed countermeasures could be implemented in the meanwhile in commercially available sensors. Such possibilities for countermeasures were not considered or foreseen in the studies when the original regulation was developed in 2004 [i.10].

Some of the proposed countermeasures and mitigation techniques are implemented in current sensors, while other techniques do need further evaluation and development before they could be implemented in commercial available sensors.

Several entities continue to study the mutual interference between automotive radars. In 12/2018 NTHSA published a study analysing the interference situation between automotive radars [i.30]and proposes mitigation techniques building and developing further approaches from the MOSARIM project. However, analysis of the approach taken in this study show, that the used models were too simplistic and therefore the obtained results were too negative.

NTHSA is planning a test campaign as the second part of the study, the comments provided by the automotive radar sensor manufacturers are expected to be reflected in plan for these tests.

In 2018 OEMs, Sensor manufacturers and universities concluded that there is a need for further studies and further development of the MOSARIM results. This lead to the creation of a new public funded project. This project is funded by the German Federal Ministry of Education and Research (BMBF). The project name is IMIKO [i.34] and it was started in 11/2018 and will run until 10/2021.

7.1.4 Influence of the bumper fascia

The bumper fascia is the plastic structure attached to the front and rear of a vehicle. The fascia may or may not be painted. The presence and the design of the fascia is dictated by the vehicle manufacturer, not by the sensor manufacturer.

An advantage of radar sensors against other automotive environmental sensors is that they can be installed behind the bumper fascia, invisible from the outside. This makes it possible to install these sensors virtually everywhere on the vehicle allowing for 360° detection. However, if the radar sensor is mounted behind the bumper fascia, the influence of the fascia structure needs to be considered during development of the radar based function. The bumper fascia structure depends on the bumper colour.

General description of transmission absorption reflection of the radar signal due to a fascia.

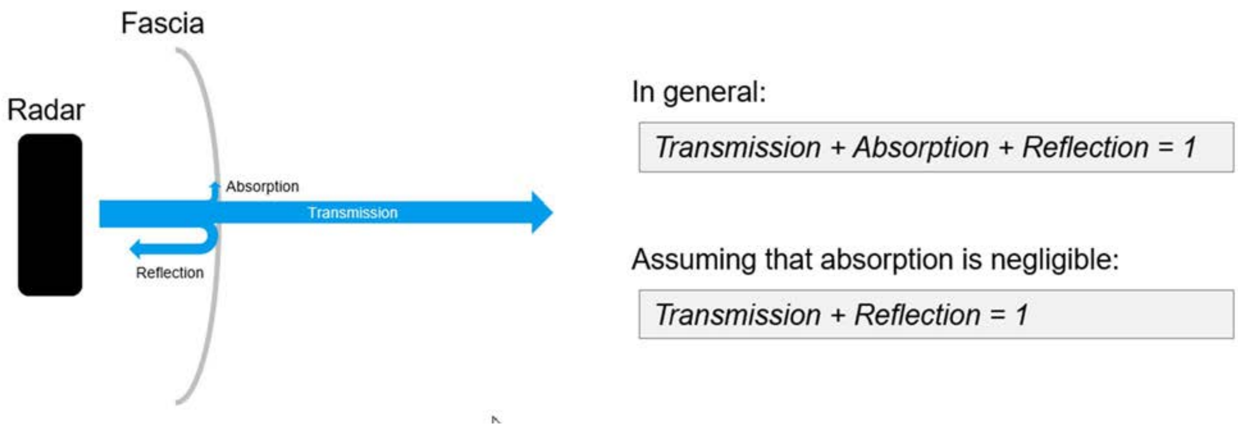


Figure 4: Illustration of radiated power splitting up into three components during interaction with bumper fasica (source: Rohde&Schwarz)

The bumper fascia normally consists of several layers, see example in Figure 5.

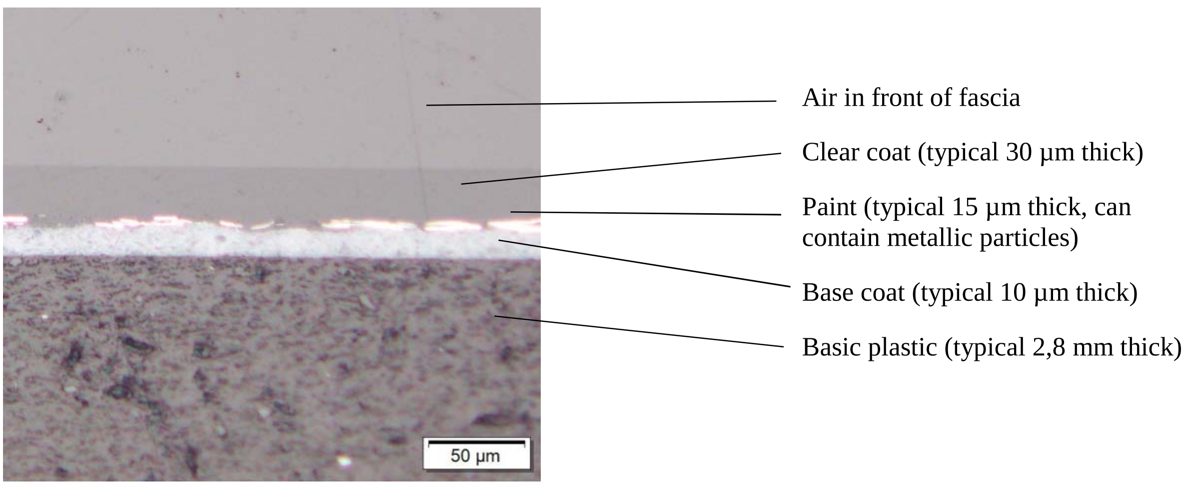


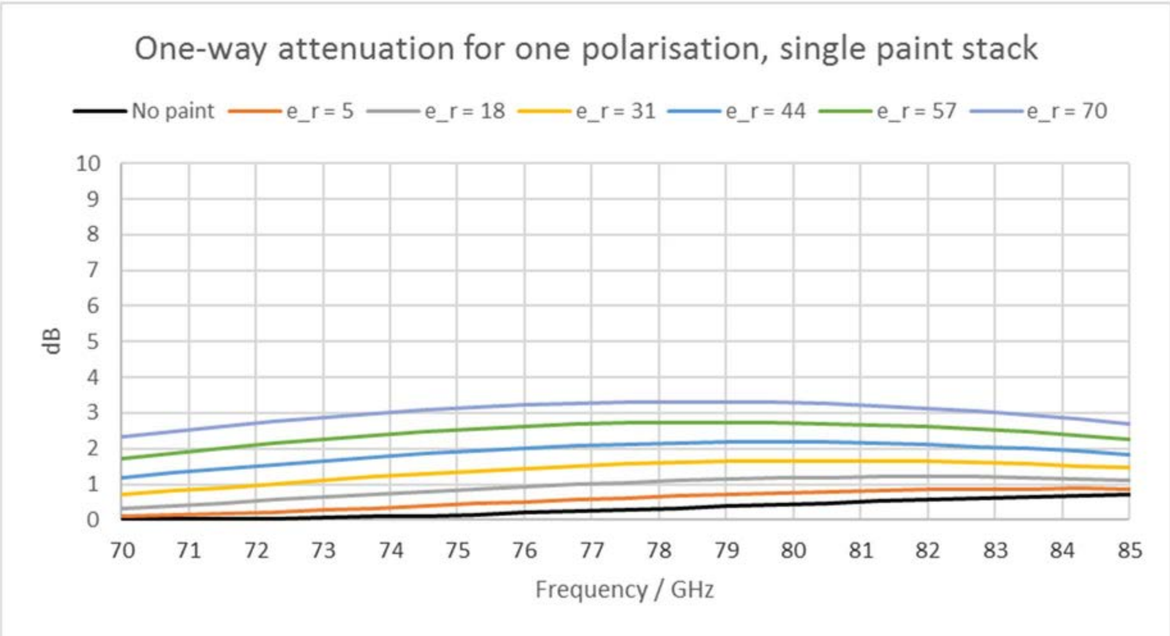
Figure 5: Cross section of an exemplary bumper fascia (source: HELLA)

Metallic particles inside the paint have a large influence on its dielectric properties (dielectric constant ε_r or dielectric susceptibility χ_e). A figure showing the dependency of the dielectric susceptibility of base coats with regards to the weight content of metal can be found in [i.20], figure 4.8.

If a bumper colour mismatch is observed during production, then the layer stack of base coat, paint and clear coat may be repeated multiple times, resulting in the range of 10 dielectric layers or more.

The below presented figures with simulation results are based on the solution of the Fresnel equation.

- Figure 6, for a planar fascia bumper with one layer stack of base coat, paint and clear coat, shows the one-way attenuation at 0° incident angle versus frequency.
- Figure 7, for a planar fascia bumper with one layer stack of base coat, paint and clear coat, shows the one-way attenuation at 79 GHz.
- Figure 8, for a planar fascia bumper with two layer stacks of base coat, paint and clear coat,shows the one-way attenuation at 79 GHz for eps_r=20 and both polarizations.
- Figure 9, for a planar fascia bumper with two layer stacks of base coat, paint and clear coat, shows the one-way attenuation at 79 GHz for eps_r=20 and both polarizations for various basic plastic thicknesses.



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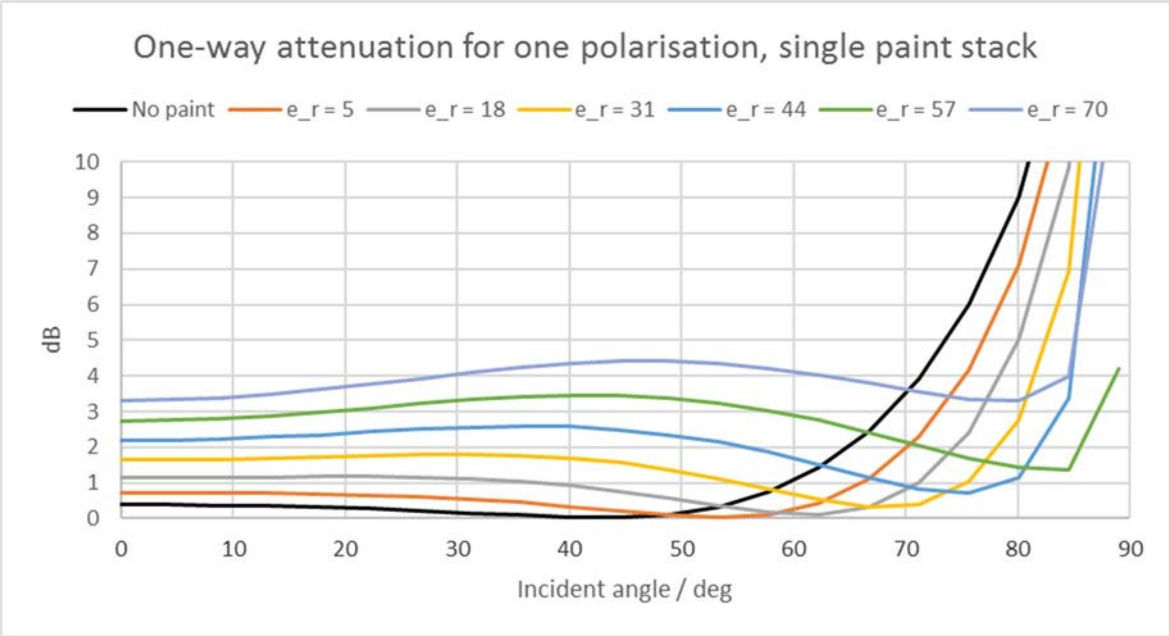
NOTE: In this figure, six different metallic concentrations are considered corresponding to six different paint colours.

Figure 6: Example of one way attenuation at 0° incident angle for planar fascia with a single stack consisting of primer, metallic paint and clear paint layers (source HELLA)



NOTE: In this figure, six different metallic concentrations are considered corresponding to six different paint colours.

Figure 7: Example of one-way attenuation at 79 GHz for planar fascia with a single stack consisting of primer, metallic paint and clear paint layers (source: HELLA)

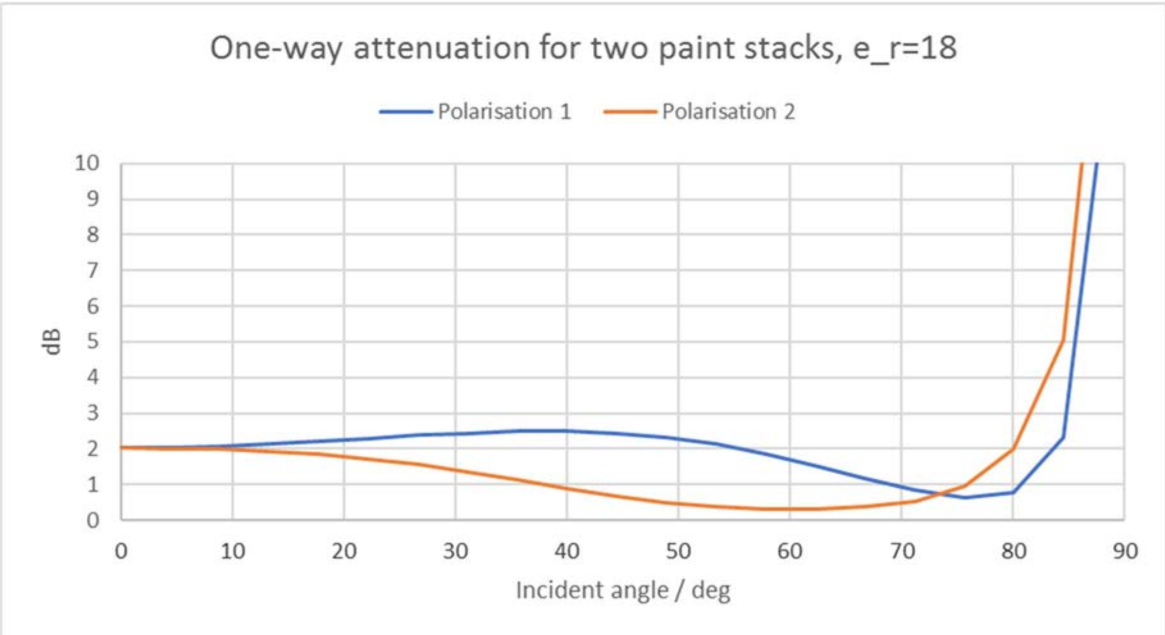


Figure 8: Example one-way attenuation at 79 GHz for planar fascia with two stacks of 3 layers each, consisting of primer, metallic paint and clear paint (source: HELLA)

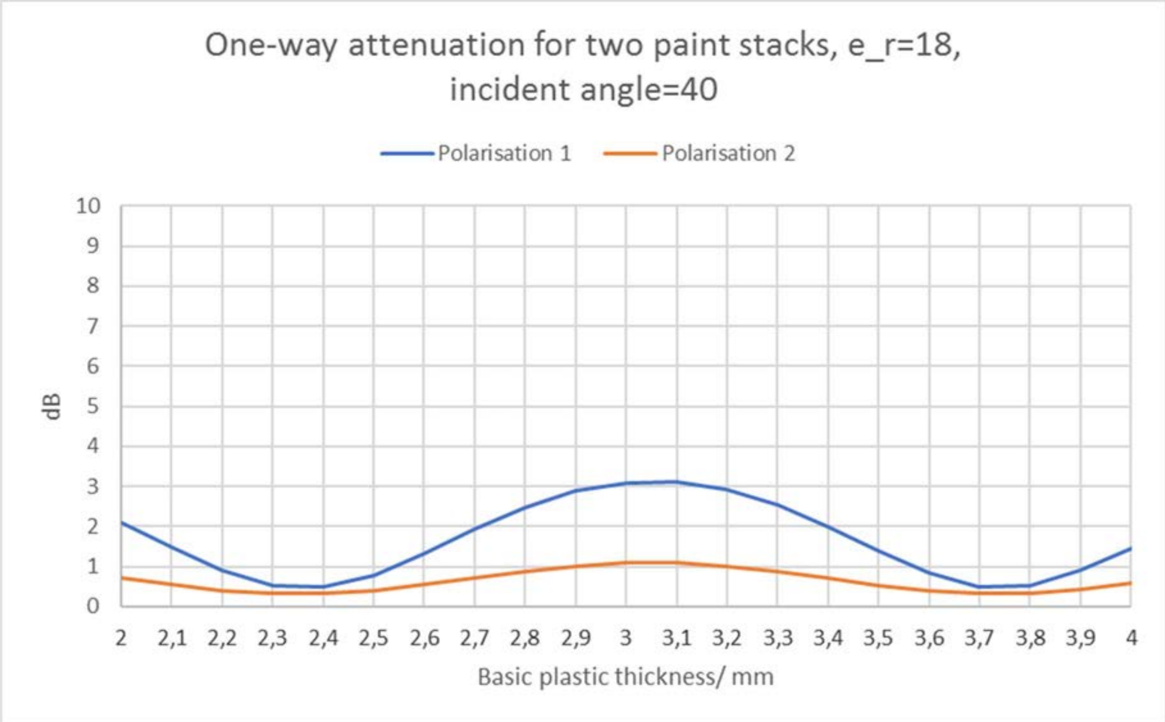


Figure 9: Example of one way attenuation at 79 GHz for planar fascia with two layer stacks of primer, metallic paint and clear paint and varying basic plastic thicknesses (source: HELLA)

From the information in Figures 6 to 9, It becomes obvious that the attenuation of the bumper fascia depends on the frequency, the incident angle, the structure of the paint, the polarization, the number of layer stacks and thickness of basic plastic. In addition, but not considered more in detail here, also the actual curved 3D shape of the fascia, varying from vehicle model to vehicle model, influences the attenuation. Finally, repair and re-painting of the bumper fascia in independent workshops can influence the attenuation.

For the following reasons the fixed limit for bumper fascia attenuation in the regulation and the relevant standard should be deleted:

- Vehicles on which the radar sensors are mounted, do not fall under the RED. Therefore Vehicle manufactures request their suppliers that the delivered components such as automotive radar sensors are CE certified.
- The attenuation of the bumper fascia is not under the control of the automotive radar sensor manufacturer. A third-party supplier under the requirements of the vehicle manufacturer manufactures the bumper with the fascia.
- The bumper fascia attenuation has a significant variation depending on material, colour and radar sensor mounting. Therefore a typical bumper attenuation cannot be specified for a clear test procedure in the harmonised standard. The variation of the bumper attenuation makes it impossible for a radar sensor manufacturer to place a product on the market under the current regulation based on a self-declaration of conformity.

Therefore, the limit in the regulation and the related standard should refer only to the properties of a sole radar sensor, but not to the combination of a radar sensor and a bumper fascia.

7.2 Status of technical parameters

7.2.1 Current ITU and European common allocations

Table 6 lists the existing spectrum allocation s and applications that are in major use in Europe according to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations [i.21] and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.57].

Table 6: Spectrum allocations and major European uses in candidate frequency range 76 GHz - 81 GHz

75,5 GHz - 76 GHz RR 5.561 ECA35	Broadcasting Broadcasting-Satellite fixed Fixed-satellite (Space-to-Earth) Amateur Amateur-Satellite	Fixed Radiodetermination applications Amateur Amateur-satellite Space research
76 GHz - 77,5 GHz RR5.149	Amateur-Satellite Amateur Radio Astronomy Radiolocation Space Research (space-to-Earth)	Amateur-satellite Radio astronomy Amateur Radiolocation (civil) Railway applications Transport and Traffic Telematics (76 GHz - 77 GHz) Radiodetermination applications Short Range Radars (77 GHz - 81 GHz)
77,5 GHz - 78 GHz RR5.149	Radiolocation (5,559 B) Amateur-Satellite Space Research (Space-to-Earth) Amateur	Short Range Radars (77 GHz - 81 GHz) Radiodetermination applications Radio astronomy Amateur Amateur-satellite
78 GHz - 79 GHz RR5.149 RR5.560	Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) Radiolocation	Radio astronomy Amateur-satellite Amateur Radiolocation (civil) Short Range Radars (77 GHz - 81 GHz) Radiodetermination applications
79 GHz - 81 GHz RR5.149	Radio Astronomy Radiolocation Amateur-Satellite Amateur	Radiodetermination applications Short Range Radars (77 GHz - 81 GHz) Radiolocation (civil) Radio astronomy Amateur Amateur-satellite

Pertinent RR/ECA footnotes quoted verbatim from ERC Report 25 [i.57]:

- *ECA 35: "In Europe the band 75,5 - 76 GHz is also allocated to the Amateur and Amateur Satellite services".*
- *RR5.149: "In making assignments to stations of other services to which the bands:…76 - 86 GHz, … are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29)". (WRC-07).*
- *RR5.559B: "The use of the frequency band 77,5 - 78 GHz by the radiolocation service shall be limited to short- range radar for ground-based applications, including automotive radars. The technical characteristics of these radars are provided in the most recent version of Recommendation ITU-R.M.2057 [i.22]. The provisions of No. 4.10 do not apply." (WRC-15).*
- *RR5.560: "In the band 78 - 79 GHz radars located on space stations may be operated on a primary basis in the earth exploration-satellite service and in the space research service."*
- *RR5.561: "In the band 74 - 76 GHz, stations in the fixed, mobile and broadcasting services shall not cause harmful interference to stations of the fixed-satellite service or stations of the broadcasting-satellite service operating in accordance with the decisions of the appropriate frequency assignment planning conference for the broadcasting-satellite service." (WRC-2000).*

7.2.2 Regulatory situation outside Europe

A summary of the existing regulation for vehicular radar in 76 GHz - 77 GHz and 77 GHz - 81 GHz is provided in Annex B. It should be noted that the information provided in Annex B is a snap-shot of the regulatory situation in the listed countries per status 10/2018.

7.2.3 Sharing and compatibility studies already available

In 2004, when developing the regulation for automotive radars in Europe compatibility studies against the relevant radio services were conducted.

The assumed technical parameters for automotive radars in ECC Report 56 [i.9] were based on the available technology at that time. The parameters and the description of automotive radars that were used in the studies were presented in ETSI TR 102 263 [i.8]. At that time, it was assumed that the 79 GHz radars would use the same technology as at that time available 24 GHz UWB radars would use.

Since then radar technology has evolved, so that the assumptions taken at that time can be considered outdated. Despite the evolution in radar technology, the relevant regulation has not been revised since then.

In preparation of implementing a national regulation for 79 GHz, several countries carried out individual studies and analysis:

- In 2012, in preparation for the development of a regulation for 79 GHz automotive radars in the US a test was conducted at Kitt Peak mm wave observatory [i.32]. For the test 2 automotive radar manufacturers provided samples. The test setup of the observatory did not reflect a real world situation. In order to be able to detect the signal of the automotive radars at the observatory an additional plane reflector was used to redirect the beam from the receiver to street level on the ground, rather than utilizing the main dish surface in order to simulate a direct line of sight interference situation.

  It was concluded that an avoidance zone of 30-40 km around the observatory would be needed, in order to keep the interference from an automotive radar below the threshold defined in Recommendation ITU-R RA.769-2 [i.63]. Further on it was concluded that in areas without direct line of sight situation or by applying mitigation measures as described in the report, smaller avoidance zones might suffice.

- In the preparation process for WRC-2015, AI 1.18, report Recommendation ITU-R M.2322 [i.26] was developed analyzing the compatibility between the existing services and automotive radar in the band 77 GHz - 81 GHz. The technical parameters of the automotive radars that were used in the studies are given in Recommendation ITU-R M.2057 [i.22].The studies provided in the report were conducted only based on the consideration of power levels:

  - It is noted in the report, that no SRS (space-to-Earth) systems have been identified to date in the frequency range 76 GHz - 81 GHz. The SRS (space-to-Earth) was therefore not considered in the report.

  - The report concludes that the theoretical studies and observations presented indicate that the required separation distance between automotive radars and incumbent services could range from less than 1 km to up to 42+ km, depending on the interference scenario and deployment environment. These results were based on worst-case assumptions and did not take into account the effects of terrain shielding, terrain occupation and the implementation of mitigation techniques to reduce the possibility of interference to incumbent services. When these factors are taken into account, the possibility of co-channel interference to incumbent services from automotive radars is sufficiently low and manageable. Therefore, it can be concluded that in the 77,5 GHz - 78 GHz band, sharing is feasible between automotive radars and incumbent services.

  - It was further concluded, that any potential cases of interference between automotive radars and incumbent services could be addressed by mitigation factors such as terrain shielding, emission power limits and quiet zones.

- WRC-2015 adopted RES 759 [i.64], that lead to the development of a new report analyzing the compatibility between the Radio Location Service and the Radio Astronomy Service in the frequency band 76 GHz - 81 GHz. This report considers automotive radar sensors as typical examples for the Radio Location Service in the band. The Report ITU-R RA.2457-0 [i.61] was published in June 2019. The conclusions in new report are similar to the conclusion provided in Report ITU-R M.2322-0 [i.26].

Past studies ignored the radar modulation (FM sweep) used by automotive radars and by doing that neglected mitigation effects and thus achieved too stringent requirements against automotive radars.

An exception is the proposal from 2011, was presented in [i.33], giving a theoretical study on interference between 79 GHz automotive radars and Radio Astronomy Service (RAS) stations was performed taking the following mitigation effects into account:

- The automotive radar is considered as instantaneously wideband because of much faster modulation speeds than the RAS integration time.

- The automotive radar signal reaching the RAS contains a random phase modulation because of vehicle.

- Movement, vehicle vibrations and limited quality of VCO used in the automotive radar sensor.

That results in the interference signal appearing at the RAS as incoherent band-limited noise. Furthermore, due to vehicle driving, the antenna gain in the direction from the vehicle to a RAS varies during.

RAS integration time and a statistical distribution is considered for that.

From all that the study derives and proposes a mitigation factor to be considered in addition to a classical I/N calculation.

Here, it is now proposed to overtake this argumentation of [i.33] in order to achieve additional mitigation but apply it to current radar parameters.

Today, automotive radars typically use analogue modulation schemes with linear chirps (see illustration in Figure 10). Chirp durations are in the order of 10 ms for slow chirps or in the order of 10 µs for fast chirps.

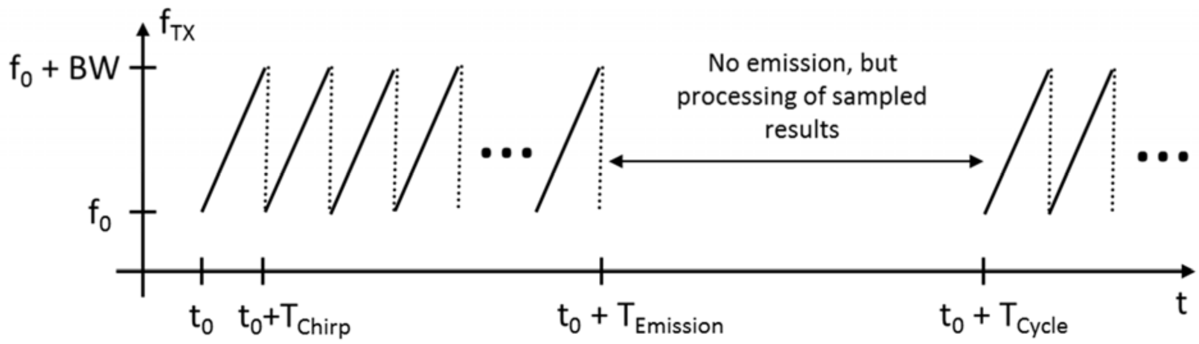


Figure 10: Illustration of analogue modulated radar transmit emission (source: HELLA)

Newly under consideration for automotive radars are digital modulation schemes, for example with phase modulation or OFDM (see illustration in Figure 11).

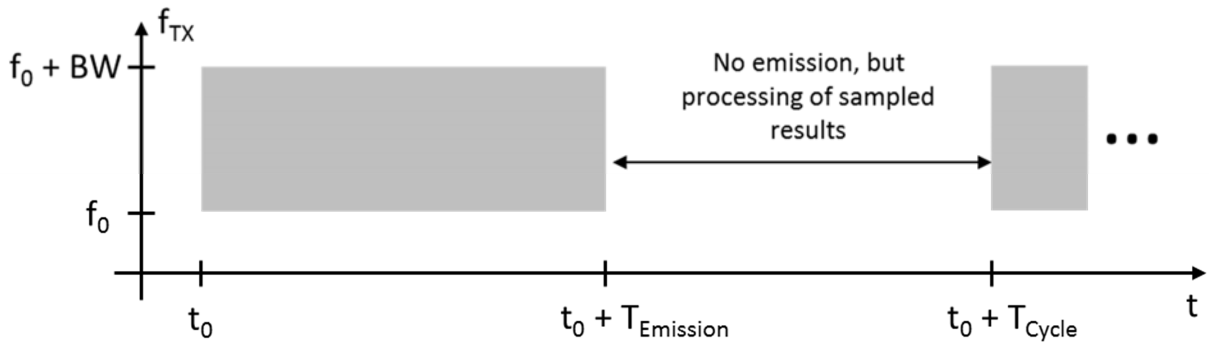


Figure 11: Illustration of digital modulated radar transmit emission (source: HELLA)

In all cases the emission follows a periodic cycle to duration T_{Cylce} (in the order of 50 ms) which is subdivided into an active measurement interval of duration $T_{Emission}$ (in the order of 20 ms) and a processing of sampled results (duration T_{Cycle} - $T_{Emission}$).

7.3 Information on relevant standards

Table 7: relevant standards for the band 77 GHz - 81 GHz

Type	Application	Frequency Ranges [GHz]	ETSI standard	Status	Responsible ETSI TC ERM
Generic	Short Range Devices (SRD)	40 GHz - 246 GHz	ETSI EN 305 550 [i.44]	Under development	TG28
SRD	Tank Level Probing radar (TLPR)	4,5 GHz - 7 GHz, 8,5 GHz - 10,6 GHz, 24,05 GHz - 27 GHz, 57 GHz - 64 GHz, 75 GHz - 85 GHz	ETSI EN 302 372 [i.45]	Cited in the OJEU	TG UWB
SRD	Level Probing Radar (LPR)	6 GHz - 8,5 GHz, 24,05 GHz - 26,5 GHz,	ETSI EN 302 729 [i.46]	Cited in the OJEU	TG UWB

Type	Application	Frequency Ranges [GHz]	ETSI standard	Status	Responsible ETSI TC ERM
		57 GHz - 64 GHz, 75 GHz - 85 GHz			
AMATEUR	Commercially available amateur radio equipment	Not specified in the standard	ETSI EN 301 783 [i.47]	Cited in the OJEU	TG 26
SRD	Obstacle Detection Radars for Use on Manned Rotorcraft	76 GHz - 77 GHz	ETSI EN 303 360 [i.48]	ETSI Published	TG SRR
SRD	Part 1: Ground based vehicular radar	76 GHz - 77 GHz	ETSI EN 301 091-1 [i.16]	ETSI published	TG SRR
SRD	Part 2: Fixed infrastructure radar equipment	76 GHz - 77 GHz	ETSI EN 301 091-2 [i.49]	ETSI published	TG SRR
SRD	Part 3: Railway/Road Crossings obstacle detection system applications	76 GHz - 77 GHz	ETSI EN 301 091-3 [i.50]	ETSI published	TG SRR
SRD	Short Range Radar equipment operating in the 77 GHz - 81 GHz band	77 GHz - 81 GHz	ETSI EN 302 264 [i.17]	ETSI published	TG SRR
Fixed Links	Characteristics and requirements for point-to-point equipment and antennas	1,3 GHz - 86 GHz	ETSI EN 302 217 [i.51]	ETSI Published	ATTM

8 Radio spectrum request and justification

The current regulation for automotive radars in the frequency range 77 GHz - 81 GHz ([i.10] and [i.11]) was developed and introduced in 2004 on the basis of non-interference/ non-protection. In [i.10] the following provisions are given:

- *that the 79 GHz frequency range (77 GHz - 81 GHz) is designated for Short Range Radar (SRR) equipment on a non-interference and non-protected basis with a maximum mean power density of -3 dBm/MHz e.i.r.p. associated with an peak limit of 55 dBm e.i.r.p.;*

- *that the maximum mean power density outside a vehicle resulting from the operation of one SRR equipment shall not exceed -9 dBm/MHz e.i.r.p.*

The mean and peak e.i.r.p. density levels that were originally proposed in the ETSI TR 102 263 [i.8]; twere derived from the limits for the 24 GHz band that were applicable from the regulation in force in 2004by considering correction factors to compensate for additional propagation losses and noise figure differences in the front-end.

These hypotheses were then used by CEPT to conduct the compatibility studies presented in ECC Report 56 [i.9]. In there, the figure of mean e.i.r.p. density of -3dBm/MHz was used as an input parameter coming from the ETSI document and was not, in any way, derived as a result from maximum interference levels to ensure protection of existing services. Consequently, it is reasonable that this limit can be reviewed based on the evolution of the technology and considering the up-to-date protection criteria of the services allocated in this frequency band.

In the same ECC Report 56 [i.9], the study related to compatibility with Amateur Service assumed several parameters, including a bumper attenuation of 6 dB. This value was then interpreted by the regulatory bodies as a unique value that would lead to a mean e.i.r.p. density level of -9 dBm/MHz. From this, it can be understood that the figure of -9 dBm/MHz does not come from a minimum value to protect allocated services but from an interpretation of studies based on outdated requirements of equipment for ground based vehicular applications.

World Radio Conference 2015 decided to allocate the frequency band 77,5 GHz - 78 GHz to the Radiolocation Service on a co-primary basis but limited to ground based radars as outlined in the RR Footnote 5.559B [i.21]. With this decision the full frequency range 76 GHz - 81 GHz is now allocated to the Radio Location Service. Details about the status and the allocations are given in article 5 of the RR [i.21].

The frequency range 77 GHz - 81 GHz plays a key role for future radar sensors because of its large available bandwidth.

Recommendation ITU-R M.2057-1 [i.22] was developed to provide the system characteristics of automotive radars operating in the frequency band 76 GHz - 81 GHz for intelligent transport systems applications.

Up to 2018 no automotive radar sensor for the range 77 GHz - 81 GHz was placed on the market in Europe for the following reasons:

a) For many years, the RF circuit technology was not powerful enough to support the frequency range at acceptable cost (Ultra-Wide Band radar around 26 GHz was more cost effective at that time). With the introduction of SiGe and CMOS RF devices some years ago that situation now has improved. Especially the migration to CMOS based RF technologies, permit the integration of RF and processing capabilities within devices, significantly reducing the cost for radar devices. These System on Chip (SoC) platforms provide the ability to implement digital modulations to significantly improve the efficient and effective use of spectrum through coding schemes. Improvements in technology facilitate sophisticated technics to enhance mutual co-existence between multiple devices utilizing both transmitter and receiver interference mitigation and ejection, such as code correlation, permitting higher densities of devices to securely and safely co-exist in close proximity.

b) For many years, a regulation for automotive radar in this band was not available in important automotive markets outside Europe. With the decision of World Radio Conference 2015 that situation started to improve as seen for example by the recent respective new regulation in the United States and in other regions and countries (see Annex B). But these new regulations are more permissive compared to the existing European regulation for 77 GHz - 81 GHz. To harmonize as much as possible the European Regulation with the regulation in other areas of the world and key markets is one main issue for the present document.

c) The European regulation for 77 GHz - 81 GHz was approved in 2004 ([i.10] and [i.11]) with the intention to transfer the known functions of 24 GHz UWB short range radars (e.g. for parking support and blind-spot detection) to the 79 GHz band and as such does not anymore meet the needs of current use cases. The usage of 24 GHz UWB short range radars was permitted according to [i.12] only for a limited time period due to coexistence problems with passive radio services and fixed radio services.

d) In the current regulation ([i.10] and [i.11]) a fixed bumper loss of 6 dB is assumed, to ensure a maximum mean power density of -9 dBm/MHz outside the vehicle. The manufacturer of a radar sensor cannot directly control the power level outside the vehicle, as sourcing and specification of the bumper and mounting and assembly of these elements are not within the responsibility of the radar sensor manufacturer. With the adoption of the RE-directive the responsibility to comply with the limit of -9 dBm/MHz outside the bumper would be that of the vehicle manufacturer. With that it is impossible for the component manufacturer to declare conformity with the -9 dBm/MHz limit.

e) The power spectral density limit in the existing European regulation is only useful for short range radar applications, but the required use cases are for short range, mid-range and long range radar applications-to support effective solutions for safety enhancement in ground based vehicles. These needs are more general and include also functions with larger detection ranges and thus larger required transmit power.

f) The use of the band 76 GHz - 77 GHz is in the meanwhile permitted in Europe for a wide range of radar applications defined as transport and traffic telematics devices [i.2] In the European regulation, the Usage includes Annex 5 of [i.1] for ground based vehicles, infrastructure systems, obstacle detection radars for rotorcraft use; Annex 4 of [i.1] for obstruction/vehicle detection at railway level crossings. This creates a more general spectrum use in this band with more potential interferers for all radars. This evolution of use in the 76 GHz - 77 GHz was not foreseen when the 77 GHz - 81 GHz regulation was developed.

To overcome the above mentioned shortcomings of the current regulatory situation of short range radar applications in the range 77 GHz - 81 GHz in Europe and to foster the further development of driver assistance systems it is proposed here to further develop the European regulation for automotive radars in the range 77 GHz - 81 GHz as described in detail in the following.

The main request is to exchange the current limit by a set of modulation bandwidth dependent limits as given in Table 8.

Table 8: proposed PSD and e.i.r.p. limits for 77 GHz - 81 GHz radar

Modulation Bandwidth	PSD - limit	Mean e.i.r.p. - limit
Up to 1 GHz	20 dBm/MHz	40 dBm
Up to 2 GHz	7 dBm/MHz	37 dBm
Up to 4 GHz	-3 dBm/MHz	30 dBm

The proposed PSD limits are dependent on the modulation bandwidth of the sensor. Typical system characteristics for TX power and modulation bandwidth of future vehicular radar systems in the band 77 GHz - 81 GHz are provided in clause 7.1.1, Table 6. From the provided values it can be concluded that the PSD of future short range and ultra-short range radar applications would still below the current limit (-9 dBm/MHz); only mid- and long-range radar applications would exceed the existing PSD limit but they require a smaller modulation bandwidth (usually around 500 MHz).

Table 9 provides the summary of elements that are requested to be changed.

Table 9: summary of the elements that are proposed to be changed

<table>
<tr><th>No</th><th>Action</th><th>Topic</th></tr>
<tr><td>1</td><td>Change:</td><td>The scope of the current regulation from automotive short range radars to Ground based vehicular radar equipment</td></tr>
<tr><td>2</td><td>Establish:</td><td>Modulation bandwidth dependent Mean e.i.r.p. limits and PSD- limits as given in the table below
<table>
<tr><th>Modulation Bandwidth</th><th>PSD -limit</th><th>Mean e.i.r.p. - limit</th></tr>
<tr><td>Up to 1 GHz</td><td>20 dBm/MHz</td><td>40 dBm</td></tr>
<tr><td>Up to 2 GHz</td><td>7 dBm/MHz</td><td>37 dBm</td></tr>
<tr><td>Up to 4 GHz</td><td>-3 dBm/MHz</td><td>30 dBm</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>Maintain:</td><td>Current 55 dBm peak power</td></tr>
<tr><td>4</td><td>Removal:</td><td>Fixed bumper attenuation of 6 dB</td></tr>
</table>

9 Regulation

9.1 Current regulation

The operation of automotive radars in the band 77-81 GHz is regulated with ECC/DEC(04)03 [i.10] and EC Decision 2004/545/EC [i.11].

ECC/DEC(04)03 [i.10] contains the following regulatory text:

- Title: *"The frequency band 77-81 GHz to be designated for the use of Automotive Short Range Radars"*.
- Considering l: "l) *that SRR-equipment is not considered as a safety of life service in accordance with the Radio Regulations, therefore SRR must operate on a non-interference and non-protected basis in accordance with the Radio Regulations"*.
- Decides 1:*"that for the purpose of this Decision, SRR equipment are defined as applications providing road vehicle based radar functions for collision mitigation and traffic safety applications"*.
- Decides 2: *"that the 79 GHz frequency range (77-81 GHz) is designated for Short Range Radar (SRR) equipment on a non-interference and non-protected basis with a maximum mean power density of -3 dBm/MHz e.i.r.p. associated with an peak limit of 55 dBm e.i.r.p."*.
- Decides 3: "*that the maximum mean power density outside a vehicle resulting from the operation of one SRR equipment shall not exceed -9 dBm/MHz e.i.r.p."*.

Decision 2004/545/EC [i.11] contains the following regulatory text:

- Title: "*Commission Decision of 8 July 2004 on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community"*.
- Article 1: "*The purpose of this Decision is to harmonise the conditions for the availability and efficient use of the 79 GHz range radio spectrum band for automotive short-range radar equipment"*.

- Article 3:
  - *"The 79 GHz range radio spectrum band shall be designated and made available for automotive short-range radar equipment as soon as possible and no later than 1 January 2005 , on a non-interference and non-protected basis.*
  - *The maximum mean power density shall be of - 3 dBm/MHz effective isotropic radiated power (e.i.r.p.) associated with a peak limit of 55 dBm e.i.r.p.*
  - *The maximum mean power density outside a vehicle resulting from the operation of one short-range radar shall not exceed - 9 dBm/MHz e.i.r.p.".*

9.2 Proposed regulation

The proposed changes to [i.10] are summarized in Table 10 and the proposed changes to [i.11] in Table 11.

Table 10: Proposed revisions to ECC/DEC(04)03 [i.10]

<table>
<tr><th>No</th><th>Reference</th><th>Proposed change</th><th>Background</th></tr>
<tr><td>1</td><td>Full document</td><td>Change Term
automotive short range radars
To
Ground based vehicular radar equipment</td><td>To widen the scope of the regulation and to avoid confusion between the use case and rf coverage of the device and the implemented functions</td></tr>
<tr><td>2</td><td>Full document</td><td>Delete references to "must operate on a non-interference and non-protected basis in accordance with the Radio regulations" e.g. in considering l and decides 2.</td><td>Elevation of the regulatory status of vehicular radar, to ensure the protection of Vehicular radar. Vehicular radar provides significant contribution to road safety for vehicle passengers and vulnerable road users: driver assistance functions and autonomous driving vehicles
In the current US regulation Automotive radar is covered under part 95M to reflect the co-primary status. Harmonization of the regulatory environment for vehicular radar with other countries e.g. USA (co-primary status) will help to further increase acceptance and deployment of vehicular radars</td></tr>
<tr><td>3</td><td>Decides 2</td><td>Change decides 2 that it reads:
… that the 79 GHz frequency range (77 - 81 GHz) is designated to include Ground based vehicular radar equipment.
The technical limits are provided in Annex 1.</td><td>Based on the justification provided in clause 8</td></tr>
<tr><td>4</td><td>Decides 3</td><td>Delete Decides 3 completely</td><td>Based on the justification provided in clause 8</td></tr>
<tr><td>5</td><td>Annex 1</td><td>Add new technical annex
Ground based vehicular radar equipment operating in the frequency range 77 GHz - 81 GHz must operate under the following limits. The respective limit applies for a single radar sensor:
<table>
<tr><th>Modulation Bandwidth</th><th>PSD -limit</th><th>Mean e.i.r.p. - limit</th></tr>
<tr><td>Up to 1 GHz</td><td>20 dBm/MHz</td><td>40 dBm</td></tr>
<tr><td>Up to 2 GHz</td><td>7 dBm/MHz</td><td>37 dBm</td></tr>
<tr><td>Up to 4 GHz</td><td>-3 dBm/MHz</td><td>30 dBm</td></tr>
</table></td><td>Based on the justification provided in clause 8</td></tr>
</table>

Table 11: Proposed revisions to EC decision 2004/545/EC [i.11]

<table>
<tr><th>No</th><th>Reference</th><th>Proposed change</th><th>Background</th></tr>
<tr><td>1</td><td>Full document</td><td>Change Term
automotive short range radars
To
Ground based vehicular radar equipment</td><td>To widen the scope of the regulation and to avoid confusion between the use case and rf coverage of the device and the implemented functions</td></tr>
<tr><td>2</td><td>Article 3,
First paragraph,
last sentence</td><td>Delete:
..on a non-interference and non-protected basis</td><td>Elevation of the regulatory status of vehicular radar, to ensure the protection of Vehicular radar. Vehicular radar provides significant contribution to road safety: driver assistance functions and autonomous driving vehicles
In the current US regulation Automotive radar is covered under part 95M to reflect the co-primary status. Harmonization of the regulatory environment for vehicular radar with other countries e.g. USA (co-primary status) will help to further increase acceptance and deployment of vehicular radars</td></tr>
<tr><td>3</td><td>Article 3,
Second paragraph</td><td>Change:
The maximum mean power spectral density shall be as given in Annex 1</td><td>Based on the justification provided in clause 8</td></tr>
<tr><td>4</td><td>Article 3,
Third paragraph</td><td>Delete completely</td><td>Based on the justification provided in clause 8</td></tr>
<tr><td>5</td><td>Annex 1</td><td>Add new Annex
ground based vehicular radar equipment operating in the frequency range 77 GHz - 81 GHz must operate under the following limits: The respective limit applies for a single radar sensor
<table>
<tr><th>Modulation Bandwidth</th><th>PSD -limit</th><th>Mean e.i.r.p. -limit</th></tr>
<tr><td>Up to 1 GHz</td><td>20 dBm/MHz</td><td>40 dBm</td></tr>
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<tr><td>Up to 4 GHz</td><td>-3 dBm/MHz</td><td>30 dBm</td></tr>
</table></td><td>Based on the justification provided in clause 8</td></tr>
</table>

Annex A:
Overview of current and future use cases

A.1 Advanced Driving Assistance Systems: descriptions of features & use cases

A.1.0 General information

Details for the listed functions and pictures can be found on the internet. Various vehicle suppliers already offer these driver assistance functions that contribute to the safety for the vehicle passengers and road users.

A.1.1 Adaptive Light Control

Matrix lighting is adapted based on inputs from ADAS sensors to control illumination on oncoming traffic, while providing maximum illumination for roadway, road signs, intersections or points of interest.

Closed loop illumination control of traffic signs, etc. to achieve optimum illumination to enhance FCM detection potential. Blanking, shaping, highlighting, adaptive aiming and path planning potential.

Key System Elements: Matrix LED Lighting, **Radar**, Camera, Localization.

A.1.2 Forward Collision Warning

Forward Collision Warning provides an early warning to the driver of a potential collision risk, prompting action by the driver to mitigate the risk. Ignoring the warning, causes the AEB function to be activated, where equipped.

Key System Elements: **Radar**, Camera.

A.1.3 Automatic Emergency Braking

AEB alerts drivers to collisions with vehicles in their path. If they do not react to the alerts, it automatically brakes to mitigate or avoid a collision. This can be demonstrated two ways:

1) camera only; and

2) fusion of a camera and Radar.

Key System Elements: **Radar**, Camera, Braking Control.

A.1.4 Automatic Cruise Control (ACC)

ACC is normally used under highway conditions and in essence, is a system which maintains a constant distance or time to a lead vehicle when the vehicle is on highway (road where non-motorised vehicles and pedestrians are prohibited). In combination with Front Corner Radar, Pedestrian & VRU (Vulnerable Roadway User with AEB, LKA features, urban scenarios down to 0 km/h are supported.

Key System Elements: **Radar**, Camera, Braking Control.

A.1.5 Enhanced Blind Spot Monitoring

Enhanced blind spot monitoring is a convenience feature, providing the driver with a warning, typically located in the rear-view mirror, for vehicles in the blind spot zone or quickly approaching the vehicle. Coverage includes merging scenarios, with the incorporation of lane marking information. Vehicles approaching in the adjacent lane are reported up to 30 m behind the vehicles (10 m/s closing speed maximum). Where Lane Keep Assist is included, steering counter torque will be provided to the driver, providing an indication that a lane change is not recommended. The driver always maintains control of the decision to change lanes.

Key System Elements: **Radar**, Camera.

A.1.6 Lane Change Assist

Lane Change Assist and cross traffic alert system extended the warning zone to support warnings at up to 70m behind the vehicle or in crossing traffic situations. Required to support high speed overtaking for European Autobahn scenarios and performance exceeding NHTSA NCAP BSD requirement.

Key System Elements: Front Camera, Corner radar.

A.1.7 Traffic Jam Assist

ACC (see clause A.1.4) is normally used under highway conditions and in essence, is a system which maintains a constant distance or time to a lead vehicle when the vehicle is on highway (road where non-motorised vehicles and pedestrians are prohibited). Traffic Jam Assist acts in combination with Front Corner Radar, LiDAR, Pedestrian & VRU (Vulnerable Roadway User) with AEB, LKA features, in urban scenarios to provide full speed range ACC capabilities including Stop & Go traffic. The system maintains the current driving lane, permitting the driver to complete lane changes.

Key System Elements: Camera, **Radar**, Corner Radar, Lidar, Steering &/or Braking Control.

A.1.8 Rear Cross Traffic Alert

Backing in a busy shopping mall parking lot (cars, shopping carts, pedestrians walking), the cross traffic alert system scans for traffic, pedestrians and range to surrounding objects. The driver is issued warnings via a mirror icon. In combination with Rear Pedestrian AEB, an expanded range of coverage is realized with the fusion of UPA, SVS and corner radar for enhanced security. If the vehicle is stationary, the driver attempts to pull away and the system detects one or more targets which may be at risk of collision, either within the intended lane/path of travel or which are likely to move into the lane/path of travel, the system provides a warning to the driver indicating location of the target at risk..

Key System Elements: Corner Radar, Rear Camera, UPA, SVS, Braking Control.

A.1.9 Front Junction-Intersection Assist

If the vehicle is stationary and the driver attempts to initiate forward motion which causes risk of collision due to some form of cross traffic or object which is stationary ahead, the system inhibits the pull-away.

Key System Elements: Camera, Corner Radar, SVS, UPA, Braking Control.

A.1.10 Highway Chauffeur

This feature is based on the functions provided by several different sensors including radar based functions that are already covered above. The system is based on data fusion from different sensor types that are mounted on a vehicle.

This feature is an on-demand autonomy solution that allows the driver to enable SAE Level 3 driving [i.31]. The driver's readiness and ability to resume control is continuously monitored. The driver is required to monitor the driving task, and when requested to take back control, they will be given 3 seconds to do so.

Highway Chauffeur handles all required driving on limited access highways with driver supervision. It handles lane management, speed modulation, and path planning.

Key System Elements: Front Radar(s), Camera, Driver Monitoring, Steering & Braking Control.

A.1.11 Automatic Lane Change

Automated Lane Change Assist supplements ACC function to autonomously initiate and execute an overtaking manoeuvre. System anticipates the need for overtaking manuever, monitors the driving situation and available opportunities to change lanes, selects the desired opportunity, initiates turn signal, changes lanes & adjusts speed to match the traffic flow. Automatically returns to the original lane after passing the preceding vehicle.

Key System Elements: Camera, 360° Radar, Steering & Braking Control.

A.1.12 Automated Parking Assist (APA)

Ultrasonic-only or camera+ultrasonic-fusion automated parking systems detects obstacles in the vehicle's path, open parking spots and performs parallel or perpendicular parking manoeuvres to park the car automatically.

In combination with obstacle detection, the Rear Automatic Emergency Braking (Rear AEB) feature will automatically brake in case an object is in the path of the vehicle supporting NCAP requirements.

Key System Elements: UPA, SVS, Steering Control, Braking Control.

A.1.13 Home Zone Automated Parking (HZAP)

This feature is based on the functions provided by several different sensors including radar based functions that are already covered above. The system is based on data fusion from different sensor types that are mounted on a vehicle.

An Ultrasonic or UPA+Vision fusion system for assisting the driver by automating the repetitive tasks such as parking in/out of known (learned) parking spots. Once the desired spot and the associated approach are stored through a short learning/training session, HZAP system will manoeuvre the vehicle autonomously to a memorized parking spot.

Key System Elements: Secure Connectivity, UPA, SVS, **Radar**, Steering & Braking Control.

A.1.14 Valet Parking

This feature is based on the functions provided by several different sensors including radar based functions that are already covered above. The system is based on data fusion from different sensor types that are mounted on a vehicle.

The driver exits the vehicle at a drop-off area and uses a remote control system, such as a fob or smart phone application, to send the vehicle away to park itself. The driver has no further interaction with the vehicle and the vehicle parks itself in a suitable parking location. The space is allocated by a carpark control system. After some time, either predefined or upon driver request the vehicle drives itself to a pickup area to meet the driver, (the summon function). The system should be capable of communicating with the driver using a remote device to allow the driver to go to the vehicle rather than summon the vehicle.

Key System Elements: Secure Connectivity, Camera, 360° Radar, UPA, LiDAR Steering & Braking Control.

A.1.15 Highway Pilot

This feature is based on the functions provided by several different sensors including radar based functions that are already covered above. The system is based on data fusion from different sensor types that are mounted on a vehicle

This feature is an on-demand autonomy solution that allows the driver to enable SAE Level 4 driving [i.31]. If the driver is required to take back control, they will be given 10 seconds to do so. Enhanced biometric, driver monitoring required.

Highway Pilot handles all required driving on limited access highways with driver supervision. It handles lane management, speed modulation, and path planning.

Key System Elements: Secure Connectivity, Camera, 360° Radar, UPA, LiDAR, Driver Monitoring, Steering & Braking Control.

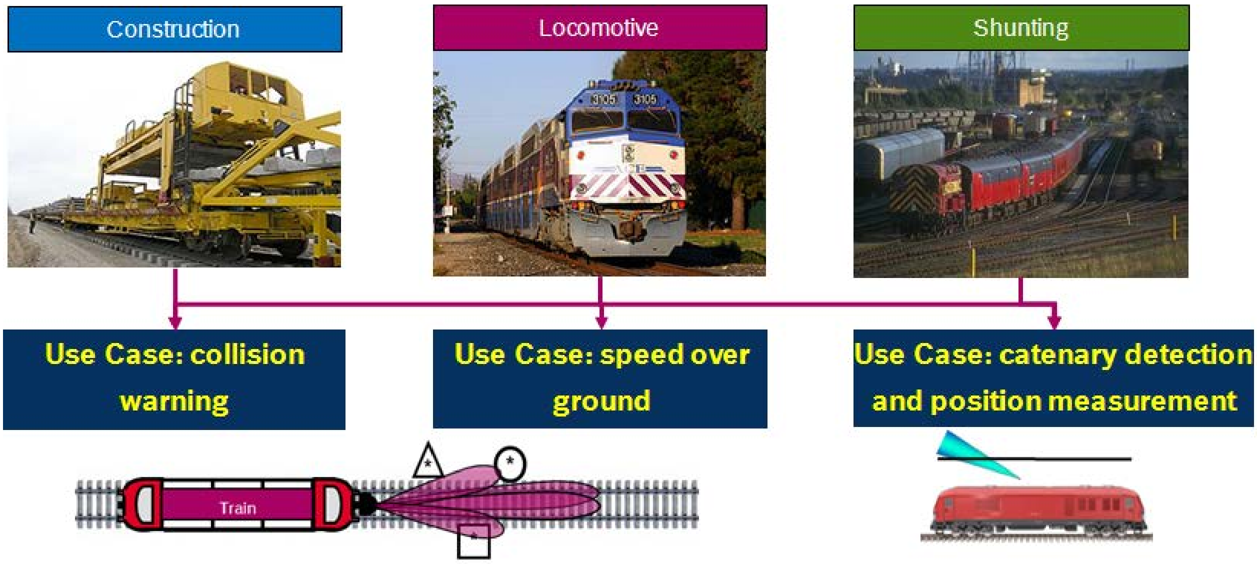
A.2 Advanced Driving Assistance Systems for other kind of ground based vehicles: descriptions of features & use cases

A.2.1 General

Automotive radar sensors can also be used in other ground based vehicles to provide assistance and safety functions. These radar sensors are covered in ETSI EN 301 091-1 [i.16] More details are provided within ETSI TR 102 704 [i.58].

A.2.2 Trains (locomotive and train cars)

In railroad environment, radar based functions can help improve the safety and operations.



- Detection of „known“ objects → for a defined breaking /stopping
- Correct speed over ground and reaction if „breaking“ needs to be corrected (shorter)
- Rolling detection

- Measurement of height and lateral position (continuous evaluation status condition during usage).
- To detect alien objects (e.g. clamps)
- To avoid damages during construction
- Could also be used for Hybrid vehicles to detect catenary

Figure A.1: Examples for radar based functions in railroad environment (source: Bosch)

Figure A.2: Example catenary detection and position measurement (source: Bosch)

Figure A.3: Example catenary detection and position measurement (source: Bosch)

Figure A.4: Collision avoidance (source: Bosch)

A.2.3 Tram/Metro

Use-cases: collision warning/avoidance and speed over ground.

Figure A.5: Collision avoidance in urban scenarios (source: Bosch)

A.2.4 Construction/farming vehicles (outdoor)

Use- cases (very comparable with automotive use-case):

- **Collision avoidance** (crossing collision avoidance/back over collision avoidance/side looking (blind spot):
  - Huge and heavy vehicles with lot of "blind spots" → increase of safety.
- **Autonomous devices** (automatic coordinated pace)
- (correct/real) **speed over ground**

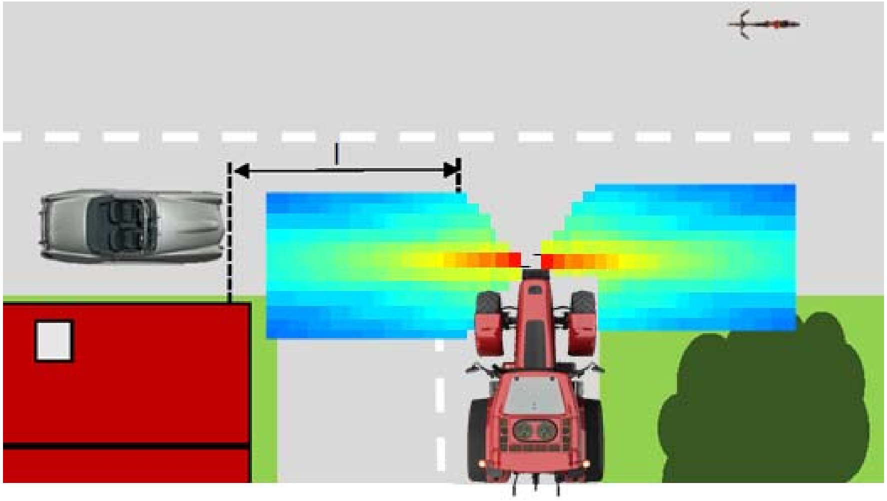


Figure A.6: collision avoidance for farming vehicles (source: Bosch)

Figure A.7: Collision avoidance for large construction vehicle (source: Bosch)

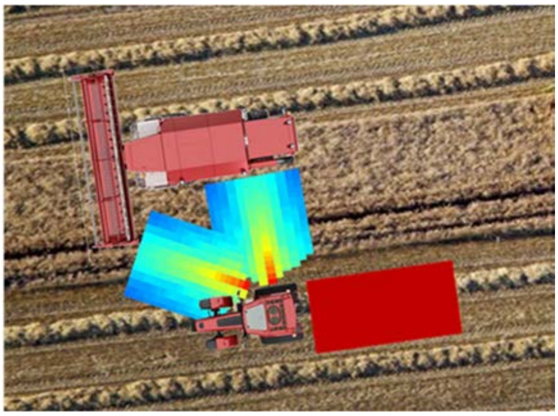


Figure A.8: Collision avoidance for farming vehicles (source: Bosch)

A.2.5 Industrial vehicles/Material handling (indoor/outdoor)

Use-cases (fork lifts, working platform):

- **Collision avoidance** (if people working in pulled out situation → detection ground objects, blind spot detection, etc.).
- **Autonomous devices.**
- **Distance** measurement (height over ground/height over headfirst).

Benefit for such sensors:

Vehicles with lot of "blind spots" and if working indoor difficult to estimate the distance till the celling (headfirst), walls or obstacles on the ground → increase of safety.

Figure A.9: Work platform: surveillance of "blind spots" (source Bosch)

Figure A.10: Work platform: surveillance of "blind spots" (source Bosch)

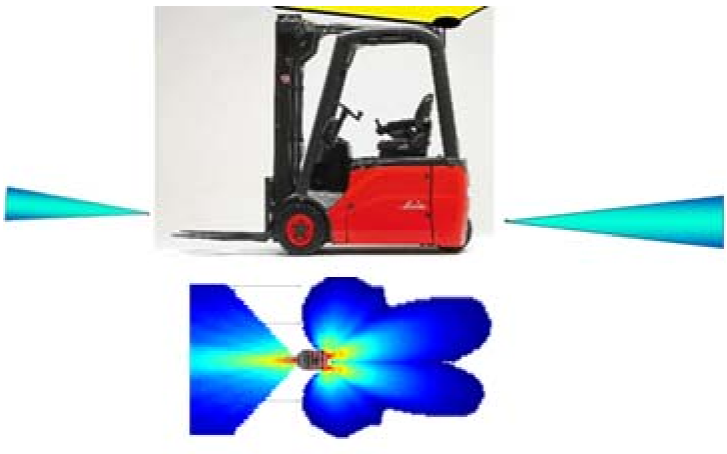


Figure A.11: Collision avoidance and protection for forklift (source: Bosch)

A.3 Vehicle safety programmes

A.3.1 Vehicle safety programmes

There are several vehicle testing organizations, which rate the available vehicles based on various defined standards. The OEMs are usually interested in fulfilling all requirements of the standards in order to get good ratings for their vehicles. The testing organizations have already developed tests to assess the safety functions that are available for the vehicles. The test organizations develop the test requirements taking into account historical accident and fatality data, the associated state of available technologies, the expected impact of improvements of enhanced driver awareness and/or controlled intervention. In many instances, features have migrated from providing driver warnings (LDW, FCW) to providing automatic reaction to known high collision risk scenarios (LKS, AEB) involving control of the vehicle's braking or steering system.

A.3.2 New Car Assessment Programs (NCAP)

NCAP is one of the most important vehicle testing programme working on several regions worldwide. In Europe, the Euro NCAP is developing feature requirements, performance & test requirements and time schedules when they will be included in the tests. These roadmaps are communicated as targeted implementation dates against which OEMs develop technology application strategies to achieve desired ratings for their vehicles. Generally, OEMs target to make available the technology to reach the maximum possible rating, while also supporting consumer choice with packages including safety technology bundled into available optional content.

A.3.3 EU NCAP

Euro NCAP is a voluntary vehicle safety rating system created by the Swedish Road Administration, the Fédération Internationale de l'Automobile and International Consumer Research & Testing, and backed by the European Commission, seven European governments, as well as motoring and consumer organizations from every EU country. The program is modelled after the New Car Assessment Program (NCAP), introduced in 1979 by the U.S. National Highway Traffic Safety Administration. Other areas with similar (but not identical) programmes include Australia and New Zealand with ANCAP, Latin America with Latin NCAP and China with C-NCAP. The document [i.59] provides the roadmap and an overview of the current timeline for the implementation of new safety related radar based functions in the EU NCAP tests.

A.3.4 US NCAP

Within the USA, the Department of Transportation's (DOT), National Highway Traffic Safety Administration (NHTSA) administers the New Car Assessment Program (NCAP). Most recently [i.25], NHTSA has conducted requests for comment on proposals for changes to the NCAP requirements for 2018 and beyond. While the US-NCAP proposals mirror the Euro NCAP in several areas, test procedures and priorities reflect analysis of the past accidents data to affect the greatest potential benefit considering conditions in the US market. Similarly, NCAP regulations in other regions reflect the unique conditions in the market, including local supply availability, setting priorities and timetables for implementation. For global OEM's, features supporting the global NCAP portfolio of capabilities and performance requirements are necessary. Accordingly, automotive radar technologies require regulatory modification to support the increasing demands for broader perception capabilities to achieve the safety enhancement desired cost effectively.

The relevant NCAP testing organizations publish safety reports on new cars, and award 'star ratings' based on the performance of the vehicles in a variety of crash tests, including front and side impacts, collisions with posts, and impacts with pedestrians. The top overall rating is five stars.

Testing is not mandatory, with vehicle models being independently chosen by Euro NCAP or voluntarily submitted for testing by the manufacturers. In Europe, new cars are certified as legal for sale under the Whole Vehicle Type Approval regime that does not always apply the same requirements as Euro NCAP.

Combined, the regulatory actions of the EU Commission and the market based product ratings of the Euro NCAP roadmaps will accelerate the implementation of radar based and radar data used in fusion solutions with other perception technologies such as cameras and LIDAR. Globally, similar actions are underway to address the growing social impact of roadway fatalities, injuries, and accidents.

Annex B: Regulation in selected countries for 76 GHz - 77 GHz and 77 GHz - 81 GHz vehicular radar sensors

The overview provides a summary of selected market areas and countries and illustrates the radio spectrum regulations for radars operating in the frequency range 76 GHz to 81 GHz. The presented table is a snapshot of the regulation at the time when the document was developed. For reference to most recent status, latest local regulatory documents should be consulted.

It is important to note, that for most countries of the listed countries the regulation and therefore approval scheme and related standard is split for the two frequency bands 76 GHz - 77 GHz and 77 GHz - 81 GHz. Following the WRC-2015 decision on automotive radars and to reflect the decision in the national regulation, in 2017 the FCC in the US has merged the frequency regulation for the whole frequency band, which is illustrated by listed frequency range.

Key parameters like power requirements and frequency band are shown in Table B.1.

Summary of the situation in key market countries

For 76 GHz - 77 GHz the technical requirements for acceptance are in principle homogenous and aligned over the listed countries and regions. Only a few countries deviate regarding the typical power parameters and the method applied for verification (examples: reference to conducted power).

For 77 GHz - 81 GHz quite a number of countries do not have yet a regulation in place or are about to prepare new regulations and standards. In addition the power requirements show big variation. Specifically the limitation of power density for dedicated usage or in relation to bandwidth will restrict the usage and function of related sensors.

Table B.1: Examples for Regulations in selected countries for 76 GHz - 77 GHz and 77 GHz - 81 GHz radar sensors (data as per 10/2018)

Country/Region	Regulation/ Radio Standard	Power (e.i.r.p. unless otherwise stated)	Remark (see note)		Regulation/ Radio Standard	Power (e.i.r.p. unless otherwise stated)	Remark (see note)
	Frequency band 76 GHz - 77 GHz				**Frequency band 77 GHz - 81 GHz**		
Australia	Radio communications (Low Interference Potential Devices) Class Licence 2000 Version of 27 July 2011	Peak: 44 dBm			Radio communications (Low Interference Potential Devices) Class Licence 2000 Version of 27 July 2011	Peak: 55 dBm	*Freq. Range* *77 GHz - 81 GHZ*
Brazil	National Agency for Communications Act No 11542 OF August 23, 2017	not moving: 200 nW/cm², front looking: 60 uW/cm², side/backward looking: 30 uW/cm² [all at 3m]			Not regulated Regulation in process?		
Canada	Industry Canada RSS-251, Issue 2 July 2018	50 dBm Peak: 55 dBm	***Freq. Range*** ***76 GHz - 81 GHZ***		Industry Canada RSS-251, Issue 2 July 2018	50 dBm Peak: 55 dBm	***Freq. Range*** ***76 GHz - 81 GHZ***
China	Micropower (Short Distance) Radio Equipment's (revision of regulation in process)	Peak: 55 dBm			Regulation in process		
Europe	ETSI EN 301 091 [i.16]	50 dBm Peak: 55 dBm			ETSI EN 302 264 [i.17]	-3 dBm/MHz (sensor) **-9 dBm/MHz** **(car)** Peak: 55 dBm	*Freq. Range* *77 GHz - 81 GHZ*
India	Very Low Power Radio Frequency Devices / Equipment for Short Range Radar Systems	37 dBm		-	Not regulated		
Japan	ARIB STD-T48 2.2	10 dBm cond burst power (40 dBi Gain -> 50 dBm)			ARIB STD-T111 1.1 Now full 4GHz is allowed	10 dBm cond burst power (35 dBi Gain -> 45 dBm) (When OBW is less than 2 GHz, less than 5 uW/MHz)	*Freq. Range* *77 GHz - 81 GHZ*

Country/Region	Regulation/ Radio Standard	Power (e.i.r.p. unless otherwise stated)	Remark (see note)		Regulation/ Radio Standard	Power (e.i.r.p. unless otherwise stated)	Remark (see note)
	Frequency band 76 GHz - 77 GHz				**Frequency band 77 GHz - 81 GHz**		
South Korea	Technical Standards for Radio Equipment (RRA Notification 2006-84 (2006.8.23)) 9. Automotive Radar System	10 dBm cond individual antenna (50 dBm)			Frequency band 77 GHz - 81 GHz allocated, standard still to be released		*Freq. Range* *77 GHz - 81 GHZ*
Russia	Appendix 1, Resolution of State Radio Frequency Committee No. 10-09-03 of 29 October 2010 "Wireless Alarm and Motion Detection Devices"	35 dBm		-	Appendix 1, Resolution of State Radio Frequency Committee No. 10-09-03 of 29 October 2010 "Wireless Alarm and Motion Detection Devices"	-3 dBm/MHz	*Freq. Range* *77 GHz - 81 GHZ*
Singapore	IMDA TS SRD Issue 1, 1 October 2016	37 dBm Stationary: 23,5 dBm		-	IDA TS UWB Issue 1 Rev 1, May 2011	-3 dBm/MHz Peak: 55 dBm	*Freq. Range* *77 GHz - 81 GHZ*
USA	FCC part 95M	50 dBm Peak: 55 dBm	***Freq. Range*** ***76 GHz - 81 GHZ***		FCC part 95M	50 dBm Peak: 55 dBm	***Freq. Range*** ***76 GHz - 81 GHZ***
NOTE: Frequency range is 76 GHz - 77 GHz - if not otherwise stated.							

Annex C:
Radar Calculations

C.1 Maximum range considerations

Based on the radar range equation the maximum range can be calculated in an ideal situation (e.g. no rain, no multipath, no bumper loss, etc.).

Radar Range Equation $$R_{max} = \sqrt[4]{\frac{P_t \cdot RCS \cdot c^2 \cdot G^2}{(4\pi)^3 \cdot f_c^2 \cdot P_{min}}} \quad (1)$$

Where:

- R_{max} is the maximum range of the radar
- P_t is the transmit power of the radar
- RCS is the Radar Cross Section
- c is the speed of light
- G is the TX/RX antenna gain
- f_c is the carrier frequency
- P_{min} is the minimum detectable signal power of the radar
- P e.i.r.p. is Pt * G

C.2 assumptions for radar sensor antenna gain values

According to typical values known from development of 77 GHz automotive radar sensors:

E-Band 76 GHz - 81 GHz antennas have approximately the antenna gain as listed in attached table, based on the basic feature set of the sensor.

Table C.1

Sensor operation/Function	Antenna gain [dBi]	Antenna gain [linear value]
Ultra-Short Range radar	6	4
Short Range Radar	10	10
Mid-Range Radar	15	32
Long Range Radar	20	100
NOTE: For given sensor operations the gain of Tx and Rx path is assumed to be equivalent: $G_{Tx} = G_{Rx}$, because similar or even same antenna structures and characteristics are used for Tx an Rx path.		

C.3 Radar cross section values for typical targets

The following values for Radar Cross Section of a child min, pedestrian, bicycle, motorcycle and car as given in Table C.2 are used for the calculations.

Table C.2

Object Reference	dBsqm	sqm
Small Child (Child Min [i.55])	-13	0,05
Pedestrian (Child Max [i.55])	-10	0,1
Bicycle [i.55]	-5	0,4
Motor Cycle	0	1
Car [i.56]	10	10

C.4 Calculation of the sensor performance for the different radar sensor types

For the radar sensor receiving path, a minimum detection threshold of -110 dBm is assumed.

A bumper loss in a range of 2 dB - 8 dB (2 way attenuation) will cause degradation of performance compared to the ideal environment.

Tables C.3 to C.7 show the typical sensor performance based on given technical parameters. The maximum detection range for the listed automotive radar types detecting the related object properties (RCS) is calculated based on the potential maximum output power.

Table C.3: Ultra Short Range Radar (USRR)

Mean EIRP/Range [m]	10 dBm	20 dBm	30 dBm	35 dBm	40 dBm
Small Child	6,2	11,1	19,7	26,3	35,1
Pedestrian (Child Max)	7,4	13,2	23,5	31,3	41,8
Bicycle	9,8	17,4	30,9	41,2	55,0
Motor Cycle	13,2	23,5	41,8	55,7	74,3
Car	23,5	41,8	74,3	99,0	132,1

Table C.4: Short Range Radar (SRR)

Mean EIRP/Range [m]	10 dBm	20 dBm	30 dBm	35 dBm	40 dBm
Small Child	7,9	14,0	24,9	33,2	44,2
Pedestrian (Child Max)	9,3	16,6	29,6	39,4	52,6
Bicycle	12,3	21,9	38,9	51,9	69,2
Motor Cycle	16,6	29,6	52,6	70,1	93,5
Car	29,6	52,6	93,5	124,7	166,2

Table C.5: Mid-Range Radar (MRR)

Mean EIRP/Range [m]	10 dBm	20 dBm	30 dBm	35 dBm	40 dBm
Small Child	10,5	18,6	33,2	44,2	59,0
Pedestrian (Child Max)	12,5	22,2	39,4	52,6	70,1
Bicycle	16,4	29,2	51,9	69,2	92,3
Motor Cycle	22,2	39,4	70,1	93,5	124,7
Car	39,4	70,1	124,7	166,2	221,7

Table C.6: Long Range Radar (LRR)

Mean EIRP/Range [m]	10 dBm	20 dBm	30 dBm	35 dBm	40 dBm
Small Child	14,0	24,9	44,2	59,0	78,6
Pedestrian (Child Max)	16,6	29,6	52,6	70,1	93,5
Bicycle	21,9	38,9	69,2	92,3	123,0
Motor Cycle	29,6	52,6	93,5	124,7	166,2
Car	52,6	93,5	166,2	221,7	295,6

If the 2 way attenuation of the bumper is introduced, the detection range is reduced. Table C.7 shows this on the example an LRR (results without bumper, see Table C.6).

Table C.7: Long Range Radar (LRR) - considering an additional two-way bumper loss of 6 dB

Mean EIRP/Range [m]	10 dBm	20 dBm	30 dBm	35 dBm	40 dBm
Small Child	9,9	17,6	31,3	41,7	55,7
Pedestrian (Child Max)	11,8	20,9	37,2	49,6	66,2
Bicycle	15,5	27,5	49,0	65,3	87,1
Motor Cycle	20,9	37,2	66,2	88,3	117,7
Car	37,2	66,2	117,7	156,9	209,3

C.5 Influence of bumper attenuation on the radar range

Table C.8: Loss in range [%] considering different attenuation values for bumper loss

Two way Attenuation	2 dB	4 dB	6 dB	8 dB
Range loss [%]	11 %	21 %	29 %	37 %

Annex D: Change History

Date	Version	Information about changes
02/2018	0.0.3	TG SRR # 32: outcome of drafting session Feb 14th,2018
03/2018	0.0.4	TG SRR # 32: outcome of drafting session March 14th, 2018
03/2018	0.0.5	TG SRR # 32: outcome of drafting session March 16th, 2018
04/2018	0.0.6	Outcome of drafting session April 3rd,2018
04/2018	0.0.7	Input document for drafting session April 25th,2018
04/2018	0.0.8	Output document drafting session April 25th, 2018
05/2018	0.0.9	Output document drafting session May 22nd, 2018
06/2018	0.0.10	Output document drafting session June 18th,2018
06/2018	0.0.11	Output document drafting session June 28th, 2018
07/2018	0.0.12	Output document drafting session July 6th, 2018
07/2018	0.0.13	Output document drafting session July 12th, 2018 (morning)
07/2018	0.0.14	Output document drafting session July 13th, 2018
09/2018	0.0.15	Output document drafting session September 11th, 2018
10/2018	0.0.16	Output document drafting session October 16th, 2018
11/2018	0.0.17	Output document drafting sessions TG SRR M37 Nov 29th, 2018
01/2019	0.0.18	Output document drafting session Jan 18th, 2019
02/2019	0.0.19	Output document drafting session Feb 11th, 2019
03/2019	0.0.20	Output document drafting session March 13th, 2019
03/2019	0.0.21	Output document drafting sessions TG SRR M38 March 26th, 2019
04/2019	0.0.22	Output document drafting session April 26th,2019
05/2019	0.0.23	Output document drafting session May 24, 2019
07/2019	0.0.24	Output document drafting session June 25th , 2019
08/2019	0.1.0	Stable draft for TG SRR approval August 28th, 2019
08/2019	0.1.1	Stable draft for TG SRR drafting 20190903 with edits provided in Doc ERMTG SRR(19)000015
09/2919	0.1.2	Stable draft - Output of final drafting session Sept 3rd, 2019 and ad-hoc drafting session Sept 4th, 2019
09/2019	0.1.3	Final draft for approval
01/2020	0.1.4	Final draft for approval - with comment: This is the version addressing the comments received during SRdocIE
02/2020	0.1.5	Final draft for approval - with comment: This is the version with additional comments under 4.1 received during SRdocPU

History

Document history		
V1.1.1	May 2020	Publication